PROVINCE OF ONTARIO
DEPARTMENT OF MINES

HON. LESLIE M. FROST, *Minister of Mines* H. C. RICKABY, *Deputy Minister*

Bulletin No. 138

Investigations Regarding the Safety of Hoisting Equipment and Hoisting Practice in Ontario Mines

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LETTER OF TRANSMISSION

To The Honourable Leslie M. Frost,
Minister of Mines.

Sir:

I beg to hand you herewith the Report on "Investigations Regarding the Safety of Hoisting Equipment and Hoisting Practice in Ontario Mines," containing Report of Committee appointed by the Province of Ontario, Preliminary Report of Ontario Mining Association Committee and Report of Inspector of Mines on the accident at Paymaster Consolidated Mines, Ltd., on February 2nd, 1945.

I have the honour to be, Sir

Your obedient servant,

H. C. RICKABY,
Deputy Minister of Mines.

Department of Mines,
Toronto, January, 1947.

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REPORT OF THE COMMITTEE APPOINTED BY THE PROVINCE OF ONTARIO

To Inquire Into and Report Upon Certain Matters Arising Out of the Accident at the Paymaster Consolidated Mines Limited, February 2nd, 1945

LETTER OF TRANSMITTAL

The Honourable Leslie M. Frost, K.C.,
Minister of Mines, Province of Ontario,
Parliament Buildings,
TORONTO, Ontario.

Dear Mr. Minister:

In accordance with the instructions contained in your letter of February 22, 1945, the Committee approved by you to inquire into and report upon certain matters arising out of the accident which occurred at the property of the Paymaster Consolidated Mines, Limited, South Porcupine, Ontario, on February 2, 1945, has completed its work and begs to present its report herewith.

Respectfully yours,

C. R. YOUNG,
Chairman.

Toronto.
March 28, 1946.

AUTHORIZATION OF THE COMMITTEE AND TERMS OF REFERENCE

Toronto, February 22nd, 1945.

Dear Dean Young:

Relative to the conversations which I have had with you in regard to the operating sections as set out in Part VIII of The Mining Act and the practices in that connection of the Department of Mines, I beg to formally approve of the appointment of the Committee which we have discussed, the same to consist of yourself, Professor T. R. Loudon, Professor E. A. Allcut, Professor V. G. Smith, Professor Lloyd M. Pidgeon, with yourself as chairman.

The Committee is appointed to inquire into and report upon the following matters arising out of the accident which occurred at the property of

the Paymaster Consolidated Mines, Limited, on February 2nd, 1945. I suggest that the Committee should in particular investigate the following points:

(1) The cause or causes of the accident;
(2) The practicability of devising improved methods of inspection for the purpose of disclosing any weakness of a hoisting rope or its attachments, or any defects in the hoisting machinery;
(3) The practicability of devising safety devices that would effectively arrest the drop of a cage or skip if the supporting rope should break or slip, or the hoisting machinery should get out of control;
(4) The possibility of improving existing regulations pertaining to the safety of operation of mining hoists.

The Government is anxious that your Committee should have a free hand in this matter, and if the above suggestions are not wide enough, would you please let me know.

I desire to extend to your Committee the fullest co-operation of the Department of Mines. I have also been assured that the Ontario Mining Association will extend to your Committee every possible assistance.

Yours very truly,

(Signed) LESLIE M. FROST.

Dr. C. R. Young,
Dean of the
Faculty of Applied Science and Engineering,
University of Toronto,
Toronto, Ontario.

A—INTRODUCTION

1. **Scope of the Investigation.** Under the terms of reference contained in the letter of the Minister of Mines, addressed to the Chairman of the Committee on the Paymaster Mines Accident on February 22, 1945, the Committee considered that its duty was to investigate matters of safety with respect to hoisting only. It has consequently not undertaken to inquire into the safety of mining operations generally. For example, it has not concerned itself with accidents having to do with explosives, fall of rock, rock bursts, stoping, horizontal transport, electrical or fire hazards, surface, mill or metallurgical operations.

Nor has the Committee thought it desirable to duplicate the inquiry conducted at the Coroner's Inquest held in South Porcupine on February 26th and 27th, 1945. It does not question the soundness of the Jury's verdict as to the proximate cause of the death of the sixteen men who lost their lives in the accident. In consequence, it has directed its efforts to a careful examination of all known causes of hoisting accidents and a consideration of means by which such accidents may be prevented.

2. **Sources of Information.** Careful study was made by the Committee of the transcript of evidence taken at the Coroner's Inquest and of the exhibits filed in connection therewith, not only to form its own opinion of the cause of the accident but for whatever light might be thrown on the general question of hoisting safety.

Four public hearings were conducted by the Committee in order to receive representations on any matters relating to the safety of mine hoisting operations. Models of safety devices were displayed for examination in a number of cases and plans, sketches, or descriptions were submitted to the Committee for further study. Two hearings were conducted at Timmins, one at Kirkland Lake, and one at Sudbury. In all 34 persons were so heard. Eighteen representatives of organized labour were present at the hearing held at Timmins on May 30, 1945.

At Toronto, the Committee questioned many persons who, it was believed, could furnish useful information relevant to the inquiry.

Written or oral proposals to the number of 48 were received; 45 of them on the subject of new or improved safety devices or procedures to arrest the fall of a cage in the event of failure of the rope or the hoisting machinery. The nature and value of the proposals will be discussed in what follows under the head of "Hoisting Ropes" (Part E), and "Safety Measures and Devices" (Part H), the topics to which they were almost exclusively directed.

The Committee as a whole inspected actual hoisting operations at 17 Ontario mines of varying size and complexity of installation. One member visited a Quebec mine in the Malartic camp in order to witness a full-scale test on a new safety device.

Visits of the entire Committee were also made to the plants of two large wire rope manufacturing companies and one large building elevator company.

Certain useful experimental work was carried out by the Committee or by others with its full encouragement. Reference is made thereto in Article 3 of this report.

An extensive study has been made of the literature relating to mine hoisting. This involved the careful examination of many reports, bulletins and scientific papers, both Canadian and foreign, and the study of the mining regulations in force in Ontario and other jurisdictions. A bibliography of the most significant literature constitutes Appendix I of this report.

3. **Experimental Work.** Partly in preparation for the Coroner's Inquest and partly at the request of the Committee, the Ontario Department of Mines tested to destruction in its laboratory at Toronto, 26 samples of the rope that failed at the Paymaster Mines and 22 samples of the companion skip rope from the same shaft. Three more samples from the skip rope were tested in the Mechanics of Materials Laboratory of the University of Toronto.

The physical properties of samples of wire from the broken Paymaster cable were experimentally investigated for tensile strength, modulus of elasticity, bending and fatigue, partly in the University laboratories and partly in the laboratories of the Hydro-Electric Power Commission of Ontario at Toronto.

Tests of corrosion products and chemical analyses of fibre cores were made in the University laboratories.

An important study was made in the University laboratories at the request of the Committee by The General Engineering Company (Canada), Limited, of the applicability of the Dumont Cyclograph to the discovery of defects in mine hoisting ropes of sizes varying from ¼ to 1½ inches in

diameter. The Committee was also made aware of other studies of electromagnetic methods of inspection conducted elsewhere and had the opportunity of witnessing certain tests in the laboratories of the International Nickel Company of Canada, Limited, at Copper Cliff.

In the mining industry of Ontario, many experimental investigations and tests of the efficacy of various types of safety devices have been made following the Paymaster accident. The Committee has been privileged to witness many of these and the results of all of the more significant ones have been made available to it. Detailed reference is made to these tests under the head of "Safety Measures and Devices", in Part H.

4. **Acknowledgments.** The Committee wishes to acknowledge the full co-operation of the Ontario Department of Mines in readily placing at its disposal all facilities and records useful for the conduct of the investigation and particularly for the extensive use made of its testing laboratory at Toronto.

The work of the Committee has been greatly facilitated by the courtesy of the Special Committee set up by the Ontario Mining Association to conduct a parallel investigation within the industry itself. It has made available much valuable information respecting practices followed in mine hoisting operations in Ontario and, in addition, the results of many recent experiments and tests. The O.M.A. Committee consisted of Messrs. R. E. Dye, General Manager of Dome Mines, Limited (Chairman); R. L. Healy, General Manager of Wright-Hargreaves Mines, Limited; and R. D. Parker, General Superintendent, International Nickel Company of Canada, Limited.

To the Hydro-Electric Power Commission of Ontario the Committee is indebted for the making of certain tests with the special wire-testing equipment available in its laboratories.

Grateful acknowledgment is made also of valuable information made available to the Committee by Mr. W. J. W. Reid, of the Otis-Fensom Elevator Company of Canada, Limited, and Mr. H. C. Crane, of the Turnbull Elevator Company, Limited.

Many individual engineers, mine operators, and workmen have assisted the Committee in contributing useful information and suggestions which it is not practicable to indicate here in detail.

B—CAUSES OF THE PAYMASTER ACCIDENT

5. **Rope Corrosion the Primary Cause.** Following a careful study of all the available evidence, this Committee is definitely satisfied that the fall of the mine cage in No. 5 shaft of the Paymaster Consolidated Mines, Limited, which occurred on February 2, 1945, with the loss of sixteen lives, was primarily due to corrosion of the hoisting rope. The Committee incidentally concurs in the verdict of the Coroner's Jury that the failure of the rope was "because of internal corrosion, of which there was no indication from external examination".

Sudden application of brakes may have substantially augmented the static stress in the rope, but it is very unlikely that failure would have occurred if the rope had been in as good condition at the point of failure as it was in the 6-ft. length that was cut from the cage end and tested in the laboratory of the Department of Mines 4½ months before the accident. The fact that the rope did not fail until extensive corrosion had

taken place, and one-half to two-thirds of the section of some wires had disappeared, is evidence that other factors that might have caused rope failure had been satisfactorily met.

The rope which failed was nominally one inch in diameter and of flattened strand, Lang lay construction. There were six strands of 27 wires each, a strand being composed of twelve outer wires of 0.069 in. nominal diameter, twelve intermediate wires of 0.043 in. diameter, and three core wires of 0.066 in. diameter. The wire material was designated as "Special Green Strand" and was purchased by the rope manufacturer to the specification mentioned in Article 12 of this report.

Chemical analysis of the steel made for the Committee revealed the following constituents:

	PERCENT
Carbon	0.80
Phosphorus	0.012
Sulphur	0.034
Manganese	0.59
Silicon	0.22

This indicates that the steel was of normal composition for typical rope wire.

The microstructure of the wire showed pearlite which had been deformed by the cold working to which the metal had been subjected in the wire drawing operation. The appearance of a polished, etched, longitudinal section was identical with that of a sample of new wire obtained from the makers of the original rope. It thus appears that the steel was similar to that presently employed in wire rope manufacture.

Inside the rope, in the region of the break, the wires were in a disastrous state of corrosion. On the outside, the wires were somewhat worn and deformed, but they were still reasonably strong.

A given outer wire showed one or other of three conditions, namely:

(a) A region with little corrosion, in which the wire had lost little section;
(b) A worn or deformed section on the outside;
(c) A heavily corroded region; in places the wire was two-thirds gone.

An 8-inch length of wire was cut into 1-inch lengths and weighed, with results as shown in Table 1.

TABLE 1

VARIATION OF CORROSION IN AN OUTER WIRE OF THE BROKEN PAYMASTER ROPE

No. of Specimen	Weight of 1-in. Length of Wire	Description
1	0.41 gm.	Light corrosion; little loss of section
2	0.36 gm.	Some corrosion
3	0.30 gm.	Corrosion severe
4	0.39 gm.	Worn or deformed
5	0.33 gm.	Worn plus corrosion
6	0.25 gm.	Heavy corrosion (⅓ remaining in places)
7	0.36 gm.	Lighter corrosion
8	0.39 gm.	General corrosion similar to that of Specimen 1

Corrosion had taken place in the interstices between the strands and inside the strands themselves. The oxide formed is magnetic and its X-ray

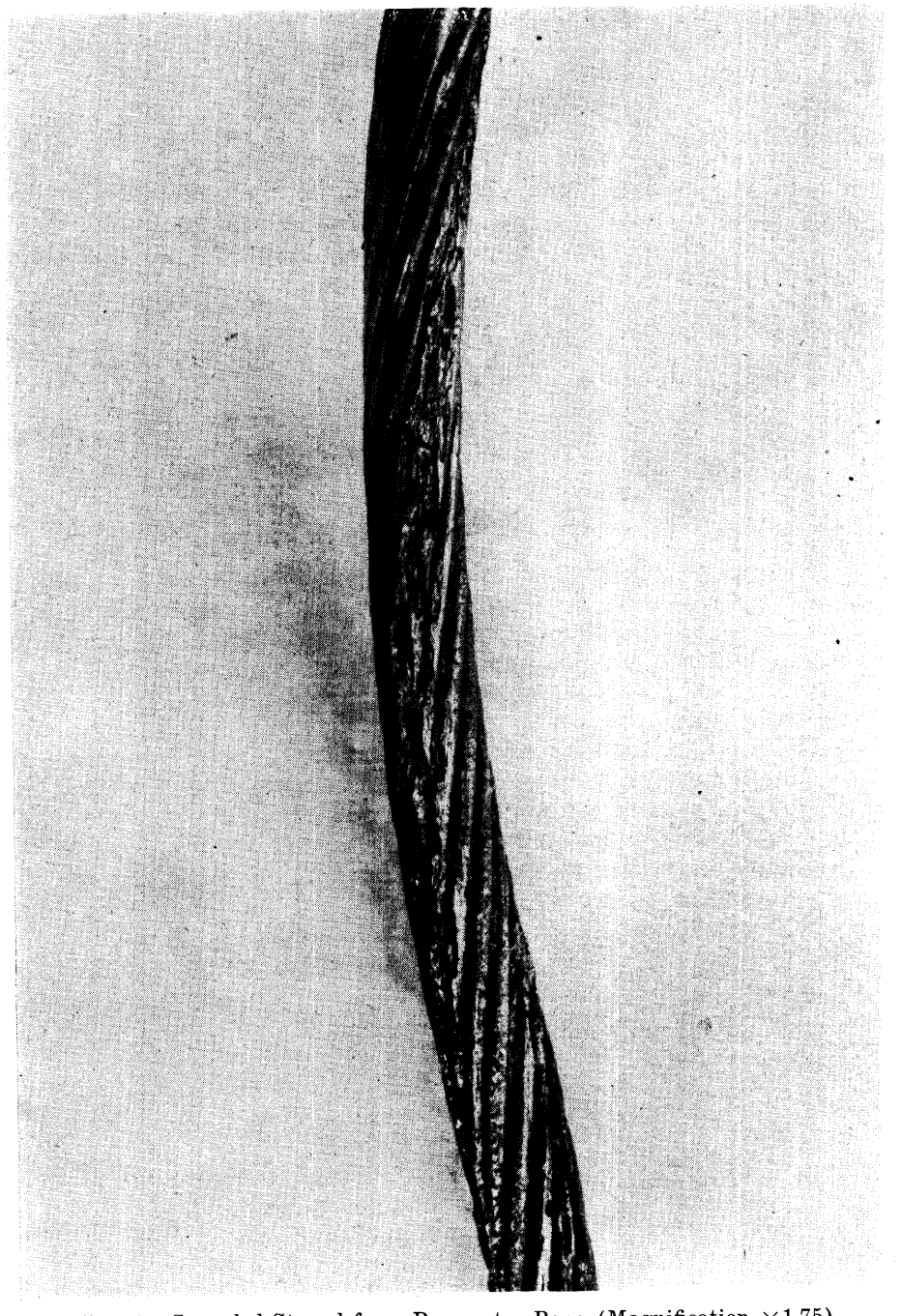


Fig. 1—Corroded Strand from Paymaster Rope (Magnification $\times 1.75$)

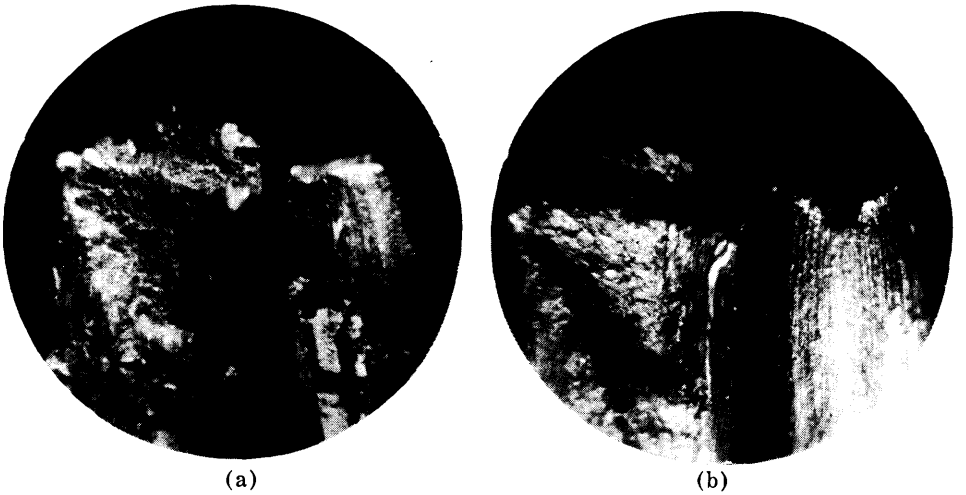
pattern is identical with that of magnetic Fe_3O_4. Fe_3O_4 is formed at low temperatures in atmospheres deficient in oxygen. The Paymaster corrosion product was normal in this respect.

Corrosion had taken place between the wires themselves and not be-

tween the wires and the hemp core. This attack between the wires was probably accelerated by fluctuating stress and perhaps by friction.

Examination of three typical specimens of the rope taken at various points above the break, and not more than 22 ft. from it, showed, in addition to considerable surface wear, bad corrosion and lack of lubrication inside the strands. Of the eleven samples taken from below the break, eight were badly corroded and it is believed that this state existed in large measure before the part of the rope below the break was immersed in water at the bottom of the shaft. When broken in the testing machine, representative samples gave off a fine brown dust in considerable quantities.

The characteristic photograph shown in Fig. 1 shows the advanced corrosion where one strand came in contact with another.



(a) (b)

Fig. 2—Fractures of Wires at Break in Paymaster Rope (Magnification $\times 25$)

Microscopic examination of wire breaks at the point where the cable failed showed two types, as shown in Fig. 2. These were:

(1) A jagged break as indicated in the left-hand specimen of Fig. 2 (a) or 2 (b), which probably took place at a corroded part. This type is common when fracture takes place at a greatly reduced section.

(2) A "drawn" break characteristic of a normal fracture. These two types are readily explained by the table above. Specimen 6 would show the brittle fracture, while for Specimen 1 it would be a drawn fracture.

Fatigue cracks were not observed in any of the number of polished longitudinal sections that were taken near the break.

The corroded wires were subjected to formal tests made for the Committee on a standard Avery bend testing machine in the laboratories of the Ontario Hydro-Electric Power Commission.

In the bend tests it was found that representative wires taken from the Paymaster cable performed badly in comparison with new wires of the same general grade as those from which the cable has been made. Table 2, exhibiting these results, shows that for wires of the same diameter,

less than half as many bends were resisted by the worn and corroded wires as by new wires of the same diameter. Moreover, there was a much greater variation of results for the Paymaster wires, evidently an outcome of their badly corroded and worn condition.

TABLE 2

BEND TESTS IN STANDARD AVERY BEND TESTING MACHINE
MANDRELS 3/16-INCH RADIUS

Nominal Diameter, Inches	Grade	Number of 90-degree Bends to Failure	Average
	NEW WIRES		
0.043	Green Strand	135, 100, 108, 116, 101, 99	109.8
0.043	Special Green Strand	65, 70, 68, 66, 62, 69	66.6
0.066	Improved Plough	36, 36, 33, 38, 33, 32	34.7
0.069	Best Plough	30, 26, 28, 28, 30, 30	28.6
	WIRES FROM PAYMASTER CABLE		
0.043	Special Green Strand — Intermediate	8, 34, 8, 39, 16, 34, 54, 8, 17, 23	25.1
0.066	Special Green Strand — Core	19, 24, 24, 14, 16, 14, 21, 16, 13	17.9
0.069	Special Green Strand — Outside	13, 20, 20, 18, 7, 25, 3, 4, 3, 5	11.8

Fatigue tests were also made on a Haigh-Robertson machine in the laboratories of the Hydro-Electric Power Commission of Ontario. Several specimens from two samples of new wire and several corroded and worn wires from a representative section of the Paymaster cable were investigated. It was assumed that the Paymaster wires were of their original diameter in computing apparent flexural stresses. Stress calculations were based on a modulus of elasticity of 29,000,000 lb. per sq. inch, and no tests were run beyond 10,000,000 cycles. Tables 3, 4, and 5 exhibit the results of the tests.

TABLE 3

FATIGUE TEST RESULTS ON NEW WIRE OF 0.069 IN. DIAMETER
GRADE—BEST PLOUGH: TENSILE STRENGTH 238,500 LB. PER SQ. IN.

Rotary Bending Stress ± lb. per sq. in.	Cycles	Remarks
63,200	10,000,000	No failure
65,650	10,000,000	No failure
65,650*	10,000,000	No failure
67,200	299,000	Failed
68,300	2,446,000	Failed

*Probable fatigue limit

TABLE 4

FATIGUE TEST RESULTS ON NEW WIRE OF 0.043 IN. DIAMETER
GRADE—GREEN STRAND: TENSILE STRENGTH 259,000 LB. PER SQ. IN.

Rotary Bending Stress ± lb. per sq. in.	Cycles	Remarks
67,600	10,000,000	No failure
77,400	10,000,000	No failure
79,500*	10,000,000	No failure
83,500	10,000,000	No failure
83,500	229,000	Failed
85,200	1,334,000	Failed

*Probable fatigue limit

TABLE 5

FATIGUE TEST RESULTS ON STRAND CORE WIRE FROM PAYMASTER CABLE OF NOMINAL 0.066 IN. DIAMETER

GRADE—SPECIAL GREEN STRAND: TENSILE STRENGTH 257,000 TO 280,000 LB. PER SQ. IN.

Rotary Bending Stress ± lb. per sq. in.	Cycles	Remarks
52,000	10,000,000	No failure
52,400	140,000	Failed
52,600	40,000	Failed
54,300	1,172,000	Failed
57,200	1,043,000	Failed
58,850	783,000	Failed

Based on a limited number of test runs, the probable fatigue limit of new Best Plough steel of 0.069 in. diameter was found to be 65,650 lb. per sq. in., or 27.5 per cent of the ultimate tensile strength. For 0.043 in. wire of Green Strand grade the probable fatigue limit was 79,500 lb. per sq. in., or 30.7 per cent of the ultimate tensile strength.

By reason of the variability of the fatigue test results for the Paymaster wire, as disclosed in Table 5, it is impossible to state with any degree of assurance the fatigue limit of this material. It is significant to note, however, that for none of the wires tested did the fatigue limit exceed 52,000 lb. per sq. in., or 19.5 per cent of the original tensile strength as prescribed in the specification.

6. **Failure of Safety Dogs the Secondary Cause.** The safety mechanism with which the Paymaster cage was equipped consisted of four dogs of the Wabi style, indicated as Type A6 in Fig. 5. Rotation of the dogs was limited by shelf angles attached to the drawbar about 3½ inches above the top of the cage. This type of stop is designated as BS in Tables 8 and 9.

It is clear from the evidence adduced at the Inquest that the safety dogs, while coming into action soon after the rope broke, failed to hold the descending cage. They took hold at some 57 feet below the 900-foot level, but, after gouging out one guide for a distance of about 20 inches and the other for 36 inches, disengaged and then in some measure took hold again. The drag and fouling of about 1130 feet of trailing rope may well have been responsible for this initial disengagement. It is evident, however, that the inability of the dogs subsequently to bring the cage to rest, arose in some measure by reason of (1) the space between the shallow teeth becoming clogged with wood shavings, thus offsetting the effect of the serrations and inducing skidding, and (2) a probable faulty setting of the linkage, or fouling of the drawbar stops.

A representative of the cage manufacturer stated at the Inquest that the opposing dogs acting on the sides of the guides should have come within 3 3/8 inches of one another. They do not appear to have done so. The dogs were spot welded in position as they were found immediately after the accident and proved to be 4 1/16 inches apart. The worn guides were about 4 7/16 inches thick in the plane of action of the dogs. Under these circumstances, had the dogs operated equally on the two faces, they would have been unable to bite deeper than 3/16 inch into either face.

It is possible that a piece of rock may have become lodged between the shelf angles on the drawbar and the cage roof, thereby greatly limiting

the dog rotation. This type of drawbar stop is objectionable unless it is housed or protected from fouling by rock or other material getting under the angles.

A detailed analysis of cage safety devices is submitted in Part H of this report and the general conclusions and recommendations of the Committee in respect of them are there presented.

C—HOISTS

7. **General.** It is fortunate for smoothness of operation and amenability to control that mine hoists in Ontario are almost always electrically operated. Steam drives are seldom used and then usually only during sinking. During the past 17 years only one main hoist driven by steam has been installed in Canada, so far as the Committee is aware.

Devices and procedures for ensuring the safety of operation of hoists are discussed in Part H of this report, entitled "Safety Measures and Devices". The Committee has incidentally noted with satisfaction that in Ontario multiple-tooth positive clutches have largely displaced the friction type. They are a simple and compact device for the smallest hoists and are a source of extra safety on the largest ones (14).

8. **Drum Size and Multiple Rope Layers.** Freedom from excessive whipping in a hoisting rope and moderation in wear are promoted by the selection of a hoist with drums large enough to avoid more than two layers of rope on the drum when the cage is at the surface. The Committee noted with satisfaction a definite trend amongst mine operators towards employing large drums with no more than two layers, since with over three layers bad winding characteristics and rope wear are invariably produced. The ideal in British and South African practice is not to exceed two layers, and if possible to use no more than one layer.

Observation of hoists in action made by the Committee confirms the general testimony of others respecting the absence of objectionable whipping between the hoist house and the head sheave when only one layer is used. This, incidentally, lessens the need for idlers and their supporting towers if the distance between centres is not too great.

A common cause of piling layer upon layer is the continued use of a hoist that while satisfactory for shallow workings, is too small when the shaft attains greater depth. The hoist at No. 5 shaft of the Paymaster Consolidated Mines, Limited, which is 5 feet in diameter, is too small for the depth of shaft, and in consequence five layers of rope may pile up on the drums when the cage is at the surface. This predetermines a shorter rope life than would be attained with larger drums under the same operating conditions and indicates a need for especial vigilance in inspection.

Crushing and destructive relative creepage are very likely to occur when multiple layers are employed. The inner layer is subjected to severe treatment in such a situation, due to the cumulative effect of transverse compression. Creeping is inevitable by reason of the extensions and contractions of the rope turns in conformity with the variation of the load hoisted.

No justification on economic grounds can, of course, be entertained for overstepping the bounds of safe practice in the matter of drum size, although it must be realized that a small mine fighting for existence is

tempted to take chances. One mine of this class, known to the Committee, was running out of ore and operated at an "experimental" depth with six layers of rope on the drum. In this case, the mine manager would have been glad to fall back on a regulation and insist upon a new hoist.

If such practices are to be tolerated, the inevitable shortening of life of the hoisting rope should be at once recognized and very special care taken to detect deterioration in it.

There is no doubt that lengthening of rope life and lessening of the chances of failure within what might be considered as a normal life are promoted by using relatively large drums. Bending stresses are kept down to a negligible value when the ratio of drum diameter to rope diameter is as much as 120. The British Wire Ropes Research Committee found that a ratio of 60 to 1 led to complete fracture of a typical regular lay rope at 500,000 bends (63).

The Committee has enjoyed the advantage of having placed before it the observations of the staff of the British Safety in Mines Research Board on the Paymaster Mines accident. That staff has presented the view that a ratio of 60 to 1 is too small and that for a 1-inch rope a diameter of 8 to 10 feet would be more suitable for both drum and sheave. This would involve a ratio of from 96 to 120. It further suggested that if such sizes cannot be achieved, consideration should be given to limiting the life of the ropes to about 18 months.

This Committee is of the opinion that strong efforts should be made to attain a ratio of at least 80 to 100 in future installations and modifications of existing ones. Not only would it keep the bending stresses moderate but would also obviate the objectionable piling up of many layers of rope on the drum.

9. **Drum Grooving and Fleet Angle.** While helical grooving of the surface of a drum lessens rope wear, the so-called parallel grooving, that is grooving in planes parallel to the drum flanges, is unsatisfactory. A rope must climb over the ridges between adjacent grooves and suffer some damage in so doing. Reporting recently on the discarding of certain large hoisting ropes in South Africa, Kenneth Paterson pointed out that when the ridges had not been chipped and ground flat at the points where the rope crossed from one groove to the next, serious breakages of wires occurred at the crossovers (69).

The ill-advised use of parallel grooving on drums was introduced to Canada from South Africa some time ago. A few installations embodying this feature still exist in Ontario, but the operators are aware of the fact that ropes on drums so grooved need special attention, especially if more than two layers of rope are used. It has been found at one property that with flattened strand ropes, rather than round strand ones, a service comparable with that attained from helically grooved drums is obtained.

Ungrooved drums, little used in Ontario, may in course of time become grooved by rope slippage, and, as most of this will occur when the rope is in some measure worn, the grooves incidentally produced will be of smaller radius than that of a new rope. To obviate damage, corrugations of this kind should be ground off.

If the fleet angle is excessive, abnormal slapping of the rope at the drum end will occur, and pronounced wear develop between wraps at the

extreme ends of the drum. As the rope climbs up on the preceding wrap at the crossover, it may jump to the second valley between the coils of the preceding layer. The next layer falls with a "snatch" into the gap so produced, and excessive wear occurs. Cutting lengths of rope from the drum end to change the position of the crossover on it is therefore particularly necessary in cases of unduly large fleet angles.

An appropriate relation between the fleet angle and the character of the drum grooving is necessary if rope crushing and wear are to be minimized.

D—HEAD SHEAVES

10. **General.** Experimental investigation has shown that, other things being equal, the larger the diameter of a head sheave, the greater the endurance of the hoisting rope (33) (82).

The observations of the British Safety in Mines Research Board with respect to the size of drums reported in Article 8 of this report are equally applicable to sheaves. John A. Roebling's Sons Company asserts in "Wire Engineering" (81) that on large mine hoisting installations using 6 x 19 rope considerable fatiguing action takes place with sheaves of 72 times the rope diameter; and further, that this action is materially reduced when the sheave diameter is increased to 80 times the rope diameter, with practical elimination when the sheaves are set at 90 times the rope diameter. Elsewhere, A. E. McClelland, of the Safety in Mines Research Board, states that head sheaves should if possible be of a diameter about 120 times the rope diameter (63).

It is the opinion of this Committee that this diametric ratio, like that for drums, should as soon as possible be brought up to 80 or 100, depending on the structure of the rope.

The use of large head sheaves is advantageous, not only in reducing bending stresses but also in offsetting the de-stranding effect which for a given arc of contact is greater for small sheaves than for large ones (44).

The endurance tests in combined tension and bending of the British Wire Ropes Research Committee (72) showed that the correct sheave diameter is more closely related to the rope diameter than to the wire diameter and should be so expressed. This arises from the fact that there is a resistance to relative movement of the wires in the different layers and the strands are semi-locked.

Unsuitable shape or size of the sheave groove may seriously shorten the life of a rope. A close-fitting circular groove is best. If its radius exceeds by more than a fitting clearance the radius of the circle circumscribing the rope, the effect is as bad as if the groove were several times as wide as the rope. A rope running on a flat drum has been shown to have an endurance of only about 40 per cent of that of a similar rope running in a close-fitting groove (82).

If the sheave groove is so narrow that the rope is pinched at the sides the reduction in life is even greater (82). This effect is very likely to occur when an old rope, of reduced diameter, is used for a long time and wears the groove to a smaller radius than that of a new rope of the same nominal size as the old one. If a new rope is run in a sheave so worn serious damage will speedily occur. Gauges for testing sheave groove radius are in frequent use in the mines of Ontario and should everywhere

be regarded as an indispensable piece of equipment. Once the dimensions of the groove have been found to be unsuitable, regrooving to the correct tolerance should be carried out. In the interests of rope life, and safety, this might well be done at each change of rope.

The British Wire Ropes Research Committee found (72) that ropes tested in grooves formed in plastic wood lasted from 2½ to 4 times as long as similar ropes tested in cast iron grooves. Cast iron was found to be, on the whole, the best of many metals tried for pulleys. Aluminum gave a longer rope life but the pulley tread showed excessive wear.

In Ontario, steel is used for sheaves at the more important properties more frequently than cast iron. For reasons of strength and security this is to be commended. Tread liners are but little employed.

Worn sheave bearings permit wobbling and produce rope vibration. Bad alignment may cause rope and sheave wear due to the crowding against a flange and broken flanges are a source of danger to the rope. More than one case of rope failure or damage in Canada has arisen from this cause.

Both for ease of operation and as a contribution to safety if a rope should break, sheaves should be so designed as to have a relatively low rotational inertia. In a number of cases the unsatisfactory operation of safety dogs has resulted in part from the drag imposed on the spring actuating the dogs by a trailing rope passing over relatively resistant sheaves. This was probably the case in the Paymaster accident of February 2, 1945, as in certain other cases noted in Table 8.

E—HOISTING ROPES

11. **General.** The most vulnerable element in a hoisting installation, and the one that by reason of inherent difficulties requires the most meticulous inspection of all, is the hoisting rope. In considering matters of safety and satisfactory service life of ropes, it is essential, amongst other things, to take into account and review briefly the more important aspects of the following matters:

(1) Characteristics of the rope wire
(2) Structure of the rope
(3) Characteristics of the core
(4) Lubrication of the rope in manufacture
(5) Storage of the rope before being put into service
(6) Capping and installation of the rope
(7) Hoist operating conditions as affecting the rope
(8) Operating stresses in the rope
(9) Factor of safety and capacity factor
(10) Factors leading to the deterioration of the rope
(11) The weakest section of a rope
(12) Inspection of ropes in service
(13) Effect of broken wires
(14) Routine testing of ropes in service
(15) Cropping at the drum end

(16) Turninig of ropes end for end
(17) Shifting of cage ropes to skip duty
(18) Lubrication of ropes in service
(19) Permitted service life of a rope

12. **Characteristics of the Rope Wire.** From several dependable sources the Committee learned during the course of its investigation that the service life of wire ropes purchased during the recent war has been found to be definitely less than that of pre-war ropes. There appears to have been no lessening in the care exercised by the rope manufacturers, or in the traditional inspection procedures followed. It must therefore be concluded that the wire of which hoisting ropes have been made recently was in at least some instances below the former standard. Inspection did not always prevent inferior ropes from passing through the hands of the manufacturer to the user. In consequence, increased necessity has arisen for rigorous wire specifications and close inspection of the product before it is incorporated in a rope.

Efforts to improve the quality of hoisting ropes have in the past been directed altogether too much to securing higher ultimate tensile strength, a property that does not ordinarily carry with it a higher fatigue limit under working conditions. Emphasis should be placed rather on securing ropes of improved fatigue and corrosion-resisting properties.

Unfortunately, resistance to fatigue in bending diminishes to some extent as the tensile strength of the steel employed is increased by drawing. Moreover, when the carbon content exceeds a certain value internal wear alters the wire structure, causing embrittlement and resultant wire fracture (72).

While the use of a material of relatively lower tensile strength will give greater ductility and increased ability to withstand bends, wire of this composition is necessarily softer than that commonly employed and would more readily suffer wear or nicking by reason of pressures and relative movements of adjacent wires.

Provided other desirable qualities are not sacrificed to any important extent, it is advantageous to use a wire that posseses sufficient hardness to give high wear resistance. Determination of the hardness indices that are associated with rope wires of the best overall properties should be envisaged in any programme of wire rope research that may be undertaken in accordance with the recommendations of the Committee set out at the end of this Article.

Rather than sacrifice the advantages of a rope made of wire of high ultimate tensile strength and shorten the service life, drums and sheaves should be used with a diameter 80 or 100 times the rope diameter and not of the minimum permissible diameter of 25 to 50 rope diameters, as sometimes set out in manufacturers' catalogues.

For cold-drawn wire in reversed bending, without axial force, and in the absence of corrosion, the limiting value of the fibre stress either in tension or compression for a large number of repetitions is about one-quarter of the ultimate tensile strength. Similarly, the limiting range of stress in reversed bending is about one-half the tensile strength.

Fatigue resistance is considerably lowered by the presence on the metal surface of grooves, scratches, or corrosion pits, which act as stress-

raisers. Plastic yield mitigates this in ductile material but is largely ineffective in a brittle material, or in one that has been subjected to excessive cold working. The effect of surface imperfections increases in severity the harder the wire has been drawn.

Steels that up to the present have been regarded as having properties that are most desirable for hoisting ropes are not particularly resistant to corrosion. Alloy, or rust-resisting steels tend to be of insufficient tensile strength, brittle or unsuitable for cold-drawing. Evidence placed before the Committee indicated that the attempt to use them has so far not been attended with any notable success.

An awkward circumstance is that cold-working of rope wire accelerates corrosion in acid water (43).

Canadian wire rope manufacturers have in the past purchased their wire from various sources, the only specification being a prescribed ultimate tensile strength and a requirement that the wire must pass certain simple torsion or wrapping tests. Yield point, elongation, reduction in area, hardness, bending resistance, etc., are not called for or determined as a condition of acceptance. The chemical composition of the steel is unknown.

The wire from which the ruptured Paymaster cable was made was purchased to an ultimate tensile strength requirement of between 257,000 and 280,000 lb. per sq. in. It was prescribed that wires must withstand, without breaking or showing any signs of splitting or other defects, not less than 28 twists in 100 diameters. In addition, it was required that the wire be wrapped 8 times around its own part and unwrapped without breaking or splitting. No bend test was specified, as rope manufacturers in Canada and in the United States do not recognize this test as a part of the specification to which rope wire must be furnished.

The Committee is of the opinion that explicit quality specifications for wire to be used in hoisting ropes should be set up and observed by manufacturers and purchasers.

Trade names of the different grades of steel for rope wire are technically meaningless to the user and do not denote any exact standard of strength or endurance. Forty years ago the Transvaal Commission on Hoisting Ropes pointed out that the designations of the steel used for them were "arbitrary and somewhat misleading" (22). In view of the great advances that have been made in the interval and of the possibility of further extension of them through research, the Committee believes that a request for a specification for such material should be placed before the Canadian Standards Association by the mining industry.

In the opinion of the Committee it should be possible to facilitate the securing of desirable properties in rope wire by specifying not only tensile strength and torsional and wrapping resistance, but also such additional matters as

(1) Limits of carbon, sulphur, phosphorus, and other significant elements
(2) Acid or basic process
(3) Cropping of ingots
(4) Alloying to promote corrosion resistance
(5) Limits of non-metallic inclusions
(6) Heat treatment

(7) Metallographic characteristics
(8) Avoidance of overdrawing
(9) Hardness

The Committee is not prepared at the present time to propose a definite steel specification for the wire of mine hoisting ropes. Some time would need to elapse before this could be done with assurance, since the history of a large number of ropes would need to be related to a specification more comprehensive than that available at present.

Some opinion was expressed in the mining areas favourable to the use of Bessemer steel. On the other hand very high grade steels are now made in the electric furnace. The Committee makes no definite recommendation in this matter of process, but desires to draw attention to the problem as one properly falling within the scope of the wire research recommended below.

Evidence of a desire to introduce definiteness in rope wire specifications is found in the British Standard Specification 236 entitled "Round Strand and Flattened Strand Steel Wire Ropes for Colliery Winding Purposes". The following requirements are laid down with respect to chemical composition:

Acid open hearth or acid electric steel;
Sulphur, not exceeding 0.040 (special acid), 0.050 (acid);
Phosphorus, not exceeding 0.040 (special acid), 0.050 (acid).

In general, this British specification represents a small improvement over present practice but something much better should be possible.

It cannot be assumed that the present ultimate tensile strength and torsion test requirements as stipulated by the rope manufacturers infallibly exclude all inferior wire. The recent rapid breakdown of a rope at Hollinger was presumably not forecast by the simple manufacturer's test.

In view of the obviously unsatisfactory situation that exists in respect of specifications for rope wire, the Committee would recommend that a programme of systematic research in this field be promoted in the Province and that the Department of Mines draw to the attention of the Ontario Research Commission the need for such an undertaking.

13. **Structure of the Rope.** So far, there has been less standardization of rope types than the interests of rope users would dictate. With the wide variations in existing operating conditions, some choice of types should, of course, be possible, but manufacturers have introduced constructions which have no special virtue other than the novelty. A greater degree of standardization should be possible. Out of it would come increased consistency of behaviour in service, and earlier development of improved inspection and maintenance techniques.

This Committee concurs in the opinion of the British Wire Ropes Research Committee that if sheaves and drums were always large enough, and excessive bending and the deterioration that arises from wrapping many layers on a drum were avoided, many of the special constructions that have been devised would not be necessary (72). Rope types should be simple and rugged. Highly flexible constructions are advantageous only

when sheaves and drums are too small. Wires should be as large as the sheave diameter will allow.

The British Wire Ropes Research Committee found that as the build up of strands becomes more complex, the interaction of the wires, naturally attended by a partial locking of strands and increased nicking and wear, has an effect that offsets and may even exceed that which is supposed to result from the reduction of bending stress through the use of smaller wires.

The strands should be so designed or built up that the wires outside the strand core have similar and equal support, lest under intense transverse compressive stresses the wires shift their position and become nicked at the points of contact. Such nicking is a focal point for deterioration.

The use of many small wires to attain flexibility introduces a number of undesirable features. They are, by reason of the relatively large surface area, less resistant to wear and corrosion than are larger wires and due to binding under heavy tension they do not act independently. The layers are not free to move on each other. In consequence, the strand becomes in effect semi-solid. The Wire Ropes Research Committee found that the use of a more flexible rope than is afforded by 6 x 19 construction (that is, six strands of 19 wires each) does not appear to be necessary unless the sheave diameter is less than 90 rope diameters.

Since heretofore the progress of wire failures has been the most dependable evidence of dangerous deterioration, it is manifest that any rope type that makes it difficult to obtain information respecting such breakages should be avoided. A large proportion of the wires employed should at some point in their paths come to the surface. Breaks or slackness would then be readily observable, particularly under slack rope conditions. Consider, for example, a 6 x 27 rope, in which only 44 per cent of the wires come to the surface, as compared with a 6 x 7 rope, for which 86 per cent become visible for external inspection. For very large ropes the use of a small number of wires would, however, necessitate using wires that would be too large to be practicable in a rope.

Characteristic evidence of the high vulnerability of small wires to corrosion was afforded by a close examination of unravelled lengths of the rope that failed at the Paymaster Mines. One 2-ft. section cut from the rope at five feet above the break showed 25 per cent of the 72 intermediate wires (0.043 in. diameter) broken, as compared with only 4 per cent of the outer wires (0.069 in. diameter).

As the rope that failed at the Paymaster Mines was of flat strand construction, the Committee gave special consideration to the suitability of this rope. Since for a new rope more wires in the flat strand type come into direct contact with the drum or sheave than is the case for an ordinary round strand rope, it would appear logical that the wear on any individual wire would be less. There is some evidence that this is the case. In one instance a 1-inch round strand rope wound with five layers on a drum of only 54 in. diameter lasted only 2½ months, while a flattened strand rope lasted five months.

Although flat strand ropes may be advantageous in so far as lessened wear and perhaps lower pressure on the core are concerned, the corrosion conditions in the wide contact between strands may be much worse, as in the case of concentration cell corrosion in lap joints. The tendency of a

metal to go into solution is influenced by the concentration of ions of that metal in the solution in immediate contact with the metallic surface. The significance of this factor is obvious when it is remembered that high resistance to corrosion is a prime requisite in a mine hoisting rope. Any feature that promotes corrosion is much more dangerous than one that produces surface wear, since the latter is easily detected. For this reason the Committee is of the opinion that for wet shafts a round strand rope is to be preferred to a flat strand one.

While steel cores have on occasion been used to meet conditions involving very heavy transverse compression, the opinion of experienced operators, in which the Committee concurs, is that for mine hoisting cables fibre cores are almost always to be preferred.

Although the distinctive flexibility and manageability of regular lay ropes is in itself desirable in both elevator and hoist practice, mining operators generally employ ropes with Lang's lay. Much careful experimentation has shown that the latter give higher endurance than regular lay ropes when bent over drums or sheaves. Their wires are curved to a much larger radius and are at the surface for a longer distance, thus giving a much greater bearing area than is given by the wires of the regular lay rope. There is a much smaller reduction of strength by wear since the wear is better distributed.

While preforming the wires to conform to the position that they will occupy in the completed strand removes the tendency of the strands or rope to untwist, there is an additional cold working involved in the shaping of the wires. It would appear, therefore, that the capacity to resist further cold working, and the length of service life, would in some measure be reduced. For this reason the building elevator companies of Canada do not use preformed ropes, as they believe the preforming renders wire breakage the more likely.

On the other hand, the Wire Ropes Research Committee of the Institution of Mechanical Engineers found that the endurance of preformed ropes under corresponding conditions of service, is better than that of ropes made in the ordinary way (72, Fourth Report).

No definite evidence came before the Committee of any distinctive disability of the preformed hoisting ropes that are now in moderate use in the mines of Ontario. There consequently appears to be no reason why, with adequate inspection, advantage should not be taken of the distinctive property of preformed ropes if operators wish to enjoy it.

14. **Characteristics of the Core.** Cores composed of steel or iron wires are less satisfactory for mine hoisting ropes than those of fibre. By lessening the rope elongation they increase the shock or oscillatory stresses. Strands are less satisfactorily bedded and tend to untwist. Rather than attempt to increase the lateral compressive resistance of the rope it would be better to lessen the number of layers on the drum.

The selection of the type and quality of the fibre core of a hoisting rope is a matter having an important bearing on rope life. It was not apparent to the Committee that much testing is done by rope manufacturers to evaluate the relative merits of cores or to control the product that is offered to them for incorporation in hoisting ropes.

Significant properties of hard fibre cores mentioned in the applicable British Standard Specification (37) are:

(1) Appropriate ratio of core circumference to rope circumference
(2) Suitable structure of core
(3) Appropriate number of yarns
(4) Transverse compressive resistance
(5) Low salt and acid content
(6) Low moisture content
(7) Full impregnation with suitable lubricant
(8) Freedom from possible bacteriological deterioration.

The core should support the strands in such a manner as to prevent the wires from being nicked while allowing relative displacement and deformation of strands when the rope is bent over a drum or sheave.

When, for experimental purposes, the core was formed in one case by a closely coiled helix of wire, the lubricant escaped very easily. This type of core did not afford a satisfactory support for the strands and it appeared unlikely that a rope constructed with it would give satisfactory operating results. When a fibre core was formed about the helix the strand support was satisfactory in laboratory tests and excessive leakage from the central passage was avoided. So far as the Committee is aware, no rope of this kind has been tested under practical operating conditions (43), but the advantage of a hollow core into which lubricant could be pumped would obviously be great.

The fibre core, with all excessive moisture removed, should be impregnated with an acid-free lubricating compound up to the extent of its capacity to absorb. This is from 16 to 26 per cent of the fibre by weight. The material used is oil, generally a paraffin base, which may or may not contain bitumen. Impregnation may or may not involve a vacuum treatment. While no definite information appears to be available indicating the ideal oil, it seems likely that a fairly simple hydro-carbon is the best that may presently be obtained.

Heavy bitumen-containing oils are heated and poured on during the closing of the rope. Practice appears to be somewhat standardized, but definite information is lacking regarding the procedure that is found most satisfactory by manufacturers and rope users. Original work in this field is desirable.

The condition of the fibre core of a used rope generally affords some indication of the condition of the metal strands themselves. Cores may be "dry" by reason of loss of grease, by reason of oxidation, or both. Tests for both of these are available.

If examination of the internal wires at the weakest section of the Paymaster rope had been possible before failure, the existing condition would have been known with certainty. The same would probably have been true if the core condition could have been ascertained or predicted. Some guide might be afforded by making a simple solvent extraction of grease in a Soxhlet apparatus in the case of test samples taken from the cage end, and perhaps oxidation tests might also be applied. At least the more useful numerical values for grease content could be reported in place

of observations like "slightly dry", which are statements of opinion and not of fact.

The application of specifications to cores for new ropes might well be considered. The fact that important clauses of the British Standard Specification, 525-1933, were suspended for the period of the war but not finally deleted, suggests that the specification was of some value in raising quality.

15. **Lubrication of Rope in Manufacture.** Lubrication of a rope in manufacture is declared to be for two purposes: (1) to reduce the internal wear from the friction attending the relative motion of the wires, and (2) to protect the wires from corrosion. While certain tests have indicated that the endurance of both regular lay and Lang's lay ropes is increased by oiling and that galvanizing produces a similar effect (33, 82), not all of them do so. As is pointed out in Article 33, there is some doubt if the first purpose is served to any important extent.

The lubricant should fill the slight roughnesses in the surface of the metal and produce a smooth surface. Strong adhesion to the metal and resistance to being squeezed out of the rope is desirable. Free acids and water should be absent.

The addition of zinc or zinc oxide has been used to prevent the so-called "fretting" corrosion (Article 23), a deteriorating effect that is possible, but probably not important, in mine hoisting cables.

Since loss of the internal lubricant occurs as the lighter fractions of the oil are squeezed out between the wires as the rope deforms, it is important, amongst other things, to select a lubricant that while lessening friction and inhibiting corrosion to a high degree will maintain a film that affords a high resistance to breakdown. The Committee is of the definite opinion that lubricant cannot be forced into the core after the rope has been closed.

16. **Storage of Rope before Installation.** Since spare ropes may be stored for several years before being installed there is danger of deterioration unless stringent precautions are taken. They should be accommodated in clean, dry, indoor quarters. Smoke, fumes, moisture, and contact with the ground or cinders are potential hazards. No specific evidence of important effects from this cause was presented to the Committee.

17. **Capping and Installation of Rope.** In most cases hoisting ropes in Ontario and Quebec mines are attached to the cage or skip by wire rope clips rather than by sockets. Socketing can be and is made dependable but Ontario mine operators on the whole display more confidence in the clips. An obvious advantage is that whatever their condition may be they can be readily inspected day by day. The Committee is disposed to favour their use.

Whatever plan may be adopted for installing a rope, great care should be taken to see that it is wound on the drum under sufficient tension to prevent it working back on the drum and "birdcaging", with consequent severe damage to or loss of the rope, a situation that has frequently developed. Satisfactory results have been achieved by passing the rope from the drum over the head sheave through an auxiliary sheave at the cage and back up to the head frame where it is secured. Lowering the cage on this bight of rope develops the necessary tension. It also makes

possible the removal of all turns from the drum and the complete rewinding under adequate tension.

Handling and hoisting convenience are furthered by taking at least some of the "spin" out of a rope, but as against this there is a loss of spring or cushioning effect in meeting shock loads or irregular braking. It is a case of realizing an advantage at the sacrifice of something else that is in itself desirable.

18. **Hoist Operating Conditions as Affecting the Rope.** Due to current methods of operating mine hoists, the tension on a hoisting rope will fluctuate considerably while either raising or lowering a cage or other conveyance.

Longitudinal oscillation will arise from either acceleration or retardation of the hoist. Retarding a descending cage by braking the drum produces an increase in the rope tension as the momentum of the cage must be arrested. Similarly, braking when the cage is ascending diminishes the tension. Oscillations accompany either of these actions. Should the deceleration exceed about one-half the acceleration of gravity the tension in the rope when the cage is ascending may fall to zero during the oscillations and then the cage falling on the slack rope produces a very large tension. Particularly large tensions may arise from "grabby" brakes. For a *constant* deceleration the theoretical mean value of the tension thus resulting (sometimes called the equilibrium tension) will exceed the static tension by an amount equal to the latter tension multiplied by the ratio of the constant deceleration to gravity. Such excess tensions are created several times during the hoisting of a load.

As an illustration, let W = the weight of the conveyance and contents, g = the acceleration of gravity, and a = the constant rate of deceleration. Then the combined pull on the rope is

$$P = m\ (g + a) = W\ (g + a)/g$$
$$= W + W\ a/g$$

If $a = 8$ ft. per sec. per sec. and $g = 32$ ft. per sec. per sec., the addition pull caused by deceleration is $W \times 8/32 = W/4$.

Important oscillatory effects may be produced by starting to hoist with a slack rope. The magnitude of these is considered in Article 19.

Irregularities of the drum surface or multiple layers of rope on the drum will also produce shock stresses in the rope. These matters have been discussed in Part C.

Investigation of the shock effects of dumping rock into skips at loading pockets indicates that these are not nearly so great as might be expected, particularly in the case of deep shafts, where the elastic extension of the cable exerts a marked damping effect (44). These should, of course, be taken into account in considering the sufficiency of the apparent factor of safety.

19. **Operating Stresses in Hoisting Ropes.** The various types of stresses that may arise in a mine hoisting rope or its constituent parts may be indicated as follows:

(1) Static stress and its variations
(2) Oscillatory stresses arising from
    (i) acceleration

(ii) deceleration
(iii) starting with slack rope
(iv) cage striking obstructions
(v) synchronization of oscillations

(3) Bending stresses

(4) Transverse compressive stresses

(5) Combination of stresses

(6) Non-uniform distribution of rope stresses amongst the wires

Static stress, that is the stress arising wholly from the dead weight of conveyance, load hoisted, and the weight of the rope will vary between that existing when the empty conveyance is at the surface and, on the other hand, when the loaded cage is at the bottom of the shaft. It is readily enough computed for any position of the cage or skip.

Dolan and Jackson (44, Nov. 1939) point out that the actual maximum stress in a rope due to deceleration is approximately double that deducible from the ratio of the average deceleration to the gravitational rate of acceleration. For a rate of deceleration of 4 ft. per sec. per sec., the maximum increase of stress is $2 \times 4/32 = 25$ per cent.

While the shock effect of starting a hoist at a high rate of acceleration with slack in a very short rope may be serious, these added stresses are much less in ordinary installations than is commonly supposed. Some tests carried out in 1877 seemed to indicate alarming shock stresses from this cause but Dixon and Hogan, in reviewing them, consider that the results have little value, in the absence of details respecting the hoisting conditions, such as length, size, and construction of the rope, the acceleration of the hoisting engine, etc., (41).

Pursuing the matter, Hogan found from actual decelerometer records that a rope 1304 ft. long from sheave to capel, starting with an 18 in. slack, was subjected to a peak stress 2.06 times the static tension, while starting with tight chains gave 1.60 times the static tension (51). Boomsliter's theory gave 2.11 as the ratio for starting with 18 in. slack, as compared with the 2.06 found by experiment.

Other experiments cited by Dolan and Jackson (44) showed that for a 4500-ft. wind, starting with 12 in. and then 22 in. of slack at a normal acceleration of 1.8 ft. per sec. per sec., gave no appreciable increase in stress. Calculation showed that to cause a 10 per cent increase in stress over the "no slack" condition 28 in. of slack would have been necessary.

Since the resilience or strain-energy that can be stored in a rope is dependent upon its volume, obviously for a particular prescribed stress a short rope is much less able to absorb shock than a long one of the same diameter. For shallow workings especial care should therefore be taken to avoid slack in ropes.

The reversal of bending of a rope in the same plane is particularly trying. The British Wire Ropes Research Committee found that the number of bends required to produce fracture is halved, and that the tension that could be taken by the rope for the same endurance is approximately three-quarters of that for bends all taking place in the same direction (72, 5th Report).

The current practice of incorporating in the factor of safety whatever allowance is made to cover bending stresses, while satisfactory if the

factor is large enough and is always observed, may be an illusory one. It has grown up from the lack of a method of computing bending stresses accurately. But although such stresses may be uncertain so far as actual magnitude is concerned, they are definitely large in those installations where drums and sheaves are small in relation to the rope diameter. The Wire Ropes Research Committee expresses the view that "almost invariably the bending stresses are greater than the direct tensile stress due to the pull" (72).

It is a fortunate circumstance that for cold-drawn wire such as is used in hoisting ropes plastic yield takes place at low stresses. Initial differences in tension between the various wires thus tends to be equalized before excessive stresses are developed (43).

20. **Factor of Safety and Capacity Factor for Hoisting Ropes.** The two methods of allowing for sufficient margin of safety between the working load and the ultimate breaking load of the rope are:

(1) Static factor of safety

(2) Capacity factor

The factor of safety, as usually interpreted, is the ratio of the test strength of the rope at purchase to the maximum load suspended, plus the weight of the cable from the head sheave to the cage or skip. It consequently varies with each position of the conveyance in the shaft, although the weight of the conveyance and its contents may be constant.

In Great Britain and South Africa the factor of safety may be from 10 to about 7, the lower figure being used for deep shafts. In North America the factors of safety are lower. The United States Bureau of Mines recommends (55) that the factors of safety for hoisting ropes be as indicated in Table 6.

TABLE 6

FACTORS OF SAFETY FOR HOISTING ROPES FOR VARIOUS DEPTHS OF SHAFTS

Length of rope, feet	Minimum factor of safety for new rope	Minimum factor of safety when rope must be discarded
500 or less	8	6.4
500 to 1000	7	5.8
1000 to 2000	6	5.0
2000 to 3000	5	4.3
3000 and more	4	3.6

The Ontario Regulations Governing the Operation of Mines prescribe for new installations in shafts less than 2000 feet deep a factor of safety of not less than 6; in shafts over 2000 feet and less than 3000 feet deep, not less than 5. There is no direct stipulation for cases where the shaft is 3000 feet or more in depth. However, no hoisting rope is to be used for raising or lowering of men when its factor of safety based on its existing strength and dead load falls below 4.5.

As compared with the U.S. Bureau of Mines recommendation, the Ontario regulations are more lenient for ropes up to 1000 feet in length, while the rules are the same for the depth range from 1000 to 3000 feet.

For new rope the Ontario requirement for depths over 3000 feet is a factor of safety of at least 4.5, although the exact value is undefined. The provision is therefore more severe than the American requirement of 4.

Dolan and Jackson, after examining the relative mining accident rates in the United States and in South Africa from 1911 to 1932, reported that while in North America lower factors of safety are accepted than is the case on the Witwatersrand, this circumstance does not influence the rate adversely (44).

There is much to be said for the view of the British Wire Ropes Research Committee that the ratio of the rope strength to the tensile load should not be called the factor of safety, because the bending stress on the wire, which is usually greater than the direct tensile stress due to the load, is neglected. An increase in the apparent factor of safety based on pure tension only arising from the selection of a larger rope may result in an actual reduction of safety, since the increase in bending stress may exceed the decrease in direct tensile stress. In any use of the term "factor of safety" it should be clearly understood that this figure does not mean precisely what it says and that it must be large enough to cover very considerable uncomputed dynamic and bending stresses.

The choice of factor of safety should be such that the combination of the computed tensile stress and the estimated bending stress should not exceed the fatigue limit of the wire. If it does, then even without the added deteriorating influences of corrosion and wear the rope will have a comparatively short life. When a factor of safety of as little as 4 on ultimate strength is used in ordinary steel structures it is presumed that all known stresses have been computed or estimated and for the factors of safety of 4½ or 5 employed in deep level hoisting at least as great precaution should be taken. On a *fatigue* basis this gives a true factor of safety of 2½ or less.

The Committee has given consideration to the method of determining rope size by making use of the so-called "capacity factor", originally proposed by J. A. Vaughan in a notable paper "The Factor of Safety of Wire Ropes Used for Winding in Mine Shafts" (76). This was based on the assumption, often justified by experience in South Africa, that the capel or cage end of the rope is generally the weakest section. The required rope strength on installation was fixed at a certain number of times the weight of the supported conveyance and its contents. This number was then the factor of safety at the capel and its magnitude was sufficiently great to ensure that the factor of safety at all other points of the rope was adequate.

While this method affords a certain rough convenience through obviating the calculation of the actual factor of safety with various hanging lengths of rope, it is illogical in principle. For a given diameter and strength of rope, the same attached load might be permitted regardless of the depth. Applied to extreme depths, the factor of safety would approach zero.

A much more important objection to the method, however, is the fact, set out in Art. 26, that the weakest section of the rope is likely to occur anywhere in its length and is generally *not* at the capel. The fundamental assumption of the method is therefore not valid in Ontario.

The Committee consequently sees no reason for departing from the

prevailing Canadian practice of basing security on the computed factor of safety at the sheave when the conveyance is at the bottom of the shaft, but recommends that this factor of safety shall take the bending stress into account.

21. **Causes of Rope Deterioration.** Deterioration of a hoisting rope at any situated point may be due to some or all of the following causes:

(1) Overstressing
(2) Corrosion
(3) Wear
(4) Embrittlement

22. **Overstressing.** Progressive deterioration through stress effects may, as pointed out by Carlson (44, June, 1940), arise through the operation of some or all of the following causes:

(1) Variation of static stress due to normal placement and removal of load.
(2) Reciprocating stress cycle occurring during each wind due to change in the hanging length of the rope and the force of inertia exerted during normal braking
(3) Vibration, uneven braking, and irregular shaft guides
(4) Shock loading
(5) Bending at sheave and drum
(6) Torsional stresses
(7) Crushing stresses

While no dangerous deterioration through the most unfavourable combination of the stresses enumerated above would occur so long as the combination is within a certain recognized limit for each material, if the sum of them is above such limit, ultimate fatigue will follow and failure occur.

Failure of a rope solely through the total stress in the wires exceeding the fatigue limit, which is about one-quarter of the ultimate tensile strength, is fortunately rare. Instances are on record, however, of this occurring through the overloading of certain groups of wires in a rope as a result of lack of equalization of tensile stresses in spinning, or due to difference in wire properties, such as the use of overdrawn wires in a metallic core.

If a wire breaks in tension with little or no local contraction, the probable cause is fatigue. A dark segment at the edges of the fracture is an indication of a previously existing fatigue crack.

Numbers of instances have been reported outside of Canada of ropes failing by fatigue inside a drum because the rope was not properly clamped to the spokes and flapped about in such a manner that repeated reversed bending caused fracture (64).

23. **Corrosion.** It is important to realize that the steel of wire ropes will corrode in pure water when oxygen is present and that deterioration by corrosion is by no means limited to operations in the presence of acid-bearing waters or to salts in solution.

Complete enclosure of the rope between the hoist house and the shaft house would not dispose of the problem of corrosion, as ropes are bound to become wet from shaft water. Moreover, moisture contained in the air trapped in or entering into the interior of a rope will suffer condensation as the rope in hoisting moves into regions above or below ground where a lower temperature exists.

The conditions under which mine ropes operate are ideal for corrosion—high humidity, free water, acids, mud, and temperature fluctuations in the rope. Corrosion plus flexure are a powerful combination resulting in the rapid destruction of steel.

Quantitative evidence exists that a deteriorating wire under reversed stress may corrode 200 times as rapidly as the same wire at rest. New surfaces are continually exposed by the bending, while the corrosion products and etched areas act as stress-raisers. It may safely be assumed that all corrosion of mine hoist ropes is stress corrosion, and when the former term is used, the latter is meant. Godfrey, in an elaborate research, showed among other things that a polished wire gave higher fatigue values than the original drawn wire, which unavoidably had scratches or slight grooves on its surface (97).

Deterioration produced by a combination of corrosion and fatigue, known as "corrosion-fatigue", may be much more severe than that due to either influence acting separately. Fatigue is likely to manifest itself by cracked or broken wires, the characteristic function of which may be readily recognized. Corrosion may take place between strands, as in the Paymaster case, with the result that the strength of the rope may fall to one-third of the original without external evidence.

Nicking or wear of the wire surfaces inside the ropes facilitates corrosion and, in its train, corrosion-fatigue. In every practicable way, therefore, surface damage or roughening of ropes should be avoided, since they accelerate both corrosion and fatigue.

Reversed bending tests reported by Dixon, Hogan and Robertson (43) indicated that wire which reached a fatigue limit of about $\pm$ 68,300 lb. per sq. in. under dry conditions with about 1,000,000 reversals, failed with the same number under a spray of London tap water at about 47,600 lb. per sq. in., and at about 17,000 lb. per sq. in. under 10,000,000 reversals. The resistance was still falling, so that it was no more than one-quarter of its value for dry wire. This occurred in a spray of water that was much less corrosive than that found in many mine shafts.

Corrosion, as an antecedent of fatigue, may be anything but obvious. Dixon, Hogan and Robertson report a group of ropes that failed through corrosion-fatigue when the amount of corrosion was "insufficient to dull the appearance of the wires and generally took the form of a slight pitting or roughening of the surface only visible under a magnifying glass".

It may generally be said that in the case of ropes that have failed in service in Canada or elsewhere, or that on removal have shown marked signs of deterioration, by far the most frequent of the obvious defects has been a marked internal corrosion augmented, perhaps, by internal wear. As in the case of the Paymaster Mines rope, the failure of which brought about the present investigation, this is often unaccompanied by any readily detected external impairment except surface wear. Corrosion takes precedence over all other causes of failure because it has defied

effective detection by present methods. It is obvious that fatigue failure of a wire will be promoted by the virtual notching or nicking that accompanies corrosion, but corrosion is really the basic cause of breakdown.

Microscopic examination of cross sections of corroded ropes has shown that the initial corrosion is found chiefly on the inside surfaces of the outer wires when they make contact with the next layer. As corrosion proceeds it is found to be most marked at the contact surfaces of strand with strand, as in the Paymaster cable (Fig. 1).

Strangely enough, little corrosion has been found next the fibre core and so core or lubricant decomposition products appear to have little influence in the rope breakdown. The water that causes the principal damage penetrates but a short distance into the interior of the rope. This suggests that the prime function of an internal lubricant is to seal the rope against the entry of water.

Studies of deterioration at contact surfaces of metal parts in machines carried out in recent years have shown that an effect analogous to corrosion may be produced by mechanical action. This is now generally termed "fretting corrosion". References to a number of papers on the subject are to be found in Section 4 of the bibliography contained in Appendix I.

Typical examples of fretting corrosion have been examined in the laboratories of the Ontario Research Foundation. A number of fatigue test specimens that had been broken in a rotating beam machine showed marked fretting corrosion on the enlarged portion of the specimen that was gripped in the collets. The specimens had been in the machine not more than four days at ordinary room temperature and at about 40 per cent relative humidity. Chemical corrosion to the extent observed could not have taken place under these conditions. Grinding off the pitted surface of steel so corroded does not always restore its fatigue strength (124).

It has been suggested that a hoisting rope, consisting of a series of metal parts in the form of wires, each one rubbing on its neighbour, might develop fretting corrosion. The Committee doubts if this is the case. The conditions under which fretting corrosion has been identified involve close fitting parts in which lubrication is ineffective because the boundary condition has been reached under the high pressure applied (122). In a hoisting rope it is a matter of slow movement of ill-fitting parts rubbing against each other.

Once corrosion has started, however, and the smooth contours of the wires destroyed by the etching and corrosion products, the relative motion of the wires will accelerate their own destruction. Friction is increased by the rough surfaces and wear and corrosion proceed hand in hand. Corrosion fatigue cracks may be formed, although they were not seen in several sections of the Paymaster cable taken near the break.

Constant effort should be exerted to prevent corrosion and to detect it when it has taken place. So far, the only practical means of retarding corrosion appears to be the addition of "dressing" to the rope. Some other effective means might conceivably be developed through research. The use of corrosion-resistant steel of the nickel-chromium type does not seem to be a satisfactory solution owing principally to the high cost and mechanical properties of these steels.

The provision of protection using metal coatings, either noble or base, to steel should be studied. Protection by zinc was recommended by the staff of the British Safety in Mines Research Board in commenting upon the Paymaster failure.

The paramount influence of corrosion on rope deterioration and the necessity of combating it makes it most desirable that a thorough study of the whole matter be included in the programme of research recommended at the end of Article 12.

24. **Wear.** Hoisting ropes suffer external wear through rubbing against the drum and the head sheave, against neighbouring turns of rope on the drum, or against obstructions in the hoist house, shaft house, or shaft.

Creeping or slipping of the rope in the drum is inevitable as is, in some measure, the external wear that proceeds from it. When the rope is wound on the drum a certain straining or elongation is produced. When it is unwound the tension on the rope may be less or more than when the winding took place. Creeping with respect to the drum or with respect to adjacent coils of the rope occurs and with it surface wear.

Slipping of the rope on the sheave may occur during periods of non-uniform acceleration or deceleration if the friction is insufficient to accelerate or decelerate the sheave at the same rate as the rope. Such slips may be avoided or lessened by reducing the rope oscillation, by reducing the inertia of the sheave, or by increasing the coefficient of friction between the rope and the sheave. This last remedy, however, would tend to increase wear from other causes than the one under consideration.

The Committee recommends that when abrasive wear on outside wires at any section exceeds 20 per cent of their area the rope be discarded.

Internal wear, unaccompanied by corrosion, is seldom the cause of rope breakage. This type of wear is promoted by the winding of several layers of rope on a drum, particularly if it is of small diameter, or use of a sheave with a groove that is too small. Severe transverse compression of the rope produces distortion, internal movement, and abrasion.

There are two types of wear, (a) abrasive and (b) plastic. In abrasive wear, the commoner type, material is removed and the cross-sectional area reduced. In plastic wear the cross-section is deformed but no material is lost.

Further investigation is required before any definite correlation can be made between the grade of steel and its resistance to abrasion. The soft ferrite of the decarburized skin has low abrasive resistance and the thinner this skin the better.

Plastic wear, a deformation rather than a loss of section, is created by intense bearing pressures between the wire and the drum, sheave, or any fixed object. Cold working has reduced the capacity of the wire to undergo further cold deformation and hence it is brittle and readily fractures when bent. Cracks started in the brittle surface layer extend into the ductile metal because of the high intensification of stress at the root of the crack.

Marked indication of cold working, or so-called plastic wear, was found in the broken Paymaster cable. Several strands from this 6 x 27 flat strand rope were examined and typical cross sections of the deformed 0.069-in. outside wires were carefully measured. Enlarged cross sections

are shown in Fig. 3, the original size and shape of the wires being indicated by dotted lines.

Sketches (a), (b), (c), and (d) all show the effect of bad corrosion as well as cold working. Case (b) is perhaps the worst, as is indicated by a groove corroded out of the inside surface into which a small wire fitted closely.

Sketches (e), (f), and (g) are sections taken in eight inches of length of the same wire. This gives a good idea of the variation which exists in cross sections from an outer contact surface to inner surfaces due to the lay of the rope. The effect of corrosion is very well shown in (f) and (g), the differences between the original and final sections being due to this action.

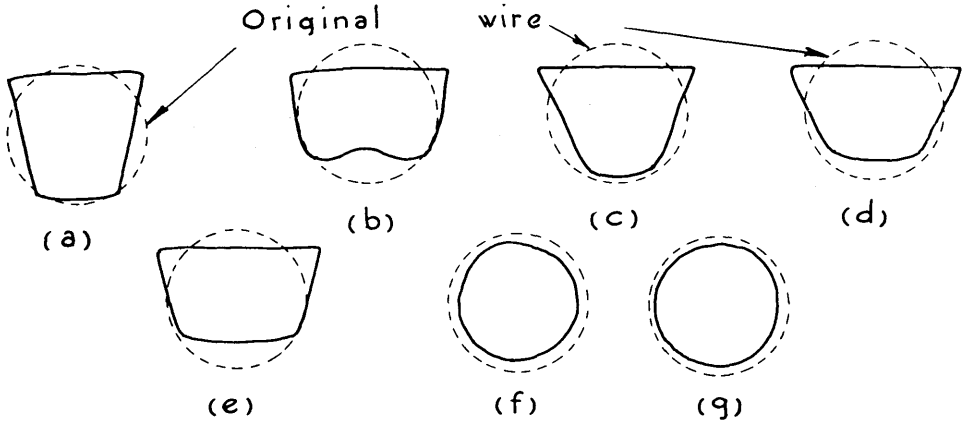


Fig. 3—Plastic wear of wires in Paymaster Rope

25. **Embrittlement.** Dixon, Hogan and Robertson, after a lengthy investigation (43), expressed doubt in 1936 of the existence of local heating at points of contact of the surfaces of hoisting ropes with other surfaces, although such might occur in haulage ropes. They reported that they found no instance of the formation of "martensite" on the surface of the many hoisting ropes they examined in the course of their investigation.

A. E. McClelland, writing in 1943 (64), asserted that while deterioration is seldom of importance in hoisting, where the rope is normally prevented from striking obstructions, it is common in haulage operations. Frictional heat produced by rubbing, grinding, or striking on other metal objects, may raise the temperature of small surface areas of the wire above 700° Centigrade. Rapid cooling then produces a hard and very brittle layer of material on the crowns of the wires that "appears to be martensite". The layer so produced cracks readily when the wire is bent in service. These cracks act as stress-raisers and initiate the formation of fatigue cracks in the normal metal at the base of the surface cracks. Fatigue fractures resulting from such surface embrittlement always occur at a worn crown and the crack always originates on the worn side of the wire.

Recent work done in the research laboratories of the International Nickel Company of Canada supports the view that martensite, rather

than some other material, is formed. Since its hardness is from 675 to 725 Brinell it is very brittle and cannot bend without cracking. Cracks so produced act as notches, creating stress concentrations lending to early fatigue failure.

Embrittlement of the kind above described may occur where the rope comes in contact with the grooves or flanges of the drum, and in multiple-layer winding, particularly at lifters or crossover points. Rubbing of the rope on itself is found to be a frequent cause—one that is most pronounced with large fleet angles.

It is probable, too, that a prevalent source of embrittlement occurs at the points of contact of the rope with the head sheave. The severity of such effects will depend on the fleet angle and the size of the sheave groove.

In view of recognized embrittlement at points of violent contact of the rope with other metal, or with itself, and the resultant promotion of fatigue, there is need for the utmost care in controlling the extent and violence of these contacts. Close and persistent observation of running ropes is essential in order to discover all important sources of this deteriorating influence.

A circumstance mitigating the danger arising from surface embrittlement is that defects which affect the surface of the wires are the least likely to cause an accident. Since the external wires will fail before the internal wires, there will in most cases be ample warning before the rope breaks. About 50% of the wires are in the outer surface of the strands, and 50% are inside. The outer wires also go inside. Any source of failure which affects the outer wires will ultimately destroy 50% of the total number. Any source of failure affecting the inside wires will destroy all the wires. The first condition is not likely to be dangerous because the destruction is taking place where it can be seen and does not involve all of the wire. In the second case, all the wires are being destroyed at locations where the destruction cannot be detected.

26. **The Weakest Section of a Rope.** In the past there has been a general opinion amongst British and South African mining engineers that the weakest section of a hoisting rope is at the capel end, that is the end next the cage or skip. Theoretical studies of wave stress reflection and kinetic oscillatory stresses generally would suggest this, in that fatigue, unaffected by corrosion would be most likely at this point. While Dolan and Jackson in their notable study (44) refrain from being dogmatic on the matter, they suggest that "the evidence points to the capel end as being the weakest section, when factors such as ultimate strength, ductility, bend and torsion tests are collectively considered".

Since the state of internal lubrication has an important bearing on the location of the weakest section of a rope, it is useful to consider the analysis by Dixon, Hogan and Robertson (43) of the relation of these two things in the case of 40 ropes that failed in service. The critical condition of dryness and dustiness throughout the cross-section with severe internal corrosion was found at the capel only about one-third as often as it was found elsewhere.

The same invesigators found that out of 85 ropes that broke in service, 22 per cent broke at, or within 10 feet of, the capel for other reasons than faulty capping. They reported also that breakages due to internal

deterioration had been found more usual in those parts of the rope that lie between the capel and the drum when the cage is at the collar of the shaft, or between the sheave and the drum when the cage is at the bottom of the shaft. These are the portions that are exposed to the atmosphere for the longest times, as the conveyances are stationary more often than they are moving.

They also reported that of the 163 ropes from which recapping samples were examined, 27, or 17 per cent, were replaced by reason of the discovery of deterioration close to the capel.

A particularly vulnerable part of a rope is that which is over the head sheave when the load is accelerated from the rest or towards the end of deceleration on the upward wind. If it should happen that this section later climbs up on a preceding layer on the drum while acceleration is still proceeding, the combination of circumstances will be particularly trying. This happened in the cases of two important ropes reported by Paterson (69). In relief, it was decided to cut 150 feet off the capel end of each rope so that the damaged sections would be wound on the drum during the full-speed portion of the wind instead of during the acceleration period.

Examination of the records of rope breakage at Ontario mines shows that there is no particular section at which failure is much more likely than at any other. Table 7 exhibits the situation in this regard. As is there indicated, out of the 48 breakages listed, failure occurred in the 6-ft. length of rope immediately above the conveyance at most in only 17 instances, or 35% of the cases. Routine tests of rope cut from the capel end would therefore in 65% of the cases not have disclosed the weakness that existed at some point outside this short length.

The results of the tests made on various sections of 44 discarded ropes by the Department of Mines Rope Testing Laboratory during the last six years show that the weak section may occur at almost any point along the portion of the rope hanging in the shaft. A study of these results shows that for the 41 ropes in vertical shafts the weak section was in no case at the capel. It occurred in the bottom 10 per cent of the rope length up to the sheave with the conveyance at the bottom in only 15 per cent of the cases. Failure at the capel occurred in only one of the three inclined shaft cases.

TABLE 7

DISTANCE OF ROPE BREAK FROM CONVEYANCE IN CASES OF ROPE FAILURE IN ONTARIO MINES

Note: Shafts vertical except where otherwise indicated.

Name of Mine	Date of Break	Primary Cause of Break	Distance of Break from Conveyance, Ft.	Remarks
Aunor	Nov. 15/44	Faulty braking	30	Slack rope
Barry-Hollinger	1930-31	Unsuitable rope	500	.....
Bidgood	Jan. 10/45	Kinking	235	Overwind earlier
Bonetal	Jan. 26/41	Crosshead froze to rope.	12	.....
Buffalo-Ankerite	Jul. 29/43	Brake failed to hold.	4000	Broke at spout

TABLE 7—*Continued*

Name of Mine	Date of Break	Primary Cause of Break	Distance of Break from Conveyance, Ft.	Remarks
Chesterville	Jan. 21/39	Overwind	0	Limit switches froze
Coniaurum	Feb. 22/35	Frozen sheave	1500	Broke at sheave
Creighton	Jul. 30/29	Skip struck pier	21	Inclined shaft
Creighton	Aug. 6/33	Skip jammed	Close to skip	Inclined shaft
Creighton	Jan. 31/37	Skip jammed	0	Inclined shaft
Creighton	Dec. 23/41	Skip axle broke	120	Inclined shaft
Delnite	Mar. 2/37	Frozen counter-balance.	Not reported	.....
Dome	May 2/45	Overwind	0	.....
Falconbridge	Mar. 27/37	Slack rope	200	Skip caught in tipple
Falconbridge	Jul. 19/37	Overwind	Short distance	.....
Falconbridge	Dec. 22/40	Overwind	Short distance	.....
Faymar	Aug. 3/40	Corrosion	250	.....
Golden Gate	May 2/38	Kinking	Few feet	Bailer
Hallnor	Jun. 10/43	Faulty braking	200	.....
Hollinger	Jun. 30/26	Brakes failed	One at drum; one at skip	Both ropes broke
Hollinger	Mar. 21/35	Corroded, brittle rope.	70	.....
Hollinger	Jun. 5/39	Kinking	200	Skip stuck in dump
Hollinger	Nov. 10/43	Skip jammed	73	.....
Jellicoe	Feb. 9/40	Weak rope	165	.....
Kerr-Addison	Oct. 7/39	Overwind	1.0	.....
Laguerre	Oct. 29/41	Cage froze to guides.	0	Slack rope
Leitch	Nov. 10/42	Worn rope	950	.....
Macassa	Dec. 18/36	Weak rope	30	.....
Macassa	Aug. 28/38	Overwind	0	.....
Macassa	Dec. 30/39	Overwind into sheave.	0	.....
Macassa	Mar. 15/40	Corrosion	2050	.....
Macassa	Nov. 17/42	Skip fouled	31	.....
McIntyre	Feb. 10/25	Socket failure	0	.....
McIntyre	Nov. 1/25	Socket failure	0	.....
Morris Kirkland	Aug. 12/40	Load fouled	130	.....
Omega	Sep. 23/43	Corrosion	108	.....
Pamour	May 24/38	Sheave axle broke	350	.....
Paymaster	Sep. 10/40	Overwind	0	.....
Paymaster	Aug. 5/42	Overwind	100	.....
Paymaster	Feb. 2/45	Corrosion	1130	.....
Sturgeon R.	Aug. 27/42	Clutch failed	2600	.....
Sylvanite	May 29/30	Overwind	0.2	.....
Toburn	Jul. 3/40	Overwind	0	.....
Upper Canada	Aug. 28/40	Weak rope	700	.....
Upper Canada	Nov. 20/41	Sheave broke	625	.....
Wright-Hargreaves	Apr. 1/38	Corrosion	127	.....
Wright-Hargreaves	Jul. 19/43	Corrosion	1738	.....

27. **Inspection of Ropes—traditional methods.** Methods of inspection of mine hoisting ropes hitherto in use have rested very largely on the observation of

(1) Appearance of the worn surfaces in relation to wear and corrosion

(2) Condition of the unworn parts of the wires in relation to nicking and corrosion

(3) Presence of broken wires

(4) Presence of loose wires, waviness, or displaced strands

(5) Change in diameter of rope at several points along its length

(6) Accelerated elongation of the rope

External wear and corrosion are relatively easy to detect and an estimate of the loss of section of the rope due to them may be made by methods that are well known. Internal damage is much more difficult to discover.

The practicability of laying open the interior of a rope in service for inspection by applying to it an untwisting couple with the aid of two properly spaced opposing levers clamped to the rope was considered by the Committee. While under a light load, perhaps no more than its own weight, a rope could be so opened, the concensus of opinion is that permanent damage might be done to the rope by such drastic treatment. Moreover, the internal examination of the strand would not be possible by this device. The Association of Mine Resident Engineers on the Witwatersrand in a statement made in 1940 condemned as bad policy the opening up of a hoisting rope by means of Spanish windlasses or spikes in order to examine it internally. It was their experience that a rope opened up in this manner does not resume its original position and this permits moisture to get inside and cause further corrosion (44).

Broken or slack outside wires are readily discovered. In most instances the person charged with detailed inspection of ropes allows the moving rope to pass slowly through his hand or through a piece of waste at the drum or collar. A protruding end quickly makes itself felt.

A difficulty peculiar to the inspection of preformed ropes is that when a wire breaks it does not spring out of place and reveal itself, as is the case with outside wires of ropes that have not been preformed. Special care is therefore necessary in their inspection.

Loose wires may arise from either excessive wear, kinking, or "birdcaging". Becoming loose, they are easily displaced over one another and such shifting leads to "mauling" and early fracture of the wire. Prompt discovery of abnormal wear or strand position is therefore of great importance (64).

Although a kink may be difficult to detect in a fully loaded rope, it will become immediately evident if the rope is allowed to become slack during inspection. Advantage should regularly be taken of this fact.

Accurate measurement of the diameter of a rope by rope calipers at distances of about 150 feet apart, staggered from month to month so as to obtain dimensional evidence of the state of the rope as a whole, is a desirable and useful procedure.

This has not always been given the attention that it deserved. The standard Machinery Record Book kept at the Paymaster Mines required that the circumference of the rope at four places be measured and recorded every month. For the rope that failed the record indicated that the diameter of the rope measured at the four places was invariably exactly one inch—the nominal diameter—throughout its life.

It should be pointed out, however, that a rope undergoing corrosion may, through retention of corrosion products, show no reduction of diameter before failure, although a rope undergoing plastic wear might show

a relatively large reduction in diameter with a very small loss of strength (43).

Although a rope used over a small sheave or drum and subject to high bending stresses may fail without adequate warning, if the sheave be of an appropriate diameter relative to the rope, some indication of imminent failure should be afforded by marked alteration in the elongation of a selected length of the rope. Periodic measurements of the stretch should be made and its rate carefully studied. The practice of the Ontario Department of Mines is to order the discard of a rope when in the semi-annual testing of samples from the cage end the elongation in about 56 in. becomes less than 2 in. Some valuable evidence respecting possible deterioration of a rope outside these relatively short test lengths might be afforded by observations of elongation of the rope as a whole.

The official regulations regarding rope inspection are prescribed in the following rules from Section 160 of The Mining Act of Ontario:

(165) The owner or manager of a mine, where a hoisting engine is in use, shall depute some competent person or persons whose duty it shall be to examine *at least once in each week* the sheave wheels, the hoisting ropes and the attachments thereof to the drums and to the counterweights, buckets, cages, or skips . . . .

(166) Such owner or manager shall also depute a competent person or persons who shall examine:

(a) *at least once in each month* the structure of the hoisting ropes with a view to ascertaining the deterioration thereof and for the purpose of this examination the rope shall be thoroughly cleaned at points to be selected by said person or persons, who shall note any reduction in the circumference of, and the proportion of wear in, the rope;

A further examination of the connection to the conveyance after thorough cleaning of the rope is also called for (Rule 178) at the *semi-annual* cutting of the rope for testing purposes.

Examination of the record of practices pursued by 16 representative operating companies in Ontario in respect of ropes, indicates that daily visual inspections are made by only one-half of the mines. Since immediate detection of such obvious defects as broken wires is essential, particularly for the older ropes, the Committee would recommend that a daily visual inspection be required by the Mining Regulations.

All but one of the properties reported weekly rope inspections, the remaining one conducting them only every two weeks. No departure from the weekly rule should be permitted.

Typical of the procedure that is followed by the larger properties is that followed at Hollinger Consolidated Gold Mines, Limited. Printed forms must be filled out as follows:

(a) WEEKLY HOIST INSPECTION REPORT. This includes reports on ropes and sheaves and is signed by the Electrician, the Master Mechanic, and the Hoist Inspector. It is followed by a weekly repair notification sent by the Master Mechanic to the heads of departments concerned, detailing the specific work to be done on each day and naming the man who is responsible.

(b) HOISTING ROPE INSPECTOR'S REPORT. This is filled in monthly for each rope and gives details of its history as well as an account of its present general condition. It is signed by the Inspector and the Foreman.

The Falconbridge Nickel Mines, Ltd., have a daily inspection of sheave wheels, idler wheels, bearings, cables and cages, the results being entered on mimeographed sheets and signed by the Inspector.

The daily cable and cage inspection report at Falconbridge is as follows:

Cage made one complete trip to try out limit switches at top and bottom of shaft.
Inspected cable and clamps, pins and draft link on top of cage.
Checked safety dogs for operation and cleanliness.
Lowered cage to 500-foot level—put on chairs and let out enough slack to see if any kinks occur in cable.

Regular daily attention to such important matters as these is to be heartily commended.

Electromagnetic testing of wire rope. Much effort has been devoted, particularly in the last twenty years, to the problems of detecting flaws or deterioration in steel wire rope by non-destructive electromagnetic methods. Attention was drawn to this possibility by Shelford Bidwell in his first studies of the relationship of magnetic permeability to the mechanical stress in steel (131). There is usually no difficulty in securing indications of the presence of artificial mechanical faults, but a real one exists in that magnetic variations arising from other causes may be even greater and mask the desired indications. Investigations, both past and present, show that the problem is an extremely difficult one.

Reporting in 1926 on a two-year research by the U.S. Bureau of Standards, R. L. Sanford stated (136):

While it is evident that there is a very close connection between the magnetic and mechanical properties of steel, the relationships are so complex that much more study will be needed before the results of magnetic tests can be interpreted with a sufficient degree of certainty to warrant their use as a practical method for routine inspection of wire rope.

Sanford's investigation was fundamental rather than applied and was carried out with direct current coils. He found that there was a fundamental lack of proportionality between magnetic indications and the degree of mechanical defect. Fatigue in the steel was not indicated in his measurements.

In 1929, T. F. Wall published two accounts (137) (139) of an alternating current means of measurement. He experimented with frequencies of 18 and 50 cycles per second and found the former slightly preferable. A field test set operating at 10 cycles per second was installed at Hatfield Main Colliery near Doncaster, England, on a 2⅛-inch rope in a 2,580-foot shaft. The results of this test have not been reported.

Dr. Wall used a single driving coil with two test coils differentially connected and compared the indication with that from a standard sample of good rope. Basically most of the methods currently proposed differ from this only in what appear to be non-essential details.

Since the principal source of rope deterioration—loss of section through corrosion and wear—necessarily involves increased stress for a given suspended load, it would be highly advantageous if magnetic variations could be correlated with metal loss. Many efforts have therefore been made to produce electrical excitation of a specimen by induced magnetic flux and by using a search coil to detect variations in the magnetic reluctance caused by the deterioration.

Several independent demonstrations or laboratory investigations in this field of inquiry have been made in Ontario during the past year, of which the Committee has been informed and which it has had an opportunity of witnessing in part.

Mr. A. D. Snider demonstrated to the Committee in March, 1945, at Kirkland Lake, a beat-frequency detector which gave sonic indications of changes in the magnetic properties of a wire rope.

A 25-cycle detector was applied to an endless ¼-in. cable by the International Nickel Company of Canada, Limited, in its laboratory at Copper Cliff. Some of these tests were witnessed by the Committee in April, 1945. The Committee has been informed that while some of the methods tried, using A.C. excitation, showed distinct promise in the laboratory, no reliable system for correlating field results with laboratory findings has as yet been devised. The apparatus indicated the presence of deterioration, and to some extent the degree, but it was not capable of differentiating between the various types.

An extensive preliminary research, using a Du Mont Cyclograph as the means of measurement, was undertaken by The General Engineering Company (Canada), Ltd., which has submitted to the Committee a detailed report of the results obtained. This work, occupying several weeks of time, was carried out in the Mechanics of Materials Testing Laboratory of the University of Toronto. The samples were all prepared in the Rope Testing Laboratory of the Ontario Department of Mines. Tests were of an exploratory nature and were made on ¼, ⅝, ¾, 1¼ and 1½ in. rope having artificial faults as follows:

(1) Corrosion
(2) Abrasion
(3) Kinking
(4) Severe crushing
(5) Broken wires

Samples were stressed during the tests, various tensions and loading cycles being used, before they were loaded to destruction.

Corrosion with acid which reduced the rope strength by about five per cent was clearly indicated by the Cyclograph but the filing of eighteen outside wires to one-half their original thickness gave no observable indication. This agrees well with some of Sanford's observations. Kinks were not indicated with definiteness and severe crushing produced definite indications only when the rope was stressed almost to failure. Broken wires were clearly indicated until the sample was vibrated, which presumably allowed the broken wires to slip and distributed the load evenly along the sample again, as was indicated by a generally lower Cyclograph reading. Over what length of rope this effect would extend in practice is not known.

The frequency used in all these tests was 7900 cycles per second which may cause some questions as to the penetration of the flux into the rope. It must be remembered, however, that wire rope is not a solid structure and that the wires weave in and out.

While from the evidence of these experiments it seems unlikely that any magnetic test will ever be able to point definitely to a particular type of mechanical fault and distinguish it from all other peculiarities, there is still a good possibility that such a test may have practical value. If daily or weekly records of the readings of some magnetic test instrument were taken from the time the rope was installed and comparisons

made, a general drift of the readings could be interpreted as general aging, but if any small section of the rope showed excessive or rapid changes in its readings that section would be suspect and a special inspection could be made of it to attempt to ascertain the physical cause or causes.

It is to investigate this possibility that long-time field trials of magnetic measurements are desirable. Not only the Cyclograph and other high frequency devices, but also low frequency devices, should receive a trial.

It must be emphasized, however, that according to the experiments performed to date, it is quite possible that a serious mechanical defect might give no magnetic indication whatever and hence magnetic inspection must, for the present at least, be in addition to the present methods of inspection and not a substitute for them. Fortunately, corrosion, which is the most difficult defect to detect physically, seems to show up clearly in the magnetic tests.

In September and October, 1945, The General Engineering Company (Canada), Ltd., undertook certain field tests of the Cyclograph in the Porcupine Camp in order to ascertain the effect on the readings produced by variations in load and rope speed, twist, vibration, etc., and to determine whether it would be possible to obtain reliable readings with ropes under normal operating conditions. The work was done in shaft No. 6 of Dome and in shaft No. 1 of the Ross Mine of Hollinger.

The results were sufficiently encouraging to point the desirability of further field work. A good indication of the amount of the suspended load was given by the Cyclograph readings. Changes in stress due to acceleration and deceleration were clearly shown. Although none of the ropes tested proved to be faulty, in some instances the readings departed appreciably from the average. It is possible that cold working of some of the wires may have been responsible for these otherwise unexplained variations. This matter is being further investigated in the laboratory. If this hypothesis is sound the only practicable magnetic test is the observation of changes. Absolute values would be almost meaningless.

Sufficient promise exists in the results of the various electro-magnetic investigations that have been conducted to justify the continuation and extension of these tests. The Committee consequently recommends that tests be made in several mines operating under normal working conditions throughout the working life of each rope up to the point of incipient failure or replacement. This would be a long-term programme since, if the average life be assumed as, say, two years, it would appear that a sufficient mass of evidence to justify action cannot be accumulated in less than four to six years.

28. **Effect of Broken Wires.** Since in hoisting ropes which pass over drums and sheaves of comparatively large diameter the direct tensile stresses are much more important than the bending stresses, broken wires should be regarded as a serious matter. When a few visible wires fail there is a considerable probability that invisible ones may have done so also, as the stress on them may be generally of the same magnitude as the stresses on the external wires that have failed. Inner wires are often the first to

break and when a few wires give way, others may be on the point of doing so.

It is consequently erroneous and dangerous to regard the strength of a rope as the sum of the strengths of the individual wires that appear to be intact, less an allowance for spinning. Fractures in visible wires are the result of some process of deterioration which is likely to have affected those that are not visible (43).

The Committee is of the opinion that the Ontario Regulations Governing the Operation of Mines are too lenient in the matter of tolerance of broken wires. For a rope used for raising or lowering men the allowance of six broken wires in one lay is excessive (Rule 175(b)). This special condition might not be realized and yet through the existence of a dozen or more broken wires in a considerable length of the rope it would be obvious that the rope should be discarded.

29. **Routine Testing of Ropes in Service.** In many instances the worst section of the rope will not be at or near the capel, that is, within the length likely to be cut off for routine testing. The utility of such testing may consequently be brought in question. It is true that these tests, which in Ontario are made every six months, may erroneously lead to the conclusion that the rope is in satisfactory condition, as in the Paymaster Mines case, where badly-corroded sections of rope existed some 1100 feet above the capel. However, if the routine tests show corrosion and a consequent impairment of resistance, the possible existence of even worse sections elsewhere is suggested. If the rope is not at once removed it would, under efficient management, be inspected with particular care during the remainder of its useful life.

Dixon, Hogan and Robertson (43) have found that in colliery operations if long lengths of rope (over 10 ft.) are cut off at each recapping and the recapping is done at intervals of three months, the worst part of the rope is almost always at the capel, but that if shorter lengths and longer intervals are adopted the worst part of the rope may be elsewhere. The Committee does not feel, however, that the device of cutting off longer samples, and shortening the interval between cuttings will automatically localize the weakest section at the capel end. It would have made no difference in the Paymaster case.

Although the routine testing of samples cut from the capel end will not necessarily disclose a dangerous condition in the rope, the tests have some value and should be continued. Not only do they periodically remove a vulnerable portion of the rope but they incidentally bring fresh rope into service off the drums, and transfer along the rope the contact points with the drum and the sheave when the cage is at various positions in the shaft.

30. **Cropping at the Drum End.** The Committee concurs in the practice, now become common, of periodically cropping off a few feet of rope from the drum end, to change the position of rope on the drum and shift to other positions portions that have been particularly exposed to wear or transverse compression, as at points of climb to the second or successive layers, or at crossovers of the ridges where drums with parallel grooving are used. Relief and realignment of the wires in the dead turns on the

drum reduces the likelihood of "porcupining" and loss of the rope after a few months service if the drum be of small diameter.

31. **Turning of Ropes End for End.** The Committee does not favour the device of turning a rope end for end for the purpose of relieving sections that may have been subjected to special deterioration. In many cases points of weakness would have developed near the capel, or cage, and which when placed as dead turns on the drum could not be readily or frequently inspected.

32. **Shifting of Cage Ropes to Other Duty.** The Committee commends the precautionary device of transferring a cage rope to skip or bucket duty when the greater part of its service life has been achieved. This is a standard practice in at least one important mine in Northern Ontario. It might well be extended.

33. **Lubrication of Rope in Service.** The Committee is of the opinion that it is impossible to force lubricant into the interior of a rope in service to an extent that would replace the original lubrication put in by the manufacturer. The benefits of cable dressing consist almost wholly of sealing off in some measure the interstices between the wires (where corrosion takes place) against the entry of moisture and retarding in lesser degree the escape of the original lubricant.

Unexpectedly, the tests of the British Wire Ropes Research Committee (72) showed, quite contrary to the earlier ones of Biggart (33), that dry ropes gave greater endurance in bending action over pulleys than lubricated ones, except for ropes having the highest bending stresses. That Committee suggested that the lubricant may act as a carrier of abrasive and damaging particles, that is, material worn from the sheave and the wire. It concluded that the correct procedure is "to lubricate the core of the rope and the wires of the strands during construction, following this during use with a coating which is selected to prevent corrosion, and which will not hold particles worn off the wire and pulley, which are so liable to promote grinding" (Fifth Report).

This suggests that the primary function of the lubricant is the prevention of corrosion and not lubrication. The less it retains metal or other abrasive particles the better.

It is of interest to note in this connection that passenger elevators operate with little or no lubricant applied to the rope in service.

Rope dressing practice exhibits no standardization and a variety of greases are employed. One case of the application of boiled linseed oil, which is a drying oil, diluted with some 15 per cent of turpentine, was noted and was stated to be giving excellent results. No "dry" cores were found in three years. A common practice involves the addition by hand or a special device of a grease consisting of 11 per cent of calcium soap, the remainder of mineral oil. "Bitumen" is sometimes added. The grease manufacturers produce a number of compounds to "meet the trade", and many mine operators rely on the recommendations of the grease salesmen.

This unfavourable situation would be improved by a research programme, the object of which would be to determine the best type of "dressing". The programme should be carried out by co-operation with the mines, the manufacturers of rope dressings, and the manufacturers

of the rope. The investigation should cover the existing types of rope dressing, but should also consider new types. If the chief object of the dressing is protection against corrosion, it may be asked if the hydrocarbon greases, as used at present, are the best materials available. Many new synthetic compounds have been developed in recent years, and a careful survey should be made to see whether any are applicable to the protection of wire rope. In view of the foregoing, the Committee recommends that:

(1) Standard specifications for rope dressings be set up after consultation between the mines, the rope manufacturers, and the grease manufacturers;
(2) The mines co-operate in a long-term programme to use these dressings under given conditions, including the methods of application, over a period of years;
(3) New synthetic compounds be examined and, if any appear to be promising, they be compared with the established hydro-carbon greases.

34. **Permitted Service Life of a Rope.** More than one person suggested to the Committee that arbitrary limits should be set to the length of time that a hoisting rope is to be allowed to remain in service. Careful study of the problem has led, however, to the conclusion that this is undesirable and might at times result in an actual lessening of security. Some of the reasons for this view are that:

(1) In many operations ropes that have been removed after two to four years of service have been in better condition than others removed after only a few months of use;
(2) The life of a rope depends very largely on the intensity with which it is worked, on the operating conditions, and on the progress of corrosion. The time factor may vary widely in importance from one installation to another installation;
(3) The fixing of an arbitrary time for removal of a rope might prompt some operators to rest on what they might choose to regard as the permitted useful life, whereas conditions might necessitate a very much earlier replacement.

It has often been contended that the allowable service life of a rope should be based simply on the tonnage hoisted, or on the aggregate of the products of the load and the distance it is moved, or on the aggregate of foot-tons per square inch. In the opinion of the Committee all of these standards of judging useful life are erroneous. Hoist installations and mine operating conditions vary widely and those factors that produce rope deterioration at any selected point are but little related to the product of suspended mass and the distance travelled by that mass, or to derivatives thereof.

Mr. W. B. Carlson has quite properly pointed out that the work which does proportionally affect rope deterioration is the work done *on* the rope, not the work done *by* it (44; June, 1940). This is the product of the total stress in the rope and the rope elongation—the sort of work that a testing machine performs on a specimen in ordinary tensile tests.

Consideration of the causes of rope deterioration set out in Articles

22, 23, 24, and 25 under the headings of Overstressing, Corrosion, Wear, and Embrittlement, shows that not one of them may be logically represented by the product of suspended mass and the distance travelled (44; June, 1940, p. 392). Numbers of trips made, numbers of load changes, stress magnitude, or stress repetition will, however, affect rope life.

Even more important, in the view of the Committee, is the influence of corrosion on the proper service life of ropes. As pointed out in Article 23, this deteriorating influence is by far the most frequently observed defect of ropes that have failed in Canada or elsewhere. Since it has but little relation to the total of foot-tons, a foot-tons per square inch, the criterion of work done does not appear to be soundly established.

F—CAGES, SKIPS, AND BUCKETS

35. **Cages.** Based upon its observations and inquiry, the Committee is of the opinion that the design and construction of cages for Ontario mines from the standpoint of safety has for the most part been excellent.

One objectionable detail was, however, noticed at a number of properties. This consists of a pair of angles attached to the drawbar with their outstanding legs a few inches above the roof of the cage. Pieces of rock might very well lodge in the space below the angles, thereby preventing the drawbar from falling and so rendering the safety dogs inoperative.

36. **Skips.** By reason of the restriction placed by the Ontario Regulations Governing the Operation of Mines on the lowering or hoisting of men in skips or buckets to sinking operations only, the hazards to those men properly using such equipment are small.

In inclined shafts, accidents have several times occurred in Ontario through the derailment of skips, with the resultant parting of the rope. This is not likely to result in injury or death unless men are using an auxiliary bucket lower down in the same compartment. Four men were killed in the Levack Mine in 1929 when fire burned through a rope in the shaft house allowing the supported skip to strike a bucket below. Presumably, a similar outcome might have occurred if the skip had fallen through rope breakage caused by skip derailment. Any men who might be riding in the skip would, of course, have been injured or killed.

37. **Buckets.** In sinking, rock loosened by blast has sometimes caused a crosshead to jam against a timber, with fatal results. Constructions which minimize such occurrences are desirable.

When ore is flowing into a bucket, a piece of rock or metal may get caught between the bucket and the side of the shaft. There is some opinion amongst miners that this could be prevented. The matter merits the further consideration of the operators.

G—GUIDES

38. **General.** Obviously, where any safety device involves the stopping of the cage by gripping vertical guides these must be adequately attached to the dividers. In some cases observed by the Committee, these connections were of doubtful strength. Sometimes the guides are held in position only by lag screws, which become corroded and give poor support.

In a drop test performed in May, 1945, at an Ontario mine, a spruce guide failed, partly because it pulled through the bolts at one end and away from the section of guide above. A better attachment might have prevented this.

Due to the objectionable practice of using dog shafts that are too short, thereby causing safety dogs to grip near the inner edges of the guides, there is a strong tendency for the guides to bend outward when the dogs come into action. Such has occurred in several instances known to the Committee. This practice has sometimes considerably lessened the effectiveness of the dogs as their full width is not then used for braking purposes. In some cases little more than half the dog width was effective. Until this is corrected the thicker the guides are perpendicular to the adjacent shaft wall the better.

British Columbia fir appears to be on the whole the most satisfactory timber for guides and is almost exclusively used in Ontario. Spruce has in some instances been reported as unsatisfactory.

The possible use of metal guides is associated with the type of cage safety used. This matter is discussed in Part H, "Safety Measures and Devices".

H—SAFETY MEASURES AND DEVICES

39. **General.** Safety in mine hoisting operations is furthered not only by the prompt discard of hoisting ropes when any doubt of their dependability arises but also by

(1) Provision and maintenance of adequate controls of the hoisting machinery, and

(2) Provision and maintenance of safety devices attached to cages or built into the shafts.

Consideration at some length will be given in what follows to these two types of safety measures.

40. **Control of Mine Hoisting Machinery.** Mechanical, electrical, or sonic devices installed in connection with the operation of mine hoists are for the purpose of preventing accidents arising chiefly from

(1) Overspeed
(2) Excessive acceleration
(3) Excessive deceleration
(4) Overwind
(5) Power failure
(6) Failure of hoistman to act due to negligence, sleepiness, illness, or death
(7) Clutch failure
(8) Brake failure
(9) Lack of clutch and brake interlock
(10) Lack of discrimination between hoisting of men and rock
(11) Starting hoist with a slack rope

Examination of the records of hoist installations for typical Ontario mines, large and small, shows that in most instances they are well provided with safety features. Naturally, when a property is in the early development stages these are less elaborate than they are when the mine becomes definitely established.

It has been suggested to the Committee that a general reduction of rope speed would conduce to safety of hoisting operations. This position is not supported by the history of hoisting accidents. In Table 8, those cases of unsatisfactory performance of safety dogs in Ontario that in any way would have been affected by rope speed are all cases for which the rope speed was moderate. Those properties that use the highest operating speeds do not appear in the list, as no failures of safeties have occurred at them.

Overspeed in Ontario mines is generally controlled, as is overwind. For the smaller hoists, control of overwind is afforded by installing limit switches at the top and bottom of the shaft. Should overtravel occur a circuit breaker will, through the agency of such switches, cut off the source of power and automatically apply the brakes. A back-out switch placed near the hoist operator will, when closed, permit backing out of an overwind position but will not permit movement of the cage in the wrong direction. An emergency switch, located near the operator, may for any reason be opened and cause the circuit breaker to cut off the source of power and automatically apply the brakes. Manual control has the disadvantage of leaving acceleration and deceleration entirely at the discretion of the operator.

For large hoists, the control is generally fully automatic and acceleration, deceleration, and rope speed are very properly not left to the judgment of the hoist operator.

Practice in Ontario generally requires that brakes must operate automatically in the event of an emergency arising. They must be adequate to bring the cage or other conveyance to rest within tolerable limits and hold it on either a descending or ascending movement.

British braking practice holds that it is very desirable to limit the maximum applied rate of retardation to less than one-half the acceleration of gravity when stopping under emergency conditions from full speed. The possibility of injury to cage occupants is thereby rendered exceedingly small. This low rate should be borne in mind when designing cage safeties to arrest the fall of a conveyance when a rope breaks or the hoist gets out of control.

In a normal hoisting cycle, decelerations applied electrically are less severe than those due to mechanical braking and the stresses set up are relatively small and can be ignored. Moreover, the maximum electrical decelerations which can be produced by unskilful or malicious handling of the control levers are less severe than the maximum due to mechanical braking in similar circumstances (21).

Under emergency stopping conditions with an electrical drive there may be some electrical retardation depending upon the rate of decay of the motor and generator fields. While the deceleration effect is not likely to be large at any time, a violent application of ungoverned brakes when the electrical effect is at its greatest, might bring the total electrical and

mechanical deceleration momentarily to a dangerous figure, before the slowing of the motor is sufficient to reduce its voltage (21). Avoidance of this situation may be attained by the use of a satisfactory brake governor.

The Committee is of the opinion that a study by mine operators of the records of experience with electrical braking systems might reveal definite prolongation of rope life and a consequent improvement in hoisting safety.

Promotion of safety for the occupants of mine cages has been undertaken with the co-operation of the rope manufacturer at Pamour by incorporating electrical conductors into the cable for the purpose of maintaining telephone communication with the surface and securing an automatic application of brakes in the case of rope failure. Conductors embedded in the individual strands of the core have given partial promise of success, but it may be that conductors in the centre of a 4-strand core, which is to be tried at Pamour, will prove satisfactory.

41. **Justification for the Use of Cage Safety Devices.** There are two schools of thought amongst mining engineers and operators with respect to the justification for the use of safety devices attached to mine cages for arresting the fall of the conveyance in the event of a rope failing or the hoisting machinery getting out of control.

One school, strong in South Africa, holds that the best safety device is a good rope, and in consequence makes but little use of cage safety attachments. They represent that if the break is far from the conveyance, that is if there is much trailing rope, or if the fall is due to a loss of control of the hoisting machinery, safety dogs are ineffective. It has further been urged that the teeth of the dogs fill up with wood shavings and that they then ride the guides without retarding value.

As against this, the other school points out that rope failures have occurred and may still occur on operations where final reliance is placed on the rope. It holds the opinion that despite the taking of every known precaution in inspection, testing, and maintenance so far devised, a rope may break, or hoisting machinery may fail to function properly, or a hoistman may become suddenly incapacitated, and that a last line of defence in the form of the best procurable cage safety should be provided. It holds that non-clogging dogs can be designed that will bite as deeply as desired.

The Committee has undertaken to examine the evidence in this matter with particular care. It presents its findings in some detail with respect to Ontario experience with cage safeties when conveyances have accidentally fallen. It further analyses the results of the many special drop tests which have been made in Ontario since the Paymaster accident of February 2, 1945. Before presenting the results of this study it appears desirable to set out the characteristics of cage safety devices generally.

42. **Desirable Characteristics of Cage Safety Devices.** When considering the merits of the many types and variations of safety devices that were examined by the Committee or drawn to its attention by those who made submissions, the following principles for the adjudging of merit were deemed to be important:

(1) The device must be simple, rugged, and reliable, should permit ready inspection, cleaning, or repair, and should require a minimum amount of attention and skill in maintenance.

(2) It must be immediate and automatic in action.

(3) If applied to the guides, it must act on both sides at once so that the forces are balanced and the guides will not buckle excessively.

(4) It should be self-adjusting to make allowance for guide wear.

(5) It must be strong enough to stop a fully loaded cage at the prevailing speed of operation and hold it until the occupants are released.

(6) It should preferably be of such form that it can be applied to existing cages, skips or hoisting machinery without excessive cost.

(7) It must stop the cage within a reasonable distance but not so suddenly as to subject the occupants to possible serious injury or death.

(8) It must not release itself if the tension is again applied to a broken rope. In some of the designs now used, the dogs may begin to grip the guides and then, if the tension is again applied to the trailing cable, they will be automatically withdrawn from the guides and the cage will fall freely. Some of the dogs illustrated in this report are so designed that, once they have passed through a certain degree of rotation, a re-application of the rope tension will *increase* their grip on the guides, giving an added degree of security. This feature should be incorporated in the safety device wherever possible.

(9) It must not be applied accidentally when the cage is bouncing.

(10) It must be comparatively easy to disengage after testing.

(11) Its operation should preferably be independent of variations in the coefficient of friction between the braking surface and the guides.

(12) It must work satisfactorily under bad operating conditions such as those produced by water, dirt, or ice.

(13) If fluid pressures are employed, it must not be put out of action by leakage of water, oil, or air at the joints.

(14) If it is mechanical in form, it must not be liable to stick from want of a reasonable amount of lubrication or bad adjustment.

(15) It must not become useless in an emergency by being clogged with shavings or other foreign matter.

(16) It must be actuated by a spring or other positive device. Mechanisms operated solely by a weight mounted in or on the cage are useless.

(17) It must be suitable for deep mines and heavy cables.

(18) If possible, it should be put into operation whenever speeds become excessive and be actuated by these excesses rather than by a reduction or loss of tension on the hoisting rope.

(19) It must be dependable despite the effect of a trailing rope.

(20) It must operate effectively if the hoisting machinery should get out of control through clutch or brake failure.

(21) It must be brought into operation immediately after the cage starts to fall and before a high velocity has been built up, as would happen if sole reliance were placed on a cushioning chamber at the bottom of the shaft.

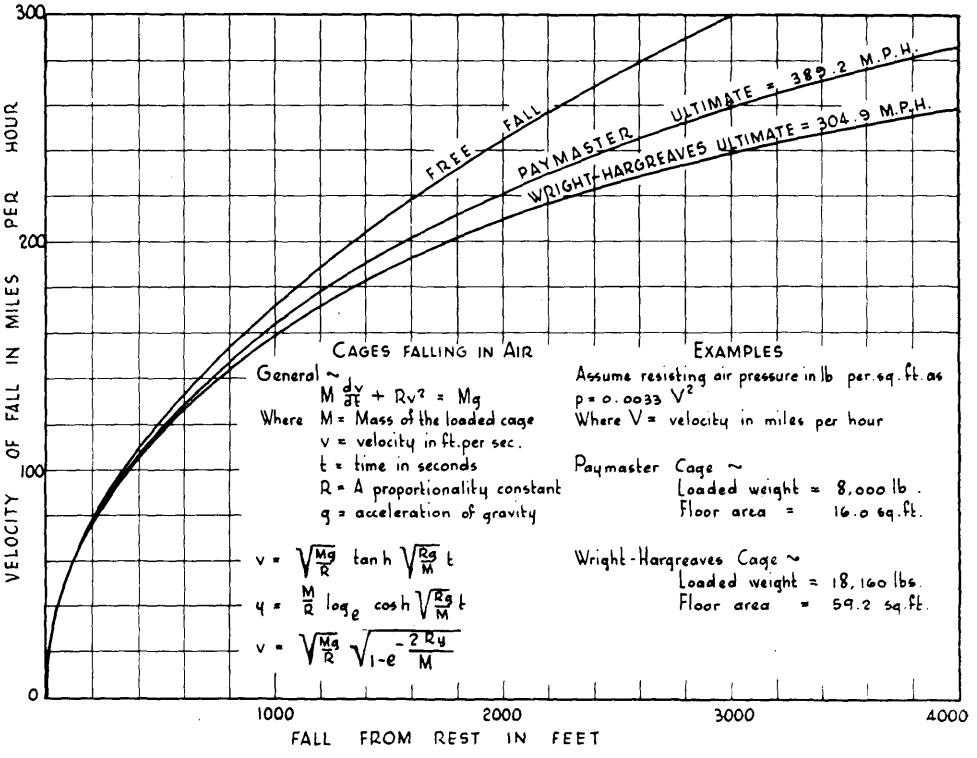


Fig. 4—Velocities of Mine Cages Falling in Air

Fig. 4 indicates the extent to which the velocities of cages falling in air build up with distance fallen. While in a mine shaft the velocities attained would not be quite so large as are shown in the figure, the comparatively free escape of air under a cage into the adjoining compartments would prevent any very great cushioning effect.

43. **Recorded Behaviour of Cage Safeties in Ontario.** Through the co-operation of the Department of Mines and the Special Committee of the Ontario Mining Association, the Committee is able to present in Table 8 a concise record of the behaviour of safety dogs in the instances where conveyances equipped with them in Ontario mines have been involved in accident.

The types of safety dogs mentioned in Tables 8 and 9 are indicated in Figs. 5, 6, and 7. These incidentally represent all of the more commonly employed devices of this kind and some that are as yet not widely used but which embody original ideas.

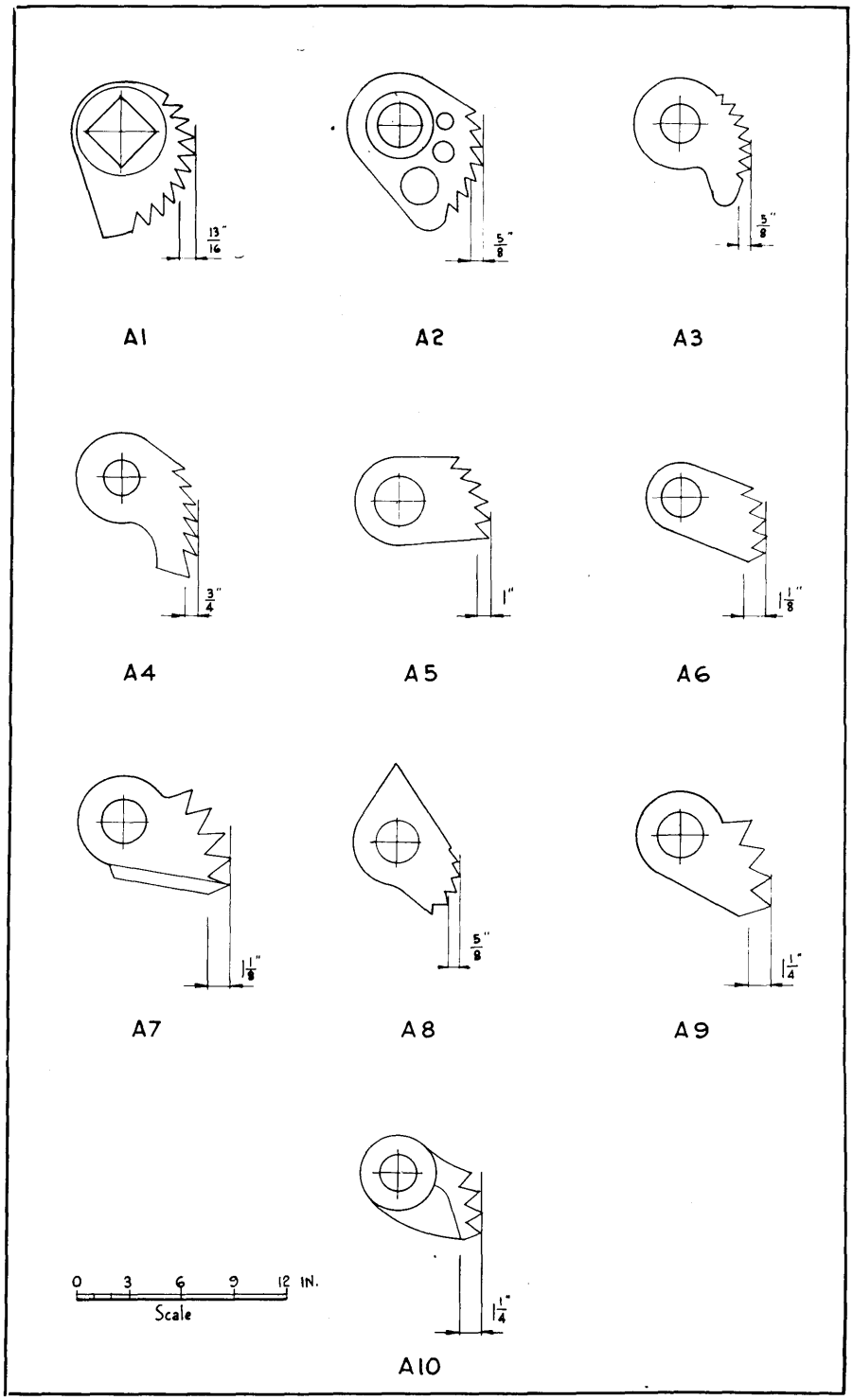


Fig. 5—Safety Dogs of Type A, Ontario Mines

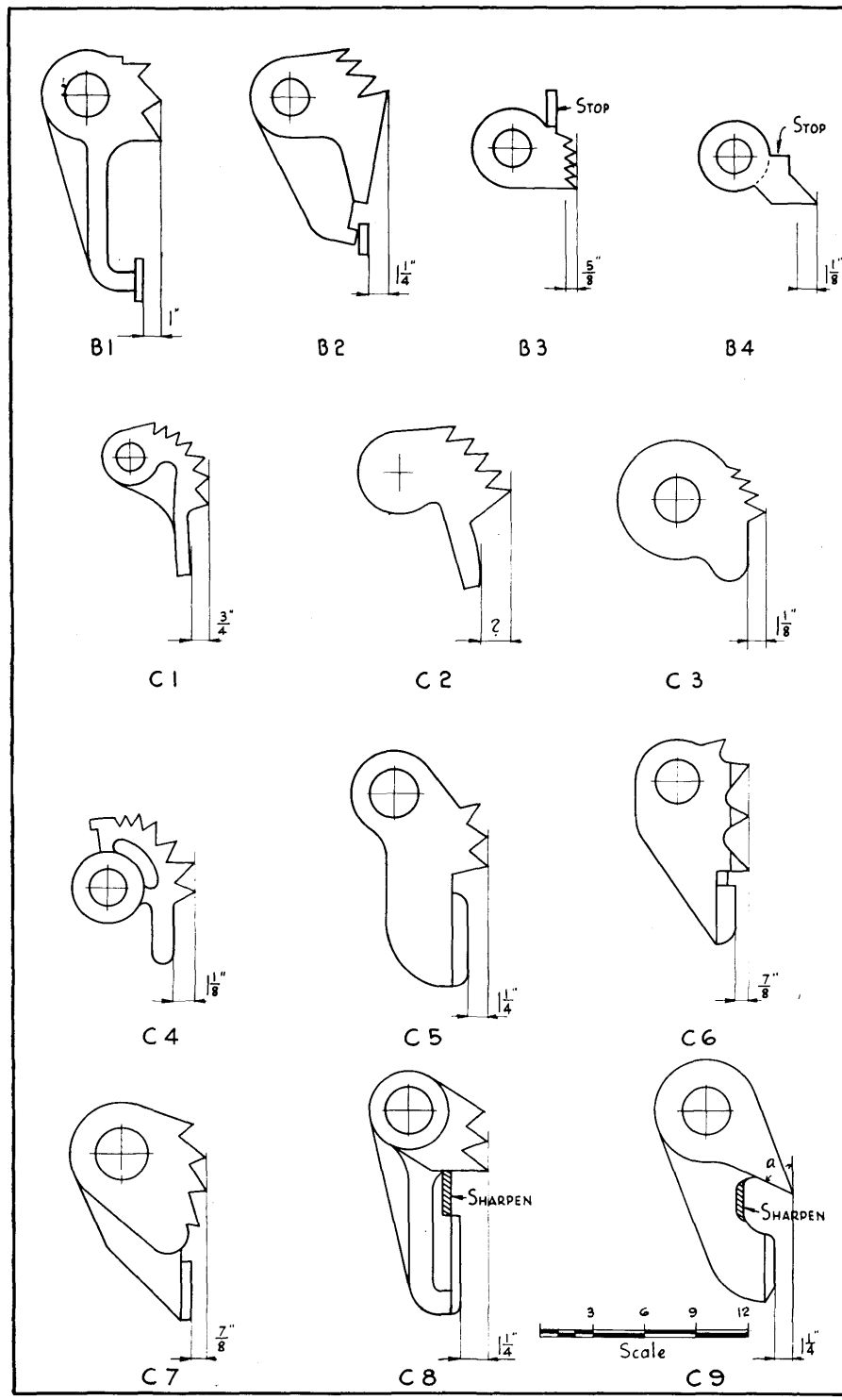


Fig. 6—Safety Dogs of Types B and C, Ontario Mines

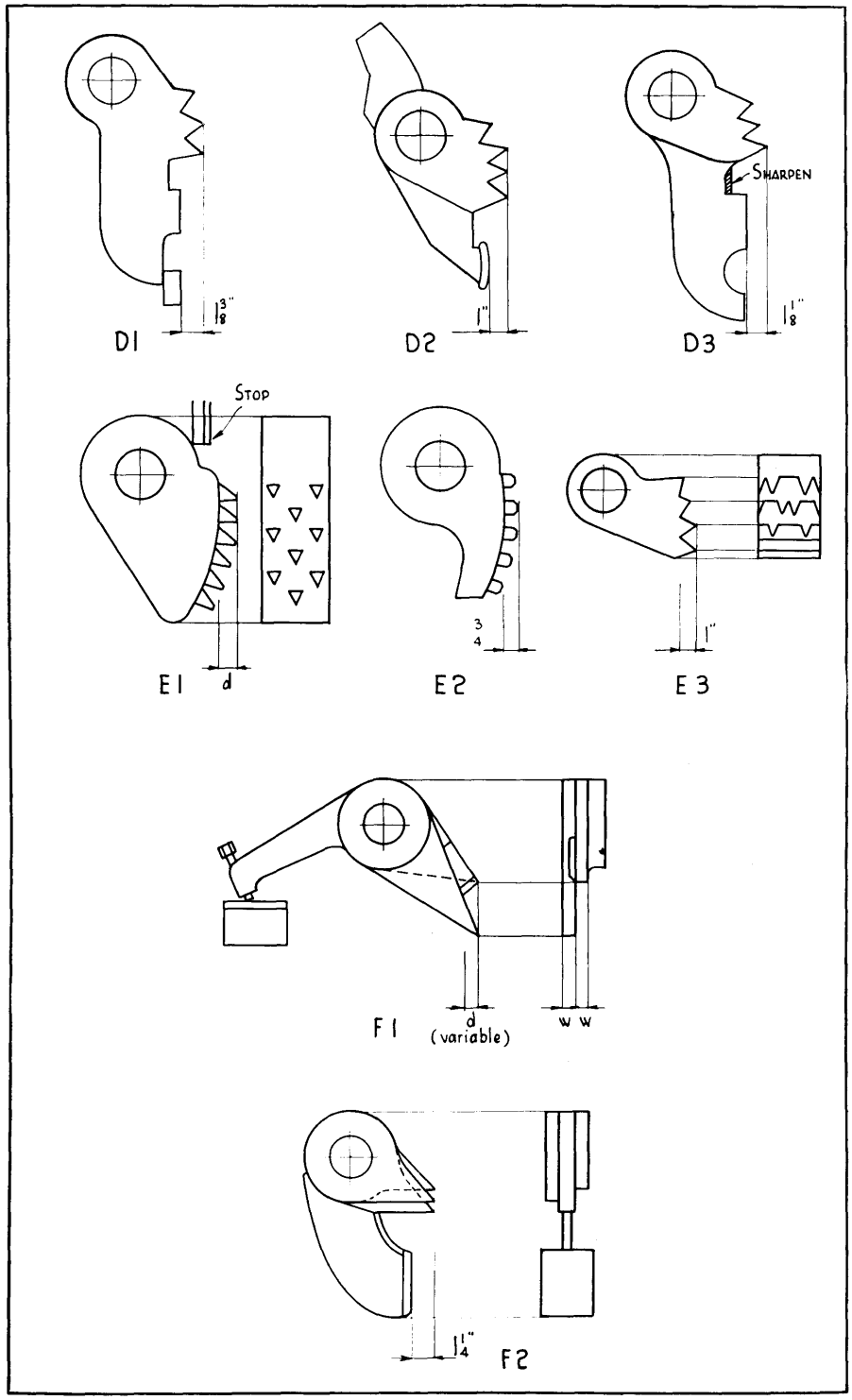


Fig. 7—Safety Dogs of Types D, E, and F, Ontario Mines

The nature of the devices to limit the rotation of the dogs and prevent them from turning over, which has sometimes occurred, is indicated at the top of the table. In certain cases, marked "BS", angles are attached to the drawbar a short distance above the cage roof and, unless stopped by pieces of rock, prevent the bar from descending too far in relation to the cage frame. "CS" indicates that some part of the dog strikes a metal stop attached to the cage; "GS" indicates that a part of the dog, other than the teeth, encounters the guide and thus provides compensation for guide wear; "SS" indicates levers or cams on the dog shafts coming up against a fixed part of the cage; while "L" shows that the dog rotation is limited only by the linkage.

Eliminating from Table 8 the five cases that are uncertain, or for which the dogs had no opportunity to function, there are 18 in which the dogs stopped the cage and 10 in which they did not. Of the 28 definite cases, therefore, 64 per cent represent effective stopping. The distances in which the stopping occurred is very short in several instances but the Committee has not learned of any serious injury being sustained by the occupants of the cages so stopped.

It is significant to note that amongst the 10 instances of dog failure, eight involve trailing ropes of from 200 to 4000 feet in length.

Accidental and undesired dogging appears to have been the initial cause that led to failure in two of these ten unsatisfactory cases. In three cases the brakes or brake-clutch interlock failed and the drag of the rope over the sheave and drum prevented the full action of the dogs.

44. **Proposals Respecting Cage Safety Devices Submitted to the Committee.** A considerable number of the 45 suggestions received by the Committee with respect to cage safety devices were unsuitable for further study because they violated one or more of the principles set out in Article 42. For instance, several devices were designed to stop a cage instantly by pushing out bolts or bars which would engage the dividers, or horizontal timbers. These would be fatal to the occupants of the cage, if it were moving at a high speed when the safety device operated. Others had large numbers of working parts, levers, links or springs, and the failure of any of these might cause the mechanism to fail at a crucial moment. The fewer and more robust the working parts, the less there will be to go wrong.

Some devices were intended to be operated by the men in the cage. The Committee is convinced that the time available for action in an emergency is too short to enable hand-operated devices to be effective; they must be automatic.

In some instances, worn guides decrease the "bite" of safety dogs to a dangerous degree, or the tightening of a broken trailing rope may prevent the safety device from operating. A satisfactory design must avoid both of these conditions.

If the cage stops too quickly, the occupants may be injured or killed, and if too slowly, it may fall to the bottom of the shaft. Safe stopping distances are discussed elsewhere in this report.

Many good ideas were based on brake shoes or other frictional devices, similar to those employed in vehicles or elevators. These work well on

dry surfaces, but may be comparatively unreliable if the surfaces are slimy or wet, as is frequently the case in practice.

Others were dependent on oil, water or air pressure acting from a cylinder or pump. Large braking pressures can be applied by these means, but leaky pistons, valves or joints may put them out of action, just when they are needed.

Instances have been cited where the spaces between the teeth that are supposed to grip the guides have been choked with wood shavings after a short distance of travel and thus have failed to stop a runaway cage or skip. Proper design will avoid this hazard.

The following is a brief analysis of the various types of suggestions, relating to safety devices, made to the Committee:

(a) Toothed or serrated dogs, similar to those now used, operated by levers, wedges or fluid pressure. Some of these had single teeth and others multiple teeth. In some instances, two additional sets of dogs were suggested in order to increase the degree of safety.
(b) Brake shoes, operating by friction on the guides. These were applied by levers, toggles, springs and worm gears. The use of water, oil or air pressure was also suggested. In some instances, both brake shoes and dogs were included in the suggested device. Trips or catches, similar to those used in engine valve gears, were also suggested.
(c) Circular toothed wheels, pressed against the guides by expanding levers and operating in a manner somewhat similar to "dogs".
(d) Tapered guides, to produce a wedging action near the bottom of the shaft.
(e) Toothed or pegged guides, to provide shearing pins or surfaces that stop the cage by a succession of small jolts.
(f) Brakes, operated electrically or magnetically, when a circuit is broken by rope failure or other causes.
(g) Extra safety cables with or without governors, which operate when speeds are too high.
(h) An air dashpot at the bottom of the shaft to provide a safety cushion.
(i) Shock absorbers, placed between the rope and cage, to prevent excessive accelerations or decelerations. Some suggestions favour placing these above and others below the cage.
(j) Seismographs and other similar devices to indicate critical or dangerous oscillations and to detect dangerous reductions in the strength of cables.
(k) Search coils and magnetic devices to detect local weaknesses in the cable, either during operation or at inspection periods.
(l) Special methods of testing brakes or dogs with the cage or skip running at full speed, as an improvement on the present method of applying the brakes as soon as the cage is released from rest.
(m) Governors, driven by frictional contact with the guides, to apply safety devices either directly or through servo-motors, when excessive speeds are attained.
(n) Methods of and special attachments for cable cleaning and greasing.

(o) Flexible tubes for supplying lubricant continually to the core of the cable and for preventing internal corrosion.
(p) Electric wires inside or outside the cable to operate safety devices, to transmit warning signals, or both.

While the question of cost must always be a minor consideration, as compared with safety of life or limb, it cannot be ignored entirely in this discussion. Undue complication is frequently an additional hazard, in itself, and there is always the possibility that elaborate and expensive safety devices, however perfect theoretically, may be no more reliable in practice than those already in use. Some of the devices suggested would entail the complete reconstruction of cages or hoisting mechanisms, or both, and such programmes should not be undertaken, unless and until the device has been subjected to a long process of testing under practical conditions. Moreover, if the use of elaborate and expensive safety devices were made compulsory, the poorer and less productive mines might be handicapped unnecessarily without any appreciable addition to the safety of their operation.

In the light of these general considerations it will be useful to review the most meritorious suggestions respecting safety devices submitted to the Committee for its opinion. They are given in alphabetical order.

G. T. Burch and C. D. McAlpine—A low voltage battery current passed into and through the hoist cable to the cage by means of slip rings on the hoist drum and two insulated wires in the cable. Breakage of current stops the hoist and applies the cage brake through a relay. Protection is claimed against broken and slack cables and runaway hoists. Brake testing is simplified. Brakes or dogs may be installed under the cage in a more protected position than that now used.

W. L. Courtney—Detection of wear, corrosion, or excessive stress by using two balanced induction coils, one surrounding a normal piece of cable and the other a moving mine hoisting cable. Differences in the inductive effects of the two would be shown on a cathode ray oscillograph.

H. L. Davy and J. King—A leaf spring, operating through a lever system, causes a crosshead to move upward (relatively to the cage) when the cable breaks. This applies brake shoes to the guides by means of a bent lever. The guides are not damaged by the brake shoes but there is no provision to meet the "trailing cable" difficulty mentioned above.

C. J. King and C. Sweet—Flat brake shoes applied by wedges, operated by cables from spur gears or "pilot dogs" in contact with the guides. A governor and trip gear acts as an overspeed device. A full-sized cage equipped with this mechanism was tested by free fall in the presence of a member of the Committee on August 1st, 1945. The guides were greased and the stopping distance at a cage velocity of 960 feet per minute was approximately 9 feet. A test made with a loose cable at 600 feet per minute gave a stopping distance of 8 feet 6 inches. (Wedges operating in a somewhat similar manner were also suggested by A. D. Chisholm, but the mechanical details were different).

M. J. Lazier—A seismographic type of recorder, to observe the fre-

quency of vertical oscillations in tests to be made daily. It is claimed that this will indicate weaknesses in the cable.

A pair of inductances, installed around the cable to form the primary and secondary of a transformer, using the cable as a core. It is claimed that the voltage output of the secondary will be an indicator of the condition of the cable.

A vibration damper between cable and cage.

G. McDonnell—Cable breakage operates a valve admitting compressed air from a reservoir to cylinders which apply brakes through wedges.

R. McIlwaine—Wedge-shaped brake shoes operated by springs when the cable breaks. Used in addition to existing dogs, if desired.

F. H. Milks—Multiple brake shoes operated by water, oil, or air pressure and controlled by a governor, if required.

J. E. Nadeau—Auxiliary safety catches operated by inclined planes and independent of ordinary dog mechanism. Cannot be released by renewed tension in a broken cable.

A. D. Polson—Flat brake shoes, operated by toggles and leaf spring. A safety catch is included to prevent accidental release of the brakes after they are once applied. (A similar suggestion was received from K. N. Tuck and O. Aubertin).

D. E. Putman—A flexible tube down the middle of the cable, through which oil is pumped to lubricate the core.

G. Ransom—A combination of dogs and wedges.

L. Renaud—A set of auxiliary dogs connected by gearing to the main dogs, causing them to grip the guides.

J. L. Rogosky—An auxiliary cable in parallel with the main cable.

R. W. Skene—A speedometer in the cage to indicate the attainment of dangerous speeds. A magnetic brake operated by generator and guide friction or by a battery in the cage when maximum safe speed is exceeded.

M. R. Smith—Motor operated by battery applies brakes through worm gear when switch is closed at high cage speed. Shock absorber between cable and cage.

A. D. Snider—Demonstrated an electro-magnetic device for detecting defects in cables.

E. B. Weir—Wedge type friction brakes with cylindrical backs giving automatic adjustment for guide wear. Trip release causes a spring to operate the brake and the speed of application is controlled by a dashpot.

45. **Application of Building Elevator Practice to Mine Hoists.** Electric elevators have been used in buildings for many years and very few fatal accidents have occurred with them. There are many points of similarity between the work to be performed by elevators and that to be done by mine hoists, and therefore the Committee made a special study of elevator design and safety appliances. The opinions of Messrs. H. C. Crane, of the Turnbull Elevator Company, Limited, Toronto, and W. J. W. Reid, of the Otis-Fensom Elevator Company, Limited, Hamilton, were sought

and obtained, and the plant of the latter company was visited by the Committee.

In general, elevators are somewhat lighter and run at lower speeds than do mine hoists, although in some instances speeds up to 1400 feet per minute are said to be employed. Moreover, elevators have multiple ropes (not less than three), any one (or two) of which is strong enough to support the load. The cage is counterbalanced by weights attached to the opposite end of the ropes. The safety device usually consists of a centrifugal governor which actuates cable-gripping jaws through a mechanically operated trip gear, so that the governor cable is gripped by the jaws when the speed rises above the safety limit. This governor cable is independent of the ropes supporting the cage and passes over sheaves at the top and bottom, respectively, of the elevator shaft. The bottom sheave is attached to a weight which slides in vertical guides and maintains a constant tension on the governor cable. When the governor cable is gripped by the jaws, the relative motion between it and the cage (or "car") rotates a shaft which is located below the cage, and this in turn actuates clamping jaws by means of screws, levers, wedges, cams or other mechanical devices. Various forms of transmission gear are employed (142), but all of them apply pressure through clamping jaws to opposite sides of T-shaped steel guides, so that there is no unbalanced side thrust and the braking force is produced by the frictional resistance of two machined steel surfaces in contact with each other. Experience shows that this type of braking action is very effective.

In spite of the favourable history of this type of safety mechanism, the Committee is of the opinion that it is not suitable for application to mine practice for the following reasons:

(1) The great depth of many mines, as compared with building heights, makes it impracticable to use the governor cable principle. The cable would be very heavy and would tend to whip around on account of its great length. The cable and its sheaves would also, in many instances, be difficult to accommodate.

(2) A safety mechanism used in a wet and dirty shaft should have as few working parts as possible and these should be rugged and simple. Neither of these desiderata exists in elevator safeties and, in some properties at least, it would be very difficult to keep the mechanism in proper working order.

(3) The coefficient of friction between the steel surfaces would probably vary with the condition of the guides, which are sometimes dry and sometimes slimy. The speed of application of the brakes might be alternatively too fast or too slow.

(4) In wet mines, particularly where exposure to sulphurous fumes is involved, rapid corrosion of guides and mechanism is probable.

(5) The adoption of this mechanism, with steel guides, would involve an entire change of construction in all shafts, so that very great expense would be incurred by all mines. This should not be a controlling factor if added safety were secured, but, in the opinion of the Committee, the safety devices used in elevator practice

might not give any greater security against accident than those at present used in mining operations. If a safety governor gear can be devised for this purpose, additional security would be obtained.

46. **Tests of Cage Safety Devices.** Valuable experimental information respecting the behaviour of cage safety devices has been made available to the Committee through the 116 reported drop tests with initial velocity that have been conducted at Ontario mines since the Paymaster accident of February 2, 1945. The first of these was made by Hollinger Consolidated Gold Mines, Limited, on February 25, 1945. With the encouragement of the Department of Mines and the Committee, many properties embarked with energy on the task of ascertaining the performance of existing and improved devices under conditions similar to those attending rope breakage. Table 9 presents the more significant facts relating to this experimentation. An analysis of the results from various points of view follows.

Frequency of Unsatisfactory Performance.—The total number of cases in which the dogs, for one reason or another, failed to act satisfactorily was fourteen, representing 12.1 per cent of the 116 tests reported. This is not to be taken as representing the degree of probability of unsatisfactory action in mine practice, as in some of these tests the objective was to determine possible limits of design or operation. These instances would not occur in an actual installation.

Apparent Causes of Unsatisfactory Performance.—In the case of the Bidgood test of May 20, 1945, the dogs were not prevented by adequate stops from turning over too far. The guides bent markedly outward under the pressure of the dogs, which was applied too near the inner edges of the guides. When for the test of July 14 levers were added to the dog shafts in order to limit the rotation, the test was successful.

The teeth of the dogs for the five Buffalo-Ankerite tests were purposely made progressively narrower and shorter, in order to discover the limit of safety. This limit was passed when the teeth were shortened to $\frac{5}{8}$ in.

Failure in the Chesterville test of September 23, occurred by reason of the shallow teeth of the dogs becoming completely clogged with wood spoil. Adoption of a dog with fewer and longer teeth brought success in the test of October 7.

In the case of the Hard Rock test for which the type of dog used has not been reported, the failure appears to have arisen from the use of unsatisfactory local spruce guides and from the failure of a guide joint.

The second Hoyle test of June 24, was characterized by a clogging of the dog teeth and a subsequent sliding of the dogs over the guide surface. Narrowing of the dogs to two inches and then to one inch brought success, although a definite splitting effect was introduced.

The first two tests at Little Long Lac were accompanied by a pronounced buckling outwards of one guide, by reason of the fact that the dogs bit too close to the inner edge of the guide.

In the Macassa test of June 6, the tail pieces of the dogs forced their

way through the wood of the guides and the dogs turned over. This difficulty would have been obviated if there had been a further stop against some part of the cage or its shoes.

Failure in the eighth test on the McIntyre experimental tower arose from the fact that the drag of the rope produced in accelerating the sheave and the hoist drum prevented the cage springs from actuating the dogs. The trailing rope effect presents the principal remaining problem in devising an effective safety dog installation.

For the first two tests at Michipicoten Iron (Josephine Mine) the dogs turned over, as a result of the tail piece cutting deeply into the guides. When rotation stops were added to the dog shafts for the third test, success was attained.

In the second test of June 3 at Pamour, the square end of the tail on one set of dogs cut deeply into the guide, the dogs turned over and the stopper chain on one dog shaft broke. The other two dogs filled up with wood spoil and slid over the guide surface.

It is reported that for the Teck-Hughes test of September 26, one of the damp guides was practically destroyed.

The Wright-Hargreaves test of October 5, was attended by a tight clogging of the dog teeth and a subsequent bouncing out and sliding of the dogs. The need for devising some means of permitting the escape of wood spoil was made most apparent.

Summarizing the apparent causes of these fourteen failures it is seen that in five instances it was due to the dogs turning over; in three to the clogging of the teeth; in two to guide buckling; in two to faulty guides or joints; in one to the dog teeth being too short; and in one to the trailing rope effect.

A study of these phenomena by mine operators has enabled them to devise means of overcoming the various difficulties presented, except perhaps that of the trailing rope.

Influence of Cage Velocity on Test Failures.—In the thirteen failure cases for which the cage velocity at the instant of the first engagement of the dogs could be computed, the velocities ranged from 900 to 1630 ft. per minute, with eight of them below 1200 ft. per min. Faulty performance cannot therefore be attributed to difficulty in dealing with high velocities. This is further apparent from the fact that in very many instances successful performance of safety mechanisms was achieved with velocities ranging from 1200 to over 2000 ft. per min. Apart from any trailing rope complication, therefore, safety installations have been made to act about equally satisfactorily for high and low velocities.

Ratio of Spring Force to Conveyance Weight.—Table 10 exhibits the frequency with which various ratios of initial spring force to conveyance weight existed in the 100 tests reported in Table 9 for which such ratios were known. No clear indication is given of the optimum value of the ratio. Success or failure appears to be influenced more by other factors than the spring force ratio.

The spring giving a ratio of 1.00 was intended for a much heavier conveyance than was used in the Macassa tests reported in Table 9.

TABLE 10

RATIO OF INITIAL SPRING FORCE TO CONVEYANCE WEIGHT IN DROP TESTS WITH INITIAL VELOCITY FOR SUCCESSFUL AND UNSUCCESSFUL CASES

Ratio of Initial Spring Force to Conveyance Weight	Numbers of Cases	
	Successful Test	Unsuccessful Test
0-0.25	3	1
0.26-0.40	32	3
0.41-0.50	3	0
0.51-0.60	12	2
0.61-0.70	18	1
0.71-0.80	17	2
0.81-1.00	4	2
Totals	89	11

Number of Teeth in Dogs.—In the thirteen failure cases for which the dog details were reported, one type had three teeth, five had four teeth, two had five teeth, three had six teeth, one had eight peg teeth, and one (Buffalo-Ankerite) had two offset wedge teeth. As a result of the frequent clogging of dogs with small teeth by wood shavings and splinters, a definite trend has set in towards the use of dogs with fewer and longer teeth and with design features that provide for the clearing away of the shavings. This was done successfully in the case of the Buffalo-Ankerite dogs (F1), those of Kerr-Addison (C8), Lake Shore (C9), and Wright-Hargreaves (F2).

Value of Stops in Limiting the Rotation of Dogs.—In the thirteen completely reported failure cases so far as safety devices are concerned, there was one that occurred with dogs having cage stops; four with guide stops; four with linkage limitation only; one with both cage stops and guide stops; and three with guide stops and shaft stops. The existence of stops will therefore of itself not preclude failure to act properly, since other features of the installation may be faulty. The record does not show any clear superiority of one type over another.

Excessive rotation may not be prevented by guide stops, that is where a tail piece of the dog bears against the guide. While this serves to compensate for guide wear, the tail piece if not widened, or equipped with a pad, may cut deeply into the guide and permit the dog to turn over. This happened in three of the thirteen cases above reported.

Compensation for wear may be secured by the use of guide stops and at the same time excessive rotation due to the tail crushing the guide may be prevented by providing a secondary stop against the cage, as in the case of the Wright-Hargreaves dogs used in the test of June 9 (D1), the Omega dogs (D2), and the Matachewan dogs (D3).

Width of Dog Face.—Examination of the cases of test failures fails to disclose any clear relation between the width of the face of the dog and the final result. The effect of width is greatly influenced by the clear distance between the guides and whether or not the full face width of the dogs or only a part of it makes contact with the guides. Extra width of dogs is of no value if they bear only on the outer edge of the guides. This

defective feature was noted in many of the installations inspected by the Committee.

Range of Deceleration Ratio.—Examination of Table 9 shows a very considerable variation in the deceleration ratio, that is, the ratio of the cage deceleration to the acceleration of gravity. Of the 101 complete cases there listed, so far as this ratio is concerned, there were 63, or 62 per cent of the total, in which the ratio did not exceed 3.0, which, as pointed out in Article 47, is the maximum deceleration ratio for which safety devices should be designed. In the case of mines that carried out a series of tests, modifying the design of the safety dogs in accordance with observed behaviour as they proceeded, there were evidences of being able to influence the deceleration ratio in the direction desired. Some examples of this are the tests of Buffalo-Ankerite, Lake Shore, McIntyre, and Wright-Hargreaves. It therefore does not seem impracticable to obtain approximately the rate of deceleration which physiological considerations permit.

47. **Development of New Safety Devices.** It is desirable that every effort be put forth by those actively concerned with mining operations for the development of new and improved cage safety devices. To be successful, a device should embody as many as possible of the qualities listed in Article 42. The most basic of these considerations from the point of view of the designer are set out briefly in what follows.

Permissible Deceleration Ratio.—Some guide to the permissible deceleration ratio is found in the existing standard practice with respect to oil buffers for passenger or freight power elevators. Their minimum total stroke, as prescribed in the Canadian Standards Association Safety Code for Passenger and Freight Elevators (144), must allow for a maximum retardation, based on governor tripping speed, of 2.5 times the acceleration of gravity.

In those instances of accidental engagement of safety dogs of mine cages where the deceleration ratio could be ascertained there is no evidence known to the Committee of serious injury to the cage occupants. For example, in the case of accidental dogging at Hallnor, on September 18, 1945, the deceleration ratio appeared to be about 4. Four of the nine men in the conveyance suffered injuries, but these were of a minor nature. In this case the dogging was due to a displaced wear plate and not to a defect in the safety device itself.

Having regard to all the circumstances, the Committee believes that a deceleration ratio of 3.00 is not excessive and recommends that efforts be made in the future development of safety devices to keep within it. As shown in Article 46, this is a goal that may be achieved by careful design.

Avoidance of Trailing Rope Effect.—Since a trailing rope, which may pass over the sheave and wind around the drum, has, through the drag developed, a strong influence towards preventing safety dogs from setting, or releasing them after they have already engaged, every effort should be made to create devices that are not subject to this hazard. It would appear that some form of overspeed governor would be best, but the long

traditional governor rope of the building elevator is undesirable in a deep, wet mine shaft.

Control of this type would incidentally prevent accidental dogging, which sometimes occurs through slackening of the rope tension by reason of striking an obstruction or through oscillation.

I—HOISTING REGULATIONS

48. **General.** The Committee has examined in detail the mine hoisting regulations in effect in many jurisdictions outside of Ontario and finds in them very few stipulations that are not covered adequately in the regulations of this province. In general, it may be said that Ontario has been a leader in this field. From time to time, however, need will arise for reconsideration of the regulations in the light of new investigations and new experience and the Committee believes that a study of this kind should now be undertaken.

Since the devising of satisfactory working rules in so important an activity as hoisting can best be done with the close co-operation of those who are actively engaged in mining operations, the Committee would recommend that steps be taken to organize a re-study of the Mining Regulations of Ontario in a manner similar to that followed when the last revision was made. The assistance of the industry should again be sought in this regard.

In addition to those changes in practice that have already been proposed in this report there have been a number suggested to the Committee by various persons as meriting careful consideration. The more important of those that refer to the specific matters coming within the reference, namely hoisting safety, are as follows:

(1) Fully qualified mechanical engineers should be employed by the government for the inspection of cables and mechanical equipment.
(2) Safety committees should be set up at each mine composed of company technicians and men from each department to work in conjunction with the mines inspector.
(3) The mines inspector should be empowered to make any necessary special inspection if complaint is received in writing from any person employed in the mine regarding alleged dangerous conditions.
(4) There should be overhead protection for men working on shaft inspection, consisting of a plate above the roof of the cage.
(5) A speed recorder should be installed on all hoists to indicate both the speed of lowering and the speed of hoisting.
(6) An interlocking device should be installed on all hoists to prevent a hoistman from overspeeding when hoisting or lowering men. He should be required to lower by means of power and not by brakes only.
(7) A hoistman should not be required to look after compressors or anything else, such as, peak loads, whistles, etc.
(8) All bulkheads or anything that might be fouled by a conveyance should be protected by an underwind safety device.

(9) Cardboard or non-conducting danger tags should be placed on or around electrical equipment.
(10) Manways should be made larger, since the space around the ladders is insufficient for men to turn around.
(11) Shock absorbers with suitable rebound control should be installed at (a) the rope attachment to the cage or skip, (b) at the head sheave by means of a suspension mounting, and (c) on the hoist brakes by a cushioning arrangement that would allow the brakes to revolve through a small angle while they come into action.
(12) No vital piece of hoisting or auxiliary equipment should be put into or continue in service without a certificate of a government inspector being periodically posted to the effect that its design, manufacture, and condition at last inspection are satisfactory.
(13) There should be a much greater resort to dynamic or regenerative braking, leaving the friction brakes to come into play only in emergency or to hold the drum stationary.
(14) Sufficient time should be allowed for thoroughly washing and drying ropes before greasing.
(15) A standard solvent should be employed for the purpose of removing old cable dressing.
(16) To ensure adequate rope inspections all hoisting ropes should be insured.
(17) Bearings on the dog shafts should be left sufficiently loose so that they will not bind and stiffen the working action.
(18) No combustible material should be used for the lining of hoist brakes.

49. **Comments on Certain Proposals.** In view of the increasing importance of the mining industry and the rapidly developing mechanization thereof, it is recommended that the inspection staff of the Department of Mines be augmented by the appointment of one or more thoroughly competent professional engineers with mechanical experience. In addition to their inspection duties, these engineers would be required to investigate and make recommendations regarding improvements in mechanical appliances and procedures. It is not proposed that the appointment of these persons would relieve the individual mines of responsibility for the routine daily, weekly, or monthly inspections of ropes or hoisting equipment. It would, however, add to the rigour of the inspection and further the development of new equipment and methods.

At a meeting of the Committee held in Timmins, and also on other occasions, the desirability of setting up joint safety committees, with membership drawn from both management and employees, was strongly advocated. This suggestion was considered seriously by the Committee, particularly as its members are fully aware of the successful operation of such organizations in factories. There are many differences, however, between the operation of factories and mines; what is good for one is not necessarily best for the other. Moreover, in the last analysis, the responsibility for safety is essentially the function of management, which must provide and maintain the necessary safety devices and arrange appropriate procedures.

The Committee is of the opinion, therefore, that it would be unwise to make mandatory the establishment of joint safety committees in all mines, particularly as, in places where the hazard is greatest (as in small or poor mines) such a system would probably be either impracticable or would result in no appreciable improvement on existing practice. The Committee feels, however, that in all mines there should be close co-operation on safety matters between management and employees, and that the opinions of the more experienced employees should be regularly sought and obtained systematically by such formal or informal organizations as may be most suitable to the local circumstances.

In the matter of complaints to the mines inspector suggested in paragraph (3) above, it is desirable that the complaint should first of all be made to the management. If that is ineffective in remedying the alleged dangerous situation, the right of complaint directly to the inspector should be recognized.

The other matters mentioned in Article 48 might best be considered in the detailed re-study of the Mining Regulations herein proposed.

J—SUMMARY OF CONCLUSIONS

Based upon its study of all the relevant facts that have come to its attention in respect of the matters set out in the reference, the Committee desires to report its principal conclusions as follows:

Causes of the Paymaster Accident

(1) Unsuspected and extreme corrosion of the hoisting rope was the primary cause of the loss of life that resulted from the fall of a mine cage in No. 5 shaft of the Paymaster Consolidated Mines on February 2, 1945. (Arts. 5 and 23).

(2) The flat-strand rope as new was of a type and quality recognized as standard and in accordance with what had been considered good practice in the mining camps of Ontario. It is, however, more vulnerable to corrosion than round strand rope. (Arts. 5 and 13).

(3) The diameter of the hoisting drum was and remains too small in proportion to the diameter of the rope. Severe crushing and unstranding stresses will exist when as many as five layers of rope are wrapped around the drum. This occurs when the cage in this installation is at the top of the shaft. (Art. 8). The head sheave is also too small in size. (Art. 10).

(4) Failure of the safety dogs to arrest the fall of the cage after the rope had broken was the secondary cause of the loss of life. (Art. 6).

(5) While before the accident the type of dog that was used at Paymaster was generally accepted in the mining camps of Ontario as one of the standard types and was widely used in them, the Committee finds that it was faulty. The teeth were too shallow, thus easily clogging with wood spoil and causing the dog to slide over the face of the timber guide without retarding value. (Arts. 6 and 46).

(6) Proper functioning of the dogs was, in the view of the Committee, prevented in some measure by a faulty setting which prevented opposing dogs on opposite faces of a guide to engage the guide deeply enough. Even a correct setting might have been offset by the lodging of

a piece of rock under the shelf angles attached to the drawbar about 3½ inches above the roof of the cage. The Committee regards this as an objectionable detail. (Art. 6).

(7) The Committee is of the opinion that the 1130 feet of trailing rope between the break and the cage probably had an important bearing on the failure of the dogs to engage the guides effectively after they had first taken hold. (Art. 6).

Hoisting Installations and Practices

(8) Drums and head sheaves in some Ontario mines are of too small a diameter to obtain the normal service life of the rope or to obviate severe bending and crushing stresses in it. Wrapping three layers of rope on a drum is not consistent with good practice. (Arts. 8 and 10).

(9) Any extension of the use of parallel grooving on drums or the installation of ungrooved drums is undesirable. (Art. 9).

(10) Sheaves with grooves worn too small for the rope that is to run in them should be regrooved from time to time, preferably with each change of rope. (Art. 10).

(11) To lessen the effect of a trailing rope in case of accident the sheaves should be designed with as small a rotational inertia as possible. (Art. 10).

(12) Specifications to which rope wire is purchased by the rope manufacturers are inadequate to secure in all cases a satisfactory grade of wire. (Art. 12). Too much emphasis has been placed on high ultimate strength and not enough on ability to resist corrosion and fatigue. (Art. 12).

(13) The use of many small wires in a rope is to be deprecated in that they are subject to high percentage loss of area through corrosion. Rather than seek a flexibility to suit small drums and sheaves, the diameter of these should be increased so as to permit ropes of sturdier construction. (Art. 13).

(14) The Committee found no evidence that the decomposition products of fibre cores shorten the life of ropes. (Art. 23).

(15) There is no evidence that external lubricant or grease can be forced into the core after the rope has been closed and put in use (Art. 15). Grease is of more benefit in protecting the rope from the entry of water from outside than in providing internal lubrication. (Art. 33).

(16) The Committee favours the use of wire rope clips rather than sockets for capping. (Art. 17).

(17) Hoists need always to be operated by competent and alert men. Excessive shock stresses may be produced in a rope and accidental engagement of safety dogs, with possible subsequent kinking, may result from improper handling of a hoist. (Art. 18).

(18) Factors of safety for hoisting ropes should be fixed with due regard to the uncalculated bending, torsional, and shock stresses. (Arts. 20 and 22). The Committee sees no advantage in the use of the so-called "capacity factor", in that it is based on the erroneous assumption that the weakest section of the rope is at or near the capel, that is, the point of its attachment to the conveyance. (Arts. 19 and 20).

(19) Corrosion is by far the most common source of rope failure in

Canada. It is often unaccompanied by any readily detected external impairment except surface wear. (Art. 23).

(20) The Committee is of the opinion that when abrasive wear on outside wires has removed 20 per cent of their area the rope should be discarded. (Art. 24).

(21) The weakest section of a rope may be at almost any point in its length, particularly in the long stretch between the sheave and the conveyance when the latter is at the bottom of the shaft. Theories based on the assumption that it is at the capel are consequently without a sound foundation. (Art. 26).

(22) Since immediate detection of such obvious defects as broken wires is essential, the Committee recommends that a daily visual inspection of hoisting ropes be required by the Mining Regulations. (Art. 27).

(23) The Committee is of the opinion that, in the case of a rope used for raising or lowering men, an allowance of six broken wires in one lay is excessive. (Art. 28).

(24) Cutting off lengths of rope at the drum end to change the cross-over points is to be commended. (Art. 30).

(25) The Committee is of the opinion that the device of turning a rope end for end is undesirable, in that it is likely to result in possible weak spots being placed where they cannot readily be detected. (Art. 31).

(26) The device of shifting a cage rope to other duty after it has seen most of its normal service life is to be commended. (Art. 32).

(27) The Committee does not favour the placing of an arbitrary limit on the permitted service life of a rope. (Art. 34).

(28) Timber guides are frequently inadequately connected to the dividers, or horizontal mine timbers. (Art. 38).

(29) The history of mine hoisting in Ontario indicates that those mines that employ high rope speeds are not more subject to hoisting accidents than are those that employ the lower speeds. (Art. 40).

(30) A study of the operation of electrical braking systems might reveal definite prolongation of rope life and consequent improvement in hoisting safety. (Art. 40).

(31) The use of properly designed cage safety devices is recommended. Such devices in Ontario have in case of accident effectively stopped falling conveyances in 64 per cent of the cases. Had these devices not been installed on the conveyances it is certain that a considerable aggregate loss of life would have occurred. (Art. 43).

(32) Certain new types of safety devices proposed to the Committee have sufficient merit to warrant further investigation and trial. (Art. 44).

(33) Building elevator practice is not adapted to mine shafts, although an overspeed safety governor that does not involve a long governor rope would be a source of additional security. (Art. 45).

(34) Safety dogs effectively stopped a falling conveyance under initial velocity in 87.9 per cent of 116 drop tests carried out in Ontario since the Paymaster accident. (Art. 46). The cause of failure in the unsuccessful cases in descending order of frequency were clogging of the teeth of the dogs, buckling of guides, unsuitable or badly connected guides, and a trailing rope.

(35) Safety dogs acted as effectively for rope speeds of from 1200 to 2000 feet per minute as for lower speeds. (Art. 46).

(36) No clear relation appears between the successful performance of the cage safeties and the ratio of the initial spring force to conveyance weight. (Art. 46).

(37) Dogs with a considerable number of small, shallow teeth are less satisfactory than those with a few deep teeth. The addition of a feature for clearing away the wood spoil by the dog itself is meritorious. (Art. 46).

(38) An acceptable ratio of the rate of deceleration to the acceleration of gravity is 3.0. Cage safeties should be designed to keep within this limit. (Art. 46).

(39) Efforts to develop improved cage safeties should be directed with especial intensity to eliminating the effect of the trailing rope. (Art. 47).

Inspection

(40) The forcible laying open of a rope in service for inspection is undesirable, in that the wires never return to their original places. (Art. 27).

(41) Observation of the diameter of ropes in service at distances of about 150 feet apart has not always been carried out as accurately as the value of these measurements would warrant. Valuable evidence as to the state of a rope might be obtained by observing the elongation of the rope as a whole. (Art. 27).

(42) While so far, a dependable correlation has not been established between the responses of an electro-magnetic apparatus and defects in a hoisting rope, either as to type of defect or degree, the results of experimentation in laboratory and at operating mines are promising. (Art. 27).

(43) Routine semi-annual testing of rope samples from the capel end, while not revealing possible sections of weakness elsewhere in the rope, yield useful information and should be continued. (Art. 29).

(44) The Ontario Regulations Governing the Operation of Mines are too lenient in the matter of the numbers of broken wires that will be tolerated in inspection. (Art. 28).

Hoisting Regulations

(45) In general, the rules respecting hoisting contained in Regulations Governing the Operation of Mines (1941) are comprehensive and thorough and amongst the best of the kind that the Committee has examined. They do, however, require re-study, in view of new investigations and experiences. (Art. 48).

K—RECOMMENDATIONS

The Committee desires to submit the following specific recommendations for action. In its opinion the adoption of these would promote the safety of mine hoisting operations in the Province of Ontario.

(1) That steps be taken by the Department of Mines to promote the use of drums and head sheaves of diameters not less than 80 to 100 times the rope diameter in future installations, or modifications of existing ones.

(2) That the Department of Mines call to the attention of the Ontario Research Commission the need for a programme of systematic research in the field of desirable properties for rope wire and that, when

the accumulated data warrant, the mining industry of Ontario request the Canadian Standards Association to prepare, with its co-operation, a suitable specification for rope wire.

(3) That the Department of Mines request the Ontario Research Commission to include in the programme of research recommended in (2) above, a thorough investigation of the means of preventing corrosion in mine hoisting ropes, including a study of existing and new types of rope dressing.

(4) That the Department of Mines and the mining industry of Ontario continue to encourage investigation of the merits of electro-magnetic methods of examination of mine hoisting ropes.

(5) That the Department of Mines investigate, or cause to be investigated, the desirability and feasibility of incorporating electrical conductors in hoisting ropes for purposes of communication between the cage and the surface and to apply the brakes automatically in the case of rope failure.

(6) That the Department of Mines encourage by active measures the development of improved safety devices that will operate effectively and within safe physiological limits, despite the influence of a trailing rope.

(7) That the Department of Mines take steps to have appointed thoroughly competent professional engineers with mechanical experience to supervise the inspection of cables and hoisting equipment and to recommend improvements in mechanical appliances and procedures.

(8) That the Department of Mines seek the co-operation of the mining industry in a re-study of its regulations respecting hoisting.

All of which is respectfully submitted,

C. R. YOUNG, Chairman.

E. A. ALLCUT
T. R. LOUDON
L. M. PIDGEON
V. G. SMITH

APPENDIX I

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Part II

PRELIMINARY REPORT OF THE ONTARIO MINING ASSOCIATION COMMITTEE

appointed by that Association at the request of the Ontario Government to consider the factors having to do with the hoisting rope failure at No. 5 shaft, Paymaster Consolidated Mines Ltd. on February 2nd, 1945

History

On the morning of February 2nd, 1945, while the shift was being lowered at No. 5 Shaft at Paymaster Consolidated Mines, Limited, South Porcupine, Ontario, the hoisting cable broke—resulting in the death of sixteen miners.

No. 5 shaft at Paymaster is a three compartment shaft extending from surface to a depth of 2685.0 feet. One compartment serves as a manway, while two are used as hoisting compartments. For hoisting ore, skips are used in both compartments. For lowering and hoisting men at the beginning and end of each shift, one skip is removed and replaced by a double deck cage.

On the morning of the accident a trial run had been made through the shaft with an empty skip and the double deck cage. Two cage loads of men were then lowered to points below the 1050-foot level without unusual incident. At the time of the accident the third double deck cage load of men was being lowered into the mine. This trip was for the 1050-foot level. When the cage had reached approximately the 900-foot level, the hoisting cable broke at a point between the hoist and the head sheave. The cage was manufactured by Wabi Iron Works, New Liskeard, Ontario, in 1938 and was equipped with safety dogs or catches of their standard design. These are of the type "B" as shown in the section of this report headed "Analysis —Free Fall Safety Dog Tests, Ontario Mines". The dogs are actuated by a leaf spring which is maintained inoperative by the pull of the hoisting cable on the draw bar of the cage.

Quoting in part from the Department of Mines' report of the accident:

> The dogs worked ineffectively. The dogs took hold when the rope broke but they either bounced out or were whipped out by the trailing rope. At the first contact they cut into the guides for only a foot to a maximum depth of not more than 5/16 of an inch on each side of the guide. The teeth probably filled with wood at this point. The dogs on the east guide then cut out for two sets and those on the west guide no more than scratched the guide. Then they gradually began to score deeper and from the top of the new guides to the bottom, they cut very uniformly to a combined depth of about 7/16 of an inch on each guide. The width of the cuts averaged about 2⅛ inches on the west guides and 1½ inches on the east guides.

A Coroner's Inquest was held at South Porcupine, Ontario, and on February 27th, 1945, the Coroner's jury brought in the following verdict:

We find the said Russell Dillon came to his death at 8 a.m. on February 2nd, 1945, in number 5 shaft at the Paymaster Mine, in the Township of Tisdale through First: "By breaking of the rope" and Secondly: Through the failure of safety dogs to function properly and stop the cage". From evidence submitted, the rope broke because of internal corrosion of which there was no indication from external examination. We consider the dogs faulty in design and operation, and recommend that all safety dogs and attachments be approved by a competent authority appointed by the Department of Mines, before permitting the use of same. Also that a study be made on the prevention of internal deterioration of hoisting ropes by a Commission appointed by the Provincial Government, and every effort be made to prevent it.

We strongly recommend that there be no delay by said Commission in making investigation of all cables, safety catches, and hoisting equipment to prevent a recurrence of this serious and deplorable accident.

We find that no blame can be attached to anyone through carelessness or neglect.

(Signed) Chas. Kemsley—Foreman
Walter Cliff
John McDonald
John Pecore
Sam Rock

Purpose

The instructions to the Committee and its notice of appointment are embodied in a letter from the Ontario Mining Association under date of February 16th, 1945, addressed to The Honourable L. M. Frost, Minister of Mines, Province of Ontario. The letter follows:

Dear Mr. Frost:

Following our discussion of the 13th instant, I am directed to advise you that the Directors of this Association at their meeting to-day were pleased to accede to your request and have appointed a committee of the Association to—

1. Consider the facts surrounding the recent hoisting accident at the Paymaster Consolidated Mines Limited;
2. In the light of such facts and of the experience of the Committee and those others who will be consulted by them, make if possible such suggestions and recommendations as may seem best to avoid recurrences of similar accidents.

It is understood that this Committee will have available to it the full co-operation of your own capable inspectional staff and officials, as also all data in their possession.

It is further understood that the report of our Committee will be available to the Technical Committee recently appointed by you in this connection.

Our Committee has further been instructed to make itself available at the call of your Technical Committee for such meetings or discussions as your Technical Committee may desire.

In giving consideration to the make-up of our own Committee our Directors considered it advisable to include therein the personnel from the three main mining camps that acted with your Department some years ago in the drafting of the present Mining Regulations—the personnel is therefore as follows:

Mr. R. E. Dye—Ass't. General Manager of Dome Mines Limited and President of this Association, *Chairman.*
Mr. R. L. Healy—General Manager, Wright-Hargreaves Mines Ltd.
Mr. R. D. Parker—General Supt., International Nickel Co,

The work of this Committee will commence immediately and will be expedited insofar as possible in order that their report may be available to your Technical Committee at the earliest possible date.

Yours very truly,

ONTARIO MINING ASSOCIATION,

(Sgd.) "N. F. Parkinson"
Executive Director.

NFP:R

Introduction

The Committee realized from the start that the subject to be examined was of such scope and magnitude that, in order to do it even a small measure of justice, full use should be made of all available relative information which had any bearing on the subject.

This involved a comprehensive search through existing literature and careful scrutiny of those articles which gave promise of carrying information or ideas which could be considered helpful. In the course of this search, the technical literature in the library of the Canadian Institute of Mining and Metallurgy at Montreal, in the private library of International Nickel Company at Copper Cliff, and others, was carefully scanned for references to hoists, hoisting cable and related matters which might be helpful in a specific way or might furnish any helpful lead or suggestion in the examination of the general subject under consideration. A bibliography of those articles of which definite use was made in the preparation of this report is to be found in the Appendix. The task at hand involved, too, the collection, correlation and further study of existing relative data regarding Ontario Mines, having to do with the general subject under examination. As the work progressed, several new lines of thought were presented which received special attention and study.

The work of the Committee has been furthered by the ready co-operation of the Inspection Branch of the Department of Mines, Mr. Daniel Harrington of the U.S. Bureau of Mines, the mechanical staff at the various mines in Ontario, by various manufacturers and suppliers of material to the mining industry, and many others. This Committee is greatly indebted to the International Nickel Company for the contribution it has made in making its staff and facilities available to the Committee.

This Committee feels that the above acknowledgements would fall far short of the appropriate if special mention were not made of the outstanding work done by members of the staff of the International Nickel Company. These gentlemen have devoted themselves to the work with enthusiasm, determination and vision which we believe can best be described as inspired. Throughout the investigation, this Committee has leaned most heavily upon these gentlemen and much of the material presented in this report is the product of their own meticulous care and devotion to the task.

This Committee is fully cognizant of the fact that its work is not now completed, as there remains considerable work to be done on several of the items which are dealt with in this report, and the hope is entertained that new and productive thoughts may yet emerge. It seems appropriate, however, that a Preliminary Report be presented at this time which will set forth the present state of the investigation.

This preliminary report is based upon the examination of a number of phases of the problem which are dealt with in the body of the report under various headings as follows:

"Analysis—Hoisting Accidents in Ontario Mines"

"Symposium on Wire Hoisting Ropes"

"Causes of Wire Failure, Other than Corrosion, in Mine Hoisting Rope"

"Analysis of Results—Special Test Ropes"

"Comparison and Analysis of Statistics and Operating Characteristics —Special Test Ropes"

"Electro-Magnetic Testing of Hoisting Ropes by the International Nickel Company of Canada, Limited"

"Deterioration by Corrosion of Mine Hoisting Rope"

"Proposed Method to Determine Amount of Metal Loss in Outer Wires of a Hoisting Rope while Rope is Still in Service"

"Safety Catches—Application and Statistics"

"Characteristics of a Good Safety Catch"

"Analysis—Free Fall Safety Dog Tests, Ontario Mines"

"Research to Determine Methods for the Detection and Prevention of Corrosion and Other Types of Rope Deterioration"

In making this presentation, the Committee wishes to make it clear that this Report is in no way final. Some of the items presented form a reasonable basis for fairly definite conclusions. In such cases conclusions and recommendations have been offered. In other instances there are reasonable grounds for differences in interpretation of the data presented and therefore the conclusions to be reached. With regard to these, tentative conclusions only are offered. With regard to still other phases of the subject, it is obvious that further work will be required in order to reach sound conclusions.

Further work is being done on several of the items enumerated above, and it is hoped that the work on these and along other lines of investigation which may be suggested, will yield further significant results. In any event, this Committee will submit a further report at a later date when results may be more nearly finalized.

In the interval it is appropriate to make the observation that it is eminently true that eternal vigilance and constant care are the price of safety in hoisting operations. It is the hope of this Committee that the presentation of this Preliminary Report, along with the salient data now at hand, may serve as a spur to further study and investigation of all angles of this most important subject.

Respectfully submitted,

ONTARIO MINING ASSOCIATION COMMITTEE,
RE PAYMASTER ACCIDENT,

R. E. Dye
R. L. Healy
R. D. Parker

ANALYSIS—HOISTING ACCIDENTS IN ONTARIO MINES

History

The accidents tabulated in the appendix under the title—"Hoisting Accidents Involving Failure of the Rope, Attachment, or Hoist in Ontario Mines" were summarized from data supplied by the Ontario Department of Mines together with some additional data from mines in the Porcupine and Sudbury Districts.

The Department of Mines' records on hoisting accidents only extend back to 1935, therefore the accidents listed in the table are not represented as being a complete tabulation of hoisting accidents in the Province.

Purpose

The data have been compiled in order to scrutinize the facts surrounding hoisting accidents in Ontario Mines and thereby determine the chief causes. Also, in cases where safety dogs were involved, to determine the ratio of success to failure in their action and in instances where the dogs failed to function successfully, to examine the causes contributing to the said failures.

Compilation of Tables

The tables contain data on 58 hoisting accidents, 53 of which occurred in vertical shafts and 5 in inclined shafts. The data on the accidents are far from complete but covered in the majority of cases the following items: company and mine, date of occurrence, type of conveyance, cause of accident, type of safety dog if present, how dog functioned, distance conveyance fell after failure, direction of travel of conveyance at time of the accident, diameter of the rope, factor of safety of rope, condition of rope at break, distance of break from shaft conveyance, and finally a brief description of the accident.

The table is divided into two sections, accidents in vertical shafts and accidents in inclined shafts. This was done because operating conditions are not the same for vertical and inclined shafts and in the case of inclined shafts, safety dogs were not involved.

Analysis of Accidents

A complete analysis of the accidents as to cause, result, type of conveyance, action of the safety dogs, and direction of travel at the time of the accident is submitted.

VERTICAL SHAFTS

In this section of the table there were 53 accidents in 36 different mines operated by 35 companies.

The 53 Hoisting Accidents Classified as to Cause

	No. of Cases	Percent
Deteriorated rope	16	30.0
Overwinds	9	17.0
Rope sheared by falling object or shaft conveyance	7	13.2
Faulty connections	5	9.4
Rope kinking	4	7.6
Conveyance fouling shaft timber or jamming in guides	4	7.6
Brake failure	2	3.8
Clutch failure	1	1.9
Loss of hoist control	1	1.9
Frozen sheave bearing	1	1.9
Sheared sheave axle	1	1.9
Split head sheave rim	1	1.9
Unknown causes	1	1.9

From these figures it is determined that the greatest single cause of rope failure is due to deterioration of the rope. In the 16 cases listed, deterioration was due to:

	No. of Cases	Per-cent
Severe corrosion with wear	9	56
Severe wear (with corrosion)	7	44

Thus internal corrosion of the rope may be said to have been the chief cause of this deterioration.

The next most important cause of rope failure is due to overwinding into the head sheave. This type of accident is due to carelessness on the part of the hoistman and should be preventable if proper controllers and overwind limit switches are kept in adjustment.

The table presented brings to light the fact that a great variety of causes, other than the deterioration of the rope, have resulted in hoisting accidents in Ontario Mines.

Result of Accident in Regard to the Rope

	No. of Cases	Per-cent
Rope parted	41	77.4
Rope failed partially	6	11.3
Rope pulled out of clamps at drum	1	1.9
Socket or attachment failed	5	9.4

Type of Conveyance

	No. of Cases	Per-cent
Cages	17	32.0
Counterbalance cages	3	5.7
Skip-cage combinations	8	15.1
Sinking buckets	3	5.7
Skips	19	35.8
Type of conveyance not stated	3	5.7

Conveyance Equipped with Safety Dogs

	No. of Cases	Per-cent
Cages	16	94.0
Counterbalance cages	2	66.6
Skip-cage combinations	8	100.0
Sinking buckets	0	0
Skips	6	31.6
Type of conveyance not stated	2	66.6

Success of Operation of Safety Dogs

CAGES	No. of Cases	Per-cent
Dogs functioned successfully	8	73.0
Dogs did not function successfully	3	
Safety dogs not involved	5	
COUNTERBALANCE CAGES		
Dogs functioned successfully	1	100.0
Safety dogs not involved	1	
SKIP-CAGE COMBINATIONS		
Dogs functioned successfully	4	50.0
Dogs did not function successfully	4	

SKIPS

Dogs functioned successfully	4	66.6
Dogs did not function successfully	2	

TYPE OF CONVEYANCE NOT KNOWN

Dogs functioned successfully	1	50.0
Dogs did not function successfully	1	

OPERATION OF DOGS FOR ALL TYPES OF CONVEYANCES

No dogs installed	19	
Rope did not part—dogs not involved	6	
Dogs installed, functioned successfully	18	64.0
Dogs installed, did not function	10	36.0

If only the 28 cases where dogs were installed and had the opportunity to function be considered, then the ratio of success to failure is approximately 2:1.

Direction of Travel of Conveyance at Time of Accident

In six of the 53 accidents in vertical shafts the rope only failed partially and as the time of occurrence is not known the direction of travel in these cases has not been considered. In the remaining 47 cases the direction of travel at the time of the accident was as follows:

	No. of Cases	Per-cent
Ascending	34	72.4
Descending	6	12.7
Stationary	7	14.9

These figures indicate that hoisting accidents occur more than twice as frequently when the conveyance is being hoisted than when descending or stationary.

Direction of Travel in the 28 Cases

When conveyance was equipped with safety dogs which had the opportunity to function:

	No. of Cases	Per-cent
Ascending	21	75.0
Descending	3	10.7
Stationary	4	14.3

In the 21 cases where conveyance was ascending, safety dogs functioned successfully 15 times or with 71.5% success.

In the three cases where conveyance was descending, safety dogs functioned successfully twice or with 66.6% success.

In the four cases where conveyance was stationary, safety dogs functioned successfully once or with 25% success.

These results indicate that the direction of travel is a factor influencing the eventual success of the safety dog action. Best results are achieved when the conveyance is ascending.

Reasons Why Safety Dogs Did Not Function

In some instances not enough data were obtained to determine the reasons why the safety dogs did not function properly. However, a summary of the 10 accidents in which the safety dogs did not operate is given here in an attempt to determine the causes: *(See following page)*

ACCIDENTS INVOLVING NON-FUNCTION OF DOGS COMPARED WITH RESULTS OF SUBSEQUENT FREE-FALL TESTS

Company and Mine	Date	Length of Rope Attached to Conveyance	Action of Dogs and How Far Conveyance Fell	No. of Tests	Free-Fall Tests Results
Aunor Gold Mines	Nov. 15/44	30 ft.	Fell 1350 ft. to bottom. Dogs scored guides all the way.	1	Type 0 dogs tested. Type E dog involved in accident.
Barry-Hollinger	1930-31	500 ft.	Fell 30 ft. to bottom. Dogs did not function.	0	No dog tests.
Bidgood-Kirkland	Jan. 10/45	250 ft.	Fell a few feet to spillage; dogs may not have had a chance to function.	2	(1) Hit bulkhead. (2) Deceleration 2.5G (after stop added).
Buffalo-Ankerite	July 29/43	4000 ft.	Fell 1700 ft. to sump; drum continued to rotate, rope cut off at spout.	5	Type N dog tested. Type C dog involved in accident.
Coniaurum Mines	Feb. 27/35	1500 ft.	Fell 1500 ft. to bottom. Dogs scored guides.	1	(1) Deceleration 1.6G.
Hallnor Mines	June 10/43	200 ft.	Fell 650 ft. to bottom. Dogs scored guides all the way.	4	(1) Deceleration 3.75G (with type U dog, shaft bent). (2) Deceleration 7.1G with type 0 dog. (3) Deceleration 4.75G with type 0 dog. (4) Deceleration 1.40G with type 0 dog.
Macassa Mines	Mar. 15/40	2050 ft.	* Fell through spill door, stopping 18 ft. below loading postion with dogs engaged, and 25 ft. above bulkhead.	2	(1) Hit bulkhead and bent dog shaft. (2) Deceleration 3.08G (stop added).
Pamour Porcupine....	May 24/38	350 ft.	Fell 500 ft. to bulkhead. Dogs only scored guides at first.	4	(1) Deceleration 4.6G (dogs filled with wood on one side). (2) Hit bulkhead (dogs filled with wood on one side). (3) Deceleration 2.62G (teeth changed). (4) Deceleration 0.936G (teeth changed).
Paymaster Consolidated	Feb. 2/45	1130 ft.	Fell 1700 ft. Dogs engaged guides immediately, but became disengaged for a short distance and acted ineffectively after that.	1	(1) Type 0 dog tested. Type B dog involved in accident.
Sturgeon River Gold Mines	Aug. 27/42	2600 ft.	Fell 40 ft. to shaft bottom. Rope sheared off at spout, dogs did not act as rope tension not released.		No dog tests.

* Original information stated: "Fell 18 ft. onto bulkhead. Dogs caught but were released by trailing rope."

Of the 10 accidents listed two cases may be ruled out as apparently the safety dogs did not have the opportunity to function. In the Buffalo-Ankerite and Sturgeon River Gold Mines accidents, the rope tension was not released until after the conveyance had hit the bottom of the shaft thus precluding the operation of the safety dog mechanism.

The results of correlating the dog action in the free-fall tests with the hoisting accidents in which the safety dogs did not function, are as follows:

Aunor Gold Mine.—Dogs apparently unsatisfactory, as type changed before free-fall test made.

Barry-Hollinger.—No safety dog tests made.

Bidgood-Kirkland.—Dogs apparently unsatisfactory as changes were made after the first test.

Buffalo-Ankerite.—Dogs apparently unsatisfactory as change was made before making free-fall test.

Coniaurum Mines.—Free-fall test satisfactory; the only apparent reason for the non-operation of safety dogs during the hoisting accident was the 1500 ft. of trailing rope.

Hallnor Mines.—Safety dogs apparently not satisfactory as type changed after first free-fall test.

Macassa Mines.—Dogs apparently faulty as adjustments made after the first free-fall test.

Pamour Porcupine.—Dogs apparently faulty as dog teeth changed and stops added after two unsatisfactory tests.

Paymaster Consolidated.—Safety dogs must have been considered faulty as dogs changed to 0 type before test made. The three hoisting accidents recorded, involving original type B dogs, resulted in two successful stops and one failure. In the latter case, the conveyance was descending with 1130 feet of trailing rope.

Sturgeon River Gold Mines.—No test made.

In the majority of cases poor design of safety-dog mechanism can be blamed for the non-functioning of the dogs. In two cases the failure of the dogs to function can only be attributed to the length of trailing rope.

Theoretically the main reasons why safety dogs do not function properly are thought to be as follows:

(1) Poor design of safety dog mechanism and safety dog cams and teeth.
(2) Rope tension not released sufficiently to permit the dogs to act.
(3) Insufficient initial spring tension.
(4) Obstructions preventing mechanism operating.
(5) Too great a clearance between guide face and dog teeth, when the guides have become badly worn.
(6) Wood in guides in such condition as not to be able to withstand safety dog action.

The failure of safety dogs to function properly may be due to any one or a combination of the above reasons. Most safety dog failures can no doubt be attributed to poor design of safety dogs and the dog mechanism,

but some failures must have been caused by the non-release of rope tension due either to the rope not parting until after the conveyance has reached the shaft bottom or to the effect of a long section of trailing rope.

The 18 hoisting accidents where the safety dog action was successful divided on the basis of the length of trailing rope are:

Length of Trailing Rope	No. of Cases	Per-cent
0–30 ft.	8	44.5
30 ft.–500 ft.	6	33.3
500 ft.–1000 ft.	3	16.6
1000 ft.–1738 ft.	1	5.6

From the table of safety dog failures two cases are found where proper dog action may have been prevented by the trailing rope which, in these cases, was more than 1000 feet in length.

Against this, there is one case on record of successful dog action with a length of trailing rope in excess of 1000 ft. (Wright-Hargreaves accident of July 19th, 1943).

INCLINED SHAFTS

There were five hoisting accidents in inclined shafts in two mines operated by the same company.

Degree of Inclination of Shafts

Varied between 50° and 65°.

The 5 Accidents in Inclined Shafts Classified as to Cause

	No. of Cases
Skip Jamming in Shaft	3
Overwind	1
Fire Burning through Rope	1

In no case could the condition of the rope be blamed for the accident.

Type of Conveyance

Skips in all cases.

Result of Accident in Regard to Rope

Rope parted in every instance.

None of the skips in question were equipped with safety dogs. This is accepted practice as authorities agree that it is not feasible to equip conveyances in inclined shafts with a positive acting arresting device.

Direction of Travel of Conveyance at Time of Accident

	No. of Cases	Per-cent
Ascending	4	80
Descending	0	0
Stationary	1	20

CONCLUSIONS

The findings of this analysis of hoisting accidents should be considered as highly important as the accidents all occurred in local mines in which the operating conditions are well known. To summarize the important findings:

Vertical Shafts

(1) The most common cause of hoisting accidents is rope deterioration due to corrosion and wear.
(2) In the 28 accidents where safety dogs were involved and had the opportunity to function, the ratio of success to failure was as 64:36.
(3) Hoisting accidents occur most frequently when the shaft conveyance is ascending. In 72.4% of the total instances the accidents occurred when the conveyance was being hoisted.
(4) Safety dogs tend to function best when the conveyance is ascending. The dogs functioned successfully 71.5% of the time in the 21 instances when the accident occurred at the time the conveyance (equipped with safety dogs) was being hoisted.
(5) The non-functioning of safety dogs in the majority of cases is due to poor design of dogs and dog mechanisms but it is considered that a long section of trailing rope tends to prevent proper dog action.

Inclined Shafts

(a) The most common cause of hoisting accidents in inclined shafts was due to the conveyance jamming in the shaft.
(b) In 80% of the instances the accident occurred when the conveyance was being hoisted.

SYMPOSIUM ON WIRE HOISTING ROPES

History and Purpose

A meeting of a group of men associated with the manufacture and use of steel wire hoisting ropes, took place at Copper Cliff, Ontario, on March 30, 1945. This meeting was sponsored by the Ontario Mining Association and was held for the purpose of determining the views and opinions of wire and rope producers regarding details of manufacture and use of these products.

Mr. R. E. Dye of Dome Mines Limited presided over the meeting as chairman. Those present and the companies represented are listed below:

R. E. Dye, Dome Mines Limited
R. L. Healy, Wright-Hargreaves Mines Ltd.
A. J. Morgan, John A. Roebling's Sons
C. Hodgson, Anglo Canadian Wire Rope Co. Ltd.
G. H. Atkinson, Anglo Canadian Wire Rope Co. Ltd.
W. E. Brown, B. Greening Wire Co. Ltd.
D. T. Morris, Canada Wire and Cable Co. Ltd.
R. P. Ross, Dominion Wire Rope and Cable Co. Ltd.
W. S. Kitchen, Plymouth Cordage Co. Ltd.
G. L. Green, Imperial Oil Ltd.
R. D. Parker, International Nickel Co. of Can. Ltd.
J. R. Gordon, International Nickel Co. of Can. Ltd.
A. F. Brock, International Nickel Co. of Can. Ltd.
P. I. Ogilvie, International Nickel Co. of Can. Ltd.
A. P. Olive, International Nickel Co. of Can. Ltd.
T. G. Bradbury, International Nickel Co. of Can. Ltd.

Two questionnaires were presented at the meeting. No. 1 refers to the specifications of the materials used in hoisting ropes, details of manufacture of rope wire and the testing and inspection of rope materials at

various stages of production. No. 2 was more general in its scope, covering questions pertinent to the use, construction, deterioration and maintenance of wire rope.

The answers appearing in the following do not necessarily represent the consensus of opinion of all present as, in some cases, only persons qualified in the topic under discussion participated.

Questionnaire No. 1

MATERIAL

Method of Manufacture

Q. 1. Is the steel produced by the acid or basic process?

A. High carbon steel for use in the manufacture of rope wire is made by both the acid process and the basic open hearth process. In the past the industry has usually favoured acid process steel for the higher quality products but present day opinion is that the basic process has advanced to such a degree in recent years that there is little difference in the quality of steels made by these two methods.

Apparently English wire producers preferred to use acid steel for their products. The opinion was expressed that this may have been due to the fact that the acid process had been in use for many years in England, possibly because the ores available were adaptable to the acid process.

Q. 2. Is killed steel used?

A. Killed steel is used for all the usual grades of steel rope wire.

Specifications (Chemical)

Q. 1. What are the chemical specifications covering high carbon hoisting wire?

A. Except over a rather wide range no specifications other than for sulphur and phosphorus are made. These are set at 0.05% maximum for both acid and basic steel on this continent and attempts are made to stay below this limit. In Britain a special grade acid steel has the specification of 0.04% max. for both sulphur and phosphorus. There also, ordinary steels are limited to 0.05% for these elements.

With specific reference to high carbon rope wire, the range of composition is usually as follows:

Carbon	0.75–0.85%
Silicon	.15– .30%
Manganese	.40– .70%
Phosphorus	.05% max.
Sulphur	.05% max.

Q. 2. Except for the specification that the steel be made by certain processes, what methods for controlling the non-metallic content of the steel are used?

A. The only precautions taken to control the non-metallic content of the steel are those normally employed in the best steel making practice. In this respect the sulphur content, in influencing the ultimate non-metallic content, is limited to 0.05% maximum.

Q. 3. Is there a specific allowable limit for non-metallic inclusions? If so, what is the limit?

A. There is no specific allowable limit for non-metallic inclusions in the steel. No inspection of either the ingot or rod is made in this regard.

Q. 4. Is a greater amount of the ingot "cropped" if it is to be rolled into rods for the manufacture of wire for hoisting ropes than would be cropped for other types of rollings? If so, what are the specifications covering cropping of ingots for wire drawing?

A. 25 to 33% of the ingot is cropped which is more than is usually discarded for common wire or ordinary steel products.

Q. 5. Is the chemical composition range of wire for hoisting ropes narrower than in wire for less important use?

A. Yes. The rope manufacturer specifies the properties of the wire required. The wire drawer chooses the ingot with the chemical composition that will best produce the required properties as developed by this process.

Q. 6. Is there a relationship between the length of rope required and the carbon content of the steel used by the manufacturer? That is, where there will be less dead weight because of a short rope, is a lower carbon wire of lower tensile strength and higher ductility made?

A. The length of the rope has no bearing on the chemical composition of the steel used as it is the factor of safety required coupled with the diameter of the rope which governs the choice of the tensile strength of the wire. Some manufacturers claim, however, that it is preferable to employ relatively low tensile wire with its attendant greater ductility and resistance to abrasion and corrosion.

DRAWING AND PATENTING

Rod

Q. 1. Is any non-metallic inclusion inspection made of that part of the rod which is thought to coincide with the location in the original ingot where segregation is usually greatest?

A. There is no non-metallic inclusion inspection made of the rod. Such inspection is not considered commercially practicable by the manufacturers. It is believed that a steel that satisfactorily withstands the drawing operation is necessarily satisfactory with regard to non-metallic content.

Wire

Q. 1. Is the first operation drafting or patenting in the drawing of high carbon wire for hoisting ropes?

A. Rods are patented before drawing. In preparation for drawing, the rod is pickled and then coated with:

(a) copper, called a flash coat,
or (b) copper and tin, called a staw coat,
or (c) lime, called a brown coat.

The above coating, in addition to the application of soap to the die, provides a lubricant for drawing and results in a smooth finish on the wire surface. It was stated that contrary to theory, the copper coating, rather than promoting subsequent corrosion due to electrolysis, actually provides a protective coating.

Q. 2. How many drafts are necessary to make the various reductions from rod to wire?

A. The number of drafts used in making the reductions depends on the behaviour of the wire during drawing and on the desired finished wire size. For large outer wires, five to six drafts are required and for smaller sizes, six or seven drafts may be used. The reduction in metallic area averages about 78% per patenting with the maximum reduction of area per draft not exceeding 25%.

Q. 3. How many patenting treatments are usually necessary to produce the various wire sizes?

A. Usually two subsequent patents after the first are required to produce all but the smaller wire sizes, for which three patents are sometimes necessary.

Q. 4. Which method of patenting is used?

A. The method of patenting employed depends largely on the particular process developed by the individual manufacturer. Both air and lead patenting are used extensively although the latter is generally used for the production of high carbon steel wire.

Q. 5 and 6. If the "double lead" process is used what is the temperature of the heating bath; of the quenching bath? If tube heating is employed, what is the heating temperature?

A. The heating temperature of any process depends on the grain size desired in the wire. Temperatures as high as 1750° F. are used to encourage grain growth within the steel so that the subsequent cold drawing will result in elongated grain of a fibrous nature. The temperature of the lead quenching bath, if such is used, is maintained at 1050-1100° F. to create the desired structure.

Q. 7. Is the making of high carbon wire for hoisting ropes usually concluded by drawing or patenting?

A. The finishing of high carbon steel rope wire is always concluded by drawing. Any subsequent heating would destroy the physical properties imparted by cold drawing.

Q. 8. If finished by drawing, is it a light draft? What would the reduction usually measure?

A. Various draft reductions are used throughout the process of wire drawing. Small reductions are not necessarily confined to the final draft.

Q. 9. Is the final tensile strength of the wire adjusted according to the carbon content of the wire?

A. Adjustment is made to the extent that the original ingot was selected according to the properties desired in the finished wire.

Q. 10. What are the corresponding ranges of tensile strength and chemical composition?

A. In Canadian and British practice, the chemical composition of the steel for the various wires is chosen so that in the rope, the large wires will have the same unit tensile strength as the small wires and therefore all the wires are stressed to the same proportion of their ultimate strengths. This constitutes the "flat band" of wire grades as contrasted with the "curved band" as used in the United States. There the smaller wires, being of the same basic stock as larger

wires, develop higher unit tensile strength because a greater number of drafts are required to produce them.

Q. 11 and 12. What amount of ductility, expressed as a reduction of area and elongation, should accompany the various tensile strengths produced in high carbon wire? What would be the corresponding bending and twisting values?

A. Ductility of wire is not expressed in terms of elongation or reduction of area. The torsion test is usually used as a measure of ductility. Bending tests are not used by manufacturers on this continent as the results have not been found to bear any consistent relationship to the other physical properties of the wire.

The British torsion specifications for wire are as follows:

(Best) Plow Steel Wire—32 torsions per 100 wire diameters.
(Special) Improved Plow Steel Wire—30 torsions per 100 wire diameters.

American torsion specifications are based upon the strength and diameter of the wire. High strength wire of the above grades for ropes 1½" diameter and larger, of 6 x 19 and 6 x 27 constructions are required to conform to 34 and 30 torsions respectively.

Q. 13 and 14. What lengths of wire are joined by welding and what are the details of the technique? What precautions are taken to prevent weld hardening or other weaknesses incurred by welding?

A. Depending on the manufacturer, welds may be made at various stages of wire production. (a) Rods may be welded together before drawing; (b) wires broken during drawing may be repaired by welding; (c) lengths of finished wire may be welded together before being laid up into rope. The claim is made, however, that for important ropes only unwelded lengths of wire are used, but this does not mean that the original rods were not joined to produce wire of continuous length.

Some manufacturers consider repairs, by welding, of wire broken during drawing bad practice and therefore put aside such wire for purposes requiring short lengths. Claims as to minimum distance allowed between welds in a single wire are somewhat conflicting but the average distance appears to be about 175 feet.

All wires are now butt welded with no new material being introduced. An automatic welding and controlled annealing process is used that removes strains and weld hardening. It is claimed that a welded wire develops 50% of its strength in tension and 25 to 60% of its original number of twists in torsion. If welding is done during the wire drawing process, however, it is claimed that subsequent drawing and patenting will increase the quality of the welded area to a point where it is almost equal to the original wire.

TESTING AND INSPECTION

Q. 1, 2 and 3. At how many stages during the drawing of high carbon wire are tests and inspections usually made? What do the tests and inspection consist of? By what standard is the final wire rejected or accepted?

A. High carbon rods are tested for tension and are inspected at the surface for the presence of laps, seams, and other surface defects. A check is also made on the roundness of the rods and if found defective they are given a light pass or two through the dies to correct the out-of-round condition. Rods failing to pass the above tests and inspection are diverted to the making of lower grade wire. Similar tests and inspections are carried out on the wires at each stage of the drawing. Measurements of wire size are made, torsion tests are carried out and rejected wire is diverted to less important uses.

No routine inspections by microscopic methods are made. Back end tests are carried out on each bundle of wire. This back end testing is considered adequate since carballoy dies have come into general use in wire drawing. The rope maker tests every bundle of wire at each end for torsion and for tension.

The acceptance of practically all rope wire is based upon meeting the tensile and torsional property requirements providing the wire is not die marked and is not "out of round".

CORE

Q. 1. What are the principal functions of the rope core?

A. The principal functions of the core are:

(1) Primarily to support the strands.

(2) To provide flexibility to the rope by allowing strand movement.

The core is not intended to provide a reservoir for rope lubricant and the amount of lubrication of the strands by the core is incidental. The purpose of the core lubricant is to prevent deterioration of the core fibres; it may also assist in the lubrication of contacting wires to a minor extent.

Q. 2. What, if any, are the specifications governing its properties?

A. Specifications for rope core are:

(1) Sisal and sisal lana—manilla was used extensively in prewar ropes. Javanese sisal lana is preferable because of its low salt content (0.1%). African sisal lana has a higher salt content (0.3%), but its use has been forced by wartime conditions. The change from manilla to sisal lana was in effect before the war.

(2) Sufficient density and resilience so that it will not break down in service due to pressure.

(3) Small diametric tolerance.

No specification is made regarding the tensile strength of core as it is not intended to add to the strength of the rope.

Rope core material possesses a pH value of 5.5 to 6.0. An attempt is made to neutralize this acidity by using a slightly alkaline lubricant.

Q. 5. What core lubricant is used? How is the lubricant introduced to the core?

A. A core lubricant should be acid-free and have a low oxidation number to prevent its deterioration in storage. Mineral base greases are generally used.

The core is lubricated by dipping the yarns into heated lubricant before weaving or the core is woven dry and then lubricated by a vacuum process.

A unanimous opinion was expressed that it is not possible to introduce lubricant to the rope core after the rope has been "laid up".

Questionnaire No. 2

Questions unanswered or only partially answered in the first part are listed.

Q. 1. What factors determine the diameters of the outer wires used?

A. The diameter of the outer wires of a rope is a function of the size of the rope and its construction.

Q. 2. Why is the strength of a rope always less than the summation of the strengths of the individual wires?

A. The actual tensile strength of the wires would apply if the wires were laid parallel to the rope axis. Due to the angle of lay, however, a horizontal component is obtained and additionally the efficiency of the rope is affected by the unequal stressing of the wires. The ultimate strength of a 6 x 19 hoisting rope is about 87½% of the sum of the strength of the individual wires.

Q. 3. What method of lubrication is advised?

A. No specific method for achieving complete lubrication was advanced although the necessity for frequent and thorough lubrication was emphasized. Methods of lubrication must be developed to meet conditions at each individual rope installation. It was suggested that rope life would be increased if ropes were removed from service at 6 month intervals and thoroughly cleaned and greased.

The disadvantage of this procedure is that it would be easy to kink or otherwise damage the rope in the course of removal and replacement which would outweigh any advantages that might be gained by the proposed method of lubrication.

Q. 4. What research has been done regarding the prevention of corrosion of interior wires? Have silicone lubricants been considered?

A. The effect of moisture inhibitors as applied to rope lubricant is being investigated. The use of a rope dressing having a lead oleate base was recommended.

Q. 5. What research has been done regarding protective coatings on wires for hoisting ropes?

A. The opinion was expressed that drawn galvanized wire has a higher resistance to corrosion and fatigue than ordinary bright steel wire. In this respect ordinary dip galvanizing, which is not considered advantageous, should not be confused with the drawn galvanizing process.

Q. 6. Are any hoisting ropes made up of galvanized wire in use in Canada or the United States? If so, where are they used and under what conditions?

A. Galvanized wire ropes have been used for the past 20 years by the Western Fuel Co. at Nanaimo, B.C. They have also been used at Kirkland Lake Gold Mines in Ontario and at some iron and copper mines in Pennsylvania. Their use by some of the above companies has now been discontinued.

Q. 7. What effect has galvanizing the wires on the ultimate strength of the rope?

A. Galvanizing as such does not lower the tensile strength of the wire. The strength of galvanized wire is from 5 to 10% less than that of bright steel wire of the same diameter due to reduction in the sectional area of the steel.

Q. 8. What percentage of diametric decrease of outer wires due to wear do you consider should not be exceeded?

A. It is recommended that diametric decrease of the outer wires should not exceed 33%.

Q. 9. What percentage of the ultimate strength of the rope do you recognize as the lower limit of fatigue stress? If this lower limit of fatigue stress is exceeded, will that cause rapid deterioration of the rope? What total stresses go to make up the fatigue stress in a hoisting rope?

A. It is stated that for dry fatigue, the endurance limit is 40 to 45% of the ultimate strength of the steel. When corrosion is present, the endurance limit is reduced to about 25% of the above or 10% of the ultimate strength of the steel. From the findings of the "Safety in Mines Research Board" of Great Britain, the endurance limit was established at 25% of the ultimate strength of the rope, in the case of dry fatigue, and no lower limit was recognized when corrosion was present.

Q. 10. How many types of wire fracture are recognized?

A. The following types of wire fracture are recognized:

(1) "Cupping" and "necking"—This type of break is due to tensile loading.
(2) Square break—This is a fatigue break caused by bending.
(3) Diagonal break—Caused by torsional stress.
(4) Jagged break—Caused by combination of torsion and bending in a fatigued wire.

Fracture types (2), (3) and (4) usually indicate fatigue failure.

Q. 11. What is corrosion fatigue? Is it a highly important factor in the deterioration of wire hoisting ropes?

A. Corrosion fatigue is the combined action of corrosion and fatigue, the corrosion initially pitting the wire and causing a notch effect which increases the local stress in excess of the endurance limit. Corrosion fatigue is commonly considered as being the most important single factor in the deterioration of a rope.

Discussion

Q. 1. High tensile strength wire versus low tensile strength wire for hoisting ropes.

A. The rope manufacturers emphasized the undesirability of demanding wire of too high tensile strength, as some other valuable properties of the steel are unavoidably reduced by the amount of cold drawing necessary to produce these high tensile strengths. It was also pointed out that the notch toughness value of high strength wire is low, thereby making it more vulnerable to fatigue. Further discussion pointed out that while a rope made from high tensile strength wire provided a high initial factor of safety, this factor

would probably decrease with greater rapidity than would be the case if a lower tensile strength wire was used. In other words, the strength gradient of a rope made from lower strength wire offers a more gradual decline with possibly a better average factor of safety. The discussion also brought out that while ropes made of high tensile strength wire proved satisfactory where used with single layer winding, ropes having lower tensile strengths gave better service with multiple layer winding. In connection with this phase of the subject the wire manufacturers felt that over a period of years the consumer had demanded ever increasing tensile strengths in ropes and the demands were met by the manufacturer at the expense of some other desirable properties. In rebutting this contention the mine operators maintained that part of the responsibility lay with the rope makers in that in their efforts to meet competitive bidding for business they may have put undue emphasis upon the high initial strength of the ropes they offered without, at the same time, pointing out the sacrifices which would be made in other highly desirable qualities in order to attain the high initial strengths offered. On their part, the rope manufacturers agreed that this was probably true.

Q. 2. Martensite.

A. Martensite can only be produced by rapidly cooling steel from above its critical temperature and in the case of this high carbon steel wire such rapid cooling must take place from above 1425° F. It has been shown that local temperatures generated by the mutual sliding of two metal surfaces is surprisingly high due to the fact that the contact is never perfect and only a small proportion of the total area is actually in contact.

It appears that local heat exceeding the critical temperature of hoisting wire steel is momentarily generated at the crown of the rope by friction between rope and other metallic surfaces normally contacted in service. These locally heated areas are then cooled, by adjacent cold metal within the wire or by the atmosphere, with sufficient rapidity to form the constituent martensite. Martensite has no ductility and must crack under bending. These cracks progress under repeated stress and eventually penetrate the normal patented structure of the wire. The question was asked that if a lower tensile strength steel was specified, could the tensile strength be obtained in a steel whose carbon content was sufficiently low to prevent the formation of martensite under operating conditions. The reply was that the carbon content could not be lower than 0.70 if adequate strength were to be obtained and it was not believed that this reduction in carbon content would avoid the formation of martensitic skin.

Q. 3. The weakest part of a hoisting rope in service.

A. The question of what was considered the weakest section in a hoisting rope brought the reply that it was not necessarily at the capel and depended on conditions prevailing at any individual installation. Also that in any installation, successive ropes would show weakness at the same points, unless the condition causing the weakness was corrected.

CAUSES OF WIRE FAILURE, OTHER THAN CORROSION, IN MINE HOISTING ROPE

History and Purpose

One of the more important factors commonly considered when deciding whether a rope should be discarded or removed from service is the number of broken outer wires observed under visual examination. The failure of individual wires is not usually related to corrosion but instead appears to be due to wear, either by its effect on the properties of the wire or by straight metal loss. Other failures often occur in wire showing little or no wear and are apparently caused by defective material.

The purpose of this investigation was to inquire into some of the causes, other than corrosion, of individual wire failure. Short lengths of 38 new and used hoisting ropes comprised the material for this study.

Introduction

For the most part the results of the investigation merely confirm the general uniformity achieved in the manufacture of high carbon steel wire. In comparison to the effect of deterioration by corrosion, the effect of variations, within reasonable limits, in composition and physical characteristics is relatively unimportant. Nevertheless certain of the more important variables encountered are significant inasmuch as they reduce, among other properties, the fatigue limit of the wire. The photomicrographs, included in this report, of wire showing variations in structure may be valuable to those so far unfamiliar with the material used in hoisting ropes.

The Wire and Patenting Process

STEEL

The term "high carbon rope wire" embraces a range of chemical composition somewhat similar to that of S.A.E. steel specification 1080. From analyses of wire from various ropes, the nominal range of composition is shown to be as follows:

C	0.75–0.85%
Si	.15– .30%
Mn	.50– .70%
P	.04 max.
S	.04 max.

Lower carbon contents have been encountered in English made wire, particularly in the smaller sizes, and this apparently is in line with some wire making practices.

There has been much discussion regarding the relative merits of acid and basic steel for the manufacture of wire. Opinions on this matter are summarized by E. E. Thum (25) in connection with his investigation into the cause of failure of the suspension rope wire in the Mt. Hope and Ambassador bridges. An excerpt from Thum's report reads as follows:

> Whether acid open-hearth steel is better than basic is a controversial point, very difficult to decide, since the evidence is so likely to be warped by prejudice or business considerations.
>
> Conversations with steel makers experienced in the art of making fine steels by both processes have brought out the opinion that acid steel is a little cleaner, is a little

more consistent in final physical tests, and has a higher elastic limit for the same carbon content. Wire drawers generally prefer acid steel for their best product, believing that it can successfully be put through a series of reductions which would cause sporadic breakage at the die in an equivalent basic steel.

This matter is one of the intangibles pervading wire drawing practice. It certainly does not mean that very fine grades of wire for springs, rope and other uses cannot be made by the basic process. Quite the contrary; great tonnages of it are so used with entire satisfaction.

Experience, therefore, indicates that there is no reason why the choice of basic open-hearth steel instead of acid for the first Ambassador and Mt. Hope bridges should be regarded as the determining factor in the failure. The fact that our common grades of merchant steel are made in basic furnaces, while acid furnaces are usually reserved for fine steels, should be ascribed to the nature of our available ores and scrap rather than an indication of the inherent capabilities of the two processes.

In the making of rope wire a more generous cropping of the ingot is carried out than for most other products. The amount of cropping is usually about 25% of the ingot and frequently further cropping of the blooms and billets is done as a safeguard against segregation of non-metallics. Hot rolled rods are finally produced from the billets and these vary in size depending on the gauge of the wire to be drawn.

LEAD PATENTING

The purpose of patenting is to develop a sorbitic structure combining the high tensile strength and ductility required to withstand subsequent cold drawing. It also removes any effect of previous cold drawing. Lead patenting is a continuous process in which the wire is heated to a point considerably above its critical temperature, then cooled by quenching in a lead bath maintained at 1050-1100° F., the temperature range in which austenite is transformed to sorbite. There are several variations of the patenting process. The wire may be heated in air, in tubes, or in a high temperature lead bath prior to quenching in the low temperature bath, the latter being known as the "double lead process." Another method, known as "old process" patenting, involves air cooling of the wire.

The wire under investigation appears to have been lead quenched. The types of heating used cannot be definitely stated as some wires are free of decarburization, indicating the "double lead process", while others show considerable decarburization indicating tube or air heating. It is thought that most of the wires examined were tube heated.

COMBINED PATENTING AND DRAWING

Prior to drawing down into wire the rods are patented for the purpose of removing heterogeneity still remaining from the ingot and developing the desired properties for cold drawing. Patented rod has a tensile strength of about 170,000 p.s.i. During the process of drawing down, two patentings are usually necessary to remove the effects of drawing and develop a new sorbitic structure for the subsequent drafts. Three patenting treatments are sometimes used in the production of the smaller diameter wires.

The final tensile strength of rope wire depends on the carbon content of the steel, patenting practice, wire drawing practice and the diameter of the finished wire. The patenting practice and wire drawing practice are particularly influential as by their combined action it is possible to produce wire of widely different mechanical properties from steel of the same chemical composition.

Metallographic Study

MATERIAL

This investigation entailed the examination of short lengths of 38 new and used hoisting ropes, 13 from the International Nickel Company and the remainder from various other Ontario mines. The rope specimens, as received, were approximately 3 feet in length and several micro-specimens from significant locations on each rope were prepared; the total number of micro-specimens resulting was approximately 200.

Many of the rope specimens submitted by outside mines were cut from new rope; in the case of used rope they were cut from the capel end at the time of recapping. Such specimens were of little value with respect to the study of wire deterioration although they contributed to the study of variables of the steel and its processing. Most of the detail work on wire deterioration was carried out on specimens from ropes which had seen considerable service and had been sampled along their entire length. Among these were specimens taken at 150-ft. intervals from the Paymaster rope.

A notable quantity of wire of English manufacture was included as well as several grades of wire marketed under such names as Best Plow Steel, Extra Special Improved Plow Steel, Acid Extra Special Improved Plow Steel, etc. These will be discussed later in the report.

PAYMASTER ROPE

As already reported in the special investigations conducted into the failure of the Paymaster rope, corrosion was the cause of deterioration. The metallographic examination of many specimens of this rope did not uncover any additional predominating causes of failure, therefore its examination only contributes to the general report which follows.

WIRE GRADES

The following grades of wire, as designated by the manufacturer, were represented in the ropes examined.

	Carbon Content by Analysis
1. Acid Best Plow Steel	0.75%
2. Special Improved Plow Steel	.70%
3. Acid Special Improved Plow Steel	.72%
4. High Grade Acid Special Improved Plow Steel	.82%
5. Extra Special Improved Plow Steel	.75%
6. Acid Extra Special Improved Plow Steel	.84%
7. High Grade Acid Extra Special Improved Plow Steel	.....

The term acid indicates that the steel was made by the acid open hearth process and it has been customary to regard such steel as being somewhat lower in non-metallic content than steels made by the basic process. From the results of analyses of non-metallic inclusions the use of the term in this sense is not justified.

A relationship apparently exists between manufacturers' designations of the grade and tensile strength. Such material descriptions as those above tend to confuse the purchaser regarding the true qualities, and since the carbon content found has no apparent connection with the degree of steel quality as implied in the name given, higher ultimate strength can

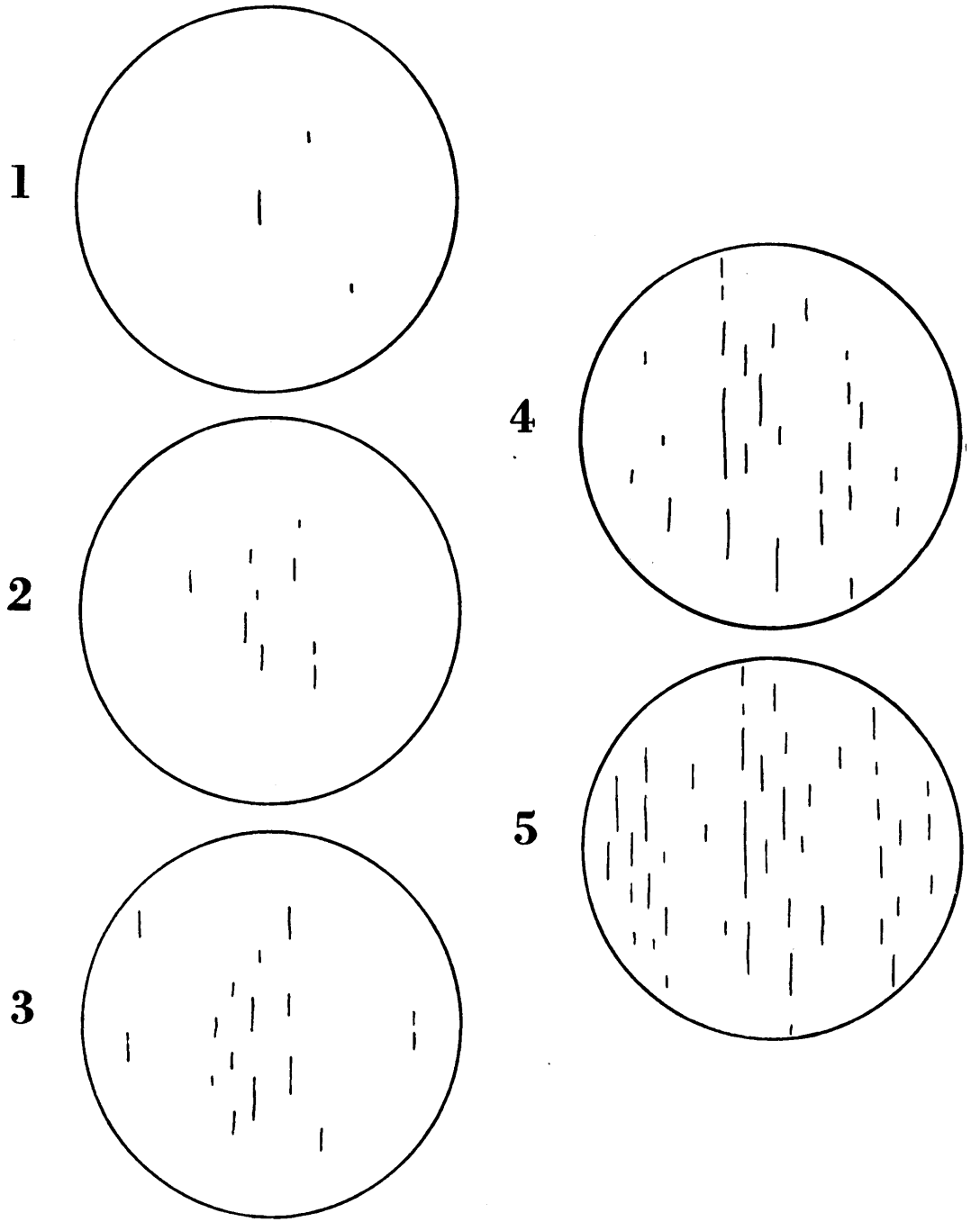


Fig. 1—A.S.T.M. Inclusion Chart

only be due to the amount of cold work put into the wire at the time of drawing. It is obvious that the purchaser of wire rope would be in a better position to evaluate the quality of competitive ropes if they were designated simply by size, construction, carbon content of the wire and ultimate strength.

In this connection, it is observed that as the ultimate strength of wire is increased by cold drawing, the fatigue endurance limit is reduced. Therefore, if wire manufacturers continue to "improve" their product merely by increasing the amount of cold work in order to increase the ultimate strength, the point may be reached where fatigue will become a much greater factor in rope failure.

NON-METALLIC CONTENT OF THE WIRE

Results of microscopic analyses of the inclusion content of wire are shown in the following table. The information is considered in three ways: the overall non-metallic inclusion content of all wire, of British wire and of various grades of steel made by the basic and acid processes. The A.S.T.M. standard inclusion chart shown in Figure 1 was used as a basis of evaluation.

NON-METALLIC INCLUSION CONTENT OF ALL WIRE—55 SPECIMENS

A.S.T.M. content	5	4	3	2	1
No. of wires, actual	17	26	8	4	0

NON-METALLIC INCLUSION CONTENT OF BRITISH WIRE—26 SPECIMENS

A.S.T.M. content	5	4	3	2	1
No. of wires, actual	6	11	5	4	0

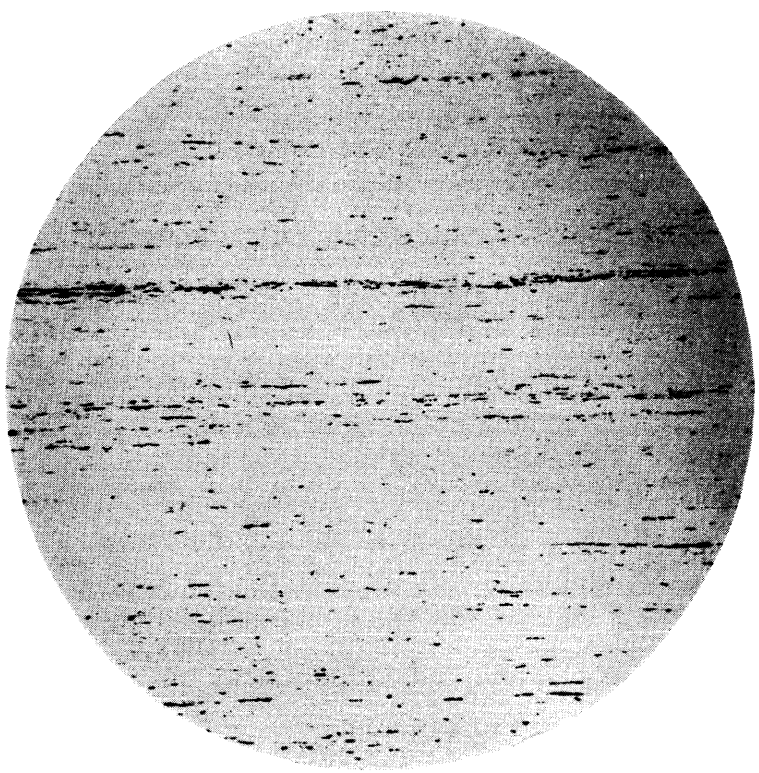
NON-METALLIC INCLUSION CONTENT OF VARIOUS GRADES OF BASIC AND ACID PROCESS STEEL—25 SPECIMENS

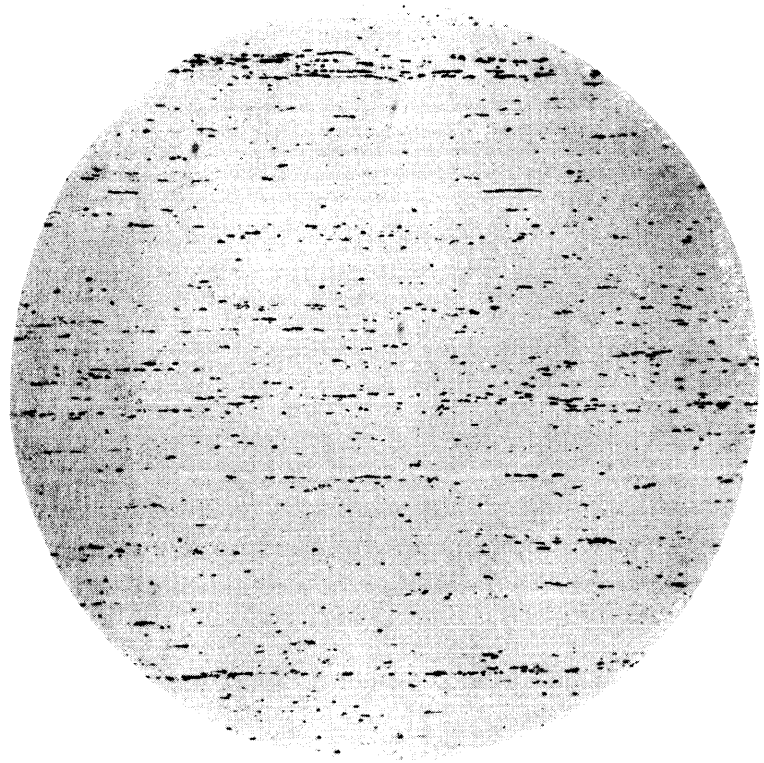
	Best P.S. Acid Grade					Spec. Improved Plow Steel					Spec. Improved P.S. Acid Grade				
A.S.T.M. content	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1
No. of wires, actual	1	1	0	0	0	3	7	1	2	0	0	1	1	0	0
	Extra Spec. Imp. P.S.					Extra Spec. Imp. P.S. Acid					Spec. Imp. P.S. High Grade Acid Steel				
A.S.T.M. content	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1
No. of wires, actual	0	1	1	0	0	4	0	0	0	0	1	1	0	0	0

The above survey shows that the inclusion content of the wires is generally high regardless of make or grade and the opinion that acid grade wire and wire made in Britain are cleaner products is hardly borne out.

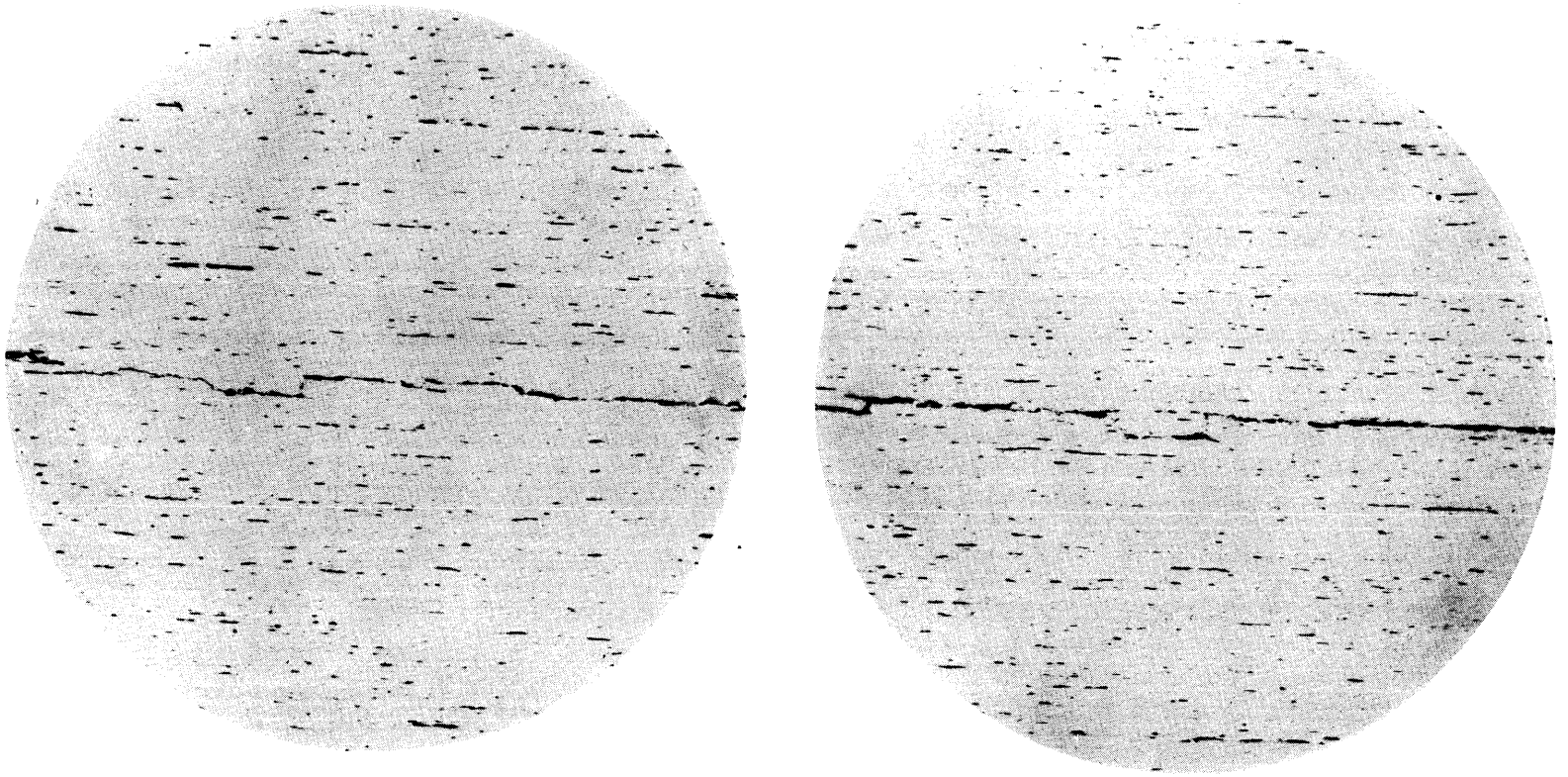
Figures 2 and 3 are photomicrographs at a magnification of 100 diameters showing the segregation of non-metallics common to some of the specimens examined. Figures 4 and 5 show the failure, by longitudinal splitting, of a wire removed from a rope that had been in service only one month. It is not claimed that the high non-metallic content initiated the crack, but the apparent relation between the inclusions and the crack suggests that the high non-metallic content has substantially lowered the resistance of the steel to crack propagation in the longitudinal direction of the wire. The effect of inclusions in lowering the fatigue resistance is markedly increased in the harder steels, a class which includes hard cold drawn wire. The non-metallic contents shown in Figures 4 and 5 are fairly typical of much of the wire examined.

The non-metallic content of wire probably does not play an important part in rope life except perhaps in individual cases as illustrated above.

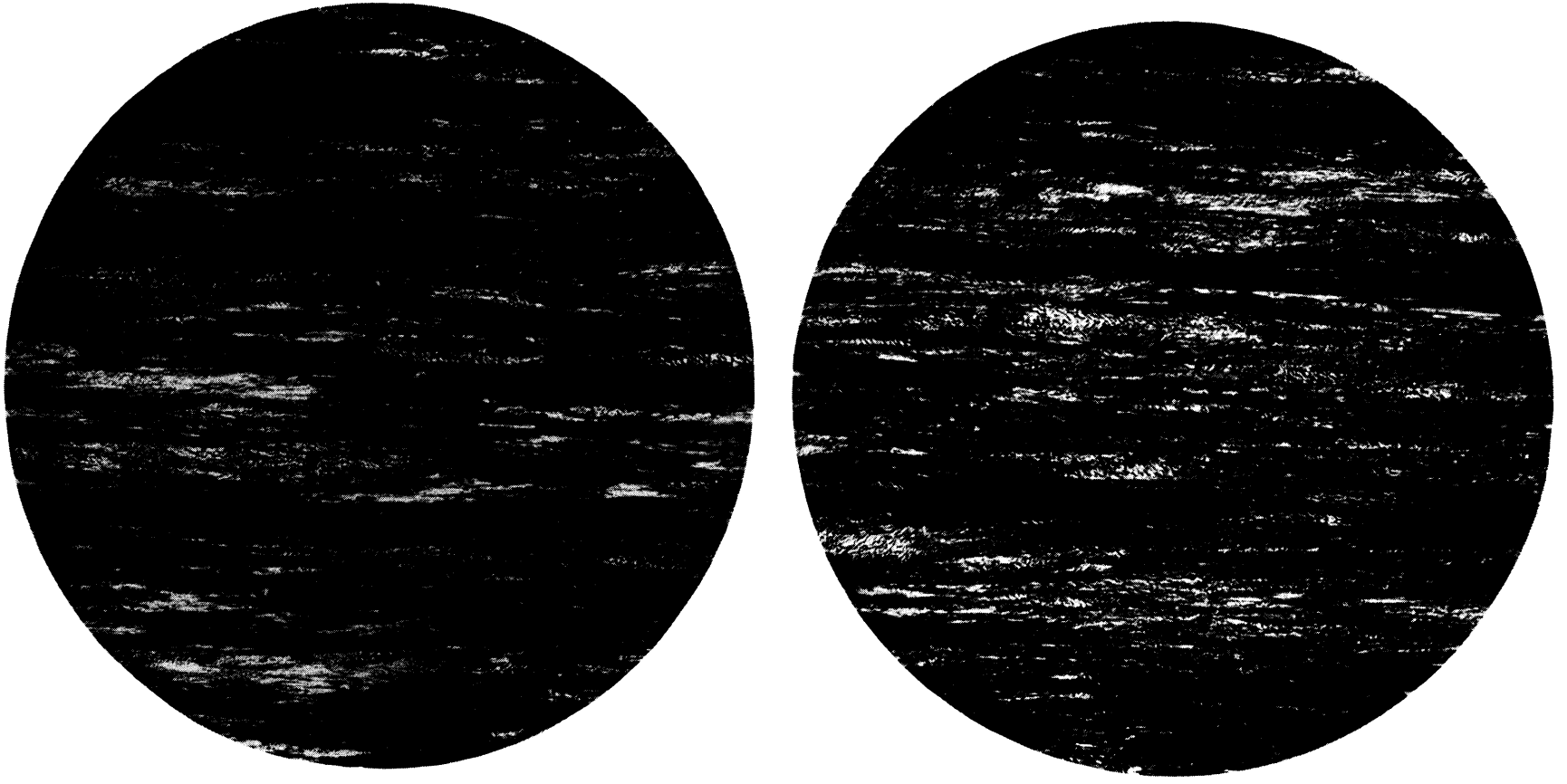




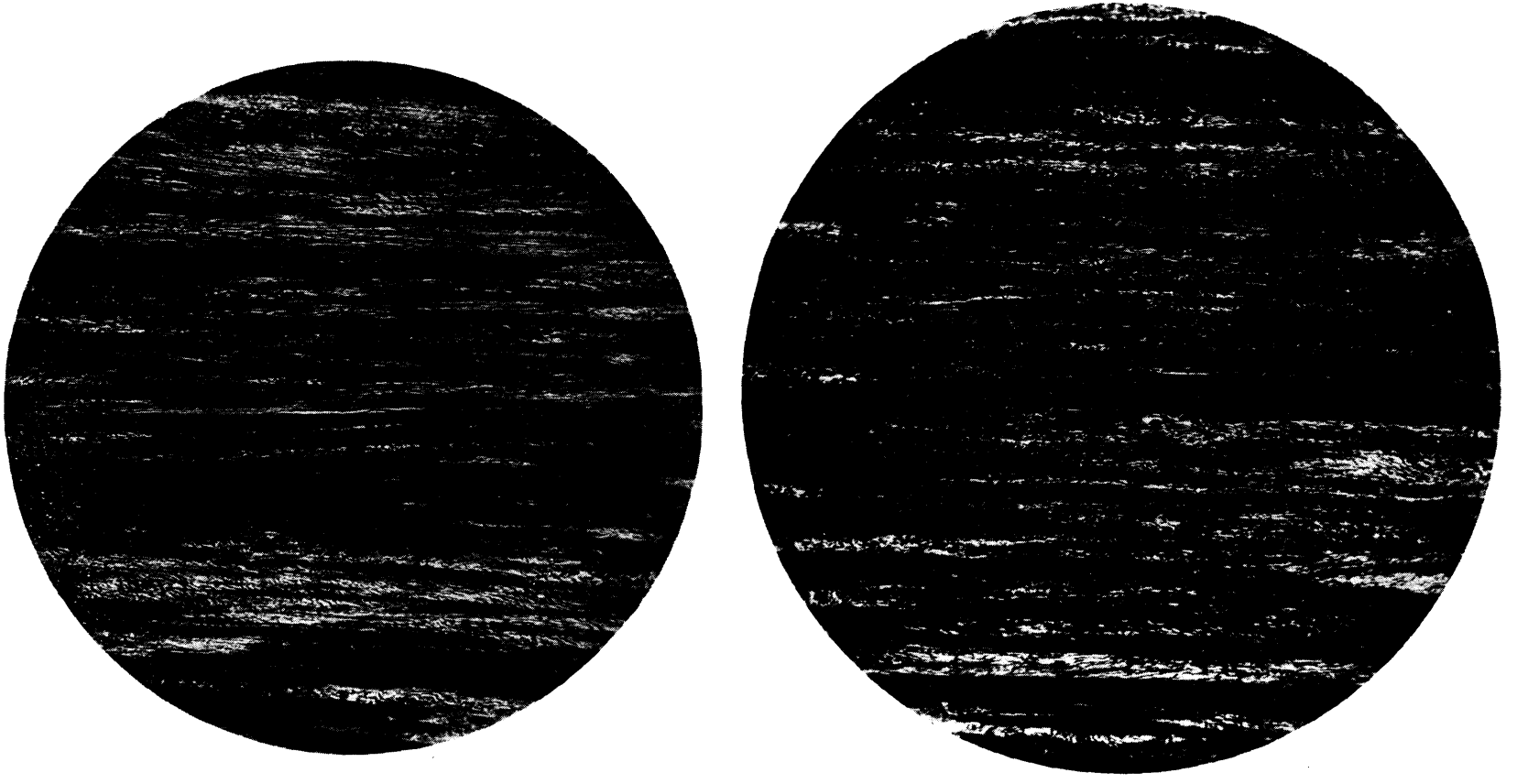
Figs. 2 and 3—Segregation of Non-metallic Inclusions
Magnification $\times 100$



Figs. 4 and 5—Relation between Longitudinal Crack and Non-metallics
Magnification ×100



Figs. 6 and 7—Lamellar Pearlite in Patented and Cold Drawn
High Carbon Hoisting Wire
Magnification ×500



Figs. 8 and 9—Effect of Cold Drawing on Lamellar Pearlite
Magnification $\times 1000$

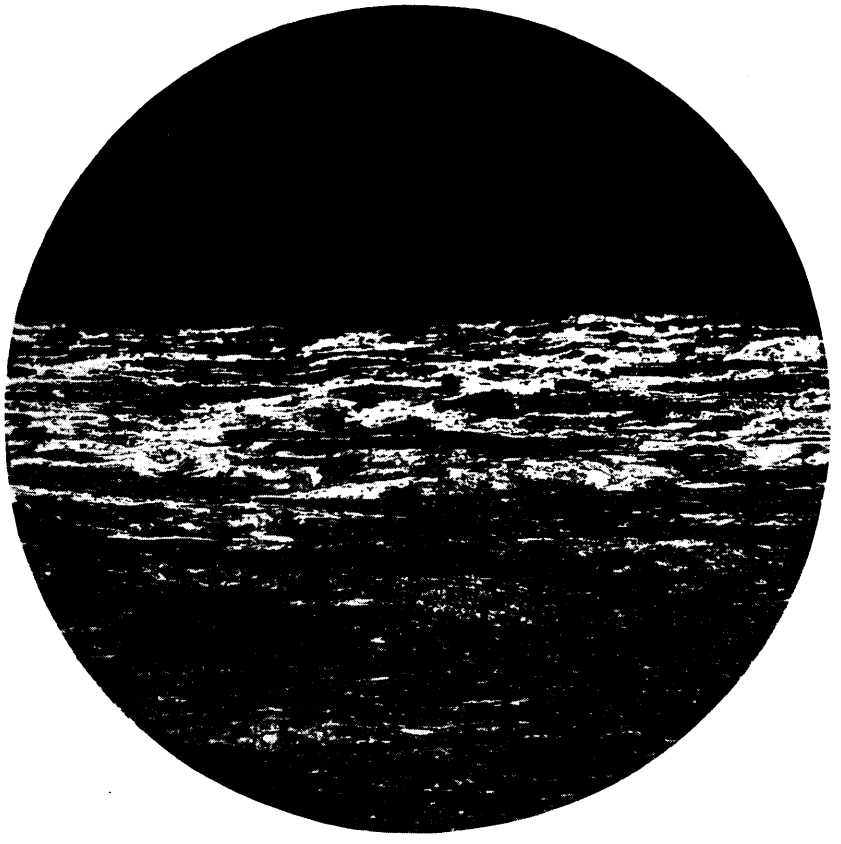


Fig. 10—Longitudal view of edge of wire. Showing surface decarburization to depth of .004 inches
Magnification ×250

Fig. 11—Cross Section view of edge of used wire. Showing fatigue crack in decarburized zone
Magnification ×500

but it is felt that as considerable care is taken to make high carbon hoisting rope wire a high quality product in every other respect the non-metallic content of the steel should be at the low rather than the high end of the A.S.T.M. scale.

WIRE MICROSTRUCTURE AND ITS VARIABLES

As stated in the brief description of the patenting process, the principal aim of that treatment is to develop a sorbitic structure. (4, 9, 22). The term sorbite is often loosely employed and may be used to describe structures ranging from finely laminated pearlite to an imperfectly developed pearlite which is granular but remains unresolved even at high magnification. The latter is usually regarded as being true sorbite. Nearly all of the structures examined in this investigation can be resolved sufficiently clearly at a magnification of 500 diameters to distinguish considerable quantities of lamellar pearlite even though it is greatly distorted by the cold drawing. The development of true sorbite, then, appears complicated by variations (perhaps uncontrollable), in the patenting process which may cause only a partial formation. These structures are illustrated in Figures 6 and 7.

Apparently little difficulty is encountered in obtaining the required tensile strength in the wire on cold drawing in spite of the mixed structures of pearlite and sorbite, the proportions of which vary considerably, and the other physical specifications required such as torsion and bending are apparently also met with adequate consistency. Because of the tendency of lamellar pearlite to form longitudinal carbide plates and isolated stringers during the drawing operation, superior properties might be obtained if it were largely absent. These brittle carbide stringers frequently appear in wire structure and are shown in Figures 8 and 9.

Patenting is an application of isothermal transformation and it is suggested that the "S" curve for 0.78% carbon steel might be helpful in obtaining totally uniform sorbitic structure if such is desired.

SURFACE DECARBURIZATION

Surface decarburization, as shown in Figure 10 was found in varying amounts on most of the wire examined. It varied in depth from mere traces to 0.004 inches and was most prevalent on British made wire. Decarburization undoubtedly occurs in the high temperature treatment of patenting and it may be assumed that "double lead" processed wire is not decarburized; although some probably occurs in tube heating, maximum decarburization takes place during air heating.

That this has an adverse effect on the fatigue resistance of steel has been demonstrated many times by defects in springs. Cold drawn wire is similarly affected (1) as illustrated in Figure 11, which shows a crack in the decarburized zone of a used wire. Cold drawn wire is, in itself, especially notch-sensitive (1) and it would seem that cracks developing in the decarburized skin would rapidly progress and cause complete wire failure.

NORMAL FATIGUE FAILURE

Examples of fatigue working alone, that is, in the absence of corrosion or surface defect, are shown in Figure 12. Surprisingly few fatigue cracks

Fig. 12—Example of Straight Fatigue
Magnification ×100

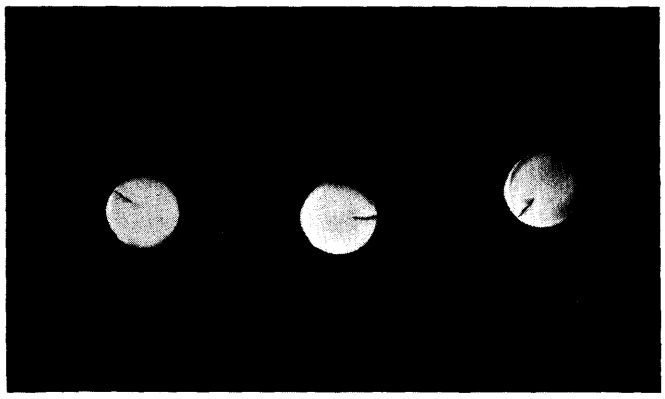


Fig. 13—Cross Section view of cracks in wire after one month of Service
Magnification ×4

of this nature were found, even in the ropes which had seen considerable service.

A type of failure which may come under the heading of "fatigue" is shown in Figures 13 to 16 inclusive. This longitudinal splitting, also

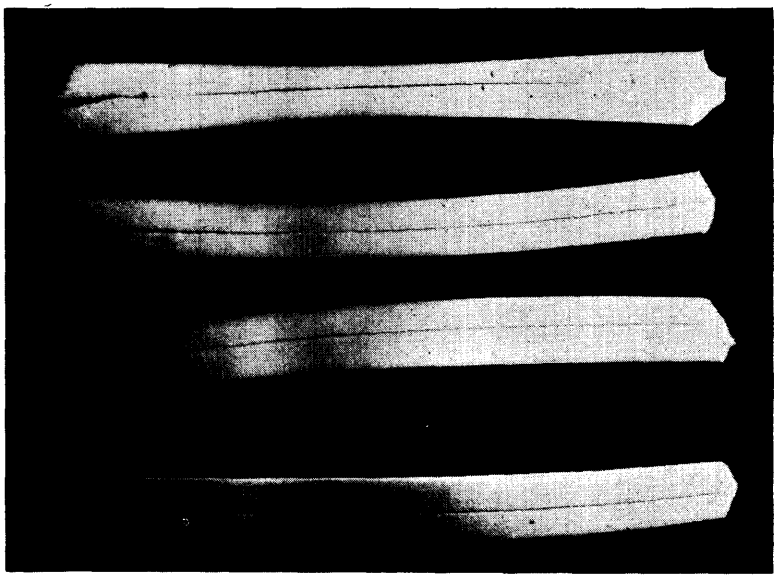


Fig. 14—Longitudinal view of cracked wire
Magnification ×4

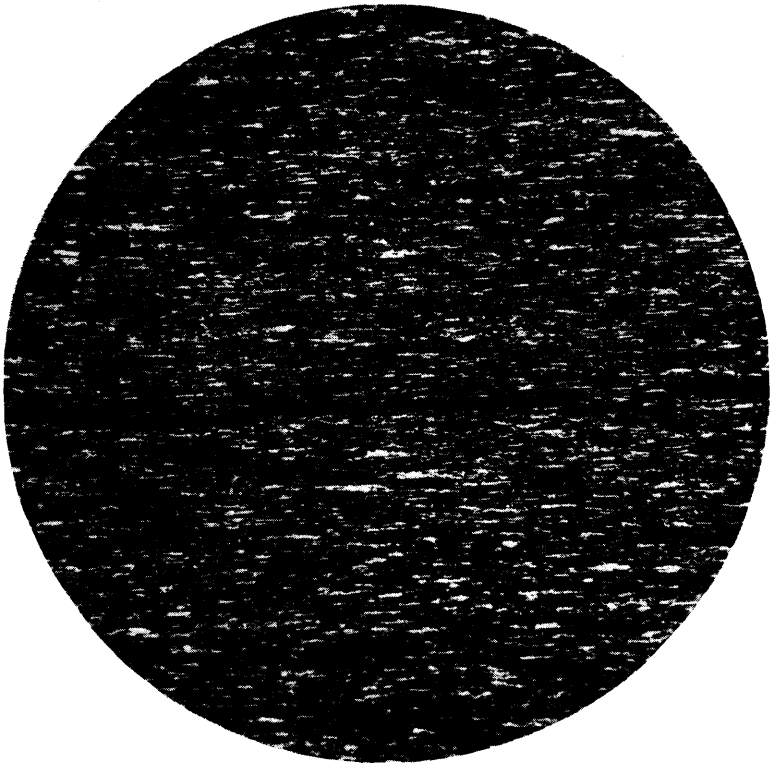


Fig. 15—Microstructure of cracked wire
Magnification ×100

shown in Figures 4 and 5, developed after the rope had been in service for only one month. The exact origin of these cracks is not known although some were traced to the surface of the rope where martensite was present. Longitudinal rather than transverse crack propagation may have been encouraged by some inherent defect in the wire or by elongated non-metallics.

WIRE FAILURE DUE TO SURFACE MARTENSITE (11, 26)

Formation of Martensite

In the heat treatment of steel, the micro-constituent known as martensite is formed by heating the steel to above its critical temperature and cooling rapidly. In the case of a plain carbon steel containing 0.80% carbon, martensite would be formed by heating above 1425° F. followed by cooling at a comparatively rapid rate such as by quenching in water.

It is evident from the presence of martensitic films at the surface of outer wires that sufficient frictional heat is generated on the crown of the rope to raise, momentarily, the temperature of the wire surface to some point above the critical range of the steel. The heated surface is then rapidly cooled by adjacent cold metal within the wire and the effect of quenching is produced, as in weld hardening.

The depth of penetration of martensite was found to vary from faint traces to 0.002 in. The surface area of the film is usually very small, indicating, as E. M. Trent (26) points out, that the area of contact with the "rubbing agent" is also very small and consequently local pressure may be very high.

Some of the martensite found on wire surfaces is untempered, and when viewed microscopically appears white and structureless. The tendency therefore to confuse martensite with decarburization is natural. Sound evidence of surface martensite is shown in Figures 17 and 18. In Figure 17, the layer is practically structureless and possibly it is untempered martensite of the tetragonal type, which is usually white etching. Figure 18 at a magnification of 1000 diameters shows the same field after coalescence of the carbide by tempering at 375-400° F. in a laboratory furnace. The result is the formation of the familiar dark etching martensite.

Effect of Martensite

As previously stated, wire failure resulting from corrosion fatigue or fatigue has not been found to any significant extent in the ropes under investigation. Instead it has been revealed that surface martensite is probably responsible for most outer wire failures in the ropes examined.

The hardness of untempered martensite in 0.85% carbon steel ranges from 675 to 725 Brinell. It is therefore very brittle and cannot withstand bending without cracking. The effect of martensite in causing cracks on wire surface is shown in Figures 19 to 23 inclusive. These brittle surfaces evidently crack under bending stresses imposed when the rope passes over the sheaves or winds on and off the drum. However caused, these cracks act as notches creating stress concentration leading to early fatigue failure, as shown in Figure 24.

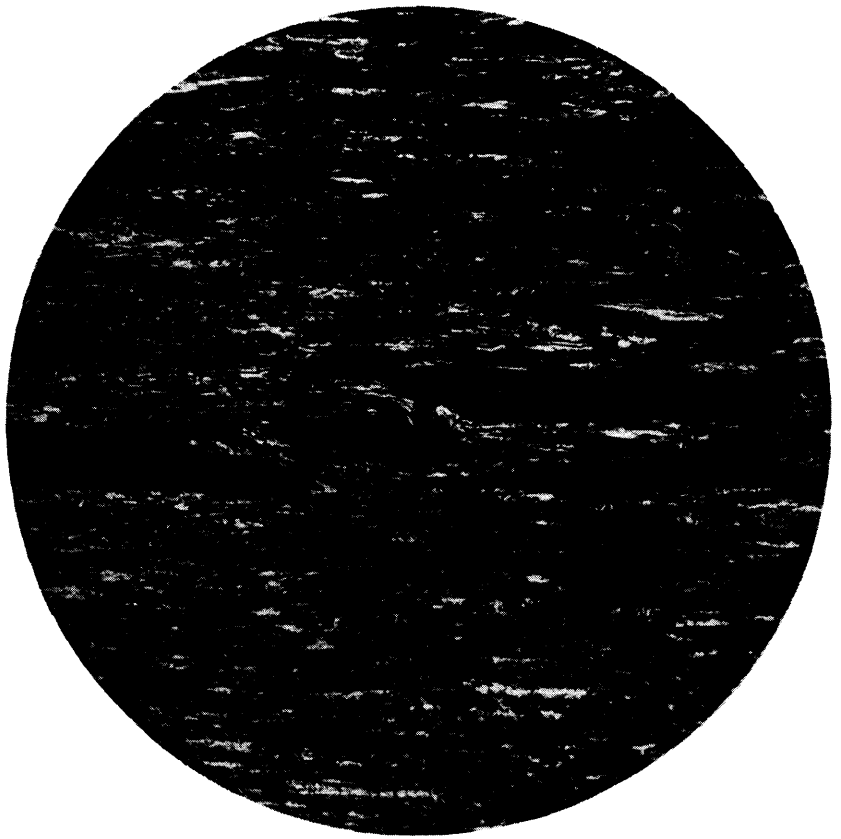


Fig. 16—Microstructure of cracked wire
Magnification ×500

Fig. 17—Martensite on Hoisting Rope. It is sometimes white etching and structureless.
Magnification ×500

Fig. 18—Same Field after Tempering. Shows familiar dark etching martensite

Magnification ×1000

Fig. 19—Martensite on Skip Rope from an Inclined Shaft. Service 13 months

Magnification ×500

Fig. 20—Martensite on a Cage Rope from a Vertical Shaft. Service 21 months

Magnification ×500

Fig. 21—Martensite on a Cage Rope from a Vertical Shaft. Service 1 month

Magnification ×1000

Fig. 22—Martensite on a Cage Rope from a Vertical Shaft.
Service 1 month
Magnification ×1000

Fig. 23—Martensite on a Cage Rope from a Vertical Shaft.
Service 1 month
Magnification ×1000

Causes of Martensitic Layers

Martensite has been found related only to external wear and no evidence of its presence in connection with internal rubbing has been revealed. The heavy contact between the rope and sheaves, and the action of the rope on the drum during winding, are responsible for external rope wear and can therefore be considered responsible for the formation of martensite.

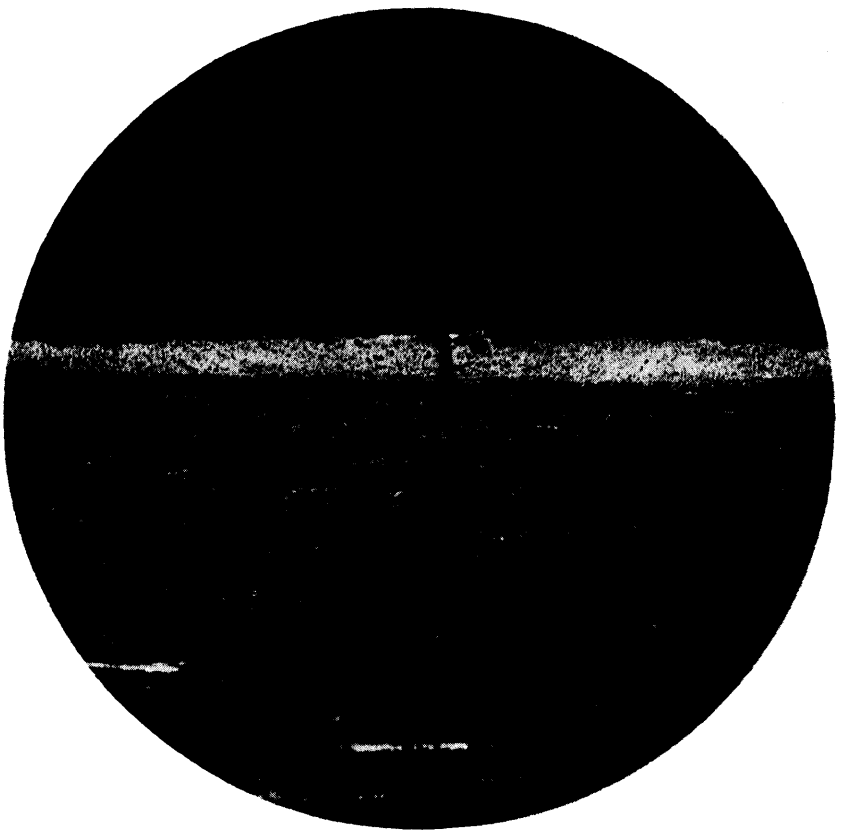


Fig. 24—Martensite and Progressive Fatigue. Cage Rope from Vertical Shaft. Service 16 months
Magnification ×500

The conditions which exist at each separate hoist installation govern the location and extent of the formation of martensite and certain general conclusions have been reached relative to its formation by the study of micro-specimens taken from ropes used at various shafts. The following is a summary of these general conclusions.

Drum Causes

The conditions predisposing to the formation of martensite at the drum appear to be as follows:

Drum Grooves.—In the case of skip hoists, rope backlash due to loading, and the oscillatory stresses entailed by sudden starting and stopping, may cause the formation of martensite at the contact point on the drum.

This theory is supported by the finding of martensite on specimens taken from the rope at this point.

Rope Lifters and Cross-Over Points.—In multiple-layer winding the severe abrasion of the rope at lifters and cross-over points is most favourable to the formation of martensite and most "drum formed" martensite has been found on specimens taken from these locations.

Abrasive Action between Layers.—Scuffing action due to rope layer contact has been found to be an unfailing source of martensite. Large fleet angles increase the severity of this action.

Sheave Causes

Idler Sheaves.—It is thought that the action of idler sheaves also causes the formation of martensite although this has not been proven. Idler sheaves have been observed to continue to rotate for five or six seconds after the rope has stopped.

Head Sheaves.—It is thought that head sheave action is a prolific source of martensite but this is difficult to prove as the section of rope coming in contact with the head sheave also comes in contact with the drum. The severity of the head sheave action is governed by the size of the fleet angle and the tolerance of the sheave groove.

Idler Rollers in Inclined Shafts.—Examination of rope specimens from inclined shafts showed that heavy martensite had developed at many points of contact with idler rollers from which the rubber covering had been worn away.

Conclusions

The occurrence of martensite and its importance is not generally recognized by most mine operators and it was the purpose of this section of the report to familiarize those concerned with the effect of this condition.

A survey of rope failures in Ontario mines has disclosed many instances of failure, or partial failure, at the cross-over point and most of these have been attributed to straight metal loss by abrasion. The causes of failures of this type might well be reconsidered in the light of the influence of cross-over points with regard to the formation of martensite. No doubt metal loss resulting from abrasion is sometimes responsible for rope failure but it is very probable that many failures attributed to metal loss have been caused by the presence of martensite.

ANALYSIS OF RESULTS—SPECIAL TEST ROPES

History

Special Testing of hoisting ropes from Ontario Mines was started in 1939 as a specialized service to Mine Operators who were particularly interested in ropes and who wished to determine the exact degree of deterioration present in certain ropes.

This Special Testing was performed by the Ontario Department of Mines Rope Testing Laboratory with the intention of assisting the individual operator to develop an improved hoisting practice. It is due entirely

to the initiative of the Department of Mines that Special Testing of Ropes has now become an established procedure with many operating companies.

The Department of Mines is to be highly commended for making possible this system of testing and Mine Operators are urged to utilize this service whenever it is felt necessary. By this means individual operators should be able to determine any improper action of the hoist itself and also to develop a sound scientific basis for the discarding of hoisting ropes.

When first inaugurated the only results obtained from the Special Tests were the figures for the ultimate strength and for the elongation of the test piece. As the Laboratory Staff gained experience and developed improved techniques the results were expanded and may now be considered to be highly informative.

Purpose

The purpose of this report is to portray graphically the results of all the Special Rope Tests performed to date (December, 1945) by the Department of Mines Rope Testing Laboratory and by means of the graphs prepared to determine whether or not hoisting ropes, which have served a normal useful life, develop a definite weak point or section. The relationship of the weak points in ropes worked simultaneously in adjoining compartments, and in ropes following one another in the same compartment, will also be examined.

General Procedure Used for Special Tests

Ropes which are selected for Special Testing are cut at regular intervals and at other important points e.g. sheave points, crossover points, capel, etc. Specimens 6.0 ft. in length are required for all ropes up to and including 1½ ins. in diameter, while 6 ft. 8 in. specimens are required for ropes larger than 1½ ins. in diameter.

Past practice was to select specimens at 100 ft. intervals for ropes up to 1000 ft. long, at 150 ft. intervals for ropes up to 2000 ft. long, and at 200 ft. intervals for ropes longer than 2000 ft. It has been suggested that specimens of all ropes subjected to Special Testing be selected at 100 ft. intervals regardless of the total length of the rope. The Rope Laboratory could then test alternate specimens throughout the length of the rope. Additional check tests could be made in the neighbourhood of the weak section of the rope to verify the results obtained.

After the rope is cut up, the specimens, properly tagged to identify them, are shipped to the Provincial Rope Testing Laboratory in Toronto to be tested to destruction.

At the laboratory the individual specimens are examined and prepared for testing by zincing the ends. The specimen is then broken in the tensile machine. Figures for the ultimate strength, for the diametric reduction of the test piece at various loadings, and for the elongation of the specimen at the instant of rupture, are obtained. The percent metal remaining in each specimen was formerly determined by comparing the respective weights of equal lengths of a worn strand and a sound strand. As this method was not considered sound the figure for percent metal remaining has now been deleted from the data sheets. Careful notes are made on the external and internal condition of the rope, strands, wires and core. The degree of deterioration due to internal corrosion and wear, and the

amount and quality of the lubricant present is noted. The type of fracture at the break is also noted. The ultimate strength of the individual specimen is reported as percent of strength remaining.

The Graphs

This report deals with 53 Special Test Ropes; 50 ropes tested throughout their length, and 3 ropes partially tested. The results of the tests have been plotted graphically against rope footage from the rope spout at the hoist drum, and may be found on pages 1 to 53 inclusive, of the appendix.

A standard form was used to plot the results of the tests, the horizontal and vertical scales being the same in all graphs. As the data were plotted on a percentage basis, the results of the tests are directly comparable from rope to rope.

The following curves were plotted for each rope provided the necessary figures were available:

(1) Percent Strength Remaining
(2) Percent Metal Remaining
(3) Percent Diametric Reduction
(4) Percent Elongation of the Test Piece

(1) Percent Strength Remaining

The percent strength remaining was computed for the breaking strength of each specimen. The figure used as the 100% strength is shown in the upper left hand margin of the graph. In some cases it was the ultimate strength of the rope as determined by the first six months' test, while in other cases where this figure was not available the test specimen with the highest breaking strength was arbitrarily selected. It is suggested here that in order to achieve uniformity the 100% strength of the rope should be either the breaking strength obtained at the first six months' test or the actual strength of the rope when new, whichever be the greater.

(2) Percent Metal Remaining

The percent metal remaining for each rope specimen was plotted as determined by the Rope Testing Laboratory.

(3) Percent Diametric Reduction

The percent diametric reduction was calculated for each test piece at a tensile stress of 10,000 lbs. for all the larger diameter ropes. In the case of the small ropes the tensile stress at which the calculation was made is indicated. The diameter of an unworn section of the rope was taken as 100%.

(4) Percent Elongation of the Test Piece

The total elongation recorded at the instant of rupture was determined as a percentage of the overall length of the test specimen.

Relationship between Curves

If a close study be made of the curves plotted for individual ropes the following features can be observed:

In all cases where the rope was markedly deteriorated when tested the Percent Strength Remaining curve has a distinct minimum point or

section which occurs at the so-called "weak point" in the rope. In some cases when the rope was in fair condition when tested the weak point is poorly defined. In some cases where there was marked deterioration the weak point is well defined or the curve may dip for several hundred feet. The Percent Strength Remaining curve must be considered the most important curve, and its shape or form should be used to compare the associated curves.

In some instances all four curves (i.e.) Percent Strength Remaining, Percent Metal Remaining, Percent Diametric Reduction and Percent Elongation, have the same general trend or form and clearly portray the weak point or section of the rope. As a general rule, however, the curve that conforms best to the Percent Strength Remaining curve is that for Percent Elongation. This is to be expected, as the breaking strength and elongation are both obtained directly from the load-extension curve recorded by the tensile machine when the rope was tested and are therefore closely associated, while Diametric Reduction and Metal Remaining are found by separate determinations.

For this reason it is thought that the reduction in area under the load-extension curve for any test piece may be taken as a sensitive measure of the degree of deterioration present.

Of the three subsidiary curves, the curve for Percent Metal Remaining bears the least resemblance to the Percent Strength Remaining curve. This finding would indicate that the laboratory Staff were correct in assuming that the method used to obtain this figure was not sound.

Location of the Weak Point on Companion Ropes and Ropes Following in the Same Compartment

In order to determine the relationship of the location of the weak points in ropes used on the same hoist in adjoining compartments and ropes that follow one another in the same compartment, a list of all Special Test Ropes used in the same shafts and compartments is given here. The location of the weak point or section in the rope is shown with reference to footage from the drum spout, together with the dates of service. Ropes worked simultaneously on the same hoist are bracketed.

ROPES USED IN THE SAME SHAFT AND COMPARTMENTS

Company & Mine	Shaft	Comp.	Reel and Rope Nos.	Weak Point or Section from Spout (Ft.)	Dates in Service
Hollinger Consolidated Gold Mines Limited	Central	No. 2	3383 224	1000 Weak (500-1000)	Jan./30–Oct./31
Hollinger Consolidated Gold Mines Limited	Central	No. 2	2508 336	398 Weak (300-600)	Sept./36–Nov./38
Hollinger Consolidated Gold Mines Limited	Central	No. 4	3678 394	398	Apr./40–July/41
Hollinger Consolidated Gold Mines Limited	No. 26	No. 3	L-39685 403	2309 Weak (2300-3070)	June/41–Oct./43
Hollinger Consolidated Gold Mines Limited	No. 26	No. 1	332 406	2604 vy. Def. Weak (2500-2750)	July/41–Sept./44
Hollinger Consolidated Gold Mines Limited	No. 26	No. 2	332 407	2604 vy. Def.	July/41–Sept./44
International Nickel Co. Limited, Frood	No. 3	No. 2	Z-3980	2000 Def. Weak (2100-2900)	Oct./38–July/39

ROPES USED IN THE SAME SHAFT AND COMPARTMENTS—*Continued*

Company & Mine	Shaft	Comp.	Reel and Rope Nos.	Weak Point or Section from Spout (Ft.)	Dates in Service
International Nickel Co. Limited, Frood	No. 3	No. 1	C-8128	1800 Not Def. Weak (1200-2600)	Mar./39–Nov./39
Creighton	No. 3	No. 4	10	2100 Not Def.	May/38–Dec./39
Creighton	No. 3	No. 4	O-2906	2687 at Capel (Def.)	Apr./43–Feb./44
Creighton	No. 3	No. 4	7244	2100 Def. & at Capel	Feb./44–Apr./45
Creighton	No. 5	No. 1	Y-7407	4400 Def.	Oct./36–Mar./40
Creighton	No. 5	No. 2	Y-9778	4400 Def.	Dec./36–Mar./40
Kirkland Lake Gold Mines	No. 2	North	Z-8912	2505 Def. Weak (1400-2600)	July/40–Aug./41
Kirkland Lake Gold Mines	No. 2	North	O-1118	1400 Def. Weak (1200-2200)	Nov./42–July/44
Macassa Mines Ltd.	Main	North	1357	1200 Very Def. Weak (600-1600)	Aug./38–Mar./40
Macassa Mines Ltd.	Main	South	1362	1470 Rope Parted	Aug./38–Mar./40
Macassa Mines Ltd.	Main	South	2176	450 Def.	Mar./40–Aug./41
Macassa Mines Ltd.	Main	North	2982	1200 Def.	Mar./40–Aug./41
Madsen Red Lake Gold Mines Ltd.	No. 2	No. 2	O-3281 A-15	1600 Very Def.	Jan./41–June/43
Madsen Red Lake Gold Mines Ltd.	No. 2	No. 1	27285 A-14	1000 Def. Weak (900-1600)	Jan./41–June/43
Omega Gold Mines Ltd.	No. 1	Cage Middle	9712 9	853 but very indefinite	Aug./39–Oct./41
Omega Gold Mines Ltd.	No. 1	West	9927 10	913 Def.	Dec./39–Oct./41
Omega Gold Mines Ltd.	No. 1	West	5620 11	1932 Rope Parted	Oct./41–Sept./43
Paymaster Consolidated Mines Ltd.	No. 5	Cage	6174 5-1-9	1835 Rope Parted	Aug./42–Feb./45
Paymaster Consolidated Mines Ltd.	No. 5	Skip	3296 5-2-5	2218 Def. Weak (1750-2750)	Mar./42–Feb./45
Pickle Crow Gold Mines Ltd.	No. 1	No. 1	41-5 32	2200 Not Def. Weak (2200-2600)	Sept./41–Apr./44
Pickle Crow Gold Mines Ltd.	No. 1	No. 2	41-4 33	2600 Def.	Sept./41–Apr./44
Upper Canada Gold Mines Ltd.	Main	No. 1	765 7	456 Very Def. Weak (200-550)	June/39–Aug./40
Upper Canada Gold Mines Ltd.	Main	No. 2	762 8	277 Rope Parted	June/39–Aug./40
Wright-Hargreaves Mines Ltd.	No. 3	West	Z-4696 90	2710 Very Def. Weak (1500-3600)	Jan./40–Sept./41
Wright-Hargreaves Mines Ltd.	No. 3	West	Z-9026 98	2712 Rope Parted	Sept./41–July/43

Giving consideration to each shaft separately, the tabulation just presented (see also graphs—appendix pp. 1-53) is the basis for the observations which follow.

HOLLINGER CONSOLIDATED GOLD MINES LIMITED

Central Shaft

In the case of the Hollinger Central shaft—ropes No. 224 and 336 followed one another in the same compartment but their service was separated by a period of 5 years. In this instance the weak points developed some 600 ft. apart. This can no doubt be attributed to a change of conditions with the passage of time, because ropes No. 336 and 394 used in compartments No. 2 and 4 on different hoists developed the weak point at the same footage, 398 ft. from the rope spout. In this latter case the hoists concerned must have the same characteristics.

No. 26 Shaft

In the case of the Hollinger No. 26 shaft—ropes No. 406 and 407 were worked simultaneously in adjoining compartments, No. 1 and 2. Both ropes developed the weak point at 2604 ft. from the rope spout. Rope No. 403 which had been used in compartment No. 3 at about the same time developed the weak point at 2309 ft. from the rope spout, with a general weakness extending from 2300 ft. to 3070 ft. from the rope spout. Thus all three ropes can be said to have developed the weak point in the same general section.

INTERNATIONAL NICKEL COMPANY OF CANADA LIMITED

Frood Mine No. 3 Shaft

In the case of Frood Mine No. 3 Shaft—ropes, reels No. Z-3980 and C-8128 were worked in adjoining compartments and during part of their service were operated as companion ropes. They developed weak points at 2000 ft. and 1800 ft. respectively from the rope spout. Here again the weak points must be considered as being in the same section of the ropes.

Creighton Mine No. 3 Shaft

In the case of Creighton Mine No. 3 Shaft—three ropes, reels No. 10, O-2906 and 7244, followed one another in the same compartment. Two of these ropes developed the weak point at the same location, 2100 ft. from the rope spout. The other rope, reel No. 0-2906, developed the weak point at the capel, 2687 ft. from the rope spout.

Creighton Mine No. 5 Shaft

In the case of Creighton Mine No. 5 Shaft—two ropes, reels No. Y-7407 and Y-9778, operated simultaneously in adjoining compartments, developed the weak points at the same location, 4400 ft. from the rope spout.

KIRKLAND LAKE GOLD MINING COMPANY LIMITED

In the case of Kirkland Lake Gold Mining Co., No. 2 Shaft—two ropes, reels No. Z-8912 and 0-1118, followed one another with 15 months separating service in the same compartment. The weak points developed some 1105 feet apart but if the two breaking strength curves be examined it will be seen that they have the same general shape with weak sections extending from 1200 ft. to 2500 ft. from the rope spout, and the weak point could develop anywhere in this section.

MACASSA MINES LIMITED

In the case of Macassa Main Shaft—two pairs of ropes following directly after each other in the same compartments. The weak points developed in approximately the same section of rope for the first pair of ropes, reels No. 1357 and 1362. In the case of the second pair of ropes, reels No. 2176 and 2982, no agreement was shown, the weak points having developed some 750 ft. apart. Rope, reel No. 2982, followed rope, reel No. 1357 in the North compartment and both ropes developed the weak point at 1200 ft. from the rope spout. No correlation was shown between the ropes that followed each other in the South compartment.

MADSEN RED LAKE GOLD MINES LIMITED

In the case of Madsen Red Lake No. 2 Shaft—two ropes, reels No. 0-3281 and 27285, worked simultaneously in adjoining compartments,

did not develop the weak point in the same section of rope. The breaking strength curves for these ropes do not conform, but the tendency is indicated for general weakness between 900 ft. and 1600 ft. from the rope spout.

OMEGA GOLD MINES LIMITED

Omega Gold Mines No. 1 Shaft—two ropes, reels No. 9712 and 9927, worked simultaneously in adjoining compartments, developed the weak point in the same section of rope. The rope, reel No. 5620, which followed rope, reel No. 9927, in the west compartment parted in service at 1932 ft. from the rope spout, more than 1000 ft. away from the weak point in rope, reel No. 9927.

PAYMASTER CONSOLIDATED MINES LIMITED

Paymaster Mine No. 5 Shaft—two ropes, reels No. 6174 and 3296, worked simultaneously in adjoining compartments, developed the weak point 383 ft. apart, but both ropes were generally weak in the same section.

PICKLE CROW GOLD MINES LIMITED

Pickle Crow No. 1 Shaft—two ropes, reels No. 41-5 and 41-4, worked simultaneously in adjoining compartments, developed the weak point 400 ft. apart, but both ropes showed weakness in the same general section.

UPPER CANADA GOLD MINES LIMITED

Upper Canada Mine main shaft—two ropes, reels No. 765 and 762, worked simultaneously in adjoining compartments, developed the weak points 177 ft. apart, both ropes were generally weak in the same section.

WRIGHT-HARGREAVES MINES LIMITED

Wright-Hargreaves Mine No. 3 Shaft—two ropes, reels No. Z-4696 and Z-9026, followed one another in the same compartment. Rope, reel No. 9026, parted in service at 2712 ft. from the rope spout; the other rope had developed the weak point at 2710 ft. from the spout, a very close agreement.

SUMMARY

Summing up the results of this analysis it is determined that:—

(a) Companion ropes worked in adjoining compartments on the same hoist develop weak points in the same section of the rope in the majority of cases.

(b) Ropes following each other in the same compartment do not develop the weak point in the same section of the rope in the majority of cases. This may be due to changes in local conditions with the lapse of time, or to other factors.

Conclusions

It can now be concluded that ropes operated simultaneously in adjoining compartments on the same hoist will usually develop weak points in the same section of each rope, but sufficient proof has not been advanced to demonstrate that the same will be true for ropes following one another in the same compartment, although such tendency is indicated.

In order to make use of the above theory for checking and discarding ropes it will be necessary to prove the theory so that there can be no shadow of a doubt.

COMPARISON AND ANALYSIS OF STATISTICS AND OPERATING CHARACTERISTICS—SPECIAL TEST ROPES

History and Purpose of Report

In order to supplement the data already obtained by the Department of Mines Rope Testing Laboratory, the Mines Association in March, 1945, sent out questionnaires to all mines that had participated in the Special Rope Tests.

The questionnaires covered all phases of rope history, usage and hoisting practice and were intended to provide a source of additional information for the intensive study and comparison of the characteristics and reactions of individual test ropes. This report comprises a tabulation and comparative analysis of the data for 44 Special Test Ropes. In all, ten tables were compiled and analysed.

Tables 1 to 8 have been compiled from data received from the following companies: Teck-Hughes Mines Ltd., McKenzie Red Lake Gold Mines Ltd., Paymaster Consolidated Gold Mines Ltd., Kirkland Lake Gold Mines Ltd., Omega Gold Mines Ltd., McIntyre Porcupine Mines Ltd., Macassa Mines Ltd., Dome Mines Ltd., Sylvanite Gold Mines Ltd., Wright-Hargreaves Mines Ltd., Pamour Porcupine Mines Ltd., Lake Shore Mines Ltd., Hollinger Consolidated Gold Mines Ltd., Falconbridge Nickel Mines Ltd., Coniaurum Mines Ltd., and International Nickel Co. of Canada Ltd. The data deals with 31 hoisting ropes tested and 21 hoist installations of these 16 companies.

Tables 9 and 10 tabulate hoisting rope data from the above mentioned companies together with additional test rope data from Toburn Gold Mines Ltd., Madsen Red Lake Gold Mines Ltd., Yama Gold Mines Ltd., Upper Canada Mines Ltd., and Pickle Crow Gold Mines Ltd.

In all, the report deals with the tests of 44 hoisting ropes from 27 individual shafts operated by 21 mining companies.

Compilation of Data

The data from the questionnaires were grouped and tabulated in order to be comparative. Ten tables were made to cover the statistics of all phases of rope usage and the hoisting operation. The ten tables are included in the appendix and are as follows:

TABLE 1—Comparison of Hoisting Ropes.
(Statistics 31 ropes)

TABLE 2—Inspections and Rope Practice.
(Practice of 16 companies compared)

TABLE 3—Comparison of Basis for Discarding Ropes.
(16 companies)

TABLE 4—Comparison Sheave Data.
(21 installations)

TABLE 5—Hoist Comparison.
(Statistics on 21 installations)

TABLE 6—Comparison of Shaft Conveyance in Vertical Shaft and Inclined Shafts.
(21 installations)

TABLE 7—Factors of Safety for Cages and Skips Compared with Capacity Factors.
(31 ropes)

TABLE 8—Work Done by Rope Compared with % Fatigue Stress of Installation.
(23 ropes)

TABLE 9—Comparison of Location of Weak Point in Special Test Ropes.
(44 ropes)

TABLE 10—Special Test Ropes—Basis on Which Ropes Should Have Been Discarded.

Analysis of Tables

An attempt will be made in this report to analyse the available data, table by table, item by item. Items which do not readily adapt themselves to analysis will be ignored. Recommendations and suggestions for improvements will be introduced where possible.

TABLE 1—COMPARISON OF HOISTING ROPES

Table 1 contains all the statistics concerning 31 ropes, (manufacturer, usage, physical characteristics, life history and work performed by rope). The 31 ropes represent 16 operating companies and were used in 20 shafts. The table is compiled in ascending order of rope diameters.

Rope Diameters

The ropes can be divided into the following groups on the basis of diametric measurement:

Diameter	No. of Ropes	Per-Cent
¾ inch	2	6.45
1 inch	2	6.45
1⅛ inch	8	25.8
1¼ inch	4	12.9
1⅜ inch	3	9.7
1½ inch	7	22.6
1¾ inch	5	16.1

Shafts, Compartments and Type of Service

The 31 ropes were used in 20 shafts, in 25 different compartments. In six cases ropes were repeats from the same shafts and compartments.

Type of Service	
Skips	11
Cages	4
Skip and Cage Combinations	10

Manufacturers

The 31 ropes were manufactured by six rope manufacturers; the division was as follows:

Manufacturer	No. of Ropes	Per-Cent
Anglo Canadian Wire Rope Co.	12	38.7
Dominion Wire & Cable Co.	6	19.4
Allan Whyte & Co. Ltd. (British)	1	3.2
B. Greening Wire Co. Ltd.	7	22.6
Canada Wire & Cable Co. Ltd.	4	12.9
Wrights Rope Ltd. (British)	1	3.2

Construction

Ropes for hoisting are normally constructed from six strands laid up around a manilla core. This was true for all the 31 ropes except one. The exception was the Wright-Hargreaves rope, reel No. Z-9026. This rope was of the non-rotating type with a wire core.

In every case the ropes were Lang's Lay divided as follows:

	No. of Ropes	Per-Cent
Right lay	29	93.5
Left lay	2	6.5

Fourteen of the ropes were flattened strand and 17 were round strand, four of the latter being Trulay Preformed.

Many claims are put forward by the Rope Manufacturers as to the superiority of preformed ropes over normally laid ropes. The most outstanding of their claims are:

(1) Reduction of internal stresses in the rope.
(2) Under load, the stress is evenly distributed among all strands and wires of the rope.
(3) The above qualities tend to give increased rope life and more efficient operation of the rope.

All four of the preformed ropes were used by one company. The indicated superiority of these ropes (see Figure 1—Comparative Work Done by Ropes) should not be accepted as proof of the manufacturers' claims, as ordinary laid up ropes may have performed equally as well under the same conditions.

In flattened strand ropes the wires of the individual strands are laid around a triangular core and with this construction the wearing surface on the crown of the rope is greater than that of a round strand rope and it is claimed the rope is more resistant to crushing. A flattened strand rope contains more metal per sq. in. of rope area and should therefore have a greater breaking strength than a round strand rope of the same diameter and in ropes of equal size the diameter of the outer wires is greater than in one made up of round strands; for example the diameter of the outer wires in a 1⅜ in. 6 x 27 flattened strand rope is 0.096 in. while in a 1⅜ in. 6 x 19 round strand rope the diameter of the outer wires is 0.087 in.

Strand Construction

Strand construction varied greatly and may best be portrayed in tabular form:

Type of Strand	No. of Cases	Per-Cent
6 x 16	5	16.1
6 x 17	2	6.5
6 x 19	10	32.3
6 x 22	1	3.2
6 x 23	1	3.2
6 x 25	1	3.2
6 x 27	10	32.3
6 x 28	1	3.2

The most popular types of strand construction are 19 wires plus filler wires and 27 wires plus filler wires.

The great majority of ropes 1½ in. diameter and greater are of 6 x 19 round strand construction. In these ropes the diameter of the outer wires varies from 0.097 in. to 0.117 in. and therefore should be used only on installations where the ratio of sheave or drum diameter to rope diameter is at least 80:1.

The majority of ropes less than 1½ in. diameter are of 6 x 27 flattened strand construction and on account of the greater wearing surface and the greater outer wire diameter flattened strand ropes are often used on installations where abrasion and wear are severe. Bending stresses are high on account of the large diameter of the outer wires therefore these ropes should only be used where the ratio of sheave or drum diameter to rope diameter is favourable, at least 85:1.

Length of Rope

The length of rope in use is determined by the physical constants of the shaft and headframe, location and diameter of hoist drum and size of fleet angle, etc. The total length of rope is not important but the maximum length of rope hanging in the shaft from head sheave is, or in other words, the maximum hoisting distance is of vital importance and governs largely the reactions of the rope and thus controls eventual rope life. This topic will be covered under separate heading. (See analysis of Table 9—Comparison of Location of Weak Point in Special Test Ropes.)

Diameter of Individual Wires

The diameter of individual wires is a function of rope size and construction and cannot be directly compared, except to say that large wire sizes 0.10 inches or greater are adaptable to conditions of extreme wear and abrasion, while the smaller wire sizes go to make up flexible ropes which should be used under less severe conditions.

Breaking Strain of Wires

Wire Manufacturers and Rope Manufacturers all agree that the breaking strain of the individual wires is a highly important characteristic of the laid up rope. In Canadian and British practice the "Flat Band" of wire grades is used. Thus, in a rope, the small and large wires have all approximately the same unit tensile strength. The ultimate strength of a laid up rope is usually from 10% to 12% less than the aggregate strength of the individual wires.

The manufacturers claim that for good wearing qualities, ropes should not be laid up from too high tensile wire as high tensile wire is extremely sensitive to skin abrasion and lacks ductility. Medium tensile wire will give longer service with less percent drop in breaking strength. The wire

from which the 31 test ropes were fabricated can be divided in the following arbitrary grades:

Tensile Strength of Wire	No. of Ropes	Per-Cent
Low tensile (200,000/240,000 lbs./sq. in.)	5	16.2
Medium tensile (224,000/268,800 lbs./sq. in.)	15	48.3
High tensile (255,000/292,000 lbs./sq. in.)	11	35.5

As can be readily seen from the above table, the great majority of the ropes fall into the medium tensile and high tensile categories. In all, these classes represent 83.8% of the 31 Special Test Ropes under consideration. This result merely proves that the majority of operators prefer medium and high tensile wire because of the added factor of safety thus obtained.

A study of Table 8 and Figure 25 will demonstrate that the medium and high tensile grades of wire are capable of producing the most work per square inch of wire in a rope, but that the manufacturers' claims in regard to the superiority of medium tensile wire are not definitely borne out.

Breaking Strength of Rope

The ultimate strength of a rope as determined by actual test is one of the most important criteria now used for discarding ropes. The method is sound fundamentally but in many cases has been abused due to the fact that the manufacturers' nominal breaking strength is used as the reference index instead of the actual breaking strength of the rope. In order to avoid confusion and to keep the method on a scientific basis, it is suggested that each subsequent six months' test be compared with either the actual breaking strength of the rope when new, or the first six months' test, whichever be the greater. In order to accomplish this it would be necessary to have all new ropes tested before they are put into use.

Many ropes gain from 5% to 10% in strength during the first six months service. (See Table 1—Breaking Strain of Rope.) After that they usually lose strength slowly until discarded. In some instances the breaking strength of the capel section of the rope at discard has been found to be higher than the breaking strength when the rope was new or at the first six months' test.

The Mining Regulations of Ontario require a test specimen of the rope to be cut from as close to the conveyance end as possible every six months. This specimen is tested for ultimate strength in the Provincial Rope Testing Laboratory in Toronto. Figures are obtained for the ultimate strength, the total elongation of the test piece at rupture, and notes taken on the general internal and external appearance of the specimen in regard to lubrication and corrosion. Immediate discard is called for if the rope has dropped 10% in strength with a corresponding decrease in extension.

It would appear that in the past too much weight has been placed on the findings of the six months' test due to the fact that corrosion which is the main factor in rope deterioration does not usually occur to a marked degree at the capel end of a rope. A full discussion of this topic will be undertaken in the analysis of Table 10.

Factor of Safety

The factor of safety at which a hoisting rope is operated determines largely the eventual service life of the rope and also has a very direct bearing on the overall safety and efficiency of the operation. Theory and

practice have demonstrated that to obtain the best results, the factor of safety should be within certain limits for a given depth of shaft.

The factors of safety required by the Mining Regulations in the important mining countries of the world are briefly summarized here and may be compared with the factors of safety listed in Tables 1 and 7.

AUSTRALIA

Depth of Shaft	F.O.S. (Men)	F.O.S. (Ore)
Above 2000'	8	6
Below 2000'	6	5

Ropes must be discarded when F.O.S. has dropped to 5 for men and 4.5 for ore and material.

UNITED STATES

U.S.A. Manufacturers' Committee Table now adopted and recommended by the U.S. Bureau of Mines.

Depth of Shaft	Min. Factor New Rope	Min. Factor Discard	% Reduction
0– 500'	8	6.4	20
500–1000'	7	5.8	17
1000–2000'	6	5.0	16.5
2000–3000'	5	4.3	14
Below 3000'	4	3.6	10

GREAT BRITAIN

Dolan and Jackson (8)—Page 116—"In Great Britain the factor of safety of winding ropes is not specifically prescribed, but Regulation 83 under the Coal Mines Act requires a factor of 7 for the capping".

BELGIUM

F.O.S. must not be less than 8.

GERMANY

F.O.S. not less than 8 for men, can be 6 for ore and material.

SOUTH AFRICA

Length of Wind	Discard Factors of Safety		
	F.O S. Men Reg. 37.11	F.O.S. Rock Reg. 34.8	Remarks
0	6.0	5.10	
1000'	6.0	5.18	Factors of Safety
2000'	6.0	5.27	should be all
3000'	6.0	5.36	above these fig-
4000'	6.0	5.45	ures.
5000'	6.0	5.58	
6000'	6.0	5.65	

INDIA (MYSORE)

Ropes must be discarded when static factor of safety has fallen to 6.

CANADA—ONTARIO

Depth of Shaft	Men	
	F.O.S. New	F.O.S. Discard
0 -2000'	6	4.5
2000'-3000'	5	4.5

As shown in Tables 1 and 7 the factors of safety values for cage and skip ropes in Ontario Mines are in line with those enforced in other important mining districts of the world.

Various methods have been suggested for determining the proper factor of safety to be used at a given installation. The "Capacity Factor Method" suggested by Vaughan (28) and later adhered to by Dolan & Jackson (8) has many advantages over the usual method.

It is a well established fact that kinetic shocks decrease as the depth of shaft increases. The Capacity Factor Method takes advantage of this fact as by it, a factor is obtained on a continuous sliding scale from surface down. The shallower the shaft the higher the factor of safety which is as it should be.

The capacity factor (safety factor at 0 ft.) having been established, the pay load is determined by dividing the ultimate strength of the rope by this factor and subtracting the weight of the skip or cage to be used from the quotient.

The factor of safety can be calculated for any depth for a given capacity factor from the formula:

$$F = \frac{y}{1 + \frac{yL}{2000\,K}}$$

Where:

F—Factor of Safety
y—Capacity Factor
L—Depth of Hoist in Feet
K—Rope Factor

K is found for an individual rope by:

$$K = \frac{\text{B/S Rope in Tons}}{\text{Wt. of Rope per Foot (lbs.)}}$$

Factors of safety were calculated for a 150-ton, 1¾ in. diameter rope, breaking strength of wire 257,000/280,000 lbs./sq. in., weight per foot 5.2 lbs., using capacity factors of 9, 10 and 12 respectively.

Hoisting Depth, Ft.	Factors of Safety		
	Cap. Fac.-9 Skips	Cap. Fac.-10 Cages-Material	Cap. Fac.-12 Men
0	9.00	10.00	12.00
1000	7.79	8.52	9.93
2000	6.85	7.43	8.48
3000	6.12	6.68	7.38
4000	5.53	5.93	6.55
5000	5.05	5.36	5.81

In above table hoisting depth is measured from sheave to lip of loading pocket or level. A study of this table will show that the Capacity Factors tentatively suggested will give factors of safety within the limits required by the Ontario Mining Act and conform with generally accepted good practice.

It is suggested that the Mining Industry of Ontario give thought to the adoption of the Capacity Factor Method for determining factors of safety.

Discussion of Table 7.—The factors of safety of installations listed in Table 1 were grouped according to depth of hoist into five groups: 0-1000 ft.; 1000 ft.-2000 ft.; 2000 ft.-3000 ft.; 3000 ft.-4000 ft.; 4000 ft.-5000 ft. Cages were separated from skips and the average factor of safety in each group was compared with the capacity factor for that depth. (See Table 7.)

In the case of man cages, a capacity factor of 12 was used; for cages when hoisting material, a capacity factor of 10 was used. In the case of skip factors, a capacity factor of 9 was used. It may be well to note that the capacity factors quoted were for a high tensile rope.

If Table 7 be examined, it will be seen that the average factor of safety for each group was higher in every case except one than the factor of safety calculated from the quoted capacity factor, (cage ropes 2000 ft.-3000 ft. hoisting distance). All skip ropes hoisting from depths greater than 3000 ft. have very favourable factors of safety.

Service Life

The average service life for the 31 ropes was found to be 633 days or approximately 21 months. This figure compares unfavourably with the 3-year statutory life of a hoisting rope in Great Britain.

There is no legal limit to the length of service life of a rope in Ontario. This would appear to be good practice provided the rope was not subject to deterioration by severe corrosion, wear and fatigue. The length of service life is not nearly as important as the total amount of work done by the rope.

Tons Hoisted

The tonnage hoisted by an individual rope does not give a true evaluation of the work done. Successive ropes on the same hoist, used for hoisting ore from a single loading pocket, can be compared directly on the basis of tonnage hoisted but cannot be compared on this basis with ropes operated in some other shaft.

Work Done by Rope

The work done by a rope during its service life is the only dependable method of evaluating the duty performed by the rope.

Where the necessary data were available the work done by each rope shown in Table 1 was calculated by formulae advocated by Mr. G. W. Sharpe (21). Mr. Sharpe develops the theory of the work performed by a hoisting rope on the assumption that, (see page 213, (21)) quote:

> The only available criterion of rope performance is the actual work it does at its hardest-worked point in quantities of unit length multiplied by unit weight for unit of effective rope area, which assessment can conveniently be expressed in foot tons per square inch.

It will be seen that Mr. Sharpe believes a certain section of a rope performs more work than any other part of the rope and thus the work done by this section of the rope should be taken as representative of the work done by the whole rope.

Mr. Sharpe maintains that up to a certain critical hoisting depth (approximately 4000 ft. for most installations), the hardest worked part of the rope is at or near the capel. When the hoisting depth becomes greater than the critical depth, then the hardest worked point in the rope is at a distance equal to the critical depth below the dump point.

The formulae developed by Mr. Sharpe and used in these computations were as follows:

$$\text{Critical Depth} = \frac{\text{Wt. of Empty Skip} + \text{Wt. of Loaded Skip} + 2\ (\text{Wt. of Rope})\ \text{Tons}}{4 \times \text{Wt./Ft. of Rope Tons}}$$

At distances less than the critical depth, the work per trip = (Wt. of Empty Skip + Wt. of Loaded Skip) × (Distance Pocket to Dump). For distances greater than critical depth, work per trip = (2 × Wt./Ft. of Rope) × Critical Depth × (Distance Pocket to Dump Less Critical Depth) + (Wt. of Empty Skip + Wt. of Loaded Skip) × Critical Depth.

The work done by each rope was calculated in foot tons, and in order to obtain comparable figures was divided by the sectional area of steel wire in each rope. (See Table 1 and also Table 8).

TABLE 2—INSPECTIONS AND ROPE PRACTICE

Table 2 portrays inspections and rope usages as practiced by the 16 Mining Companies listed. Direct comparison of methods used is not practical, but an attempt will be made to reduce the table so that the average can be ascertained and the individual case compared with that figure.

Daily Inspections

Daily inspections were limited in every case to visual inspection of the rope as it wound off the drum or passed over the head sheave. In the latter case the sheaves were inspected as well as the rope.

Inspected ropes daily	50% of companies
Did not inspect ropes daily	50% of companies
Inspected ropes semi-weekly	1 company

It would seem that the best practice would be to inspect the ropes visually every day. This should determine any gross deterioration.

Weekly Inspections

Weekly inspections were more detailed than daily inspections and consisted in the majority of cases of running the rope slowly through the bare hand or through a piece of waste to detect broken wires. Wear and broken and slack wires were determined in this way. This inspection was carried out either at the collar or at the hoist drum. Fifteen of the 16 companies made this inspection. One company inspected ropes every two weeks.

Location of Inspection	No. of Cases	Per-Cent
Inspected at drum	8	50.0
Inspected at collar	3	18.7
Did not state where	5	31.3

Monthly Inspections

All 16 companies made a detailed monthly inspection to determine the state of deterioration of the rope. The monthly inspection was made in the same manner as the weekly inspection except, that in addition to the usual examination, the rope was carefully cleaned at certain selected points and the diameter measured.

Cleaning was done by several methods: Cleaning fluid, steam and air jets, and waste or wire brush. Cleaning fluid might be objected to on the ground that it might wash all lubricant from the strands and core. Cleaning the rope by the use of steam or air jets might promote corrosion unless special precautions were taken to dry and relubricate the rope at these points. It is recommended that waste or a brush be used to clean the rope. A light lubricating oil might be used to soften the old hardened rope dressing.

The rope was calipered at footages which varied from 100 ft. to 1200 ft. apart. Common practice was to caliper the rope every 150 ft. Three diameters should be taken at each point calipered to ensure accuracy. Wear, corrosion, broken and slack wires were noted in nearly every case.

Lubrication

In order to maintain a hoisting rope in good condition frequent adequate lubrication is necessary. An analysis of the causes of deterioration —Table 10—shows that corrosion and internal wear are the chief factors that cause rope deterioration. These types of deterioration can be inhibited by the use of the correct lubricants properly applied.

As shown in Table 2, lubrication was carried out in many different ways by the 16 companies involved. There did not seem to be any standard method of applying the lubricant and numerous different lubricants were used. Only two of the 16 companies stated how frequently the lubricant was applied.

An analysis of the data from the questionnaire follows:

Location Where Lubricant Applied	No. of Cases	Per-Cent
At drum	6	37.5
At collar	6	37.5
At sheave	2	12.5
Did not state where	2	12.5

Method of Application	Percent
Lubricating box	39.6
Applied by hand	21.9
Spray gun	20.8
Constant drip at sheave	9.4
Brushed on	8.3

Lubricants Used.—Twelve different kinds or combinations of rope lubricant were used and it would be almost impossible for all of them to possess the qualities desirable in a good rope lubricant.

From a close scrutiny of the subject, it is very apparent that improvements are necessary in both the character of the rope lubricants and the methods of application.

The suggestion is made here that some improvement would be achieved with the lubricants now available if the lubricating procedure was done in steps:

(a) All dried and caked rope dressing should be first removed. Cleaning fluid is not advocated. Some automatic process combining a brushing action with a high pressure air jet might be devised.
(b) After the rope has been cleaned and dried, a light penetrating lubricant which contains a corrosion inhibitor should be forced into the strands. This light lubricant would perform two functions:
    (1) Wash out dirt, powdered lubricant and corrosion products.
    (2) Lubricate the interior of strands thus reducing corrosion and wear.
(c) If necessary, a heavy protective coating of rope dressing which should be elastic and have good tenacity can be applied to protect the surface of the rope from wear and abrasion.

Rope Handling Practice

A perusal of the rope handling practice used by the companies when installing a new rope demonstrated that the majority of operators were fully cognizant of the importance of handling a new rope with due care.

The concensus of opinion was that when installing a new rope on the hoist drum, the rope should be carefully handled on the reel and should be wound under tension from the reel over the head sheave onto the drum; precautions should be taken against kinking and the release of spin; turns should be positioned on the drum with a wood or lead hammer; the rope should be examined for obvious defects as it winds on.

Release of Spin

Sixty-two and a half percent of the companies involved released spin from the rope when necessary or at certain specified intervals; 38.5% of the companies did not remove spin at any time.

It is sometimes necessary to remove a certain amount of spin from a rope as often as the spin becomes concentrated at the capel end of the rope and causes the shaft conveyance to bind against the guides. All spin should not be released from Lang's lay ropes as this has a tendency to cause rapid deterioration. Release of spin should always be controlled.

Measurement of Diameter of New Ropes

The Companies were agreed that the diameter of a new rope should not be measured until after the rope has been placed in service.

It is suggested that a new rope be used in regular hoisting operations for a period of one week before making the final diametric measurements. These measurements should be taken at several points on the rope.

Crossover Points Changed

The crossover points on the hoist drum where the rope changes from one layer to the next generally show accentuated rope wear due to the action of the rope lifter combined with the heavy abrasive action of the rope being dragged across adjacent turns of the lower layer. The latter action is especially noticeable if the fleet angle is unfavourable.

Of the companies canvassed, 62.5% changed the position of the crossover point at some time during the life of the rope by cutting a section of rope from the spout end. The time between cuttings varied from 6 weeks to a year and the length of rope cut off varied from 4 ft. to 40 ft.

A study of the Hoisting Accidents in Ontario Mines tabulated in another section of this report shows that there were 5 cases of failure or partial failure of the rope at crossover points. Laboratory studies indicate that these failure may be due to a combination of wear and fatigue caused by the development of martensite on the worn crowns of individual wires. In order to prevent this, it would seem that changing the crossover point or points is essential on installations where there are two or more layers of rope on the drum.

It is therefore suggested that the crossover point be changed three to four times during the life of the rope. The length of rope cut off would be determined by the diameter of the hoist drum and the length of rope affected by the crossover action.

Are Ropes Reversed?

The companies were agreed that ropes should not be reversed. This is sound practice as reversing a rope may tend to accelerate the rate of deterioration. When reversed, the weak point in the rope may be moved into a zone of high kinetic stress or greatly increased abrasion. Ropes have often been known to fail in service shortly after they had been reversed.

TABLE 3—COMPARISON OF BASIS FOR DISCARDING ROPES

Due to lack of explanation, this portion of the questionnaire was not answered in the manner intended. Actually, each operator should have been asked to check off his own practice on the list of 15 items given. In many instances, every question was answered for the individual rope, consequently no real comparison of methods could be determined.

Most operators adhere to certain definite criteria for discarding ropes and there is no doubt that criteria carefully established on the basis of experience with individual hoist installations should be used in preference to any cut and dried general procedure.

A hoisting rope should never be discarded on the basis of one or two criteria only and it is felt that the individual operator should broaden his field and include as many variables as possible. In the majority of cases, the variables involved in discarding a rope are highly intangible but persistent and careful observation should reward the operator with longer safe rope life.

An analysis of the individual items of Table 3 follows:

SERVICE	Percent
Note No. of days' service	87.5
Note the tonnage hoisted	44.0
Note the work done by rope	0

The work done by a rope during its service life is important and should be calculated for each rope. Tonnage hoisted by a rope is not a true measure of the work performed if hoisting is done from more than one loading point.

Reduction in Diameter

All the operators took note of the diametric reduction of the rope. Diametric reduction is one of the most important criteria for discarding ropes and is normally caused by wear and corrosion, but can be due to crushing of the rope or permanent elongation of the individual wires.

Products of corrosion sometimes remain in the rope and in that case, the diametric measurement does not give a true evaluation of actual deterioration. In some instances, a diametric increase will be noted. This can be due to very severe internal corrosion or extreme wear accompanied by a basketing or loosening of the outer wires of the strand.

The figures given as a basis for discard varied between 5% and 12.5% —average 7.9%. The actual average diametric reduction obtained for 41 Special Test Ropes (see Table 10) was 7.1%. (Diametric reduction taken at 10,000 lbs. pull for the weakest point in the rope.)

Broken Wires

The questionnaires showed that 87.5% of the companies discarded ropes on the basis of broken wires. Figures given varied from 12 wires per unit length to 30 wires in the whole rope.

The presence of broken or cracked wires indicates the onset of fatigue, and that rapid deterioration of the rope will follow. Six broken wires per lay is the maximum allowable by the Regulations. This figure appears to be too high and grave concern should be felt if 20 or 30 broken wires occur in 30 feet.

Percent Wear of Outer Wires

Fifty percent of the companies were cognizant of the percentage of wear of outer wires. Figures given varied from 15% to 30% wear, average 22%. The best authorities claim that the outer wires should never be permitted to wear more than 20%.

There are two main types of wear—that due to abrasion, and that due to plastic wear resulting from the deformation of the individual wires.

Uniform wear of outer wires should not be considered serious, but excessive wear at one point should be investigated and the cause corrected if possible.

Corrosion	Percent
Note external corrosion	87.5
Note internal corrosion where possible	87.5

Corrosion is the greatest single cause of rope deterioration and should be watched for carefully. This topic will be covered at length in another report.

Slack Wires

Slack wires were noted by 93.7% of the companies. This item is important as it generally indicates that the rope should be discarded immediately due to excessive wear, fatigue and corrosion.

Reduction in Breaking Strength

All companies discarded ropes on the basis of reduction in breaking strength. Few figures were given. The limits were from 10% to 12% reduction in strength based on the first six months' test. For 41 test ropes (see Table 10), the average figure for the capel was 3.4% reduction in strength during the life of the rope.

Percent Elongation

The percent elongation of the test piece is important in estimating the degree of fatigue present in the rope and 94% of the companies took note of this percentage. Only two figures were given as a basis for discard

—if below 1.5% and if below 3%. The average percent elongation of test piece at the weakest point in the rope for 41 Special Test Ropes (See Table 10) was 2.6%.

Evidence of Fatigue

Only 50% of the operators took notice of the presence of fatigue. Fatigue only occurs towards the end of the useful life of a rope, as after fatigue sets in, the rope will deteriorate very rapidly. The presence of fatigue is not always readily apparent and can only be observed when breaks or cracks occur in the wires.

Lubrication of Strands and Core

The degree of lubrication of strands is observed by 87.5% of the companies and 94.0% of the companies noted the condition of the rope core. Both of these points are important as rope life is controlled largely by wear or corrosion of interior wires of strands, or corrosion between strands. Whenever the six months' test piece is cut from a rope, this opportunity should be taken to determine the condition of the strands and core of the rope.

Reduction in Area under Load Extension Curves

Only 18.7% of the companies concerned were interested in this item. The reduction in area under the load extension curve is a function of reduction in breaking strength and the change in elongation of the test piece.

The reduction in area under the load extension curve portrays the condition of the rope more accurately than either the breaking strength or the percent elongation taken separately. The method was first suggested by Dolan & Jackson (8) and has received favourable comment from Mining Engineers in South Africa.

It is suggested that mine operators should determine the area under the load extension curve for the first six months' test and compare this figure with that obtained for subsequent six months' test for all ropes. In this manner an important and accurate criterion for discarding ropes might be established.

Presence of Corrosion Fatigue

Only 62.5% of the companies concerned were cognizant of the presence of corrosion fatigue. This is not surprising as corrosion fatigue, particularly in the early stages, is rather difficult to recognize and it is doubtful if, except in the most advanced cases, it can be recognized without a microscope.

Recent laboratory findings tentatively indicate that corrosion fatigue is not a common form of deterioration in ropes used in Ontario Mines, although, according to Hogan (13), McLelland (16), Dolan & Jackson (8), etc., it is cited as one of the most common causes of rope failure in England and South Africa.

TABLE 4—COMPARISON OF SHEAVE DATA

Table 4 contains all statistics connected with head sheaves and idler sheaves for the 21 hoist installations. The various inspections made are also tabulated. An analysis of the data follows:

Diameter of Head Sheaves

In order to have an efficient installation with low bending and torsional stresses, the ratio of sheave diameter to rope diameter should be at least 80:1. In Canadian and U.S. practice, a ratio of 80:1 is considered good, but in British and South African practice, a ratio of at least 100:1 is advocated.

An examination of the ratios of sheave diameter to rope diameter given in Table 8 will show that in 78.3% of the installations listed the ratio was in excess of 80:1.

Material

Of the 21 installations listed, 62% have steel sheaves, 38% cast iron sheaves.

Construction

In every case, the sheaves were of the bicycle type with solid rims.

Tread Liners

Only 19% of the installations had removable tread liners. Eighty-one percent did not have liners.

Type of Bearings

	Percent
Plain Babbitted Bearings	57
Anti-Friction Bearings	43

Idler Sheaves

No idler sheaves used	57
Idler sheaves used	43

The value of idler sheaves on some installations is rather doubtful.

Sheaves Regrooved

Only 25% of the companies concerned regrooved sheaves. The period between regrooving varied from each change of rope (less than two years for the average rope) to a maximum of 4 years.

South African and British operators claim that rope life can be very definitely increased if sheaves are grooved at each change of rope. It is important to keep the proper sheave groove tolerance for the diameter of the rope, because if the tolerance is reduced below the minimum, wear and abrasion of the rope are accelerated. The correct tolerance can be maintained by periodic regrooving and for best results, this should be done at each change of rope.

Inspections

The routine inspections can be analysed as follows:

	Percent
Inspect sheaves daily	56.2
Inspect sheaves bi-weekly	6.3
Inspect sheaves weekly	37.5

Groove Depth Measured

	Percent
Inspect rims and measured groove depth once a month	50.0
Inspect rims and measured groove depth every two months	6.25
Inspect rims and measured groove depth every six months	6.25
Inspect rims and measured groove depth once a year	12.5
Inspect rims and measured groove depth periodically	25.0

Good practice would be to inspect rims and measure groove depth several times a year. To do this, proper sheave groove templates should be used. In cases where wear is severe, plaster casts of the groove could be made and compared with an original.

Sheaves Dismantled Periodically for Inspection

None of the Companies completely dismantled sheaves for inspection but one operator dismantled and inspected the sheave bearings every 6 months.

TABLE 5—HOIST COMPARISON

Table 5 contains all the important specifications of the 21 hoists used in conjunction with the 31 Special Test Ropes listed in Table 1.

In an analysis of this table no direct comparisons will be made as it is not possible to compare directly small installations with large installations.

General Specifications

The rope pull of the hoists varied from a minimum of 6000 lbs. to a maximum of 50,800 lbs.

Rope speeds varied from a minimum of 600 feet per minute to a maximum of 3000 feet per minute. Average rope speed was 1760 feet per minute.

Drum Specifications

All hoists had cylindrical drums except one, which had bi-cylindro-conical drums.

Cylindrical Drum Diameters varied from a minimum of 3 ft. to a maximum of 12 ft.

The drum of the bi-cylindro-conical hoist was 12 ft. in diameter minimum with a maximum of 25 feet.

The comparison of the ratios of rope diameters to drum diameters is shown in Table 8.

	Percent
Installations with grooved drums	90.5
Installations with plain drums	9.5

Layers of rope on the drums varied from a maximum of five layers in two cases, to a minimum of one layer in two cases.

Clutch

	Percent
Installations equipped with friction type clutches	19.0
Installations equipped with multiple tooth positive action clutches	57.2
Installations with no clutch	23.8

Every installation equipped with a clutch had brake and clutch interlocked.

Brakes

	Percent
Installations with post brakes	95.2
Installations with band brakes	4.8

Operation of Brakes

Manually operated	9.5
Oil operated	66.7
Air Operated	23.8

Brake Lining

Basswood brake blocks	66.7
Asbestos base brake blocks	33.3

Hoist Motors

Three types of motors used:

	Percent
Air Motors	4.8
A.C. Motors	61.9
D.C. Motors	33.3

Two types of connection to hoist are used:

	Percent
Motor direct connected to hoist	23.8
Motor geared to hoist	76.2

Safety Features

No attempt will be made to analyse the various safety features. It is apparent that the great majority of the hoists are well equipped.

TABLE 6—COMPARISON OF SHAFT CONVEYANCES IN VERTICAL SHAFTS

Table 6 is not readily adapted to analysis as individual operators have designed the equipment to suit their own needs. Thus, the Table stands as a statement of fact.

Type of Conveyances

	No.	Percent
Skips	7	36.85
Cages	5	26.3
Skip-cage combinations	7	36.85

Material Conveyance Constructed

	No.	Percent
Nickel steel	4	21.1
Mild steel	7	36.8
Aluminum and steel	8	42.1

Construction

	No.	Percent
Riveted	16	84.3
Riveted and welded	3	15.7

Safety Dogs

	Equipped with Dogs	Not equipped with Dogs
Skips	1	6
Combination	6	1
Cages	4	[1]1

[1]Counterbalance.

Runner Wear Plates

	No.	Percent
Hardened steel	10	55.5
Steel	3	16.6
Mild steel	5	27.8

Guides

Material guide constructed from:

	Percent
Wood (94% B.C. fir; 6% spruce)	88.9
Steel (Ship's channels used in all cases)	11.1

Types of Chairs Used

	Percent
Chains and hooks	71.5
Spring type bumper	14.3
Hydraulic bumper pads	7.1
Solid chairs	7.1

Loading Time

Average loading time from data given was 9 seconds.

Excessive Wear on Guides at Loading Pockets

	Percent
Operators experienced wear at loading pockets	57.2
Operators did not experience wear at loading pockets	42.8

Comparison of Shaft Conveyances in Inclined Shafts

There are only two installations in this category therefore a comparison can be made by merely inspecting the table.

TABLE 7—FACTORS OF SAFETY COMPARED WITH CAPACITY FACTORS

This table contains factors of safety for the 31 Special Test Ropes grouped according to hoisting depth. The table has been thoroughly discussed under Factors of Safety, Analysis of Table 1.

TABLE 8—WORK DONE BY ROPE COMPARED WITH PERCENTAGE FATIGUE STRESS OF INSTALLATION

Table 8 has been constructed on the basis of the total work done by each rope, and the ropes are listed in descending order of merit. Figure 25 shows graphically the work done by each rope in foot tons per square inch of steel in the rope.

The items shown in this table have been taken directly from the questionnaire or have been computed from available data. In all, 23 ropes are involved, and the table has been designed to indicate the physical characteristics that tend to govern the efficiency of the hoisting operation and therefore the total work performed by the rope. For purposes of comparison it will be considered that the work done by the 8 leading ropes in the tables is satisfactory and the characteristics of these ropes used as the base reference.

If the effects of wear and corrosion be ignored then the following factors are thought to influence the total work done by a rope.

(1) Tensile strength of the steel in the rope.
(2) Hoisting depth.
(3) No. of loading points.
(4) Type of operation (skip or cage).
(5) Diameter of rope.
(6) Ratio of diameter of sheave to diameter of rope.
(7) Ratio of diameter of drum to diameter of rope.
(8) Total stress on rope.

An analysis of the table follows:

(1) Tensile Strength of Wire in Rope

	Leading 8 ropes	Other 15 ropes
High tensile	5	5
Medium tensile	3	6
Low tensile	0	4

Thus it is indicated that high and medium tensile wire will produce more actual work per rope, but the tendency is not well defined.

(2) Hoisting Depth

	Average depth of hoist
Leading 8 ropes	3220 feet
Other 15 ropes	2540 feet

In the case of the 8 leading ropes, the average hoisting depth was 3220 ft. and would have been nearer 4000 ft. if the one exception Pamour Porcupine (hoisting depth 2020 feet) had been eliminated. The findings here support the theory that in deep shafts kinetic shocks are greatly reduced and thus have less effect on the operation and life of the rope.

(3) and (4) Number of Loading Points and Type of Operation

In the case of the 8 leading ropes, every rope had been used for hoisting ore by skip from a single loading pocket. The other 15 ropes were skip ropes hoisting ore from several loading points or cage ropes used for general service requiring stops at numerous levels.

From the evidence produced it is clearly demonstrated that the efficiency of a rope is greatly affected by the number of loading points and the type of operation.

(5) Diameter of the Rope

It is doubtful that the diameter of the rope will affect the efficiency of the operation, all things being proportional. It may be, however, that the large diameter ropes, 1½-in. to 1¾-in., are better able to withstand wear and abrasion. The eight leading ropes are all 1½-in. or greater in diameter except in the case of Pamour Porcupine which was 1⅜-in. in diameter. The other fifteen ropes varied from ¾-in. to 1¾-in. in diameter.

(6) Ratio of Diameter of Sheave to Diameter of Rope

Leading 8 ropes (limits 82:1 to 96:1)	None below 82:1
Other 15 ropes (limits 64:1 to 96:1)	5 below 80:1

(7) Ratio of Diameter of Drum to Diameter of Rope

Leading 8 ropes (limits 80:1 to 96:1)	None below 80:1
Other 15 ropes (limits 48:1 to 96:1)	7 below 80:1

For efficient operation, ratio of diameter of sheaves or drum to diameter of the rope should be at least 80:1 as bending and crushing stresses tend to become too high when this ratio is not adhered to as a minimum. Results obtained in Table 8 bear out this statement for both sheaves and drums.

(8) Total Stress on Rope

The total stress imposed on a hoisting rope is the most important of the factors that affect rope efficiency. This variable is generally expressed as a percent of the ultimate strength of the rope and is then termed "Percent Fatigue Stress". The term was first coined by Hitchen (10).

The total stress imposed on a hoisting rope during operation is due to a combination of the following stresses:

(a) Static stress.
(b) Kinetic stress.
(c) Bending, crushing and torsional stresses.

There are other factors acting on a rope but their total effect is small and cannot be evaluated. Therefore, in the computations that follow, they will be ignored.

Static Stress.—The static stress is made up of the following loads:

(1) Weight of shaft conveyance (tons).
(2) Weight of pay load (ore, men or material) (tons).
(3) Weight of the rope hanging in shaft (tons).

Fig. 25—Special Test Ropes—Comparison of work done per square inch of metal in Rope

Kinetic Stress.—The kinetic stresses that a rope is subjected to during operation are due to a combination of the following:

(1) Shocks due to loading.
(2) Changes in acceleration.
(3) Oscillation and vibration of the rope.
(4) Shocks due to improper alignment of guides, etc.

Bending, Crushing and Torsional Stresses.—Bending, crushing and torsional stresses occur when the rope is passing over the head sheave or is being wound on the hoist drum.

Calculation of Stresses

Static Stress.—The static stress was readily obtained from data furnished in the questionnaires, but the kinetic and bending stresses had to be calculated.

Kinetic Stress.—It has been demonstrated theoretically by Boomsliter (2), Vaughan (29) and others, and proved experimentally by actual accelerometer readings obtained by Hogan (12 and 13), Hitchen (11), Dolan & Jackson (8) that the maximum kinetic stress on a rope in some cases exceeds 1.5 times the total static load, but that with modern electric hoists equipped with air or oil operated brakes, the kinetic stresses rarely exceed 50% of the total static load for shafts less than 2000 ft. in depth, and 25% of the total static load for shafts more than 2000 ft. in depth. Therefore, in the calculations to be made for shafts less than 2000 ft. in depth the sum of the kinetic stresses will be taken as 50% of the total static load. For shafts more than 2000 ft. in depth the sum of the kinetic stresses will be taken as 25% of the total static load except when there are loading points above the 2000 ft. level, in which case the kinetic stress will be taken as 50% of the total static load. It is admitted that figures obtained in this manner will be purely arbitrary but nothing better can be done except by actual accelerometer tests at individual installations.

Bending Stress.—Bending, crushing and torsional stress occur at the head sheave or hoist drum and are largely dependent on the ratio of the diameter of the rope to the diameter of the head sheave or hoist drum. Bending, crushing and torsional stress will all be evaluated under the single term bending stress. This will not be absolutely accurate but will do for comparative purposes.

The bending stress was calculated from the well known formula:

$$S = \frac{Ed}{D}$$

where:

S = Stress due to bending (tons/sq. in.).
E = Young's Modulus for rope (tons).
d = Diameter of outer wires of rope (ins.).
D = Diameter of Hoist Drum (ins.).

In the calculations made, Young's Modulus "E" was assumed to be 6000 tons. This is an average figure determined for a large number of ropes.

Calculation Percentage Fatigue Stress

The total stress on the rope is the sum of the static stress, kinetic stress and bending stress. In order to obtain percent fatigue stress, the total stress on the rope was taken as a percent of the ultimate strength of the rope and the breaking strength at the first six months' test was used for this purpose.

Results obtained in Table 8:

PERCENT FATIGUE STRESS

Leading 8 ropes (limits 20.1% to 24.9%) ..... All under 25%
Other 15 ropes (limits 23.0% to 45.4%) ....Only 3 ropes under 25%

Hitchen (11) claims that for efficient operation the percent fatigue stress of an installation should always be below 25% of the ultimate strength of the rope. The findings here support this statement as for all the leading 8 ropes the percent fatigue stress is under 25%. Only three of the 15 other ropes were under 25%.

High bending stresses will often cause the percent fatigue stress to exceed the 25% value. If 5 tons per sq. in. be considered the maximum allowable value for bending stress, then it will be found that none of the leading ropes exceed this figure, but ten of the fifteen other ropes exceed 5 tons per sq. in. for bending stresses. Some relief in this direction can be obtained by using a rope fabricated from smaller diameter wires.

Conclusions

It must be concluded that if wear, corrosion and other factors of rope deterioration be disregarded, then the most important factors governing rope efficiency, and therefore the total work that can be done by a hoisting rope are:

(1) Total stress on the rope.
(2) Hoisting depth.
(3) Number of loading points and type of operation.
(4) Ratio of diameter of rope to diameter of drum or sheave.
(5) And to a limited extent the diameter of the rope and the tensile strength of the wire from which the rope is laid up.

Finally, in order to obtain highest efficiency and maximum total work from a rope, the percent fatigue stress must be less than 25% of the ultimate strength of the rope.

TABLE 9—COMPARISON OF LOCATION OF WEAK POINT IN SPECIAL TEST ROPES

Table 9 is divided into two sections—ropes in vertical shafts and ropes in inclined shafts, and is a compilation made from data obtained from the results of 44 Special Test Ropes tested during the past six years by the Provincial Rope Testing Laboratory in Toronto.

The ropes are listed in ascending order of the maximum length of rope normally hanging in the shaft (sheave to lowest level or loading pocket) and the table is intended to show the location of the weakest point in the rope with respect to the capel or conveyance end. The location of the "weak point" was determined from figures provided by the rope test data sheets.

Theory

Most authorities on rope behaviour claim that the capel end, or that section of a rope closest to the shaft conveyance, is the hardest worked portion and therefore may be considered to be the section most likely to become weak. The results of the investigation tabulated in Table 9 do not support this claim.

A hoisting rope in operation may be said to be made up of three distinct sections which function as a whole to perform the hoisting operation. These sections are not subject to the same degree of stress.

When the conveyance is at the lowest hoisting point in the shaft the sections are as follows:

(a) The dead turns of rope remaining on the hoist drum.
(b) The rope extending from the drum to the head sheave.
(c) The rope hanging in the shaft to which the conveyance is attached.

The (a) Section of Rope

The dead turns on the drum function as a safety feature and tend to keep the rope from being unduly stressed at the point of entrance to the rope spout. This section of rope is subject to bending and crushing stresses and to some tensile stress, and wear and abrasion also take place if there is a full second layer of rope on the drum. The total stresses involved are not as high as in other parts of the rope and the weakest point very seldom develops here. If it does, it can generally be traced directly to some mechanical defect in the hoist.

Of the 44 Special Test Ropes studied, only two ropes developed the weakest point in the (a) section. They were as follows:

Case 1.—Coniaurum Mines, reel No. Z-474 developed the weakest point in the rope at the rope spout. There were five broken wires at this point and the rope was worn and badly corroded. Undue wear and corrosion of the rope at or near the rope spout would suggest some unusual conditions. There were seven dead turns and 2¼ layers of rope on the drum. While the number of layers on the drum may explain the wear, the reason for the corrosion is not apparent.

Case 2.—Lake Shore Mines, reel No. Z-8039 developed the weakest point in the rope at 20 ft. from the rope spout. At this point there were 3 broken wires and the rope was worn on one side. There were five dead turns on the drum and 2½ layers of rope. Wear on one side of the rope suggests a severe scrubbing action when fleeting on the second layer.

Both of the above ropes also developed well defined weak points in the (c) section of the rope as is normally expected. In both cases the weak point in the (a) section of the rope apparently developed because of some mechanical defect, thus they will be considered as exceptions to the general rule and disregarded.

The (b) Section of Rope

The function of the section of rope extending from the drum to the head sheave is to transmit the drum pull to the rope hanging in the shaft. Therefore, this section of the rope is subject to the maximum tensile stress imposed by the hoisting operation and to bending and crushing stresses at the drum. As it never passes over the head sheave this section

is not exposed to severe wear, or subject to the high kinetic stresses developed in the (c) section of the rope, the kinetic shocks being nearly all damped out by the head sheave.

None of the 44 Special Test Ropes developed the weakest point at this section. This must be considered as highly significant and may be due not only to the fact that the total stresses in this section of rope are of a lower order than those in the (c) section, but also to the fact that this section of rope is less likely to become badly corroded.

The (c) Section of Rope

The section of rope hanging in the shaft is subject to more direct and indirect stresses than any other part of the rope. The direct stresses are comprised of the total static load, the kinetic stress load, and the bending, crushing and torsional stresses. The indirect stresses are induced by the effects of wear, corrosion and fatigue.

It has been demonstrated theoretically and practically that the kinetic shocks due to changes in acceleration of the conveyance are among the greatest forces imposed on the hoisting rope. In very shallow shafts this force may rise to more than twice the total static load.

The section of rope hanging in the shaft is subject to more wear and abrasion than either of the other sections. In an average installation, 97% of its length has to travel over the head sheave and 89% is wound onto the hoist drum. Thus it can be readily seen that the section hanging in the shaft is the hardest worked part of the rope and it is logical to assume that the weak point should develop here.

Theoretically, it can be demonstrated that the weakest point in the rope should develop at or near the capel end for shafts less than the critical depth. For shafts greater than the critical depth, the weak point should occur at the point of maximum work, at a distance below the head sheave equal to the critical depth.

Numerous papers have been written on this subject but in the majority of cases, the conclusions were based on theoretical grounds only. The outstanding authors on this subject were Boomsliter (2), Vaughan (29), Dolan & Jackson (8) and Sharp (21). Dolan & Jackson have the following to say on this subject, (P. 86 of (8)):

> Despite the fact that the rope at sheave and drum end is more heavily stressed than the capel end, it is an ingrained conception amongst Mining Engineers that the weakest section of the rope is the capel end. The formation of this opinion is due to acquired practical experience of the corpus of the profession, before theoretical investigation into wave stress reflection and other kinetic oscillatory stress enables a reasonable explanation of the known facts.

Mr. Jackson goes on to say that he had eight discarded ropes cut up and tested throughout their length by the G.M.E. Laboratory. The evidence of these tests was *not conclusive,* but pointed to the capel end as being the weakest section when factors such as ultimate strength, ductility, bend and torsion tests were collectively considered.

Analysis of Table 9

In Table 9, the location of the weakest point is shown with respect to the conveyance or capel end of the rope. For purposes of comparison, this distance was converted to a percentage of the maximum length of rope hanging in the shaft (sheave to lip of loading pocket or lowest level).

In the next column, the most commonly used loading points or levels were listed as a check.

As has been previously stated, the 41 Special Test Ropes in vertical shafts were listed in ascending order of the maximum length of rope in the shaft. If the column headed % B/A (A = Max. length of rope hanging in shaft, ft.; B = Distance of weak point from capel, ft.) be examined, it will be seen that the weak point can occur at almost any point along the section of rope hanging in the shaft.

The location of the weak point with respect to the capel can be grouped as follows:

	No. of cases
At capel end (0 to 25%)	10
In central section (25% to 75%)	25
At sheave end (75% to 100%)	6

The average location of the weak point in the rope for vertical shafts was at 47% of the length of rope hanging in the shaft from the capel end, or approximately at the half-way point in the shaft. In no case did the weakest point occur at the capel. In six cases it occurred within 10% of the capel end and within 5% in only two cases.

The conclusion can therefore be drawn from the results of the tests on the 41 Special Test Ropes from vertical shafts that the weakest point does not occur at or near the capel in the great majority of hoisting ropes.

Discussion

The argument may be advanced that as Government Regulations call for a test length to be cut every six months from the capel end of the rope, the new end thus formed did not have a chance to become as weak as some other section of the rope. As many of the ropes were discarded 4 to 5 months after the last six months' test and did not show weak points at the capel there is little support for this argument. Also, the Falconbridge rope, reel No. 1171, was only in service 170 days and therefore did not have a six months' test piece cut from it. The weak point in this rope occurred 1340 ft. from the capel.

In the case of ropes longer than the critical depth, the hardest worked point and therefore, theoretically the weakest point, occurs at a distance below the sheave equal to the critical depth for that installation. This point is some distance from the capel and thus is never cut off by the six months' test but remains and moves upward during the life of the rope.

Five of the 41 Special Test Ropes in vertical shafts were longer than the critical depth. They were as follows:

Mine and Company	Reel No.	Critical Depth as % of Rope Hanging	Location of Weak Point from Capel % of Rope Hanging
INCo, Creighton No. 5	D-3105	99.0%	77%
Wright-Hargreaves	Z-4696	98.3%	41%
Wright-Hargreaves	Z-9026	98.3%	41%
INCo, Creighton No. 5	Y-7407	98.4%	6%
INCo, Creighton No. 5	Y-9778	98.4%	7%

It is obvious that the weak point did not occur at the critical depth for any of these ropes and can only be said to be close in the case of Creighton ropes Nos. Y-7407 and Y-9778. These two ropes were worked under ideal conditions in a new and reasonably dry shaft and on a new

hoist with single layer winding. The ropes were in service for 1250 and 1185 days respectively and had plenty of opportunity to develop the weak point at the critical depth.

If Table 9 be examined, it will be seen that in the majority of cases ropes that were operated simultaneously on the same hoist and in adjoining compartments of the same shaft developed the weakest point at approximately the same location, and that ropes that followed one another in the same compartment quite often developed the weakest point in the same general location. In the latter case the agreement was not nearly as close as in the former.

This result would lead to the assumption that local conditions are the variables that tend to create the weak point in the rope, and that these conditions may change over a period of time. This topic is fully discussed in Analysis of Results—Special Test Ropes.

Ropes that were operated simultaneously on the same hoist and in adjoining compartments or followed one another in the same compartment are listed here with the dates of service. Ropes operated simultaneously in adjoining compartments are bracketed.

Mine	Shaft	Comp.	Reel No.	% B/A	Dates in Service[1]
Omega	No. 1	West	9927	72	Dec./39–Oct./41
Omega	No. 1	Middle	9717	72	Aug./39–Oct./41
Omega	No. 1	West	5620 (Except)	7	Oct./41–Sept./43
Macassa	Main	North	1357	72	Aug./38–Mar./40
Macassa	Main	South	1362	62	Aug./38–Mar./40
Macassa	Main	North	2982	69	Mar./40–Aug./41
Macassa	Main	South	2176 (Except)	93	Mar./40–Aug./41
Hollinger	No. 26	No. 3	L-39685	37	June/41–Oct./43
Hollinger	No. 26	No. 1	No. 406	26	July/41–Sept./44
Hollinger	No. 26	No. 2	No. 407	26	July/41–Sept./44
Hollinger	Central	No. 2	2508	94	Sept./36–Nov./38
Hollinger	Central	No. 2	3383	75	Oct./39–Nov./41
Hollinger	Central	No. 4	3678	96	Apr./40–July/41
Wright-Hargreaves	No. 3	West	Z-4696	41	Jan./40–Sept./41
Wright-Hargreaves	No. 3	West	Z-9026	42	Sept./41–July/43
Creighton	No. 5	No. 1 Skip	Y-7407	6	Oct./36–Mar./40
Creighton	No. 5	No. 2 Skip	Y-9778	7	Dec./36–Mar./40
Upper Canada	Main	No. 1	765	57	June/39–Aug./40
Upper Canada	Main	No. 2	762	36	June/39–Aug./40
Madsen Red Lake	No. 2	No. 1	27285	51	June/41–June/43
Madsen Red Lake	No. 2	No. 2	O-3281 (Except)	4	June/41–June/43
Pickle Crow	No. 1	No. 1 Skip	41-5	20	Sept./41–Apr./44
Pickle Crow	No. 1	No. 2 Skip	41-4	4	Sept./41–Apr./44
Frood	No. 3	No. 2 Skip	Z-3980	53	Oct./38–Mar./39
Frood	No. 3	No. 1 Skip	C-8128	73	Mar./39–Nov./39

[1]Brackets indicate simultaneous operation.

Location of Weak Point in Rope, Inclined Shafts

The stresses and the factors tending to deteriorate ropes operated in inclined shafts are not the same as in vertical shafts, therefore no correlation can be made between these two categories.

The location of the weak point of ropes in inclined shafts was as follows: At the sheave, at the capel and at 27% of the length of rope in the shaft from the capel. Here again the tendency is for the weak point to develop away from the capel, but as there are only three ropes in this class the resulting data are not conclusive.

Conclusions

It is felt that the weight of evidence presented by this examination of the data concerning 44 Special Test Ropes, from 21 Mining Companies, operated in 23 mines, in 27 individual shafts, is sufficient to conclude that the *weakest point* in a rope *does not as a rule develop at* or near *the capel,* but that it can occur at almost any section along the rope normally in the shaft; and that this weakening of the rope is due not only to the stresses imposed on the rope by the hoisting operation but to various other factors, chief of which is thought to be corrosion. This latter conclusion is supported by the fact that ropes operating simultaneously on the same hoist and in adjoining compartments of the same shaft often develop the weakest point at approximately the same location in the rope.

It is suggested that water or exhaust air entering the shaft at a given horizon will cause the onset of corrosion in a certain section of the rope. This corrosive action together with the normal wear and vibratory stresses to which the rope is subject while hoisting, will cause the rope to become weakened in that section. The pH of the shaft water or condensate will influence the rate of deterioration of the rope.

The conclusion that the weakest section does not occur as a rule at the capel or conveyance end of the rope should be considered as of major importance to all users of hoisting ropes and would indicate that in the past, too much weight has been placed on the findings of the six months' test required by the Mining Act of Ontario.

It is not intended here to deprecate the value of this test, but it would seem that recognition of this fact would indicate that data gathered by careful routine inspection of the rope should be considered as important as the findings of the six months' test. The results of the test should be used to supplement data gathered by other methods.

TABLE 10—BASIS ON WHICH ROPES SHOULD HAVE BEEN DISCARDED

Table 10 is a compilation made to include all the Special Test Ropes that have been tested to May 1st, 1945. The data recorded were taken from the Provincial Rope Testing Laboratory's data sheets and from the Rope Questionnaires.

The ropes are listed in ascending order of the maximum length hanging in the shaft, and the table is designed to compare reduction in strength, during the life of the rope, at the capel and at the weak point in the rope. The percent diametric reduction and percent elongation of the test piece at the weak point is also shown.

The condition of the rope, strands and rope core at the weak point is shown for each rope. From these data, the more important factors of deterioration were selected and listed. The final column details the reasons why the individual ropes should or should not have been discarded.

Ropes in Vertical Shafts

The average percent reduction in breaking strength of the ropes at the capel, from the first six months' test to the time the rope was discarded, was determined to be 3.4%. At the same time, it was found that the average reduction of strength at the weak point in the ropes was 23.2%. In all cases, the breaking strength of the rope at the first six months' test was taken as 100%. It was also determined that the average

reduction in strength at the weak point in the rope when compared with the breaking strength of the capel end at discard was 20.7%.

The average diametric reduction of the test piece at the weak point was found to be 7.1% of the original diameter, and the average elongation 2.6%.

It can now be said that an average rope that has served its useful life will have suffered a reduction in strength of 3.4% at the capel end, and will more than likely have developed a weak point in that section of the rope normally in the shaft where the reduction in strength will be 23.2%. At the weak point in the rope, the diametric reduction will be 7.1% and the elongation of the test piece 2.6%. A rope in this condition should be discarded immediately. Unfortunately this data can only be obtained by testing the rope to destruction throughout its length. This demonstrates the need for an efficient fool-proof non-destructive method for testing ropes.

Ropes in Inclined Shafts

Only three of the Special Test Ropes were operated in inclined shafts. It was determined for these ropes that the average reduction in breaking strength at the capel was 9.7%. The reduction in strength at the weak point in the ropes averaged 12.0%. The average diametric reduction of test piece was 3.5% and the average elongation was 2.9%.

These figures, while not conclusive due to the limited number of ropes involved, show the same trend as ropes used in vertical shafts. At discard, the reduction in strength at the capel end of the rope is not as great as at some other portion of the rope hanging in the shaft.

Marked Factors of Deterioration

The concensus of opinion is that the chief factors of rope deterioration are corrosion, wear and to a lesser extent fatigue. Usually a combination of the above factors leads to the eventual discard of the rope.

Of the total of 44 Special Test Ropes, only 6 were not markedly deteriorated by corrosion, wear or fatigue. Five of the 6 ropes were in fair condition when discarded.

If only the 38 severely deteriorated ropes be considered, then the order of occurrence of the various forms of marked deterioration were as follows:

	No. of cases	Per-cent
Marked corrosion	35	92.0
Marked wear	29	76.5
Marked fatigue	28	74.0

These figures establish corrosion as the major factor of rope deterioration. Hogan (12 & 13) and McLelland (16) both claim that corrosion and particularly corrosion fatigue are the chief causes of rope deterioration in British mines. The presence of corrosion fatigue is extremely difficult to establish without the use of a microscope, and while corrosion fatigue may have been present in some of the 44 Special Test Ropes, tentative laboratory findings indicate that it is not a common cause of rope deterioration in Ontario Mines. Thus it must be considered that corrosion alone is the most common and serious form of rope deterioration.

The results of the tabulation indicate that wear is the next most com-

mon cause of rope deterioration. This result is to be expected as every hoisting rope will show some degree of wear when discarded.

The tabulation shows that fatigue is the third most important of the major factors of rope deterioration. This result is not clear cut as it was established on the basis of relatively little evidence. In this compilation, the occurrence of split or broken wires, or jagged fracture of the wires at the point of failure of the test piece was considered as denoting the presence of fatigue.

In view of these facts, it is suggested that considerable laboratory and microscopic research be undertaken to establish the relative importance of corrosion, fatigue, and corrosion fatigue in the deterioration of hoisting ropes used in Ontario mines.

Corrosion

Corrosion being the most important factor in rope deterioration merits special attention. There is no question but that in order to increase the overall safety of the hoisting operation, the first and most important step would be to prevent or inhibit the onset of corrosion.

Corrosion of wire hoisting ropes is undoubtedly due to the action of shaft water and it has now been established that the mechanism of corrosion in hoisting ropes is electrolysis.

The electrolytic action takes place in the crevices between strands and between the wires in the strands. The portion of wire to which air has free access becomes the cathode and the anode is formed in the crevice between individual wires or strands where the oxygen concentration is low. In the absence of oxygen and with an excess of hydrogen ions the reaction is accelerated. The ferrous hydroxide is oxidized to hydrated ferric oxide which reacts with more ferrous iron to form magnetite, Fe_3O_4, the most common corrosion product to be found in wire ropes.

An examination of a number of severely corroded ropes has established the fact that the most severe corrosion occurred at points where strand touched strand. Severe corrosion was also noted between the first and second layers of wires on the outer side of the strands. Little corrosion apparently occurred between the strands and the rope core.

Corrosive action is started when mine water or condensate enters the interstices of the rope. The mine water may seep or drip into the shaft, or be deposited on the rope or shaft timber as a condensate. It has been noticed that ropes operated in an upcast shaft often deteriorate very rapidly from corrosion. The rate of corrosion is determined by the relative acidity or alkalinity of the shaft water.

Conclusions

It is apparent that the onset of corrosion can be prevented or at least inhibited by keeping the hoisting rope dry. This result may be achieved in two ways:

(1) By preventing any water from entering a shaft used for hoisting.
(2) By the use of special lubricants with the quality of preferentially wetting steel.

The first method is not practical as in order to keep the timber in good condition and prevent fires, shafts must be kept relatively wet.

However, the free entrance of acid or alkaline mine water to the shaft should be prevented.

It is suggested that all Mining Companies in Ontario determine the pH of the water in every operating shaft. This figure, together with information on the quantity and horizons of entry would assist in determining the approximate point at which maximum corrosion should be expected to occur in the hoisting ropes, and may determine to some extent the rate of deterioration.

The most logical method of preventing corrosion in a hoisting rope is by the application of special lubricants. Improvements in the characteristics of hoisting rope lubricants have not kept pace with other developments in the lubricating field and it is to be hoped that discoveries made during the war years will now be utilized.

It is understood that several of the lubricant manufacturers both in Canada and the U.S.A. are now carrying out research in an effort to discover suitable lubricants to inhibit corrosion in ropes. No doubt, these companies will eventually be successful in their research, but in order to speed the process, the suggestion is made that mine operators should co-operate closely with the lubricant makers and the rope manufacturers to develop a good lubricant and perfect the procedure of application.

ELECTRO-MAGNETIC TESTING OF HOISTING ROPES BY THE INTERNATIONAL NICKEL COMPANY OF CANADA LIMITED

History

The need for a reliable non-destructive method of testing hoisting ropes has long been felt by mine operators, and it has been suggested that such tests might most readily be made by electro-magnetic methods.

Electro-magnetic testing of hoisting ropes is not new, many circuits having been devised during the last half century, but as far as is known the perfect magnetic tester has yet to be developed.

As early as 1902 the South African Mine operators experimented with magnetic comparator methods for testing hoisting ropes ((23) "Wire Ropes for Hoisting"), but failed to produce a serviceable circuit.

German investigators have done extensive work on non-destructive testing of hoisting ropes by electro-magnetic methods. For example, between 1907 and 1932 no less than 10 German patents on these methods were taken out ("Electro-Magnetic Testing of Wire Rope" by Hansjoerg Mackh (15)). In the same paper it is stated that the "Westfuelischer Bergwerkskasse" regularly used a d.c. magnetic method for inspecting ropes with internal wire breaks or visible breaks plus internal breaks, and that the same device was used for "Testing of shaft hoist ropes, which have been used continuously for two years, (according to the mining police authorities they must then be taken out of service) so as to be permitted to keep a rope, still in good condition, longer in service." Unfortunately, very little information is now available on the methods used and results obtained by the Germans.

In England numerous experiments were carried out and some practical

application was made of electro-magnetic methods for testing hoisting ropes by T. F. Wall (31). In his paper entitled "Electro-Magnetic Testing of Wire Ropes" Mr. Wall describes several interesting experiments and the construction of an alternating current search coil for detecting deterioration in wire ropes. An apparatus of this type was built and installed at the Hatfield Colliery for checking hoisting ropes. The report does not mention the results achieved.

The U.S. Bureau of Standards experimented for more than a year with d.c. methods for the detection of deterioration in hoisting ropes (Fisher (10) U.S. Bureau of Standards Journal, No. 26, 1928, P. 730) but made little actual progress, and came to the conclusion that d.c. methods were not suitable for testing wire ropes.

The first electro-magnetic test of one of the International Nickel Company's hoisting ropes was made at Copper Cliff in March, 1944, by Mr. P. S. Cavanaugh, chief Metallurgist for The A. B. DuMont Laboratories Inc. of Passiac, N.J., in demonstrating a type No. 244, Cyclograph.

Two samples of 1½-in. diam. hoisting rope were tested. One sample was from a new rope and the other was from the capel end of a rope which had been used at No. 3 Shaft Creighton Mine and which had been taken out of service after it had been heavily stressed when the skip became jammed in the shaft.

Mr. Cavanaugh reports on this test as follows: (Progress Report RP 117-P17, March 7, 1944, Page 4):

> One sample had not been in use and when passed through the cyclograph coil gave a constant full-scale reading. The other sample had been badly stressed in service when a skip became jammed in the shaft. When this piece of cable was put in the cyclograph coil the average reading over its length was much lower than for the unused cable. At three sharply defined points the cyclograph quenched completely, indicating an area of high local stress. On visual examination one of these spots was seen to be bruised.

After the test, the rope specimen in question was unstranded and the individual wires carefully examined by the Mines Mechanical Department in order to determine the cause of the strong stress indications shown by the cyclograph. No evidence was found of a nature to explain this except at one point, where some distortion of wires in one strand was noted. Subsequently tensile tests made by the Ontario Department of Mines Rope Testing Laboratory on samples taken from the rope at 150-ft. intervals throughout its length showed that the sample, cut from the capel end of the rope, had lost approximately 20% of its original strength.

Nothing further was done to advance the investigation until interest was again revived by the Paymaster disaster, although it was recognized that electro-magnetic methods for detecting deterioration in hoisting ropes had distinct possibilities.

Purpose

The purpose of this report is to describe the electro-magnetic tests carried out by the International Nickel Company of Canada, Limited, and to detail the results obtained.

Theory

Corrosion and wear are the two chief causes of deterioration in hoisting ropes. Both of these factors produce a direct loss of metal resulting in a reduction in section of the wire in a rope, and it would seem feasible

to set up some electro-magnetic comparator method for determining the metal loss. Metal loss in a hoisting rope can be correlated in most instances with loss of strength, and it may be possible to correlate magnetic variations with loss of strength and in this manner develop a suitable non-destructive method for checking the ultimate strength of a hoisting rope while still on the hoist.

As a rule the outer wires of a hoisting rope are the first to fail and the breaks can be detected by sensory methods. The magnetic testing method adopted, besides detecting corrosion and wear should detect kinking, broken wires and fatigue. There is little doubt that all the various causes of rope deterioration have a total effect on the magnetic reluctance of the test specimen and it might be difficult to distinguish tensile effects or the stresses introduced when laying up the rope from changes in the magnetic characteristics caused by kinking or fatigue. While it would be highly desirable to detect all important types of deterioration an electro-magnetic apparatus which would only determine, by comparator methods, metal loss in any section of a rope would be extremely useful.

Magnetic Methods Available

All electro-magnetic exploratory methods for detecting deterioration in hoisting ropes are based primarily on electrically exciting a specimen by induced magnetic flux and by using a search coil to detect variations in the magnetic reluctance caused by the deterioration. Magnetic excitation can be obtained either by direct current or alternating current methods.

The majority of investigators have found d.c. methods unsuitable since the results are not consistent, probably on account of the previous magnetic history of the specimen. The magnetic characteristics of steel are affected by changes in tensile stress, fatigue and work hardening. The physical changes brought about by these variables result in corresponding changes in permeability and magnetic reluctance. These effects are far more noticeable when d.c. excitation rather than a.c. is used and this is particularly true concerning the effects of local internal strains in a rope which have no significance from the point of view of mechanical strength, but do have a great effect on the magnetic permeability. Magnetization by a.c. methods does not depend on the previous magnetic history of the specimen because the magnetism passes through a complete hysteresis loop for every cycle of current and if the specimen is well saturated with flux, changes in permeability due to tensile effects are hardly noticeable. An e.m.f. of 25 cycles per second was used in the majority of experiments since eddy current losses are high with a.c. methods of excitation unless low frequency current is used.

Electro-Magnetic Tests Performed

The electro-magnetic tests performed may be divided into two sections.

Field Tests on a large diameter hoisting rope.

Laboratory Tests on small diameter wire rope.

It should be stated that although a test was carried out on a full length hoisting rope, this test was made after the rope had been removed from the hoist.

The initial experimental work was done in the Electronics Laboratory at Copper Cliff where all the apparatus described in this report was built.

The work was done by the Electrical Department in co-operation with other members of the staff engaged in research on hoisting ropes.

The initial experimental work consisted mainly of designing and testing coils for electro-magnetic experiments and of building amplifiers to record magnetic fluctuations. A power supply with regulated voltage was also constructed.

In all, five main methods or circuits were used for magnetically testing ropes or rope specimens. These tests will be described in the order performed.

TEST No. 1—FIELD TEST—CREIGHTON

After preliminary laboratory experiments, an apparatus was evolved to test a full length hoisting rope. This test was carried out in the Creighton Mine No. 5 Shaft hoist house on a recently discarded cage rope.

The rope had been in service for 21 months in No. 3 cage compartment of No. 5 Shaft and had been removed because of reduction in diameter, broken wires and evidence of internal corrosion. It was a 1¾-in. diam. Extra Special Improved Plow steel, 6 x 19, 12/6/1 with 6 filler wires, Lang's lay rope with manilla core. The breaking strength when new was 293,000 lbs.

Equipment Used

Two special rope reels, one equipped with a post brake and the other driven by an air motor, were placed 60 ft. apart and the rope was wound from one to the other under tension simulating hoisting.

The electrical apparatus consisted of two identical independent search coils wound on 11½-in. diam. circular forms. The primary and secondary windings were co-axial and each consisted of 316 turns of No. 20 magnet wire.

The power supply for the primary coils was 15 watts at 600 cycles per second. The secondary windings were connected in series opposition and in order to reduce the secondary coil output to zero with two identical rope specimens in the coils, a resistance condenser network was introduced into the primary circuit. The output of the secondary coils was amplified and rectified. Magnetic fluctuations were recorded on an Esterline-Angus 0-5 milliampere d.c. recording meter.

The apparatus was designed primarily to measure eddy current loss. Thus in order to reduce the permeability of the rope specimen in the coil and make it behave more or less like a non-magnetic material, a d.c. coil of approximately 3000 turns of No. 30 wire was wound over both the primary and secondary coils. The d.c. windings were energized by 150 milliamperes of regulated direct current. The test could be made by running the rope through the coils placed in tandem or through one coil balanced against a standard rope specimen placed in the other coil. A schematic diagram of the circuit used for this experiment is shown in Figure 26.

Preliminary Tests

Trial tests in the laboratory had proved that the apparatus was sensitive but tended to go out of balance easily; consequently all leads, to and from coils, required shielding to prevent pickup from outside sources.

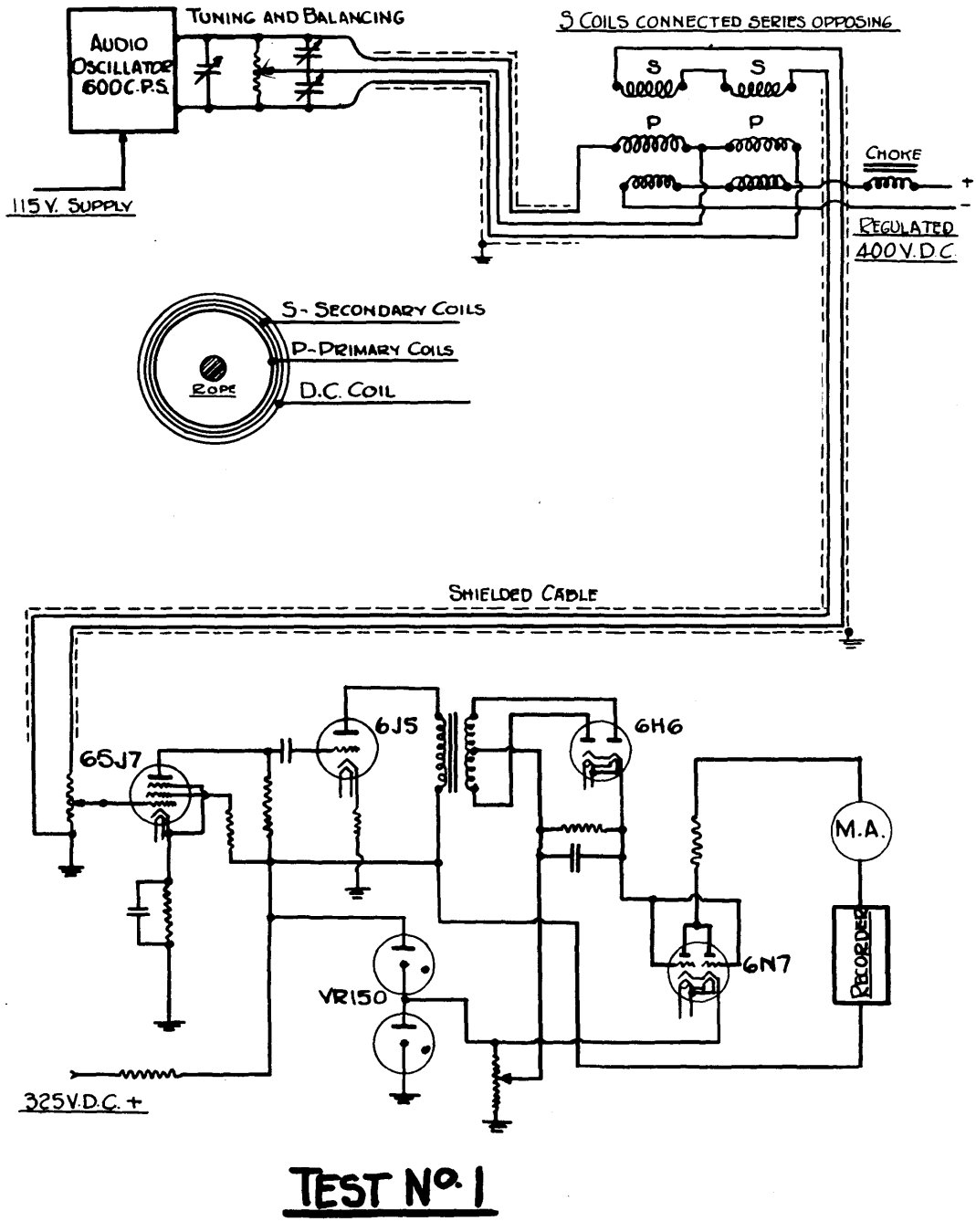


Fig. 26—Schematic diagram of circuit used in Test No. 1

The effect of eddy current loss was tested in the laboratory in the following manner: two bundles of 100 wires each were placed concentrically in the search coils which were then brought to balance by the resistor condenser network. Compressing the wires manually changed the meter reading of the output; releasing the wires caused the meter to return to the original reading.

Procedure for Tests

Two methods were used for testing:

(a) The two coils were placed in tandem about seven feet apart on the rope and the apparatus brought to balance when the coils were over a sound and unworn section from near the drum end. The rope was then run through the search coils which checked adjacent sections of the rope. With the coils arranged in this manner, broken wires could be readily detected, but no other determinations could be made.

(b) One coil was placed on the rope and a 5-ft. unworn specimen of the same rope was placed in the second coil. The coils were balanced to obtain the zero reading and the test rope run through the search coil at a steady speed of 30 feet per minute. 3000 ft. of rope was tested and a chart of the fluctuations due to deterioration was made on a recording meter.

The experiment was discontinued because the apparatus went out of balance due to variable voltage and other causes.

Results

With the coils in tandem as described in (a) the presence of a broken wire was clearly indicated by a sharp peak on the chart.

With the coils in position as described in (b) numerous wide fluctuations from the norm were recorded which could not be interpreted by visual examination of the exterior of the rope and which at the time were not understood. At other points on the rope, severe external wear with definite signs of internal corrosion resulted in reasonably constant deflections of almost maximum amplitude.

To check the results of the electro-magnetic test, specimens were cut from the rope at 100-ft. intervals throughout its length and sent to the Provincial rope testing laboratory where they were tested to destruction.

The percent ultimate strength together with the percent diametric reduction and percent elongation were plotted for each specimen and to correlate the results of the magnetic test with the actual condition of the rope, the mean recorded meter readings were plotted at the same intervals as the other rope characteristics.

The curve of the mean recorded meter readings showed a remarkable correlation with the actual breaking strength except at one point 600 ft. from the rope spout. This favourable result, illustrated in Figure 27, was not determined until some time after the magnetic test had been completed. The apparatus was discarded because of the difficulty of maintaining zero balance due to various unsatisfactory features of design. Temperature variations also seemed to cause difference in capacity between windings, tending to create an unbalanced condition.

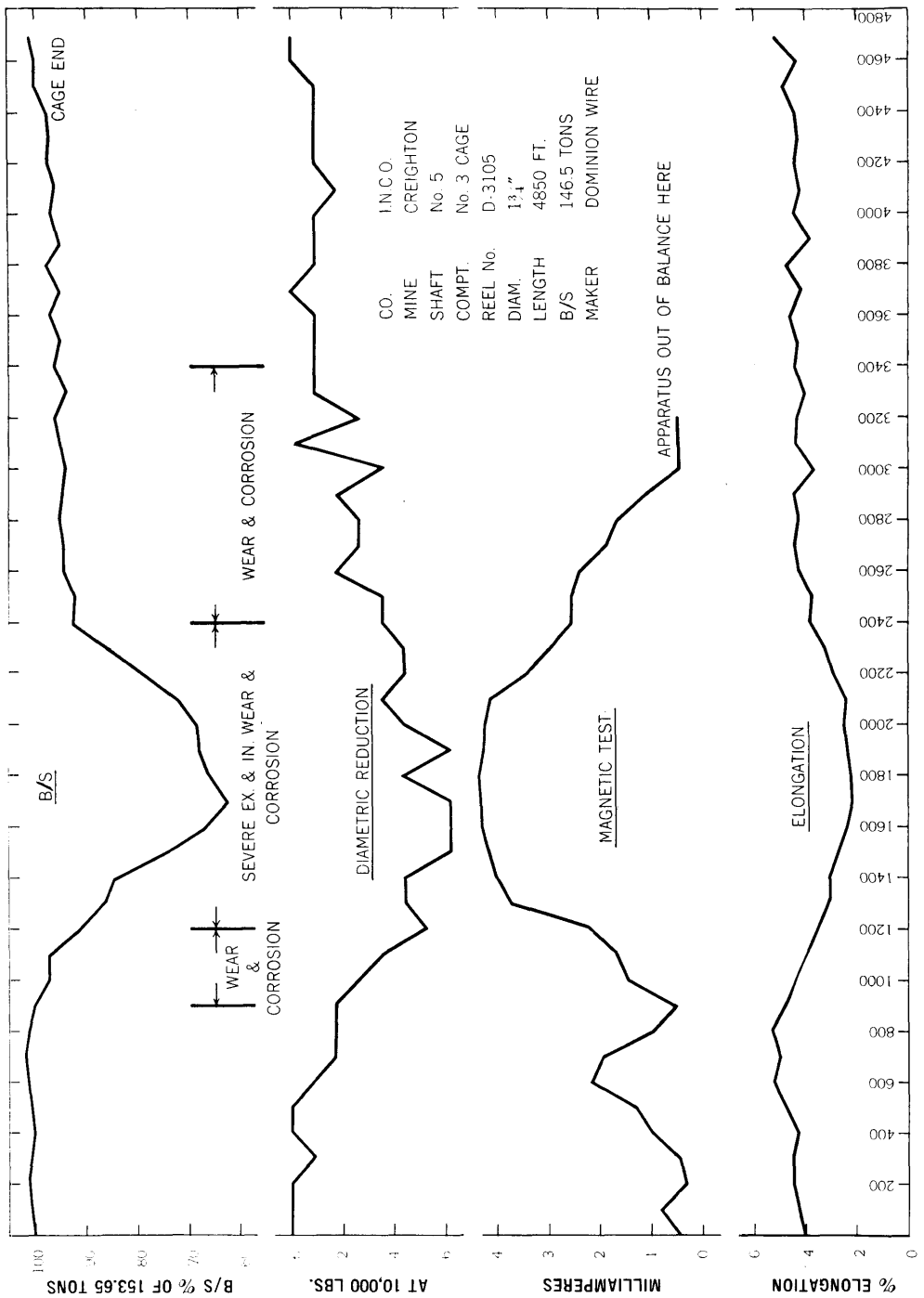


Fig. 27—Magnetic Readings compared with Physical Properties of Rope

The one favourable result obtained with this apparatus warrants further investigation.

LABORATORY TESTS

General Description of Method and Apparatus Used

After the initial field test it was decided that development of electromagnetic testing apparatus would be accomplished most readily in the laboratory and that in the meantime no further field tests would be made.

As large diameter hoisting ropes are unwieldy to handle in the laboratory, a new ¼-in., 6 x 19 regular lay rope, manufactured from Best Plow steel and having a breaking strain of 2.5 tons, was used in the laboratory experiment.

Rope Machine

In order to simulate hoisting conditions and have the rope move steadily through the search coils, an endless rope 70 ft. long was rigged over the three pulleys placed to form a triangle. One of the pulleys was driven by a 1-h.p. electric motor through a train of gears to give a rope speed of 30 ft. per minute.

Provision was made by means of a spring type strain gauge to vary the rope tension as desired.

Imperfections Tested

The capabilities of the different circuits were tested first on a section of new undamaged rope and then on imperfections created in the endless rope by damaging it in various ways. To facilitate observations, the limits of each imperfection were indicated by a different coloured paint. The imperfections were as follows: a splice in the rope, a corroded section, a work hardened section, an abraded section, a kink and cut wires.

At the splice there was an addition of 17% metal and the amplitude of the deflection produced by the splice was used to gauge the magnetic reactions of the other imperfections. It should be pointed out that as the circuit was arranged so that all imperfections gave a positive reading on the recording meter, it was not possible to determine from the chart whether a deflection represented an addition of metal or a metal loss.

TEST No. 2—D.C. EXCITATION

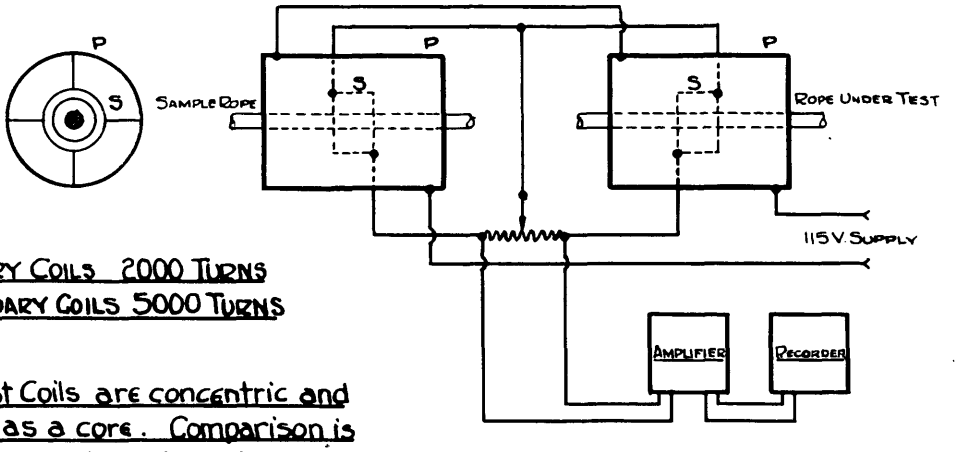
During the laboratory phase of the investigation, several d.c. methods were used to excite the search coils; since results were identical only one method need be described.

The apparatus consisted of a simple yoke, one leg of which carried a d.c. coil and the other leg a pickup or search coil. The rope section under test completed the magnetic circuit. Fluctuations in the output of the search coil were indicated by means of a sensitive galvanometer, but the readings could not be correlated with the actual condition of the test rope, consequently testing by d.c. methods was discontinued.

TEST No. 3—A.C. EXCITATION

A schematic diagram of the circuit used for this test is shown in Figure 28.

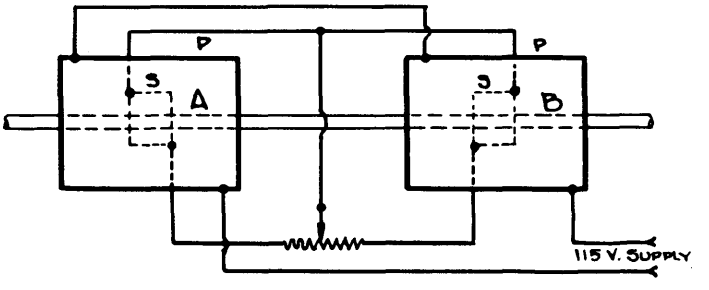
The apparatus consisted of two identical pairs of coils with primary and secondary windings. The primary coils were wound with 2000 turns each and the secondary or search coils with 5000 turns each. The secondary



P-PRIMARY COILS 2000 TURNS
S-SECONDARY COILS 5000 TURNS

These Test Coils are concentric and use Rope as a core. Comparison is between a sample section of rope and that under test.

TEST NO. 3A



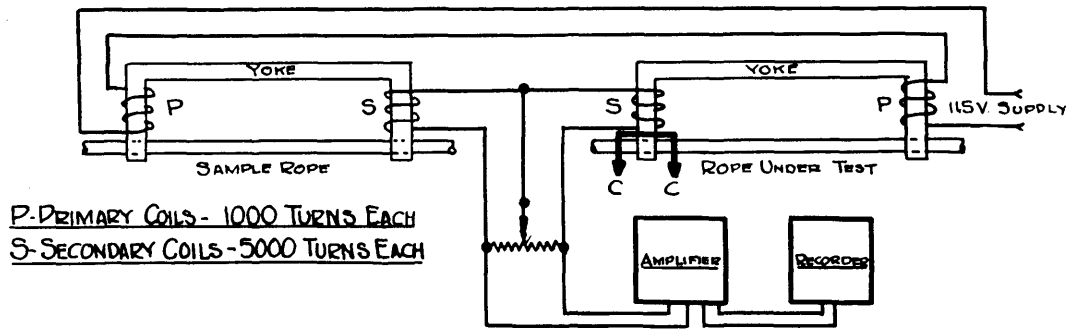
Test Coils connected as shown. Balances Section A against Section B of the rope under test. and is a comparison between adjacent sections of the same rope.

TEST NO. 3B

Fig. 28—Schematic diagram of circuit used in Test No. 3

coils were made smaller than the primary coils and placed inside them so as to embrace all the flux passing through the rope.

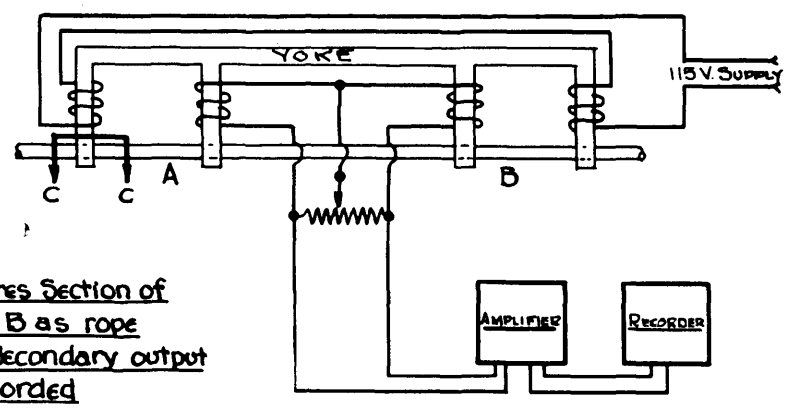
The primary windings were connected in series with a 115-volt 25-cycle source of power and the secondary windings were connected in series opposition with a potentiometer connected across the output and the centre tap of the secondary windings. This potentiometer was used to reduce the voltage from the search coil to zero when identical samples



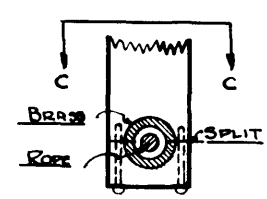
P-PRIMARY COILS - 1000 TURNS EACH
S-SECONDARY COILS - 5000 TURNS EACH

Primary Coils are connected in series and magnetize two separate yokes. Secondary Coils are connected series opposing. The output is connected to a potentiometer and amplifier. Recorder is a 0-5 milliampere type. Comparison is between sample rope and the rope under test.

TEST No. 4A.



This method compares Section of rope 'A' with Section B as rope passes thro device. Secondary output is amplified and recorded



TEST No. 4B.

Fig. 29—Schematic diagram of circuit used in Test No. 4

of rope were being run through the coils. The standard amplifier shown in Figure 26 was used to increase the voltage from the search coils, and the d.c. recording meter previously mentioned was used to obtain a record of the fluctuations.

The coils were used in two separate tests No. 3A and No. 3B.

Results—Test No. 3A

In this test one pair of coils was placed on the test rope and brought to balance with the other pair containing a new 3-foot sample of the test rope. This circuit did not give satisfactory results because the rope moving in the field of the search coil tended to throw the apparatus out of balance, and d.c. on the moving rope affected the sensitivity. These irregularities produced fluctuations on the chart which could not be interpreted and which masked fluctuations indicating the imperfections.

Results—Test No. 3B

In this test the two sets of coils were placed on the test rope in tandem. It was thought that this method could be used to detect broken wires, but it was unsuccessful.

TEST No. 4

This apparatus gave the best results of any tested in the laboratory. A schematic diagram of the circuit is shown in Figure 29.

The apparatus was made up of two identical pairs of coils, each pair consisting of one primary and one secondary coil wound on opposite ends of a steel yoke. The primary and secondary windings contained 1000 turns and 5000 turns respectively. The primary coils were connected in series with a 115-volt 25 cycle source of power. The secondary or search coils were connected in series opposition. The centre tap of the secondary was connected to the movable arm of a potentiometer which was connected across the output terminals of the coils. The output voltage of the secondary or search coils was amplified, rectified and recorded on a 0-5 milliampere Esterline-Angus d.c. recording meter. The 25-cycle source of power was used as it was desired to keep eddy current loss to a minimum and to secure maximum flux penetration of the rope specimen under test.

This apparatus was used in two different ways as shown in Figure 29.

Results—Test No. 4A

One yoke was fitted to the rope under test, and a standard specimen of new rope was introduced into the coils of the other yoke. The output of the search coils was balanced when an undeteriorated section of the test rope was in the yoke. When balance was attained the rope was run through the search coils and the deflections produced by the imperfections recorded on a chart.

This circuit gave the best results of any tested in the laboratory. The deflections produced by the various imperfections were reproduced exactly in form and amplitude at each rotation of the endless rope, the undeteriorated sections of the rope registering as a straight line.

The apparatus gave consistent deflections on the following imperfections: splice, corroded section, work hardened section, abraded section, and kink, but did not detect the presence of cut wires. The percent metal remaining at each damaged section of the test rope was not determined and therefore no effort was made to calibrate the apparatus.

This experiment was repeated using various degrees of rope tension. Increases or decreases in tension were found to change the position of the zero or initial reading and affected the amplitude of the readings but did not alter the general order of the deflections obtained.

Results—Test No. 4B

The coils were connected in tandem as shown in Figure 29, Test No. 4B, both pairs of coils being placed on the rope to be tested. This method was found to be not nearly as sensitive as the circuit used in Test No. 4A, and did not consistently detect broken wires as was hoped.

TEST No. 5—RESISTANCE TEST

It was suggested that the degree of deterioration could be checked by comparing the resistance of a rope in good condition with the resistance of a worn deteriorated section of rope.

For this test, two 10-ft. specimens of 1¾-in. diam. rope were specially prepared. One specimen was from a new rope and the other from a used rope worn on the exterior and showing severe internal corrosion. The rope specimens were securely served six inches from the ends and the wires broomed out and carefully cleaned. The ends were then cased in zinc to ensure that all wires were connected.

Electrical contact was made through the zinced ends to the specimens which were connected in series and the voltage drop was taken across each specimen with a constant current through both, and as the temperature of the specimens was identical, there was no voltage variation due to temperature difference.

The resistance drop for a 10-ft. piece of new rope was 0.00072 ohms and for a similar length of used rope was 0.00074 ohms, or a difference of 0.000002 ohms/ft.

This result indicated that field determinations of differences in resistance due to rope deterioration are not now practicable.

Summary of Results and Conclusions

The results of the electro-magnetic rope testing experiments performed can be summarized as follows:

(1) Direct current methods of excitation of search coils were found to be impracticable because the magnetic readings obtained could not be correlated with the condition of the rope specimen.

(2) Alternating current methods of excitation of search coils produced favourable results in the laboratory when used in conjunction with the proper type of coil. The circuit shown in Figure 29 was found to give the best results. With this apparatus, constant magnetic deflections were obtained for a given degree of rope deterioration.

(3) The results of Test No. 1 (Figures 26 and 27) indicate that, with some alterations, the circuit as described might be used to obtain readings which could be correlated directly with the breaking strength of the test rope.

(4) It was determined by laboratory experiment that detection of deterioration by measuring the variations of the electrical resistance of the specimens is not now practicable.

Finally it can be concluded from the results of the tests that: The more important types of deterioration in hoisting ropes can be detected by electro-magnetic exploratory methods in the laboratory, although considerable experimental work will have to be undertaken before any of the

circuits developed can be applied directly in the field. The apparatus indicated the presence of deterioration and to some extent the degree, but was not capable of differentiating between the various types.

DETERIORATION BY CORROSION OF MINE HOISTING ROPE

History and Purpose

The verdict of the coroner's jury at the inquest held to inquire into the death of Russel Dillon killed in the hoisting accident due to rope failure at the Paymaster Mine, Feb. 2, 1945, stated in part, "From the evidence submitted, the rope broke because of internal corrosion of which there was no indication from external examination".

The investigation reported in the following was conducted for the purpose of determining the factors comprising internal corrosion or any other form of metal loss, and by so doing indicate the course to be followed in minimizing this type of failure.

Considerable work was carried out on specimens cut from the Paymaster rope. In addition valuable information regarding corrosion in its early stages and its progression was obtained from various other ropes submitted by several Ontario mines.

Introduction

The results of this investigation agree with the general findings of most investigators that internal corrosion, or corrosion in combination with internal wear, is by far the most serious cause of deterioration of mine hoisting rope used in contact with mine water.

The importance of corrosion fatigue and fatigue alone has not been overlooked but very little evidence of these types of failures was found in the ropes examined.

Internal Corrosion

Since corrosive attack in mine hoisting rope takes place internally, it is not generally detected in external examination and is not revealed to its full extent by the regular six months' Government tests carried out at the Department of Mines.

No proven method for preventing or substantially retarding corrosion has resulted from this investigation. It is felt, however, that information has been gained from examination of several ropes in various stages of deterioration which should indicate the direction to be followed in the search for a solution to the problem.

It has been the practice of the International Nickel Company to examine visually the internal condition of hoisting ropes by selecting a short length for this purpose at the times of recapping. Observations made in these examinations supplement the laboratory study of internal corrosion which is reported herein.

Principal attention was given to the investigation of the Paymaster rope which failed in service on February 2, 1945. Corrosion was most advanced in this rope although the products and progress of corrosion were typical of all ropes examined. The remarks which follow, therefore, are in general pertinent to all ropes investigated.

Corrosion Products

Advanced corrosion was present in most of the ropes examined and an abundance of loose corroded material was obtained for examination by unravelling several feet of strands from each rope. Many of the observations were made after cleaning the grease from the products with a solvent.

The colour of the products collected ranged from light brown to coal black, and binocular examination at a magnification of 30 diameters revealed minute particles of free steel. X-ray diffraction analyses of overall samples revealed two principal constituents, magnetic oxide (Fe_3O_4) and goethite ($FeHO_2$).

In some of the samples $Fe_2O_3H_2O$ was identified, as was metallic iron.

The products collected from all ropes showing reasonably advanced corrosion were strongly sensitive to the a.c. magnet. It was observed, however, that samples particularly black in colour were most strongly magnetic on account of a high percentage of magnetite. The brown samples, higher in goethite which is non-magnetic, were also readily moved by the magnet because magnetite and steel particles were mixed with the goethite in sufficient quantity to cause a magnetic reaction.

The prevalence of Fe_3O_4 as one of the major products of corrosion in hoisting rope is apparently due to the presence of an oxygen concentration cell. In explaining the presence of magnetic oxide, Mr. F. L. LaQue of the International Nickel Company's Development and Research Department suggests the following mechanism of corrosion.

> The probable mechanism of the corrosion reaction involved an oxygen concentration cell with the steel in the crevices between touching strands being anodic to steel exposed to aerated water on the outer surface of the rope. Evidently the combination of grease and the tightness of the cable prevented air (oxygen) from getting into the crevices between the strands, although sufficient water to promote corrosion was able to seep into these spaces, possibly through capillary action.
>
> The low oxygen content of the water getting into the rope crevices was indicated also by the fact that X-ray analysis of the corrosion products disclosed them to contain large amounts of Fe_3O_4 which is the normal product of corrosion of iron in contact with substantially air free water.

Nature of Products in Primary Stages

X-ray analyses were also carried out on the initial products of corrosion found inside the strands of a rope removed from service after six months. The wires, although quite wet with lubricant, were mildly corroded due to the presence of numerous beads of water, and brown and black deposits were present within the lubricant. Each of the deposits was analysed by X-ray diffraction. The brown material was identified as a mixture of goethite ($FeHO_2$) and magnetite (Fe_3O_4) containing a small amount of hydrated ferric oxide ($Fe_2O_3H_2O$). The black material again showed a strong Fe_3O_4 pattern with a small showing of $FeHO_2$. From this analysis of corrosion in its early stages it may be assumed that the ultimate presence of Fe_3O_4 and $FeHO_2$ is the result of oxidation of ferrous iron to ferric iron, the latter reacting with more ferrous iron to form Fe_3O_4.

Internal Wear and Corrosion

After corrosion has advanced beyond the oxide film stage it is difficult to determine whether internal metal loss is due mainly to corrosion or wear. It has been noticed from the examination of various ropes that

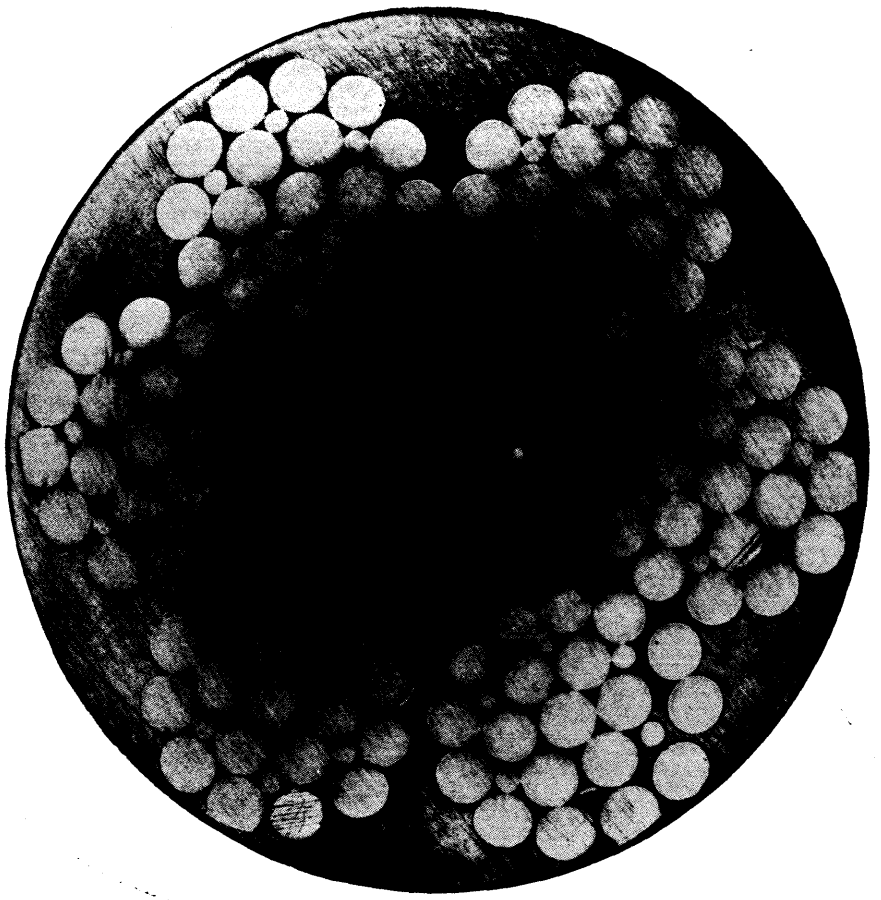


Fig. 30—Photo No. 1

Fig. 30

CROSS-SECTION VIEWS OF PORTIONS OF CREIGHTON ROPE TAKEN AT POSITIONS INDICATED ON FIG. 31. (MAGNIFICATION $\times$ 2½.)

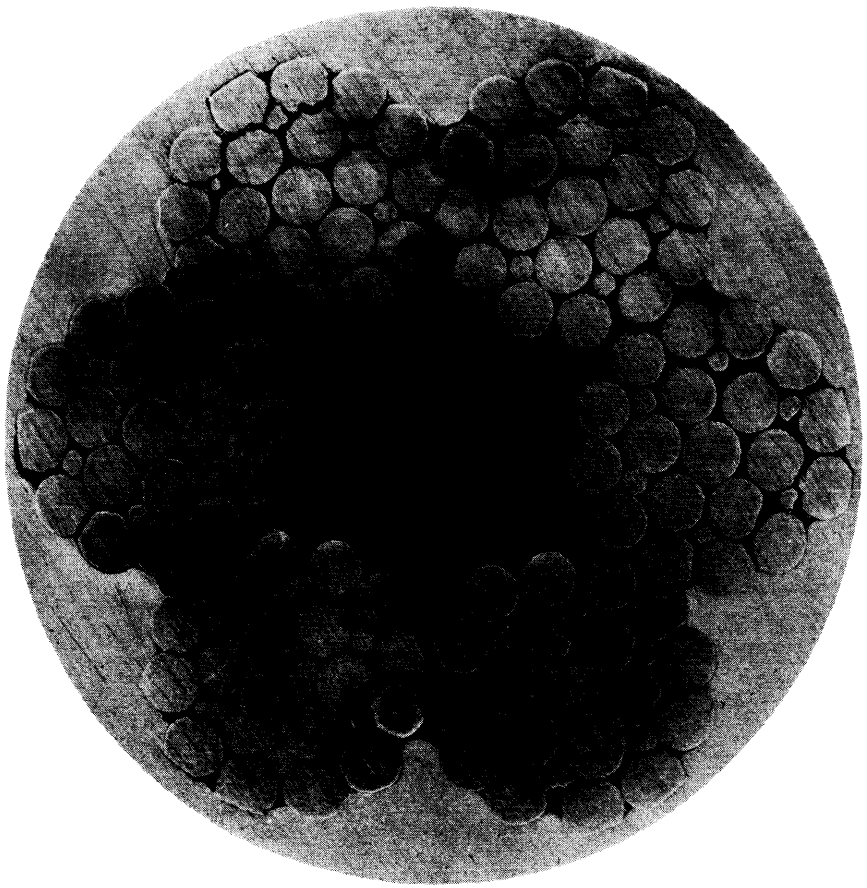


Fig. 30—Photo No. 2

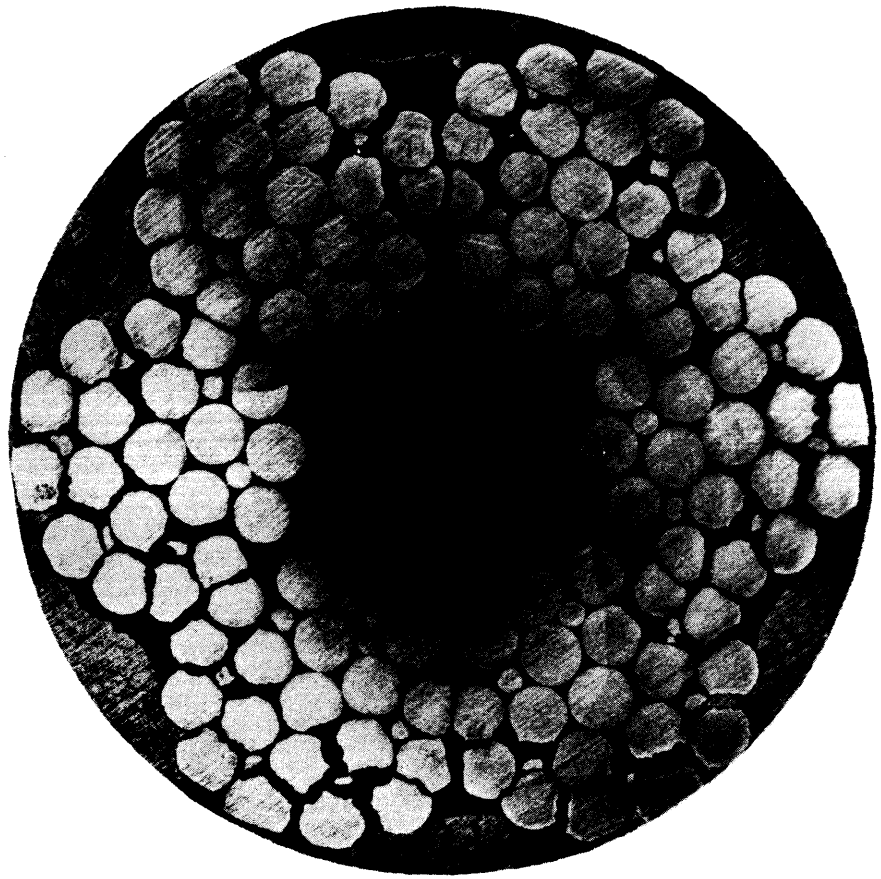


Fig. 30—Photo No. 3

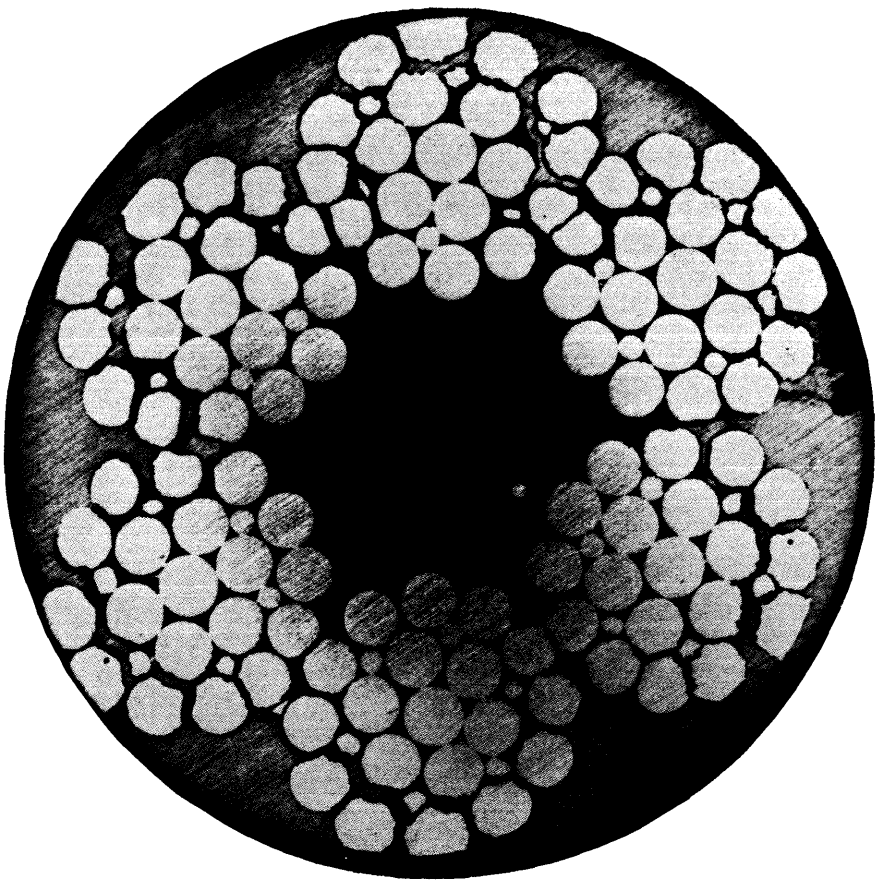


Fig. 30—Photo No. 4

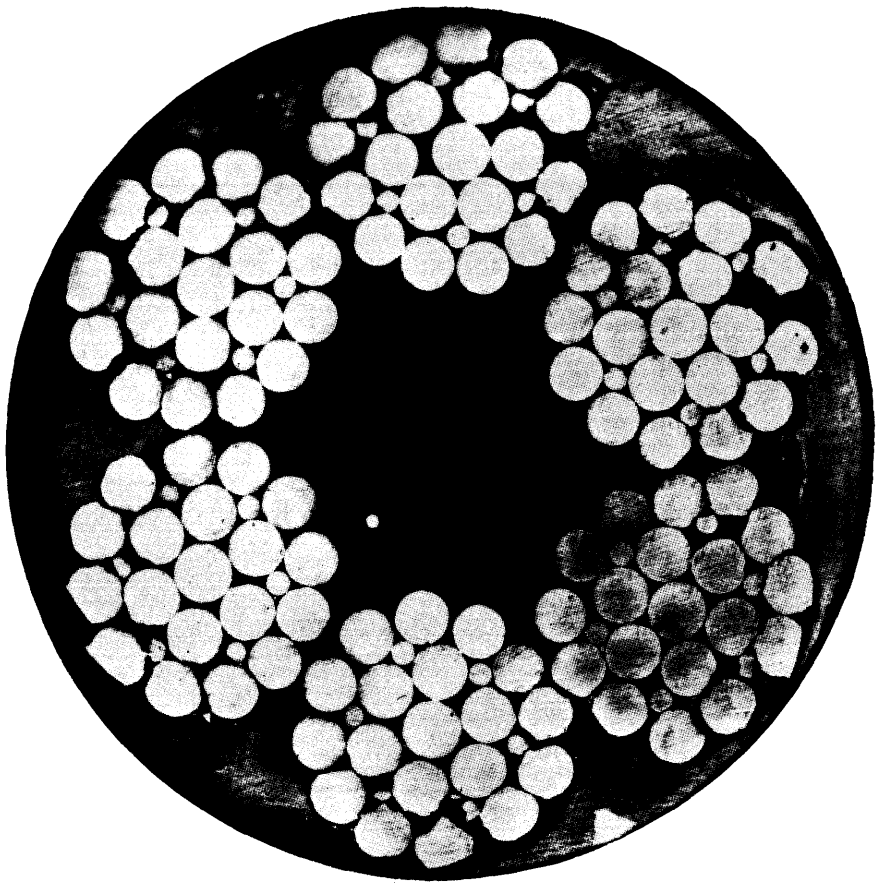


Fig. 30—Photo No. 5

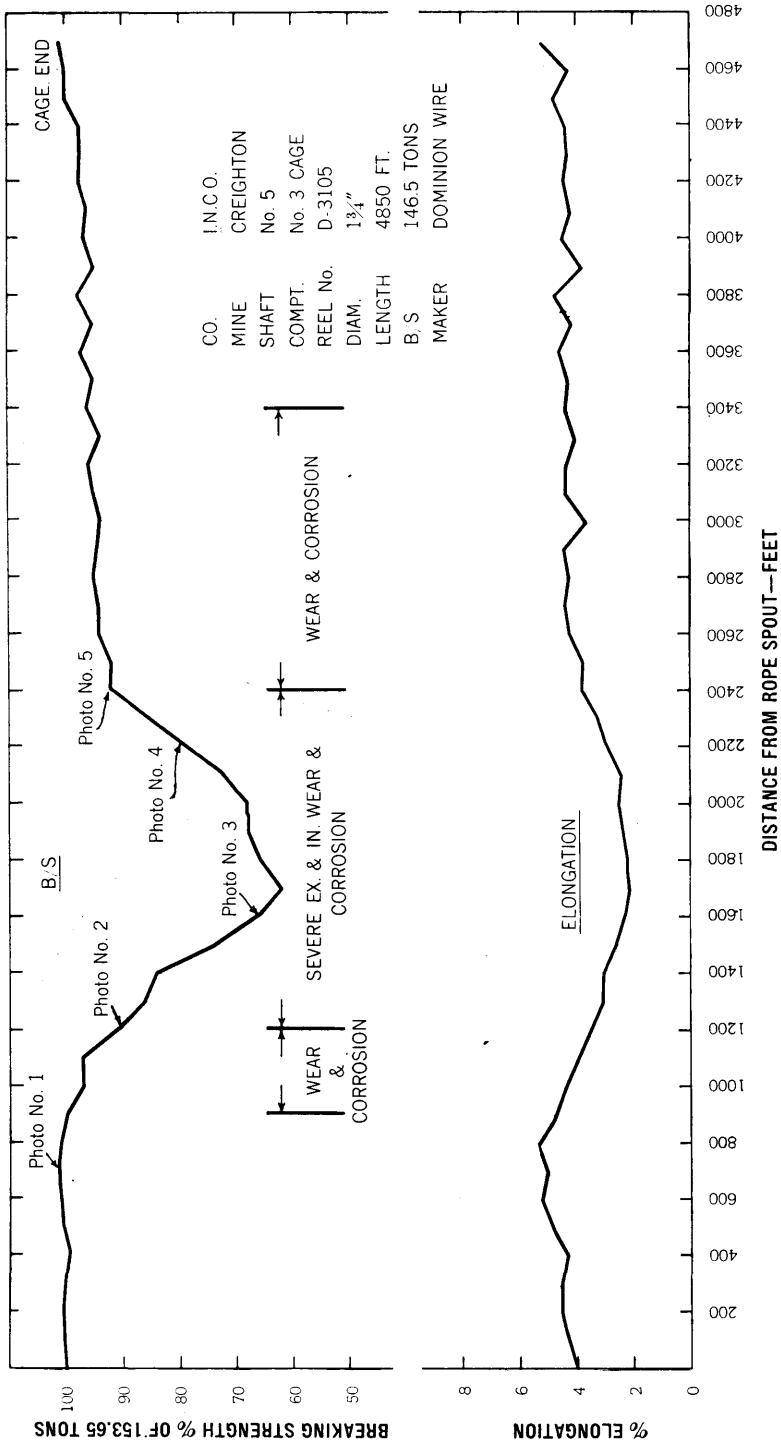


Fig. 31—Chart of rope showing location of photographs shown in Fig. 30

considerable grooving takes place in the wires where the strands are in contact, due to their normal movement caused by the flexing of the rope in service. The grooving has been observed comparatively early in the life of a rope, that is before the onset of corrosion, and occurs regardless of what would seem adequate lubrication. With the advancement of corrosion after breakdown of lubricant the line of demarkation between wear and corrosion becomes obscure but it is plausible that normal internal wear, which otherwise would not be serious, is greatly accelerated by corrosion inasmuch as the decayed metal abrades much more rapidly. There would seem to be little value in attempting to differentiate sharply between internal wear and corrosion and therefore their combined action will hereafter be referred to as corrosion.

External Wear

There can be no doubt that metal loss due to crown wear takes place but the appearance of the outer wires is apt to be misleading. A cross section examination of a used rope will reveal, in many cases, considerable plastic deformation of these wires which under ordinary external examination might be classified as heavy wear. The cross section view of such ropes, Figure 30, exhibits the plastic flow and flattening and suggests that the external metal loss is not as great as previously believed.

It is probable that external corrosion also contributes to metal loss in some small degree.

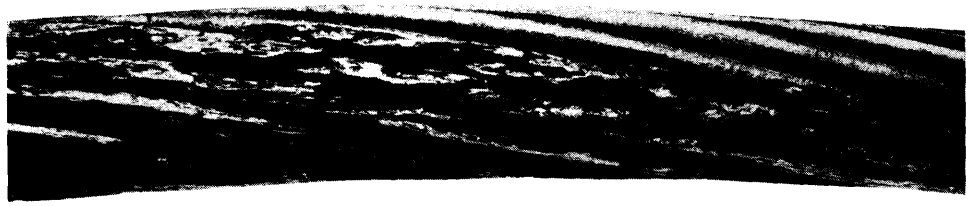


Fig. 32—Side view of corroded strand showing longitudinal grooving
Magnification ×2½

Penetration of Corrosion and Lubricant Requirements

Considerable information as to the progression of corrosion can be gained by preparation of full section specimens taken at intervals from a used rope. This is illustrated by the photographs, Figure 30, of five such specimens showing various degrees of corrosion and by the graph, Figure 31, in which the location of the specimens is shown in conjunction with the curve of breaking strength of the rope. The rope under examination had been used for hoisting men and supplies in the cage compartment of No. 5 Shaft at Creighton Mine for 1 year and 9 months under normal moisture conditions.

The extent of corrosion and the corresponding loss of strength in each specimen are shown on the graph. The progression of corrosion and its attack on various wires as illustrated in the photographs indicate the penetrating and lubricating properties required in a rope dressing.

In the many discussions of lubrication during the course of this investigation the view has often been expressed that penetration proper-

ties sufficient to carry the lubricant to the hemp core are necessary. Examination of the photographs, particularly No. 2, will reveal that although corrosive attack is internal and cannot be seen, it is nevertheless largely confined in its early stages to the under side of outer wires and the contacting side of the next layer. In the more advanced stage, No. 3, the greatest metal loss has occurred where strands are in contact. This is largely due to the grooving previously described, which is shown in the side view of a strand in Figure 32. It will also be noted in Figure 30, that the wires in contact with the hemp core are virtually unattacked, which has been found to be the case in all ropes regardless of their general corroded condition even when the lubricant in the hemp core has decomposed to a tarry or in some extreme cases to a brittle material. From these observations one might conclude that penetration of lubricant to the hemp core, while ideal, is not the prime requisite but rather that some penetrating power is necessary with greater emphasis on water repelling properties. The question naturally arises as to whether the internal lubricant used when laying up the rope would need replenishing if all water could be repelled during service and this naturally depends on what is considered normal rope life. Observations indicate that in the three years currently regarded by the International Nickel Company as being the maximum life for cage ropes, the internal lubrication would not become deficient, either by drying out or by squeezing out, to a point inducing internal wire deterioration if all water could be repelled. With regard to the penetration of lubricants applied periodically to the surface of the rope, little, if any, penetration to the interior of the strands has been observed although some penetration is occasionally obtained between strands.

It appears that the principal function required of a rope lubricant apart from minimizing external wear is to prevent the beginning of corrosive action by repelling water at the rope surface, that is, in the crevices between strands and in the minute spaces between the outer wires of individual strands. (Refer to photos in Figure 30.) The possibility of any considerable quantity of lubricant penetrating to the core from the application of lubricant to the rope while in service appears at this stage unlikely and the value somewhat questionable as the wires in contact with the hemp core have been found in all the ropes examined to be in relatively good condition.

It can be reasoned that corrosion, once started, is impossible to check due to the eventual loosening of the wires and strands which increases considerably the movement between them. The effect of particularly severe corrosion on a rope is revealed in Figure 33, Photo 2, which shows the extent of corrosion near the break in the Paymaster rope; for comparison, an uncorroded section of the same rope is shown in Photo 1. It is evident that the loosening of the wires shown here, and the interwire and strand wear which accompanies such loosening has increased the rate of deterioration as well as facilitating the entrance of water.

The task of checking corrosion by subsequent lubrication, therefore, is much more difficult than that of preventing corrosion from starting. The evidence already presented points to the use of a rope lubricant with principal properties as follows:

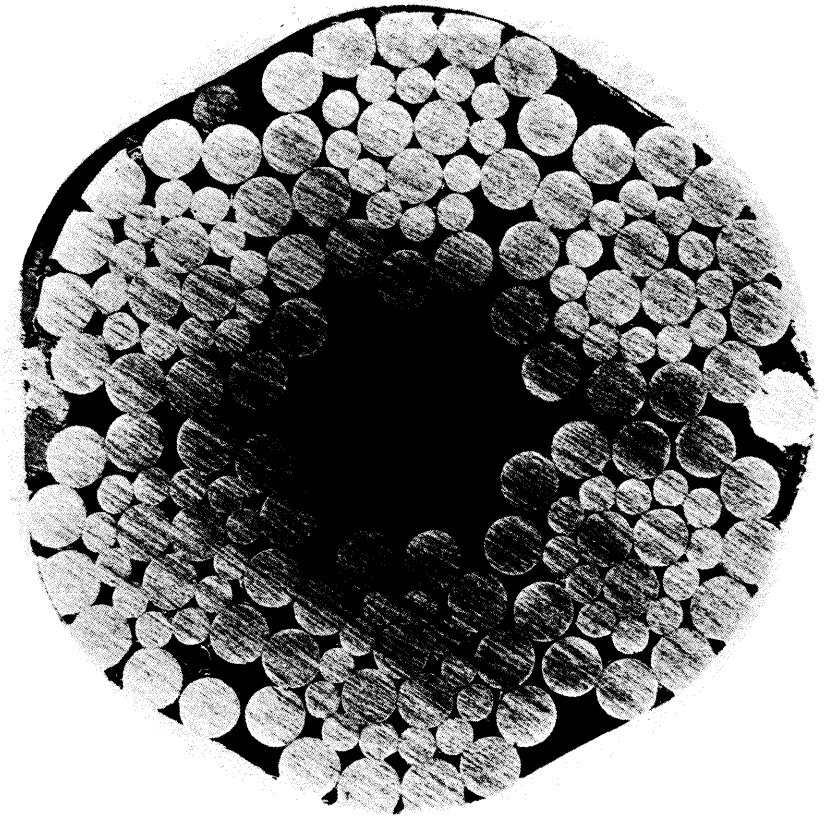


Photo 1

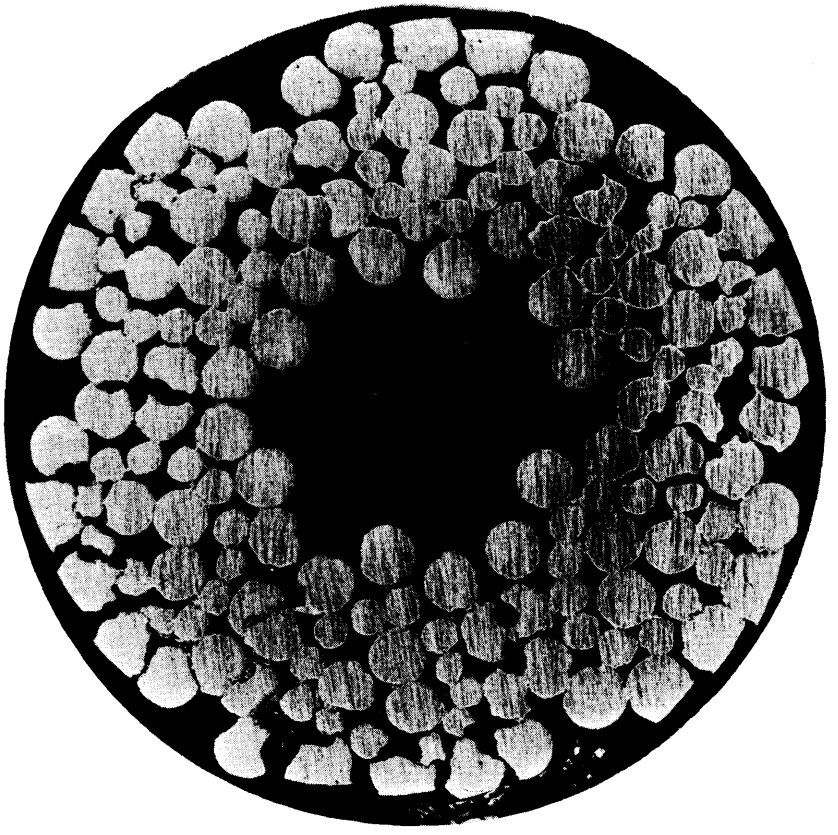


Photo 2

Fig. 33—Cross-section views of portions of Paymaster Rope taken at positions indicated on Fig. 34
(magnification ×5)

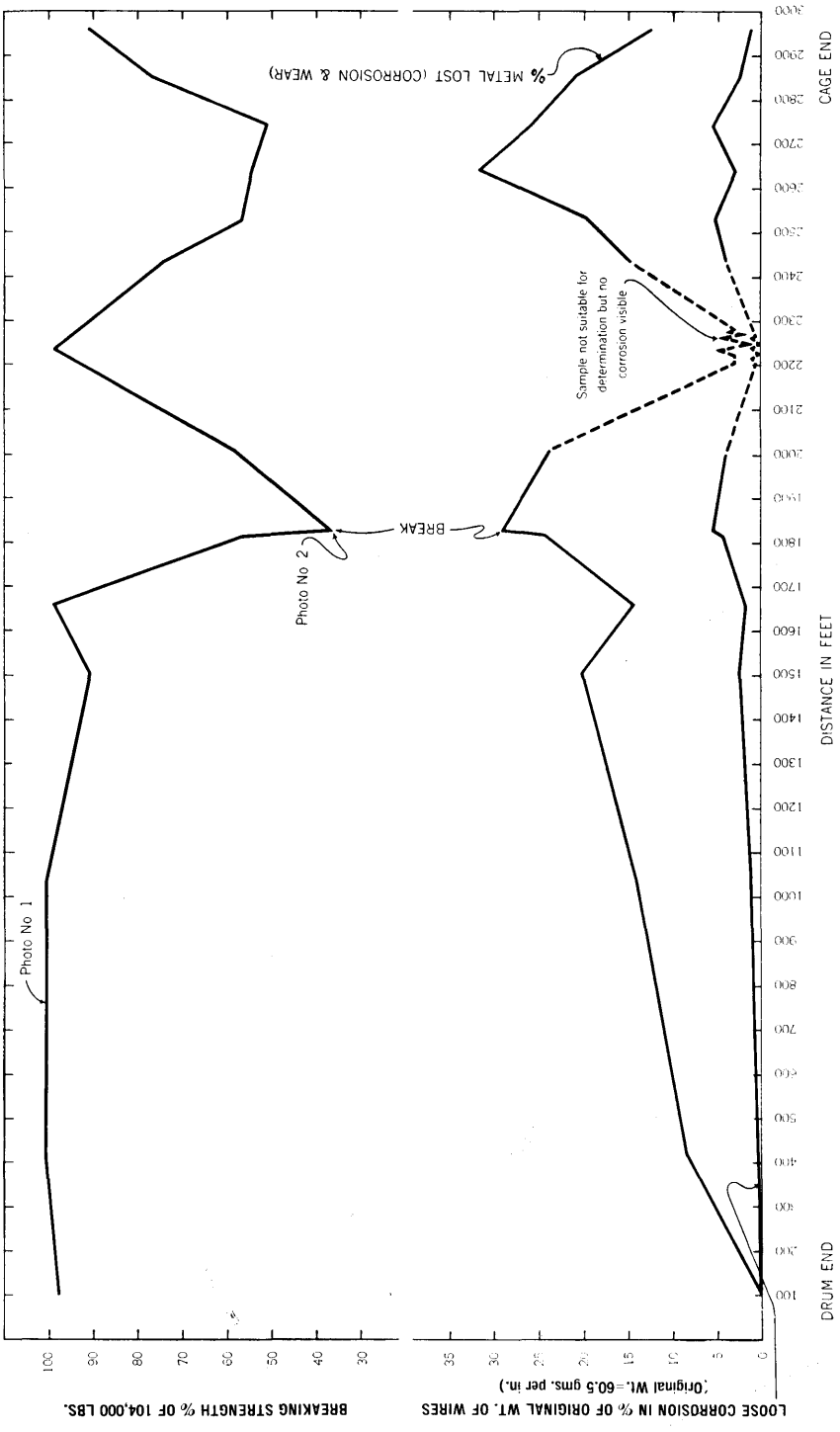


Fig. 34—Rope from Paymaster Consolidated Mines Limited. No. 5 Shaft—Cage Compartment Construction 1" 6 x 12/12/3

(1) It must have a greater capacity than water for wetting steel. (It is known that some of the principal oil companies have recently developed for the Armed Forces several corrosion preventatives, among which is one especially designed to displace water on metal surfaces by physically removing it through preferential wetting of the metal by the oil. Such a lubricant is not directly applicable to ropes because of its doubtful lubricating power, but it is suggested that similar wetting properties could be introduced into the regular rope lubricant.)

(2) It must not be decomposed by mine water.

(3) It must be sufficiently penetrating to effect a seal against water. (Considerable penetration would probably accompany the very low surface tension required for wetting properties.)

(4) It must have enough lubricating properties that when applied as an external dressing it will protect the rope against wear.

The difficulty of producing a lubricant having these combined properties might necessitate the use of more than one lubricant. In this regard it might be possible to apply the lubricant having special water repelling properties when the rope is laid up. The external rope dressing, however, which aparently must be a heavier material, should be made water repellent and substantially penetrating by proper additives. These suggestions may or may not be considered practical by the lubricant manufacturers since the concept of a lubricant for service application having penetrating properties, i.e. low viscosity, is hardly compatible with the fundamental requirement of such lubricant. The latter, being the property of adhering to the surface and between individual wires and strands in adequate quantity, implies high viscosity. The attempt in practice to apply hot, a dressing which, when cold, meets the latter requirement is evidently not as satisfactory as might be thought due to the chilling effect of the cold rope.

PROPOSED METHOD TO DETERMINE AMOUNT OF METAL LOSS IN OUTER WIRES OF HOISTING ROPES WHILE STILL IN SERVICE

History

Up to the present, no practical non-destructive method for determining the actual amount of metal loss due to corrosion and wear in a hoisting rope, in service, has been developed.

A substitute method has now been advanced to accurately determine the metal loss of the outer wires of a hoisting rope while the rope is still on the hoist.

The method, while it cannot be designated as truly non-destructive, if properly utilized, need cause no more damage to the rope than would be caused by one or two broken wires and certainly provides vital data for the discarding of ropes.

Purpose

The purpose of this report is to describe the proposed method of determining the amount of metal loss in the outer wires of a hoisting rope and thereby estimating the degree of deterioration.

Description of Method Used

The method consists of cutting one of the outer wires of a strand and removing a small section of wire 1½ in. long, from the worn portion at the crown of the rope.

The specimen is cut accurately at right angles to the axis of the wire at the point of minimum section. This small portion of wire is mounted vertically in a bakelite mould and the sectionalized surface of the wire brought to a high polish by metallographic means. A photomicrograph is made of the polished wire section using a magnification of 15 diameters. In the photomicrograph the sectional area of the wire is enlarged 225 times.

The cross-sectional area of the worn wire is found by measuring the area of the enlarged wire section in the photomicrograph with a planimeter and dividing by the known enlargement. The original sectional area of the wire can be computed from the wire diameter obtained by actual measurement of an unworn outer wire or from the manufacturer's "Rope Certificate". The metal loss is found by subtraction and expressed as a percentage of the original sectional area of the wire.

The condition of the outer wires of a hoisting rope can be used to gauge the degree of deterioration present in the rope with reasonable accuracy because these wires are subject to more factors of deterioration than any of the other wires in the rope.

The exterior surface of the outer wires is subject to extreme wear and abrasion and in many instances the wires are deformed plastically. The inner surface of the wires is subject to varying degrees of corrosion and erosion. As has been shown, except where the wires touch one another between strands, corrosion is most severe on the inner surface of the outer wires of the strands. ("Deterioration by Corrosion of Mine Hoisting Rope".) The condition of the outer wires can conveniently be expressed as percent metal loss or loss of section, and this should be related directly to loss of strength in the rope.

The method is still in the experimental stage but it is hoped that by correlating percent metal loss of the outer wires for individual test pieces of Special Test Ropes with the loss in strength of the test piece, eventually a curve may be established from which metal loss of the outer wires may be translated directly into the percent strength lost.

Experiments have proved that for a given section of rope almost any of the outer wires may be taken as representative of the wear at that section. This is due to the fact that wear usually takes place evenly around the periphery of the rope.

Cutting the Wires

The method described should not be used until at least 75% to 80% of the normal rope life for the particular hoist installation has elapsed. The cutting of a wire should be done very carefully so as not to damage the neighbouring wires in the strand. Wires should be cut at points in

the rope where maximum deterioration is to be expected. In this respect the results of Special Rope Tests may be used to determine the section where the weakest point in a rope for a particular hoist installation may be expected to occur.

Normally not more than two wires need be cut for a test and the cuttings should be at least 50 ft. apart. After the initial test it should only be necessary to make tests once a month until the rope is discarded. If the average life of a rope is considered to be 24 months the tests would entail the cutting of from 4 to 6 wires which, is spread over a hundred feet of rope, should not cause a serious loss in strength.

Wires which break naturally during service may be taken advantage of and used for the tests.

Disadvantages of the Method

The method possesses several disadvantages, chief of which are thought to be as follows:

(1) This method of determining the condition of a rope if used indiscriminately may result in serious damage to the rope and may contribute to the failure of the rope.

(2) The method entails a certain amount of photomicrographic work. The majority of mines are not equipped to do this work and would therefore have to have it done at some outside laboratory. Receipt of the results might be delayed and in the meantime the rope would have deteriorated further.

These disadvantages can no doubt be overcome, and if utilized generally the method should provide accurate effective data for the discarding of ropes.

An Example of the Method

Figure 35 included in this report shows two sectional photomicrographic enlargements of wire samples taken at 1100 ft. and 1250 ft. respectively from the skip end of a rope used on a large high speed ore hoist.

The specimen cut 1100 ft. from the skip was found to have lost 22.6% in sectional area, and the specimen cut 1250 ft. from the skip was found to have lost 22.3% in sectional area. These two figures agree closely, despite the fact that the specimens were cut 150 ft. apart on the rope, and due to plastic deformation do not even have the same shape.

In the photomicrographs the flattened crown of the wires face the upper left hand corner of the sheet, and the extreme plastic deformation can readily be seen as well as the severe metal loss due to erosion and corrosion on the interior side of the wires.

The rope in question was removed from service directly after test. During its life it had given excellent service and there were no broken wires. It is thought that, in this case, plastic deformation, although severe, was not as serious as the loss of metal due to corrosion and erosion.

The following figures determined for another rope tested throughout its length indicate that there is a close relationship between loss of metal of the outer wires and reduction in breaking strength of the rope.

Fig. 35 (a)—Cross Section of Outer Wire Cut from Rope, 1250 ft. from skip. Loss of Metal = 22.3%

Fig. 35 (b)—Cross Section of Outer Wire Cut from Rope, 1100 ft. from skip. Loss of Metal = 22.6%

Specimen	Loss in Section of Outer Wires	Loss of Breaking Strength
1200 ft. from rope spout	6.99%	8.8%
2200 ft. from rope spout	19.39%	20.9%

A tentative figure of 20% maximum allowable loss of sectional area for the outer wires has been set as a discarding factor for round strand ropes. This figure may later have to be revised. As no experiments have been made with flattened strand ropes no percentage of allowable metal loss has been established for this type of rope.

Conclusion

It is suggested that this method of obtaining the loss in section of the outer wires of a hoisting rope and thereby determining the loss of strength at any point in the rope be tested by the Mining Industry of Ontario, and if proven satisfactory, be adopted as a standard procedure. It must be emphasized again that the method should only be utilized in the latter half of the life of the rope, and great care should be exercised when cutting wires.

SAFETY CATCHES—APPLICATION AND STATISTICS

History

This report is a compilation made from various sources, chief of which is the Report of the Transvaal Commission (19). The Mining Acts of various Countries, States, and Provinces have also been quoted extensively in regard to regulations governing the use of safety catches.

The statistics given here on the operation of safety catches have been gleaned from the Report of the Transvaal Commission (19), the Records of Mr. Daniel Harrington, Chief of the Health and Safety Branch of the U.S. Bureau of Mines and from the Statistics on Hoisting Accidents in Ontario Mines.

Purpose

The purpose of this report is to examine the arguments for and against the use of safety catches on mine shaft conveyances, together with available statistics on the results of their action, and thereby reach a conclusion as to whether safety dogs or catches on conveyances in vertical mine shafts constitute a hazard or add to the general safety of the hoisting operation.

Introduction

Statistics show that travel by elevator in large buildings or by cage in vertical mine shafts, both dependent on wire rope for support, are among the safest known methods of transportation. To quote from "Wire Ropes for Mines" by M. A. Hogan, (13) P. 733:

> Vertical shaft winding must be reckoned amongst the safest forms of transport, a result which reflects credit alike on the rope makers and users.

Mr. Hogan goes on to say that the average number of hoisting ropes in use in vertical shafts in British coal mines would be 4,800. The average number of rope failures due to all causes would be 7.8 per annum. If

attention is limited to breakages due to deterioration of the rope or the capel, this figure is reduced to 6.3.

Since the average life of a rope is between two to two and-a-half years, this means that only one rope in 340 (or 0.30%) broke in service. Fortunately, the majority of breakages occurred during coal-winding operations, which was to be anticipated since the loads and winding speeds when winding minerals are, as a rule, greater than when winding men.

Wire rope users, particularly those in the mining field, have long recognized that the use of high quality rope for hoisting is of prime importance. A wire hoisting rope is subject to deterioration by wear, corrosion and fatigue, and if this deterioration is allowed to progress far enough, the rope may fail without warning. For this reason, in vertical shafts when men are being hoisted, it would seem that any device that would prevent the uncontrolled descent of the cage should the hoisting rope fail, would add greatly to the ultimate safety of the operation.

Safety catches or safety dogs come under the heading of such devices. There are many types of safety attachments in use on skips and cages in mine shafts all over the world, but as far as is known, none may be considered perfect. It has been said "That the best safety catch is a good rope". However, the best of ropes may fail through deterioration or other causes and the addition of a safety catch, even though it is known that it will only be effective 50% of the time, will be an added factor of safety.

No unanimous opinion has been reached by the Mining Industries of the various important mining countries of the world as to the desirability or otherwise of utilizing safety catches on mine shaft conveyances for the transportation of men. This is largely because no safety catch has as yet been designed, the operation of which can be absolutely relied upon.

The mining laws and regulations in force in the various countries differ widely on this subject. In some countries the use of safety catches on shaft conveyances for hoisting men is compulsory, in others, safety catches are recommended but their use is not enforced by law. In many of the countries or provinces where the use of safety catches is compulsory, the Regulation is so worded that it is possible to evade their use under certain circumstances.

This difference of opinion stands as a barrier to the universal use of safety dogs or catches on mine shaft conveyances and should not be overlooked when trying to evaluate the true worth of safety catches.

Laws and Regulations Governing the Use of Safety Catches on Mine Shaft Conveyances

The laws and regulations governing the use of safety catches on cages for some of the more important mining countries of the world are given here. In the majority of cases the Regulation is quoted directly.

GREAT BRITAIN

In Great Britain safety catches on man conveyances are not required by law but strict regulations on the care and inspection of the rope are enforced. British Mining Engineers have been more or less adverse to the use of safety catches as tending to complicate the conditions of hoist-

ing and lowering men without positively securing any compensating advantages.

GERMANY

In Germany, in the coal fields of Dortmund and the Ruhr, the use of safety catches is compulsory on cages for hoisting men.

SOUTH AFRICA

In South Africa, where some of the deepest mines in the world are operated and where technical advance is kept on a high plane, safety catches are compulsory wherever applicable. Section 34 (10) (a) of the Act reads:

Construction of Cages: Cover:

No cage, skip or other means of conveyance shall be used for the raising or lowering of persons in vertical or steeply inclined shafts except for the persons engaged in sinking operations, repairs, or examination of shaft, unless it is provided with a proper roof or cover on the end nearest the surface, and where applicable, with safety catches approved by the Government Mining Engineer.

UNITED STATES

In the U.S.A. there is considerable latitude in the mining laws and regulations for individual States. The majority of the States, however, conform to the recommendations as set forth in U.S. Bureau of Mines Information Circular 7002. "Safety Catches and Arresting Devices for Cages, Skips and Cars in Mine Shafts and Slopes" (27) (d):

In the interest of safety in mining, the Bureau of Mines recommends:

(1) That cages or skips used for hoisting or lowering men in vertical and steeply inclined shafts shall be provided with safety catches designed to prevent falling of cage or skip if the hoisting rope or other connection break; and,

(2) That cars used for hoisting or lowering men with ropes in slopes shall be provided with arresting devices, other than ordinary brakes, that come into action if the hoisting rope or other connections break.

In presenting this decision, it is recognized that the principal requirements for safety in hoisting operations are the use of hoisting ropes of ample size and strength to provide a factor of safety recognized as adequate by the best engineering practice; their proper care, protection against undue wear and corrosion, and frequent inspection; and immediate removal of ropes from service when inspection or tests cast doubt upon their further safe serviceability.

There is no device known to the Mine Safety Board that can be relied upon absolutely to arrest the cage, skip or car in all conceivable contingencies under which hoisting ropes or connections in mine shafts and slopes may fail; therefore, over-reliance upon such devices or relaxation of attention to hoisting ropes is dangerous. Where recommended devices are employed, they should be inspected daily and subjected to actual drop tests at frequent regular intervals; where guides are used, they should be inspected often to insure proper maintenance.

The above statement by the U.S. Bureau of Mines Safety Board sums up the situation in a very fitting manner, and no one can entirely disagree with their findings.

Excerpts from the laws re safety devices on skips and cages for various states are quoted below:

Pennsylvania

Bituminous Mines, Pennsylvania, 1937, Article VIII, Page 57, Sections 1, 2 and 3, Safety Catches:

The operator or superintendent shall provide every cage used for hoisting persons . . . with efficient safety catches, which shall be tested every two months.

Montana

Montana Quartz Mining Laws, Chapt. 299, Page 5, Sec. 3427:

It is unlawful for any person to sink or work through any vertical shaft, where mining cages are used, at a greater depth than 200 feet, unless the shaft is provided

with an iron bonneted safety cage to be used in lowering and hoisting employees or any other persons. The safety apparatus, whether consisting of eccentrics, springs or other devices, must be securely fastened to the cage, and of sufficient strength to hold the cage loaded at any depth to which the shaft may be sunk.

Nevada

State of Nevada, State and Federal Mining Laws 1939, Page 31, Section 10480, Safety Cages in Mines:

The wording is similar to the Montana code except that safety cage is required in vertical shafts over 350 ft. deep.

California

State of California Mine Safety Orders, Order 1733, Page 41, Conveyances for Hoisting or Lowering Men in Vertical Shafts:

(a) The cage, skip or bucket, except as provided in paragraph (b) of this order, used for hoisting men in vertical shafts over 50 ft. in depth shall be covered by an iron bonnet, shall travel in guides and shall have safety dogs that will hold the fully loaded cage, skip or bucket should the hoisting rope fail.

(b) Buckets used for hoisting or lowering men in sinking operations, when the shaft does not exceed 100 ft. in depth, need not comply with paragraph (a) of this order.

Illinois

State of Illinois, General Mining Laws, Equipment and Operations of Cages and Hoisting Engines, Section 10, Clause (c) (d) (1) (2) (3) and (4), Page 32:

(c) Every shaft in which men are hoisted and lowered must be equipped with a cage, or cages, fitted to guide rails running from the top to the bottom. Said cages must be safely constructed; they must be furnished with sheet-metal covers adequate to protect persons riding thereon from falling objects; they must be equipped with safety catches.

Utah

Industrial Commission of Utah, General Coal Mine Safety Orders, Section 43, Page 50, (a) (Section 1540 X 1, Coal Laws):

It is unlawful for any person or Corporation to sink any vertical shaft, where mining cages are used, to a greater depth than 200 feet unless the shaft is provided with an iron bonneted safety cage to be used in lowering and hoisting employees, or any other person. The safety apparatus, whether consisting of eccentrics, springs or other device, must be securely fastened to the cage, and of sufficient strength to hold the cage loaded at any depth to which the shaft may be sunk.

Arizona

State of Arizona Mining Code, Hoist Equipment and Operations, Clause 2793, Page 6:

It shall be unlawful for the operator of any mine to permit the hoisting or lowering of men in any shaft deeper than 300 feet, excepting in shafts in the process of sinking . . . and every cage or skip used for hoisting men shall be provided with a safety catch of sufficient strength to hold the cage or skip wtih its maximum load at any point in the shaft in the event that the hoisting cable should break.

CANADA

In Canada each Province has its own mining code. Excerpts from the regulations governing the use of safety catches are given here for some of the Provinces.

Alberta

The Alberta Mining Regulations do not call for safety catches on cages. However, the mining in this Province is confined to comparatively shallow coal mines.

Ontario

From the Handbook of Regulations Governing the Operation of Mines, being Part VIII and Sections 174, 175 and 176 of Part IX of the Mining Act of Ontario, Page 74, 141 (d) Safety Appliances.

The safety appliance shall be of sufficient strength to hold the cage or skip with its maximum load at any point in the shaft, as provided in clause (b) of Rule 166 of this section, but the Chief Inspector may give permission in writing for hoisting without safety appliances if he is satisfied that the equipment is such that a maximum safety is provided.

Pages 83 and 84, 166 (b) Safety Appliances to be Tested Monthly.

At least once a month, the safety appliances of the cages or other shaft conveyances, so equipped, by testing same under load conditions; such test to consist of releasing the cage suddenly in some suitable manner, so that the safety catches shall have opportunity to grip the guides, and in case the safety catches do not act satisfactorily, the cage or other shaft conveyance shall not be used further for hoisting men until the safety catches have been repaired and been proved to act satisfactorily.

Quebec

From the Handbook of Regulations for the Safety and Protection of Workmen in Mines and Quarries, Division XIV of the Quebec Mining Act, Page 13:

No. 32 Travelling in Vertical or Steep Shafts.

When in a vertical shaft or one inclined to more than 60 degrees from the horizontal, travelling is done in a bucket, a skip or a cage. This bucket, skip or cage must travel on rigid guides and be provided with guard rails, safety catches and a hood. However, this regulation does not apply to shaft sinking operations.

No. 33 Safety Cages to be Used.

In vertical shafts over 400 feet in depth, safety cages shall be provided for the raising or lowering of men. These cages shall be equipped with safety catches of a type approved by the Inspector of Mines and sufficiently strong to hold the loaded cage in case of rupture of the hoisting cable. . . . This regulation does not apply to shaft sinking.

Manitoba

From Regulations under "The Mines Act", Pages 30 and 31:

No. 142 Cage or Skip for Handling Men.

Except during sinking operations, whenever a shaft or winze exceeds two hundred feet in vertical depth, a suitable cage or skip equipped as required by Rule 144 shall be provided for lowering or raising men in the shaft or winze.

No. 144 Construction of Cages and Skips.

All cages or skips for lowering or raising men shall be constructed as follows:

(d) Safety Appliances

The safety appliances shall be of sufficient strength to hold the cage or skip with its maximum load at any point in the shaft, as provided in clause (b) of Rule 167 of this section; but the Director may give permission, in writing, for hoisting without safety appliances if he is satisfied that the equipment is such that a maximum safety is provided.

No. 167 (b) (ii) Page 35. Safety Appliances to Be Tested Monthly.

At least once a month the safety appliances of the cages or other shaft conveyances, so equipped, by testing same under load conditions, such test to consist of releasing the cage suddenly, in some suitable manner, so that the safety catches shall have opportunity to grip the guides; and in case the safety catches do not act satisfactorily, the cage or other shaft conveyance shall not be used further for hoisting men until the safety catches have been repaired and proved to act satisfactorily.

British Columbia

From the Act to Regulate the Working of Metalliferous Mines, Quarries, and Metallurgical Works, Chapter 189, Construction of Cages and Skips, Section 93 (d) Safety Catch:

The safety appliance shall be of sufficient strength to hold the cage or skip with its maximum load at any point in the shaft, as provided in clause (b) Rule 110; but

the Chief Inspector may give permission, in writing, for hoisting, without safety appliances, if he is satisfied that the equipment is such that a maximum safety is provided.

This applies to all cages or skips for lowering or raising workmen.

Monthly Examination of Cages and Appliances, Section 110 (b):

At least once a month the safety appliance of the cages or other shaft conveyances, so equipped, by testing them in some suitable manner, so that the safety catches shall have opportunity to grip the guides; and in case the safety catches do not act satisfactorily the cage or other shaft conveyance shall not be used further for hoisting workmen until the safety catches have been repaired and been proved to act satisfactorily.

Nova Scotia

The Metalliferous Mines and Quarries Regulations Act, 1937, Page 38, Chapter 3:

RULE 113—HOISTING MEN—No person shall be lowered or hoisted, or allow himself to be lowered or hoisted, in a shaft, winze or other underground opening of a mine:

(b) In a cage or skip except as provided in Clause (a) Rule (113) and Clause (e) Rule (116), which is not provided with a hood, dogs, and other safety appliances approved by the inspector:

RULE 116—All cages or skips used for lowering or raising men shall be constructed as follows: (d) The safety appliances shall be of sufficient strength to hold the cage or skip with its maximum load at any point in the shaft as provided in Rule (109) subsection (b) of the section; but the Inspector or Deputy Inspector may give permission, in writing, for hoisting, without safety appliances in an inclined shaft, if he is satisfied that the equipment is such that a maximum of safety is provided.

History of Commissions That Have Been Appointed to Investigate the Failure of Hoisting Ropes

From time to time fatal accidents have occurred in different mining localities due to the sudden failure of a hoisting rope. These accidents, often involving the death of a whole group of men in a mine cage, have invariably stimulated the interest of local or regional governing bodies who were responsible for the formulation of regulations for the prevention of accidents in mines.

In many instances Commissions were appointed to investigate these accidents and, if possible, to suggest methods for improving the types of safety catches in use or to devise some method of insuring the non-failure of the hoisting rope.

A brief history of the appointment and findings of the most famous of these Commissions is given here:

ENGLAND

From the Report of the Transvaal Commission (19) Page 5, Paragraph 25:

In England a Royal Commission under the presidency of Sir Frederick Abel, was appointed in the '80's; the report of this Commission, however, was not in favour of the employment of safety catches.

GERMANY

The Dortmund Mining District Commission was appointed in 1899 following the failure of a rope through an overwind which resulted in the death of 17 miners at the General Blumenthal Mine in Germany in 1898. Quoting some of the findings of this Commission, pages 6 and 7 of the Report of The Transvaal Commission (19):—

Regarding the compulsory use of safety catches, the Dortmund Commission (without ignoring the fact that no safety catch yet produced is infallible, on the ground

that the proportion of success to failure during the above period of 12 years is as 24 to 12, and that there is no case on record of personal injury due to the action of safety catch) is in favour of their retention until statistics prove that they cause more accidents than they prevent, subject naturally, to their being kept in perfect order and having the springs frequently and periodically renewed.

SOUTH AFRICA

One of the most famous of these Commissions was appointed in 1905 by the Right Hon. Earl of Selborne, Governor of the Transvaal, to investigate the hoisting accident at the Robinson Deep Gold Mining Co. Ltd., in which the winding rope broke allowing the cage, with 44 natives on board, to fall to the bottom of the shaft. The men were all killed.

The Commission was known as *The Transvaal Commission on the Use of Winding Ropes, Safety Catches and Appliances in Mine Shafts* and was composed originally of 23 members, all technical men. The Commission was very active for a number of years and made an intensive study of the care and use of wire ropes, safety catches and other appliances. The findings of this Commission were bound into an 87 page booklet which provides a comprehensive source of information on the above subjects even to this day.

The findings of the Transvaal Commission shall be referred to from time to time in this paper.

To quote the findings of this Commission on safety catches, page 53, paragraph 166 of (19):

> Seeing that the possibilities of a satisfactory safety catch for vertical shafts have been established, the Commission recommends that the present Regulation[1] shall remain in force, and that the applicability of any particular safety catch should be left to the Government Mining Engineer to decide.

In recent years several committees have been appointed in various countries to study safety in mines and, in particular, the failure of wire hoisting ropes and associated problems.

The Safety in Mines Research Board was appointed in England in 1924. This Committee has done much research work in connection with the failure of wire hoisting ropes.

In 1934, the German Wire Rope Research Committee was appointed.

The U.S. Bureau of Mines have a branch called "The Mine Safety Board". This committee has from time to time made suggestions re hoisting ropes and the use of safety catches and other safety appliances.

Statistics on the Failure of Hoisting Ropes and the Operation of Safety Catches

Statistical tabulation of records is by far the most accurate way to determine the true value of any appliance, safety or otherwise. Only very scanty statistics are available on the failure of hoisting ropes and the subsequent operation of safety devices on skips or cages in mine shafts. Even this scanty information, however, will demonstrate that in a vertical shaft a conveyance equipped with safety catches has a better chance of coming to rest unharmed should the rope fail, than one that is not so equipped.

[1]See South African Mining Regulations regarding safety catches, 34 (10) (a) as quoted on page 173.

The Action of Safety Catches in the Dortmund Mining District, Germany[1]

In the 12 year period from 1890 to 1902, statistics compiled in the Dortmund District on the operation of safety catches on various shaft conveyances were as follows:

	No. of Cases	Per-cent
Safety catches held	126	58
Catches did not hold	54	25
Catches acted when not required	37	17
Total	217	100

If only the 180 cases be considered in which the safety catches should have operated:

	No. of Cases	Per-cent
Safety catches held successfully	126	70
Catches did not hold	54	30

This gives a ratio of success to failure of greater than 2:1. The Dortmund Commission go on to say that in the instances where safety catches did not act several were due to the neglected condition of the catches, shafts and guides.

The above record clearly indicates that even at this early date the operators of the Dortmund Coal Mines had considerable success with the installation and operation of safety catches on mine shaft conveyances.

South African Statistics on Rope Failures and the Operation of Safety Catches

The following statistics are quoted from the Report of the Transvaal Commission (19) and cover a 2½ year period ending December 31, 1906, pages 46-47, starting at paragraph 143:

In the statistics published hereunder, it will be seen that the only instances of the successful operation of safety catches occurred at the time of an overwind on the up-trip. These may be supplemented by the three similar but later cases mentioned in paragraph 124.

ACCIDENTS IN WHICH THE ROPE OR CONNECTION BROKE

Total number of accidents 51, of which 13 were fatal.

Accidents due to faulty rope	8
Accidents due to faulty connections	10
Accidents due to other causes which broke the rope or connection[2]	33
Total	51

Of these 51 accidents, the cage or skip was fitted with safety catches in 9 cases, 2 of which were successful and 7 unsuccessful.

Cases in which an efficient safety catch would have saved life	13
Cases in which an efficient safety catch would have saved property	28
Cases in which an efficient safety catch would have been useless[3]	10
Total	51

[1]Transvaal Commission Report, Pages 6 and 7.

[2]These accidents were due to overwind, skips being derailed, engine driver losing control of engine or drum, rope jumping pit-head sheaves, truck coming loose in cage, skips jamming in shafts, etc.

[3]These cases include skips coming off the track on the incline and those in which the drum had become disconnected from the engine, the engine-driver losing control and the skip going to the bottom of the shaft before the rope broke.

The two instances in which the safety catches acted successfully were on the up-trip. Of the seven instances of unsuccessful operation quoted above, two were on the up-trip and five were on the down-trip. Three were cases in which the cage reached the bottom of the shaft before the rope broke.

In one case, the supplementary safety chains supported the load so that in this and the three preceding cases, the catches did not have a chance of coming into operation, the king-bolt spring remaining compressed. In two cases, the cams of the safety catch were not properly designed, the angle of the wedging action being too great.

If only the nine cases be considered when cages were equipped with safety dogs, then:—

	No. of Cases	Per-cent
Catches operated successfully	2	22.2
Catches did not operate	7	77.8

Of the seven instances where safety catches did not operate successfully, in four cases the catches were not released and in two cases the catches were of poor design.

The above figures are not very conclusive since the number of cases where safety catches were involved is too small to be used as final criteria of the general action of safety catches. They do indicate, however, that safety catches are more likely to be effective when the conveyance is ascending than when descending.

Do Safety Catches Tend to Cause Accidents?

From time to time, authoritative persons make the statement that safety dogs or catches are a distinct hazard. This claim has been investigated in a limited way and it has been determined that although in some cases the safety catch may have contributed to the accident, in no instance could the dogs be blamed entirely for the accident and there is no case on record where personal injury has been suffered because of safety catches attached to a mine shaft conveyance.

A recent article from South Africa gives the following opinion. To quote from a paper by W. G. Jackson (14) page 6:—

The Schrader or Undeutsch catch is attached to the conveyance. Its function is to interfere with the guides or runners in the shaft in the event of a broken rope and apply pressure on the runners or guides and bring the detached conveyance to rest.

There is considerable diversity of opinion as to the value of this type of safety device.

The mathematics of the case have been ably dealt with by A. L. Egan, and numerous experiments have been carried out. High speed cinematograph films of similar devices have been taken and analysed.

The device may be of some use in the case of a rope breaking on a down-going conveyance travelling at low speed. It is certain, however, that the device in use and those that have been tested *are more of a danger to persons riding in a mine shaft than they are a safety measure.*

Their use is to be deprecated.

Mr. Jackson apparently *considers* the *safety catches* now used in South African mines of *little value* and a *distinct safety hazard.*

The opinion that safety dogs or catches should not tend to cause accidents if they are properly designed and carefully inspected and tested from time to time is amply supported by the findings of both the Dortmund Commission and the Transvaal Commission. At pages 6 and 7 of the Report of the Transvaal Commission (19), the fact is brought out that the Dortmund Commission found that there was no case on record of personal injury due to the inadvertent action of safety catches, despite

the fact that in the 12 year observation period safety catches were known to have acted 37 times when not required.

Again, to quote from the Report of the Transvaal Commission (19) Page 47, Paragraph 147,

> Statistics conclusively show that safety catches of themselves are not necessarily an additional source of danger to persons travelling in mine shafts, while on the other hand they have saved life on many occasions.

SUMMARY AND CONCLUSIONS

Findings

The findings of this report are that safety catches on conveyances in vertical shafts are not a safety hazard but rather add to the general safety of the hoisting operation. This conclusion is upheld by the findings of the Dortmund Commission of 1898, and the Transvaal Commission appointed in 1905. Further supporting this conclusion is the fact that safety catches are required for man conveyances in vertical shafts by the Mining Regulations of many of the important mining countries of the world.

The mining regulations regarding safety catches are briefly summarized:—

Great Britain.—Safety catches not compulsory.

Germany.—Safety catches were compulsory.

South Africa.—In vertical or steeply inclined shafts, safety catches are required where applicable for man conveyances.

U.S.A.—The following important mining States require the use of safety catches on man conveyances in vertical shafts: Pennsylvania, Montana, Nevada, California, Illinois, Utah and Arizona.

Canada.—The following Provinces require the use of safety catches on man conveyances in vertical shafts: Ontario, Quebec, Manitoba, British Columbia and Nova Scotia.

In Ontario, Manitoba and British Columbia hoisting men in conveyances not equipped with safety catches is allowed if permission in writing to do so be obtained from the Chief Inspector of Mines.

Summary of Statistics

To briefly summarize the statistical data on the action of safety catches and safety dogs presented in this report and the "Analysis—Hoisting Accidents in Ontario Mines".

Country	No. of Instances Safety Catches Operated Successfully	Safety Catches Did Not Function
Germany	126	54
South Africa	2	7
Canada	18	10
Total	146 or 67%	71 or 33%

Conclusions

Thus from all sources examined, it is established that:

(1) The ratio of success to failure of the operation of safety catches is approximately as 2:1.

For Ontario Mines, the figure is 64:36.

(2) Most rope or attachment failures occur when the shaft conveyance is being hoisted.
For Ontario Mines, the figure is 72.4%.
(3) Safety catches have the best chance of functioning successfully when the conveyance is ascending.
For Ontario Mines, the figure is 71.5% successful operation of catches when conveyance is ascending.
(4) In the free-fall safety dog tests recently carried out by various Ontario mining companies the majority of safety dog failures can be attributed to faulty design of the dogs and dog mechanisms. The data for actual hoisting accidents indicate, however, that a long section of trailing rope on the falling conveyance tends to prevent proper safety dog action in cases where the safety dog is designed to be actuated on the full or partial release of rope tension.
(5) Safety dogs or safety catches on conveyances in vertical shafts, if properly maintained, do not constitute a safety hazard but add to the overall safety of the hoisting operation.

CHARACTERISTICS OF A GOOD SAFETY CATCH

History

During the past 40 years safety catches have improved little in design or mode of operation. This observation is based upon a comparison of the safety catches now in use at the majority of Ontario Mines and the safety devices tested and recommended by the Transvaal Commission appointed in 1905. (See (19) Pages 58-73 inclusive—Tests of Safety Catches.)

The Transvaal Commission (19) carried out extensive tests on several different types of safety catches. Their findings on the results of these tests were as follows (19), Page 53, paragraph 168:

> The Commission while not wholly satisfied that any of the safety catches tried entirely meet the requirements of such an appliance, considers that, of the designs submitted, the following give the best results:
> For vertical shafts with wooden guides, the Undeutsch; for vertical shafts with wooden guides, the Schweder; for vertical shafts with steel guides, the Schweder; and for inclined shafts with steel rails, none at present; the Commission advise early trials of suitable designs.

The Undeutsch safety catch consists essentially of four arms, two for each guide, actuated through camshafts by a powerful coil spring when rope tension is released. The arms are each equipped with three knives $1\frac{3}{16}$ ins. long, and a slight rotation of the cam shafts causes the knives to penetrate the guides. Stops control the depth of penetration. Once the catches have taken hold, a very powerful pull on the draw bar is necessary to release them.

The Schweder safety catch consists of two pairs of shoe type brakes operated by gas under pressure. A release in the tension of the rope opens a valve on a cylinder of carbonic acid gas at 800 lb./sq. in. and the brake shoes are forced against the sides of the guides by a pressure which exceeds 10,000 lbs.

Purpose

The purpose of this report is to enumerate the desirable characteristics and attributes of a good safety catch and thereby establish a basis for criticizing existing types and for judging the degree of perfection to be attained by newly introduced types.

Desirable Characteristics of a Safety Catch

The desirable characteristics and attributes of a safety catch are thought to be as follows:

(1) The safety catch should be actuated the instant the rope parts. Most existing types of safety catches are designed to operate only on a release of rope tension. It is recognized that the safety catches may be prevented from functioning properly due to insufficient release of rope tension caused by a long section of broken rope trailing behind the falling conveyance and it is believed that in the case of a clutch or brake failure operation of the safety mechanism is precluded by reason of the rope being still under tension.

(2) If cam type safety dogs are used, they should be so designed that a slight initial rotation will be sufficient to set them in action.

(3) The safety cams should be so arranged that once the dogs are set, no further pull on the draw bar will cause a release or counter-rotation of the dogs.

(4) If springs are used to actuate the safety catches, the tension of the spring should be such that pulsations in the hoisting rope will not tend to operate the catches inadvertently. The correct spring tension for each installation should be determined experimentally.

(5) The difference between the amount of retarding force supplied by the action of the safety catches on the guides and the weight of the loaded cage or skip is the force available for retardation of the conveyance. If the retarding force of the safety catches is only just equal to the weight of the loaded conveyance, then the downward motion of the conveyance will not be retarded in any way and it will continue to fall at the velocity attained at the instant the catches go into action. The rate of retardation is determined by the amount of surplus retarding force produced by the safety dog action. This should not be too great as in that case the occupants of the cage are liable to be injured by the abrupt nature of the stop.

(6) Safety catches should be designed to arrest the conveyance no matter what the speed (within reasonable limits) or the direction of travel. The deceleration should not be greater than 2G at rope speeds varying from zero to the maximum hoisting speed, under varying load conditions.

(7) The retarding force produced by the safety catches should, as much as possible, be independent of normal wear on the guides.

(8) The direction of application of the retarding force should be such that the guides and supporting shaft timber are maintained in position.

(9) The safety catches having arrested the conveyance should maintain it in that position until it can be hoisted away.

(10) The mechanism should be of simple construction and capable of being readily examined.

Comparison of the Main Types of Safety Catches

The main types of safety catches for conveyances operated in vertical mine shafts are:

(a) Cam type safety catches that can only be used with wooden guides.
(b) Wedge type safety catches for wooden guides; some types are adaptable for use with steel guides.
(c) Shoe type brakes which can be used on either wood or steel guides.

Of the types of safety catches commonly used to-day, the cam type is by far the most popular. There are many individual designs of this type, all of which have one or more of the following disadvantages:

(1) Erratic action due to the fact that even for the best designs they do not fully compensate for guide irregularities.
(2) A tendency for the teeth to fill with wood causing the catches to become ineffective.
(3) The tendency of the majority of the catches of this type to be too abrupt in their action.

Cam type safety catches equipped with knives or individual teeth are apparently superior to the usual serrated type but can not be made to fully compensate for excessive guide wear. Within the past year good progress in the design of safety dogs has been made but much remains to be done before a completely satisfactory design can be recommended.

Wedge type safety catches for shaft conveyances are not commonly used. According to the report of the Transvaal Commission (19), their action, when used in conjunction with wooden guides, was not satisfactory due to the sudden nature of the stop. When wedge type catches are used with steel guides, according to the elevator safety code, the hoisting speed should be limited to 100 ft./min. or less.

It is not known whether shoe type brakes are used on shaft conveyances anywhere, but safety catches of this type were thoroughly tested and highly recommended by the Transvaal Commission (19).

Safe Retarding Distance

One of the most important characteristics of a good safety catch is that not only should it function when the need arises, but that it should bring the shaft conveyance to rest in a reasonable distance.

Safety catches with a high degree of positive arresting action are comparatively easy to design, but if the deceleration is too abrupt there is danger that the occupants of the conveyance may be killed or seriously injured. Such a possibility has to be avoided by utilizing a comparatively long stopping distance.

There has been much argument and controversy as to what is the safe minimum arresting distance for a mine shaft conveyance or an elevator. Medical men who have specialized in aviation research may be able to say what maximum deceleration, in terms of "G", the human body can safely withstand, but these figures are not now easily obtained. The only readily available figures published on this subject are the tables of allowable maximum and minimum stopping distances to be found in Safety Code Manuals for Elevators. These tables give maximum and minimum stopping distances for a fully loaded car, and for a car with

only the operator (150 lb. load) in it. The allowable stopping distances listed in Canadian and U.S. Safety Code Manuals for Elevators are identical.

The figures quoted here are taken from the Canadian Engineering Standards Association Safety Code for Passenger and Freight Elevators (5), Section 91, Rule 911, Pages 103, 104 and 105:

RULE 911

CAR AND COUNTERWEIGHT SAFETY TEST

(a) An overspeed test with contract load in the car shall be made of the safeties of each new elevator before the elevator is placed in regular service except that governor controlled instantaneous type safeties shall be tested at contract speed, the governor being tripped by hand; and broken rope instantaneous type safeties shall be tested by obtaining the necessary slack rope to cause them to function. For wedge clamp, gradual wedge clamp and flexible guide clamp safeties, this test shall be made to determine whether the safety will operate within the allowable limits of the maximum and minimum stopping distances. Overspeed tests shall be made with the cables attached and with all electric apparatus operative except for the overspeed contact on the governor.

For a.c. elevators, where the contract load is unable to bring about overspeed, the safety governor shall be tripped by hand at maximum obtainable speed.

Test of the safeties with safe lifting load in the car shall not be made.

(b) The maximum and minimum stopping distances of car and counterweight safeties of the wedge clamp type shall be within the limits as given in the following Table.

TABLE XI

WEDGE CLAMP SAFETIES

Governor Tripping Speed Ft./Min.	Max. Stopping Distance for Car with Rated Load (feet)	Min. Stopping Distance for Car with 150 lb. Load (feet)	Min. Stopping Distance for Car with Rated Load (feet)
300	2.0	1.0	1.3
400	2.8	1.2	1.6
500	4.0	1.4	2.0
600	5.2	1.6	2.4
700	6.8	1.9	3.0
800	8.6	2.3	3.6
900	10.7	2.7	4.4
1000	13.0	3.0	5.2
1200	18.4	4.0	7.0
1500	28.2	5.7	10.4

(c) The maximum and minimum stopping distances of car and counterweight safeties of the gradual wedge clamp type shall be within the limits as given in the following Table.

TABLE XII

GRADUAL WEDGE CLAMP SAFETIES

Governor Tripping Speed Ft./Min.	Max. Stopping Distance for Car with Rated Load (feet)	Min. Stopping Distance for Car with 150 lb. Load (feet)	Min. Stopping Distance for Car with Rated Load (feet)
300	7.0	1.5	2.2
400	7.8	1.6	2.5
500	8.6	1.8	2.8
600	9.9	2.1	3.3
700	11.0	2.4	3.8
800	12.2	2.7	4.5
900	13.5	3.0	5.2
1000	14.6	3.5	6.1
1200	17.3	4.5	8.0
1500	21.2	6.2	11.2

(d) The maximum and minimum stopping distances of car and counterweight safeties of the flexible guide clamp type shall be within the limits as given in the following Table.

TABLE XIII

FLEXIBLE GUIDE CLAMP SAFETIES

Governor Tripping Speed Ft./Min.	Max. Stopping Distance for Car with Rated Load (feet)	Min. Stopping Distance for Car with 150 lb. Load (feet)	Min. Stopping Distance for Car with Rated Load (feet)
300	1.6	0.6	0.8
400	2.5	0.8	1.2
500	3.6	1.0	1.5
600	4.8	1.2	2.0
700	6.4	1.5	2.6
800	8.2	1.8	3.2
900	10.4	2.2	4.0
1000	12.8	2.6	4.8
1200	18.0	3.5	6.7
1500	28.2	5.2	10.0

(e) For elevators having a contract speed of 475 f.p.m. or more, the pull-out of the governor cable from its normal running position until the safety jaws begin to apply pressure to the guide rails shall be 30 in. or less.

Stopping distance is actual slide as indicated by the marks on the rails.

All elevators in both Canada and the U.S. are tested periodically to determine that the safeties function in the manner prescribed and that the maximum and minimum stopping distances are not exceeded. Elevator Safety Code figures of allowable stopping distances must have been arrived at as a result of time tested experience. The results achieved certainly seem to indicate this. For example, it has been stated that every day, at least two of the 30,000 elevators operated in New York City go on the safeties, generally without ill effects to the passengers.

In Ontario Mines most man cages travel at speeds not in excess of 1500 feet per minute. Therefore, if the table given below, showing the allowable stopping distances with the equivalent deceleration in terms of gravity at this speed, for different types of elevator safeties, be examined, it will be seen that the maximum deceleration allowed is 60 ft. per sec. or 1.87 G for flexible guide clamp safeties.

FOR GOVERNOR TRIPPING SPEEDS OF 1500 FT./MIN.

Type of Clamp	Maximum Stopping (Car & Rated Load)		Minimum Stopping (Car & 150 lbs.)		Minimum Stopping (Car & Rated Load)	
	Distance	Equiv. G	Distance	Equiv. G	Distance	Equiv. G
	feet		feet		feet	
Wedge Clamp	28.2	0.34	5.7	1.76	10.4	0.94
Gradual Wedge Clamp	21.2	0.46	6.2	1.57	11.2	0.88
Flexible Guide Clamp	28.2	0.34	5.2	1.87	10.0	0.97

This table shows that with flexible guide clamp safeties the elevator operator is expected to withstand a deceleration equivalent to 1.87 G. Saw tooth type safety catches used in conjunction with wooden guides obtain their retarding force by plowing or deforming the wood. This tends to

give a decided cushioning effect, and this action should at least be comparable with that obtained by flexible guide clamp elevator safeties. The Committee believes that 2.0 G may be considered as the maximum allowable deceleration of a mine cage transporting men.

The importance of establishing maximum and minimum stopping distance cannot be over-emphasized. These figures should make allowance for variations in guide wear and cage loads. It is obvious that if the retarding force provided by the safety catches is comparatively weak, then the conveyance under variable load conditions may not be decelerated sufficiently and crash to the bottom of the shaft.

The stopping distances that can be obtained by a given set of safety catches under variable conditions should be established by experiment. Tests should be made under actual or simulated operating conditions.

The Transvaal Commission (19) (P. 50, PP. 155) used a shock meter calibrated on the free fall system to indicate the extent of sudden arrest. In two trials a two-ton cage was arrested from an initial velocity of 20 feet per second in 13 feet and 15 feet 3 inches. The shock meter registered 4.4 inches and 3.25 inches respectively. Practically the same results were obtained in other tests with a longer drop and a greater initial velocity. The shock meter readings demonstrate the suddenness with which the full braking action of the safety catch is developed. It would be almost impossible to develop a safety catch where the braking action is uniform for the full length of the engagement on the guide.

The Transvaal Commission (19) recommended a stopping distance of from 12 to 30 feet dependent on the initial velocity of the shaft conveyance.

It is not the intention to recommend any particular type or design of safety catch mechanism, as it is believed that a great deal of intensive work and experimentation under operating conditions must be done and the results correlated before a definite recommendation can be made.

ANALYSIS—FREE-FALL SAFETY DOG TESTS ONTARIO MINES

History

The Paymaster Disaster of February 2nd, 1945, greatly stimulated interest in safety dogs and the result of their action. The majority of mine operators had, up until that time, been content to test the safety appliances by the method prescribed in the regulations, but since have carried on extensive free-fall tests in order to improve existing types of safety dogs.

Quoting from the Ontario Handbook of Regulations Governing the Operation of Mines, Page 83, Sect. 166 (b) Safety Appliances to be Tested Monthly:

> At least once a month the safety appliances of the cages or other shaft conveyances, so equipped, by testing same under load conditions; such test to consist of releasing the cage suddenly, in some suitable manner, so that the safety catches shall have opportunity to grip the guides; and in case the safety catches do not act satisfactorily, the cage or other shaft conveyance shall not be used further for hoisting men until the safety catches have been repaired and been proved to act satisfactorily.

This test, while it proves the workability of the safety dogs may not simulate normal operating conditions as the speed of the conveyance is generally low and deceleration is not taken into consideration.

The free-fall safety dog tests analysed in this report were all made under simulated operating conditions, at conveyance speeds equal to or greater than maximum rope speed of the hoist concerned. Therefore, the tests constitute a record of the actual capabilities of the various types of safety dogs involved.

Purpose

The purpose of this report is to analyse the results of the safety dog tests reported in "Tabulation of Results of Free-Fall Tests—Safety Dogs on Shaft Conveyances in Ontario Mines" and determine the type or types of dog that have been most successful.

Tabulation

The safety dog tests tabulated represent the work of 42 different mining companies who carried out the tests entirely on their own initiative. In some instances, the tests were undertaken at considerable labor and expense to the company concerned.

Between February and October, 1945, a total of 84 tests was reported to the Ontario Mining Association. The tests tabulated should not be considered as embracing all safety dog tests made in Ontario mines, as testing is still under way at some properties.

The tabulation is to be found on page 58 of the appendix under the heading, "Tabulation of Results of Free-Fall Tests—Safety Dogs on Shaft Conveyances in Ontario Mines". A second sheet, "Types of Safety Dogs Used in Ontario Mines" portrays the type of dog used in each test; each type is designated by a letter.

Procedure Used for Test

The procedure used for all tests is not known but a great many were performed in the headframe of an operating shaft, a substantial bulkhead being placed at the collar of the shaft to stop the conveyance in case the dogs did not hold.

The conveyance was hoisted to the required height and secured by a special trip hook. The rope was removed and the safety dog mechanism so arranged as to be actuated after the required distance of free-fall necessary to produce a velocity equal to the maximum hoisting speed of the conveyance. After dropping the conveyance, measurements were made to obtain the necessary data required for computing the results of the test.

Results of Tests

The success or failure of a safety dog test cannot be judged solely on the fact that the dogs arrested the conveyance as the nature of the stop must also be taken into consideration. Too abrupt a stop may seriously injure or even kill the occupants of the cage.

The question of safe stopping distance has been thoroughly discussed in a prior section of this report—"Characteristics of a Good Safety Catch"—wherein it was proposed to limit the maximum allowable decelera-

tion to 64.4 ft./sec./sec. or 2.0 G when based on the acceleration due to gravity.

Therefore in the analysis of these safety dog tests, any test in which the deceleration achieved was 2.0 G, or less, will be considered good. Tests in which the deceleration was between 2.0 G and 3.0 G will be considered fair. Any test in which the deceleration exceeded 3.0 G will be considered a failure and is classed with the tests in which the safety dogs failed to function properly, the conveyance hitting the bulkhead. It is emphasized that the allowable deceleration values given are tentative only and subject to revision in the light of further findings.

Analysis

As the tabulation only gives the results of the various tests with few additional details, it must be assumed that all safety dog mechanisms were in good condition when tested although it is likely that in some instances they were in poor condition and in need of adjustment or repair prior to the test. Under these circumstances the only possible basis for analysis is the success or failure of the tests.

No. of companies participating	42
Total No. of tests	84

RESULTS OF TESTS

	No. of cases	Per-cent
Hit bulkhead[1]	10	11.9
Deceleration 2 G or under	24	28.6
Deceleration 2 G to 3 G	15	17.9
Deceleration over 3 G	35	41.6

Only 28.6% of all the tests can be considered entirely successful resulting in a deceleration equal to or less than 2.0 G; 17.9% of the tests may be considered fair as the deceleration was between 2.0 G and 3.0 G, only slightly higher than the maximum allowed, and in these cases the dogs in question may have needed only minor adjustments to give the required results.

In 41.6% of the tests, although the dogs arrested the conveyance the rate of deceleration was too high, being in excess of 3.0 G, and in 11.9% of the tests the safety dogs did not function as intended, the conveyance crashing to the protecting bulkhead at the shaft collar. Therefore 53.5% of the tests are considered failures.

Tests of Particular Interest

Lightest Load

Lightest load stopped successfully by two pairs of dogs on two guides: —Cross Lake Mine (O'Brien) test of April 7, 1945, a *2500-lb. load* arrested from an initial velocity of 870 ft./min. at a deceleration equivalent to 1.32 G. Type T dogs used for the test. Guides were new 3¾ x 3¾ inches.

[1]In the case of McLeod Cockshut No. 2 Shaft test of April 22, 1945, the cage was not stopped by the dog action but became jammed in the shaft when the dogs turned up. Therefore although a deceleration of 1.4 G was recorded the test must be considered a failure as the conveyance would probably have hit the bulkhead had it not become jammed in the shaft.

Heaviest Load

Heaviest load stopped successfully by two pairs of dogs on two guides: —Dome Mines tests of May 22 and May 25, 1945, dogs arrested *19200 lbs.* from initial velocities of 1397 and 1437 ft./min. at decelerations equivalent to 0.72 G and 0.535 G respectively. Type H dogs used for the tests; both stops made on worn guides 6¾ ins. x 5¼ ins. (New guides 7½ ins. x 5½ ins.)

Maximum Velocity

Maximum velocity from which a successful stop made: Hollinger Mine test of March 22, 1945, dogs arrested 9793 lbs. From an initial velocity of *1614 ft./min.* at a deceleration equivalent to 2.0 G. Type O dogs used on guides 4 ins. x 8 ins. (new).

Best Stop Made by Four Pairs of Dogs on Four Guides

Best stop made by four pairs of dogs on four guides—Falconbridge Nickel Mines test of June 24, 1945, a 16300-lb. load arrested from an initial velocity of 1366 ft./min. with a deceleration equivalent to 1.51 G. Type C dogs used on four full size guides (5⅜ ins. x 7⅜ ins.).

Lowest Rate of Deceleration Achieved

Lowest rate of deceleration achieved—Dome Mines test of May 25, 1945, a 19200-lb. load arrested from an initial velocity of 1437 ft./min. with a deceleration of *17.2 ft./sec. 2 or 0.535 G.* Type H dogs used on two worn guides 7 ins. x 5½ ins. (New guides 7½ ins. x 5½ ins.)

Construction of Safety Dog Mechanism

	No. of Cases	Per-cent
Equipped with stops	48	57.2
Not equipped with stops	32	38.0
Not stated	4	4.8

In the 48 cases where dogs were equipped with stops—

	No.	Percent
Successful tests	16	33.3
Fair tests	8	16.7
Failures	24	50.0

In the 32 cases where dogs not equipped with stops—

	No.	Percent
Successful tests	7	21.9
Fair tests	7	21.9
Failures	18	56.2

The trend is indicated that dogs equipped with stops tend to be more successful in operation than dogs not so equipped.

Dogs Compensate for Wear on Guides

	No. of Cases	Per-cent
Dogs do compensate	25	29.8
Dogs do not compensate	56	66.6
Not stated	3	3.6

In the 25 cases where dogs compensate for wear on guides—

	No.	Percent
Successful tests	10	40
Fair tests	7	28
Failures	8	32

In the 56 cases where dogs do not compensate for wear on guides—

	No.	Percent
Successful tests	14	25
Fair tests	8	14.3
Failures	34	61.7

This comparison shows that safety dogs which tend to compensate for guide wear are greatly superior in their action to those which do not tend to compensate and indicates the importance of designing safety dogs to compensate for guide wear.

Spring Tension

The report of the Transvaal Commission (19) states in reference to safety catch spring tension, Page 49, Paragraph 154 (4):

> The tension in the spring should be as small as possible certainly not more than half the weight of the empty cage—so that the catches shall not be brought into action, when not required, by the pulsations of the winding rope.

The tabulation for initial spring tension is incomplete, but from the figures available the ratios of initial spring tension to weight of empty conveyance fall into the following groups:

Spring Tension Ratio	No. of Installations
0.3—0.4	6 or 27.3%
0.4—0.5	1 or 4.5%
0.5—0.6	3 or 13.7%
0.6—0.7	6 or 27.3%
0.7—0.8	4 or 18.2%
0.8—0.9	1 or 4.5%
0.9—1.0	1 or 4.5%

This shows that the tendency in Ontario Mines is to utilize higher spring tensions than recommended in the Report of the Transvaal Commission (19). It is felt that the 0.5 ratio recommended by the Transvaal Commission is close to the optimum value but further experiments should be performed to confirm this.

Remarks

This column contains a record of any unusual incident which occurred during the tests and in some cases shows why some of the tests resulted in failure.

In eight cases the dog shafts were bent during the tests.

In five cases the dogs filled with wood chips and were forced out.

In one case the dogs were not equipped with stops and rotated up and out of the guides.

In five cases stops to limit rotation of the dogs were added after the tests.

In four cases the guides were bowed out by the dog action.

RESULTS OF TESTS—VARIOUS DOG TYPES

Type of Dog	No. of Tests	Hit Bulkhead	Deceleration 0–2 G	Deceleration 2 G–3 G	Deceleration over 3 G
O	15	0	5	3	7
B	8	1	1	3	3
E	8	3	1	1	3
M	8	0	4	3	1
H[1]	7	0	5	2	0
N	5	1	2	0	2
U	5	2	0	0	3
S	4	1	0	2	1
Q	3	0	0	0	3
G	2	1	0	0	1
K	2	0	1	0	1
P	2	0	0	0	2
R	2	1	0	0	1
A	1	0	1	0	0
C	1	0	1	0	0
D	1	0	1	0	0
F	1	0	0	0	1
J	1	0	0	0	1
L	1	0	0	0	1
T	1	0	1	0	0
V	1	0	0	1	0
W	1	0	0	0	1
X	1	0	1	0	0
Unknown	3	0	0	0	3
Total	84	10	24	15	35

[1]In two cases the dogs were Type G fitted with Type H teeth. These two cases were considered as Type H tests.

IN THE 10 CASES WHERE CONVEYANCE HIT BULKHEAD

Type of dogs involved	B	E	N	U	S	G	R
No. of instances	1	3	1	2	1	1	1

IN THE 24 CASES WHERE DECELERATION WAS 2 G OR LESS

Type of dogs involved	O	B	E	M	H	N	K	A	C	D	T	X
No. of instances	5	1	1	4	5	2	1	1	1	1	1	1

IN 15 CASES WHERE DECELERATION WAS 2 G–3 G

Type of dogs involved	O	B	E	M	H	S	V
No. of instances	3	3	1	3	2	2	1

IN 35 CASES WHERE DECELERATION WAS GREATER THAN 3 G

Type of dogs involved	O	B	E	M	N	U	S	Q	G	K
No. of instances	7	3	3	1	2	3	1	3	1	1

P	R	F	J	L	W	Type Not Known
2	1	1	1	1	1	3

SUCCESS VARIOUS DOG TYPES BASED ON DECELERATION

Type of Dog	No. Tests	Success under 2 G	Success 2 G–3 G	Failure
O	15	33.4%	2.0%	46.6%
B	8	12.5%	37.5%	50.0%
E	8	12.5%	12.5%	75.0%
M	8	50.0%	37.5%	12.5%
H	7	71.4%	28.6%	.....
N	5	40.0%	.....	60.0%
U	5	.....	.....	100.0%
S	4	.....	50.0%	50.0%
Q	3	.....	.....	100.0%
G	2	.....	.....	100.0%
K	2	50.0%	.....	50.0%
P	2	.....	.....	100.0%
R	2	.....	.....	100.0%
A	1	100.0%	.....	.....

SUCCESS VARIOUS DOG TYPES BASED ON DECELERATION—*Continued*

Type of Dog	No. Tests	Success under 2 G	Success 2 G–3 G	Failure
C	1	100.0%	.....	.....
D	1	100.0%	.....	.....
F	1	.....	.....	100.0%
J	1	.....	.....	100.0%
L	1	.....	.....	100.0%
T	1	100.0%	.....	.....
V	1	.....	100.0%	.....
W	1	...	.....	100.0%
X	1	100.0%	.....	.....

From the above table the most successful dog types which have undergone at least five tests are selected. Listed in order of success, they are:—

DOG TYPE	NO. OF TESTS	SUCCESS DECELERATION UNDER 3 G
H	7	100.0%
M	8	87.5%
O	15	53.4%
B	8	50.0%
N	5	40.0%
E	8	25.0%
U	5	0.0%

All the remaining dog types were tested less than five times and until tested further will not be taken into account.

Summary and Conclusions

In 88.1% of the tests the conveyance was arrested by the action of the safety dogs and 46.5% of the tests can be considered satisfactory; 28.6% entirely so, as deceleration was less than 2 G; and the additional 17.9% fairly so as deceleration was between 2 G and 3 G, a deceleration greater than is desirable but not likely to cause serious injury to the occupants of the conveyance. The 39 successful tests were divided among 14 types of safety dogs but as some of the types were tested only once or twice the results in these cases are not considered conclusive. Considering only the types which were tested five times or more, types H, M, O and B were the most successful, operating satisfactorily in 50% or more of their tests.

The results show that in many instances where a series of free-fall tests was performed the later tests showed great improvement over the earlier tests of the series. This improvement in performance was obtained by alterations such as the addition of stops, changing the width and/or design of the safety dog teeth, changing the depth of penetration, making the dogs compensate for guide wear, changing spring tension and other changes.

The great interest shown recently by the majority of mine operators in Ontario in the testing of safety dogs is highly gratifying and in many instances has led to the discovery of some fault or defect in the mechanism of the safety dogs at certain installations. The various companies are to be commended on their efforts and should be encouraged to keep on with the tests.

The aim of future tests should be to produce a simple design of safety dog, reliable under all conditions and readily adaptable to conveyances of varying weights and capacities.

RESEARCH TO DETERMINE METHODS FOR THE DETECTION AND PREVENTION OF CORROSION AND OTHER TYPES OF ROPE DETERIORATION

History

The Paymaster Disaster of Feb. 2nd, 1945, has stimulated intense research into the application of safety catches and the care and upkeep of hoisting ropes. Among other Mining Companies in Ontario, the International Nickel Company of Canada Ltd. initiated research into the causes and prevention of deterioration in hoisting ropes. This work was carried out in the Research Laboratory at Copper Cliff and preliminary findings indicated that corrosion was the main factor in hoisting rope deterioration. As a result of this finding, the Ontario Mining Association Special Committee on ropes requested that the problem be referred to Mr. F. L. LaQue, Corrosion Expert for the International Nickel Company Inc., New York, N.Y., Development and Research Division.

Mr. LaQue was eminently suited to the task, not only in view of his previous experience, but also because of the numerous connections he had established with laboratory staffs and research workers of other companies during the war years, while acting as a consultant on corrosion problems to the U.S. Navy. These connections placed him in a position where he could greatly facilitate the research programme outlined in connection with the detection and prevention of deterioration in hoisting ropes.

In order to familiarize himself with local operating conditions and other factors of the problem Mr. LaQue visited Copper Cliff in June, 1945, and inspected several of the company's hoist installations. He returned to New York and from there initiated the investigations to be described.

Purpose

The purpose of this report is to enumerate the various investigations started by Mr. LaQue and where possible to detail the results obtained.

Research Undertaken

The research programme initiated by Mr. LaQue can be said to have been diverted into two main channels:—

(1) Research work at the Bayonne, New Jersey Laboratories of the International Nickel Company Inc., New York, N.Y.
(2) Research and Investigations by numerous other Companies.

The different problems investigated were as follows:

(a) Determination of the causes of rope deterioration with special reference to corrosion, wear, fatigue and the development of martensite.
(b) Checking the constituents of the steel wire in hoisting ropes to ensure that the manufacturers were maintaining required standards.
(c) Checking on the possible use of corrosion resistant steels for making wire for hoisting ropes.
(d) Investigating the possible use of metallic and other coatings to protect individual wires of hoisting ropes.

(e) Detection of the presence of corrosion by non-destructive test methods.
(f) Testing of lubricants and greases and the development of corrosion inhibiting types.
(g) Determining the causes of rope core deterioration.

Shortly after his return to New York in June, 1945, Mr. LaQue prepared a memorandum on his preliminary findings. A summary of these findings is given here.

Quoting from Mr. LaQue's report of June 30th, 1945:

Summary of Report by Mr. F. L. LaQue, June 30, 1945

1. "Corrosion appears to be the principal factor in deterioration of wire rope in our mines as well as many others in Ontario.
2. "The most promising way to help the situation appears to be the use of more appropriate protective oils or greases and better methods of application. Work in this direction has been started already.
3. "The possible use of baked phenolic coatings applied to wires before manufacture into rope is to be investigated.
4. "The possible use of water repellent silicone compounds is to be investigated.
5. "It does not seem to be practical to use a corrosion resisting steel for these ropes.
6. "It does not seem to be likely that the use of zinc coated wires would solve this problem on account of the rapid corrosion of zinc by our mine waters.
7. "Other metallic coatings would be corroded too fast or would promote accelerated local attack at breaks or pores in the coatings.
8. "Corrosion fatigue seems to be less important than straight corrosion in causing wire deterioration as determined by our Laboratory findings.
9. "It is not believed that metallurgical characteristics of the rope wire have been important in determining the nature or extent of the deterioration that has occurred except in a few special instances.
10. "There is, at present, no satisfactory non-destructive method of examining wire rope in use to determine either the extent or progress of internal deterioration by corrosion or other effects."

The various phases of the investigations are described here, together with the names of the companies that collaborated in the experiments. Whenever possible the results of the tests will be given.

RESEARCH AT BAYONNE LABORATORIES, N.J.

Four specimens of mine hoisting rope with various degrees of deterioration, including one sample of the Paymaster Rope were subjected to an intensive laboratory examination in the Bayonne, New Jersey, Laboratories of the International Nickel Company Inc., New York, N.Y. The results of this examination were as follows:

(1) Deterioration in all ropes was the result of corrosion and, probably, fretting at the lines of contact between wires in a single strand and between strands.
(2) Adequate lubrication by means of an extreme pressure lubricant perhaps containing a polar compound for protection against corrosion is recommended.

(3) No evidence of fatigue was found, but in one case, surface embrittlement due to the formation of martensite on the worn crown of individual wires was noted.

NON-DESTRUCTIVE METHODS FOR THE DETECTION OF INTERNAL CORROSION

Two different companies undertook to investigate various non-destructive methods for determining the presence of internal corrosion in hoisting ropes. In each case two specimens of large diameter hoisting rope were furnished for the tests, a specimen of new rope, and a specimen with severe internal corrosion.

X-Ray Photographs and Magnetic Comparator Methods

The Bethlehem Steel Company, Shipbuilding Division, Quincy 69, Massachusetts, undertook to investigate the possibilities of the detection of internal corrosion by X-ray photography and also by electro-magnetic comparator methods. This work was carried out under the direction of Mr. Paul Ffield, Superintendent of Development and Research.

In December, 1945, Mr. Ffield reported that radiographs of the corroded sample had been made using a one million volt X-ray apparatus and stereoscopic technique but that the corrosion in the cable could not be detected. This was possibly due to the technique used being not sufficiently sensitive.

Up until now (January, 1946) no report on the electro-magnetic test has been received.

Use of the "Penetron" Device

The Texaco Development Corporation, New York, N.Y., has developed an apparatus for measuring non-destructively the wall thickness of closed vessels and pipes by the use of X-rays and gamma rays. This instrument is called the "Penetron Device" and it is now manufactured and distributed by the Engineering Laboratories, Inc., 610-624 East Fourth Street, Tulsa 3, Oklahoma. This latter company has promised to investigate the possible use of the Penetron for detecting and measuring internal corrosion in wire ropes, but as yet, no report has been received from them.

COATINGS FOR STEEL WIRE

The Bakelite Corporation, 30 East 42nd Street, New York 17, N.Y., were contacted with the intention of determining the possibilities of using baked phenolics for protecting the individual wires of hoisting ropes.

In connection with the above, Mr. A. J. Weith, Assistant Manager of Research and Development and Mr. H. F. Robertson of the Bakelite Corporation had a meeting with Mr. F. L. LaQue in New York on Sept. 7th, 1945. The results of this meeting were set out in a report and were as follows:

It was decided that the baked phenolics and polyethylene were not suitable for coating hoisting rope wire, because of low adhesion, difficulty of application and readiness with which they would be eroded without any self healing properties.

It was suggested that some of the high boiling point amines might be introduced into the rope core when the rope was laid up. These amines would tend to neutralize the acid in any water entering the rope and might react with the grease and rope dressing and saponify them. How-

ever, due to their volatile nature, the amines might escape if not sealed in the rope.

It was also suggested that the "UCONS", synthetic organic compounds with lubricating properties, might be used as hoisting rope lubricants, although the ability of the "UCONS" to inhibit corrosion is uncertain and their penetrating properties are unknown.

The principal characteristic of these compounds is that they maintain a relatively constant viscosity over a wide range of temperatures; some are water miscible, and others water insoluble and might be used in the same way as polar compounds. The "UCONS" are produced by the Carbide and Carbon Chemicals Corporation, 30 East 42nd Street, New York 17, N.Y., an associate company of the Bakelite Corporation.

SILICONE OILS AND GREASES

The General Electric Company, 1 River Road, Schenectady 5, N.Y., were contacted in order to determine their views on the possible use of Silicone oils and greases as lubricants and corrosion inhibitors for hoisting ropes.

Mr. W. T. Eveleth of Silicone Sales, General Electric Co., represented the company in the above matter but unfortunately was unable to answer the majority of questions put to him as apparently no research has been done by his company in connection with the use of Silicone oils and greases for lubricating wire ropes. However he did state that:

> These oils are naturally hydrophobic and having a lower surface tension, we believe would tend to coat the surface of steel more readily than petroleum oils. Silicone oils can be furnished with corrosion inhibitors.

Experiments would have to be tried to determine if Silicone oils were suitable for lubricating hoisting ropes. Some of the disadvantages are that they are high priced and at present difficult to obtain.

LUBRICANT IMPROVEMENTS

The Standard Oil Company of Pennsylvania and the Imperial Oil Limited of Canada are making a joint research in order to improve lubricants and methods of application for hoisting ropes. This work is being directed by Mr. Maurice Reswick and Dr. Sproule for the Standard Oil Co. and Imperial Oil, Ltd., respectively.

In order to facilitate the research, members of the staff of both companies visited Copper Cliff in July, 1945, and were given the opportunity to observe the operation of several of the International Nickel Company's hoist installations.

To date no final results of this research have been received but it is understood that progress is being made.

THE SHELL OIL COMPANY

The Shell Oil Company was contacted in connection with new developments in corrosion inhibiting oils. Under date of September 24th, 1945, they replied as follows:

> At this time we have no product to prevent internal corrosion of wire ropes. However, we are working on the problem of preventing internal corrosion of wire ropes and as soon as we have any information that might be of value, we will get in touch with you.

GREEN CABLE LUBRICANT

Mr. V. C. J. Peterson, Development Engineer, of the Hazard Wire Rope Division, American Chain and Cable Company, Inc., Wilkes Barre, Pa., was contacted concerning the Green Cable Lubricant manufactured and used by the above company. He replied that:

> Our new Green Cable Lubricant is a wire rope compound that is intended only for application to wire ropes as they are manufactured. . . . One of the outstanding properties of this new lubricant is its ability to adhere more firmly to the steel wires of a wire rope. We do not recommend this product for application to wire ropes after they are placed in service.

SLIPIT FORMULA 100

"Slipit Formula 100" is a highly penetrating oil or lubricant manufactured by Lloyds Laboratories Reg'd., 21 Aylmer Ave., Toronto 31, Ont. Mr. E. P. Cumming of the Lloyds Laboratories Reg'd. had requested the co-operation of several wire rope manufacturers and users in testing the capabilities of Slipit Formula 100 as a hoisting rope lubricant.

In connection with these experiments, the Canadian Westinghouse Company Ltd. of Hamilton, Canada, carried out some tests with specimens of dry wire rope to test the penetrating qualities of Slipit as applied to rope. The specimens were heated by Infra Red radiation then immersed in Slipit. The results of these tests have as yet not been made known.

Before making any field tests it was thought advisable to investigate the corrosion inhibiting qualities of Slipit. As a result of this investigation it was decided not to proceed with the proposed field test.

EXAMINATION OF FIBRE CORES FROM STEEL CABLES

It was suggested that deterioration of the fibre cores in wire hoisting rope might be due to the action of fungi and bacteria which in turn might contribute to the deterioration by corrosion of the steel wires. In order to check this theory 6 samples of rope core in various stages of deterioration were supplied to Dr. W. F. Clapp of The William F. Clapp Laboratories, Duxbury, Massachusetts, a consultant on cordage problems.

Dr. Clapp was assisted in the examination of the cores by Mr. Reed of the Plymouth Cordage Company, Mr. M. Reswick of the Standard Oil Development Company, Dr. Prindle, formerly Professor of Biology at Iowa State College, and Dr. Jennison who is Professor of Bacteriology at The Massachusetts Institute of Technology.

Dr. Clapp determined from this study that it was evident that the action of fungi or bacteria had not been an important factor in the deterioration of wire rope cores, the cores being chiefly damaged by mechanical action.

Summary of Investigations by Mr. F. L. LaQue

From time to time Mr. LaQue has detailed the progress made in the various phases of the investigation by summary reports. These summaries give details of progress made not only in the U.S.A., but also by the Research Department of the International Nickel Company of Canada Ltd. at Copper Cliff, Ontario. The summary reports are quoted here verbatim:

SUMMARY OF INVESTIGATION INTO DETERIORATION OF WIRE ROPES IN MINES, SEPTEMBER 6, 1945

I. Re Factors in Deterioration

1. Internal corrosion was the principal factor in deterioration of wire ropes examined so far.
2. Fatigue and corrosion fatigue have not been major factors.
3. Fretting may have been a contributing cause of deterioration.
4. The cleanliness of the wire with respect to non-metallic inclusions was not an important feature.

II. Re Rope Materials

1. It does not appear to be practical—for mechanical reasons—to solve the problem by changing the composition of the wires—as by using stainless steel or other corrosion resisting alloy.

III. Re Coatings for Wires

1. It would not be desirable to coat the wires with a metal more noble than steel.

2. The coating metals less noble than steel, zinc, cadmium and aluminum would be attacked by the waters in the INCo mines at too high a rate to enable them to survive very long. Consequently, other possible solutions of the problem should be explored before going to the use of wires coated with zinc, cadmium or aluminum. Zinc coatings are worthy of earlier consideration in mines where the water is not acid and does not carry appreciable amounts of copper or iron in solution.

3. Discussions with manufacturers and research organizations concerned with organic coatings that might be applied to individual wires before stranding (Union Carbide & Carbon Corporation and Mellon Institute) have led to the conclusion that none of these is worth considering for the job. The opinion was expressed that hard organic coatings, such as baked phenolics, would not withstand the abrasive action between wires and strands. Some previous experiments with such coatings showed that not only were they expensive to apply but did not perform well in service, so that further consideration of them was abandoned. The following statement from the Bakelite Corporation summarizes the situation as follows:

> At the present time we are inclined to doubt whether it is worthwhile pursuing investigations leading to the applying of any type of coating material to wires which are later to be assembled into large cables.

4. The Bakelite Corporation suggested impregnation of cables with waxy type materials, such as polyethylene, vinyl compounds or high melting waxes. Of these, they rated polyethylene as most promising on the basis of its overall physical properties and low temperature coefficient. A meeting with the Bakelite people to discuss the practical aspects of the use of polyethylene is scheduled for September 7th.

5. The Stonor-Mudge Fellowship at Mellon Institute expressed the opinion that a silicone formulation would be too brittle for this service. This opinion is being checked with the Resins and Insulating Materials Division of the General Electric Company who have not yet given us their answer.

The possibility of incorporating silicone in greases remains open and no doubt will be considered by the oil companies who are working on the problem.

IV. Re Rope Dressings

1. It is believed that the best chance of reducing internal corrosion of wire ropes is through improvements in the oils or greases used for rope dressing and in their method of application.

2. Observations of the methods of dressing ropes during manufacture have shown that these are satisfactory for the kinds of dressing being used —without regard to the effectiveness of the dressings for preventing corrosion in service.

3. The manufacturers of wire ropes are willing to co-operate in applying any improved practices that may be proposed for dressing ropes during manufacture.

4. The research organization of the Standard Oil Company of New Jersey and the Imperial Oil Company of Canada are undertaking an investigation to determine the best kind or kinds of dressing to be used and the most effective way to apply the compounds. This will include dressing of the ropes during manufacture, as well as during use, so as to insure that the one will be compatible with the other. As a background to this investigation, representatives of the oil companies have visited the plant of a rope manufacturer, (Anglo-Canadian Wire Rope Co.), and our mines so that any procedures that may be suggested will be based on firsthand knowledge of the conditions under which they will have to be applied. Detailed recommendations will be received from the oil companies after they have completed their preliminary studies.

5. While main reliance is being placed on the development work being undertaken by the oil companies mentioned, suggestions from other sources are being given appropriate attention as a basis for possible future action. The proposal to experiment with Slipit Formula 100 comes within this category.

V. Miscellaneous

1. The association of internal corrosion with deterioration of the fibre cores of ropes has indicated the possibility that this core deterioration may be a contributing factor in wire failures. Since this deterioration of cores may be due to the action of fungi or bacteria, it is proposed to check up on this with the idea of including some compound to prevent such action of organisms in the treatment of the rope cores. Samples of deteriorated cores are to be examined by the William F. Clapp Laboratories who, in co-operation with the Plymouth Cordage Company, will outline an appropriate treatment for core ropes for this service.

VI. Non-Destructive Inspection of Ropes in Service

1. An extensive investigation at Copper Cliff has established that the magnetic comparator method is not sufficiently sensitive to make it reliable for measuring the progress of deterioration of wire ropes in service. Further tests along this line are being made by the Research Laboratory of the Shipbuilding Division of the Bethlehem Steel Company at Quincy, Massachusetts, who are currently using the magnetic comparator for a somewhat similar purpose.

2. The Bethlehem Steel Company are also investigating the possibility of using X-ray equipment to disclose internal deterioration of samples of wire rope that have been sent them for the purpose.

3. Through the Engineering Laboratories, Inc., Tulsa, Oklahoma, an investigation is being made as to the possibility of using the Penetron developed by the Texaco Development Corporation and which uses gamma rays from a radio-active source as a means of disclosing the extent of internal corrosion of wire ropes. Specimens have been sent them for examination by their device.

4. Explorations of the possibility of using resistance measurements to disclose the extent of wire deterioration have been discouraging.

SUPPLEMENTARY SUMMARY OF DEVELOPMENTS IN INVESTIGATION OF DETERIORATION OF WIRE ROPES IN MINES—DECEMBER 6, 1945

1. X-Ray Examination of Corroded Cables

No report has been received from Bethlehem Steel Company, Shipbuilding Division, Quincy, Massachusetts, concerning their efforts to detect and measure the extent of internal deterioration of wire cables by a non-destructive technique making use of X-rays.

2. Gamma-Ray Examination of Corroded Cables

No report has been received from the Engineering Laboratories Inc., 610-624 East Fourth Street, Tulsa, Oklahoma, concerning the possibility of using their "Penetron" device—gamma-ray technique—for the non-destructive inspection of wire ropes to determine the extent of internal deterioration.

3. Slipit Formula 100

A study of a sample of "Slipit Formula 100" indicated that this material did not have characteristics that would warrant immediate practical trials of it as a preservative for wire ropes in mines.

4. Rust Preventive Compounds—Shell Oil Company

In response to a specific inquiry, the Shell Oil Company in a letter dated September 24, 1945, signed by K. J. Schmaelzle, Division Department Manager, Industrial & Technical, reported as follows:

> At this time we have no product to prevent internal corrosion of wire ropes. However, we are working on the problem and as soon as we have any information that might be of value, we will get in touch with you.

5. Silicone Compounds

In response to a further effort to check up on the possible use of silicone to protect wire ropes from corrosion, Mr. W. T. Eveleth of the Silicone Sales Department of the General Electric Company, Schenectady, New York, reported as follows:

> I have no idea whether or not a silicone oil or grease would give the protection required for the service conditions which you may encounter in cable for use in mines. At the present time we are not in a position to supply samples of silicone greases, but a silicone oil could be tried under service conditions if suitable arrangements could be made to apply the coating. For experimental use, it would be desirable to have a rust inhibitor added to the oil.

The quoted price was $7.00 per pound for the LT grades, and $8.00 per pound for the NV grades in small lots—up to 5 gallons.

After receiving this reply, the following additional questions were submitted to the General Electric Company:

A. Could advantage be taken of the reported property of silicone treated surfaces in resisting subsequent wetting by water?
B. Could the wires be treated with silicone before being incorporated in the rope so that subsequently they would be wetted with difficulty by corrosive water that might seep into the rope?
C. Would the use of the common oils or greases on silicone treated wires destroy any advantage of the silicone treatment?
D. Can you furnish silicone oils and greases containing corrosion inhibitors?
E. If you can't supply an inhibited silicone oil or grease, can you tell us what corrosion inhibitors have been added to silicone oils and greases successfully?

Answers to some of these questions were included in the following statement from the General Electric Company under date of October 16th, 1945.

Unfortunately, we do not have the answer to most of these questions. I think it would be a case of making trials under various conditions to determine results. These oils are naturally hydrophobic in nature, and having lower surface tension, we believe would tend to coat the surface of steel more readily than petroleum oil. Silicone oils can be furnished with corrosion inhibitors under the designation R.I.

No steps have been taken to arrange for trials of silicone oils, since it is felt that these may be postponed until the possibilities of the more usual rust preventives have been explored further.

6. Green Cable Lubricant

An inquiry was directed to the Hazard Wire Rope Division of the American Chain & Cable Company concerning their "Green Cable Lubricant" featured in their advertising. The following quotations are from a letter from V. C. J. Peterson, Development Engineer, dated October 18th, 1945.

Green Cable Lubricant is a wire rope compound intended only for application to wire ropes as they are manufactured. One of the outstanding properties of this new lubricant is its ability to adhere more firmly to the wires. We do not recommend this product for application to wire ropes after they are placed in service. One of the most successful methods of maintaining mine hoisting ropes is to alternately treat the rope with oils having a high penetrating characteristic and heavy bodied lubricants that will adhere to the surface of the ropes.

7. Improved Cable Lubricant—Imperial Oil Company

Under date of November 30th, 1945, it was reported that Dr. L. W. Sproule of the Imperial Oil Limited, Sarnia, has made continued progress in the development and laboratory testing of improved mine shaft cable lubricants. It is expected that this work will be concluded by the end of December and that a meeting to discuss his findings and to lay out a plan of further action as regards field trials will be arranged around the middle of January, 1946, in New York City.

8. Polyethylene

At one time, polyethylene was considered for protection of wire ropes, but after further discussion with representatives of the Union Carbide & Carbon Company it was decided that this proposal should be abandoned because of the inadequacy of the material from the standpoints of applicability, adhesion, resistance to abrasion and self-healing properties.

9. Amines

It was suggested that high boiling point amines might be used to advantage, by being applied to the fibre cores and serving as neutralizers

of acid in the waters. It would be necessary to prevent escape of the amines by sealing them in with some sort of oil or grease applied to the outsides of the ropes. No action has been taken on this suggestion.

10. Ucons

It was suggested that the synthetic lubricants known as Ucons might be useful as rope lubricants and dressings. Their principal characteristic is their constant viscosity throughout a wide range of temperature, and especially at very low temperatures. However, the ability of the Ucons to inhibit corrosion is uncertain and their penetrating properties are not well known.

It seems unlikely that these compounds will be tried until the possibilities of the more conventional lubricants have been explored further.

11. Deterioration of Cable Cores by Micro-Organisms

Although there have been differences of opinion as to the frequency, extent and practical significance of the deterioration of cable cores as a factor in the internal corrosion of wire ropes, it was decided to have some typical core samples examined for evidence of the destructive effects of bacteria or fungi.

Samples for this study represented sections—(a) from the Paymaster Rope No. 6 cut 1351 feet from drum, and No. 2 cut 1825 feet from drum; (b) from Stobie Rope cut 1943 feet from drum; (c) Levack Rope cut 978 feet from drum; (d) Creighton Rope—A1 cut 315 feet from drum, No. 2 cut 1852 feet from drum.

The core samples were examined by Dr. William F. Clapp of the William F. Clapp Laboratories, Duxbury, Massachusetts. His principal conclusion that biological deterioration, if present, was insignificant was supported by Dr. Prindle, formerly of Iowa State University, and Dr. Jennison, Professor of Bacteriology at Massachusetts Institute of Technology. Dr. Clapp's detailed report on the individual samples has not yet been received, but the following preliminary remarks may be of interest:

A. Without identifying the exact cause, Dr. Clapp found the cores to be damaged—the fibres averaged four or five inches in length as compared with a probable original length of four or five feet. The most probable forms of damage appeared to be mechanical crushing and cutting of the fibres by the wires.

B. Water having a pH as low as 3.5 should not seriously affect the fibres.

C. A study of preservatives for wire rope cores does not appear to be of prime importance.

12. Occurrence of Martensite near Surface of Wires

Measurements of the hardness of the wire surface in affected regions have tended to confirm T. G. Bradbury's opinion that the local development of martensite at the surface in heavily worn areas of wire ropes is fairly common.

Conclusion

The results of the investigations promoted by Mr. LaQue clearly indicate that corrosion must be considered the most important factor in the deterioration of hoisting ropes and that no practical method is now

available to protect the wires of a hoisting rope from corrosive attack but it is thought that corrosion may be inhibited or prevented by the use of new and improved lubricants to be applied during the manufacturing process and/or after the rope is in service on a hoist. This investigation is being continued and will be carried on until some definite conclusion is reached.

CONCLUSIONS AND RECOMMENDATIONS

In order to direct attention to the more important findings resulting from the preliminary investigations carried out under the direction of this Committee, the conclusions reached and recommendations made to date are briefly summarized.

The majority of hoisting accidents in Ontario mines due to rope failure are caused by deterioration of the ropes by corrosion and wear.

Hoisting accidents occur most frequently and safety dogs are more likely to function successfully when the conveyance is ascending.

Most cases of unsuccessful dog action are attributable to poor design of the safety dogs and safety dog mechanism but it is considered that for descending conveyances a long section of trailing rope tends to prevent successful dog action.

In all accidents due to rope breakage where safety dogs were involved, the ratio of success to failure was 2 to 1.

Free-fall safety dog tests have already led to a marked general improvement in safety dog performance although a great deal of intensive work and experimentation under operating conditions must be done and the results correlated before a definite type or design of safety dog can be recommended for general use throughout the Province of Ontario. This safety dog should consistently arrest a falling conveyance at a deceleration not greater than 2 G.

Safety dogs or catches on man cages in vertical shafts do not constitute a safety hazard and if properly maintained add to the overall safety of hoisting operations.

All grades of acid and basic process wire of both British and American manufacture taken from used hoisting ropes show non-metallic content generally near the upper limit of the A.S.T.M. scale. It is felt that rope performance would be considerably improved if rope wire could be produced with non-metallic content generally at the low rather than the high end of the scale.

When installing a new rope precautions should be taken against kinking and release of spin. For a rope in service release of spin should be controlled and no more should be released than necessary to keep the conveyance from binding against the guides. After the rope has been in service for one week the diameter should be carefully measured and this measurement used as a basis for determining diametric reduction.

The crossover points should be changed three or four times during the life of the rope.

Except in inclined shafts, hoisting ropes should not be reversed.

The committee feels that thought should be given to the adoption of the "Capacity Factor" method for calculating the required ultimate strength of the hoisting ropes to be used in mine hoisting installations.

The weakest point in a rope does not necessarily occur at the capel or conveyance end, and the information obtained from routine inspections should be used to supplement the data from the statutory tests as a basis for discard.

Fatigue was not found to be a common cause of wire deterioration.

Examination of numerous wire specimens indicated that films of martensite on the surface of the outer wires of hoisting ropes were responsible for most outer wire failures. The formation of martensite is related only to external wear and therefore probably to heavy contact between the rope and sheave, the rope and drum and, except in single layer winding, the rope and rope. The location and extent of formation is governed by conditions existing at each installation.

Examination of hoisting ropes from various Ontario mines confirms the general findings of most investigators that internal corrosion or corrosion in combination with internal wear is by far the most serious cause of the deterioration of wire hoisting ropes.

No practical method for preventing or substantially retarding corrosion is now available. It is felt, however, that information has been gained indicating that improved lubricants and methods of applying them will go far towards solving the problem, and research along these lines is being continued.

Experiments have indicated that internal corrosion cannot be detected by X-ray photography using stereoscopic technique.

Experiments indicate that the more important types of deterioration in hoisting ropes can be detected in the laboratory by electro-magnetic exploratory methods but much remains to be done to establish their practical value.

A promising non-destructive method of checking the strength of a hoisting rope in service, by measuring the sectional area of a 1½-in. length cut from one of the outer wires of a strand to determine the loss of section of the outer wires and consequently the loss of strength of the hoisting rope, is being investigated.

Recommendations

This committee recommends that section 175 (a) and (b) of the Regulations be revised and that the restrictions placed on the retention of hoisting ropes in service be expanded to include factors other than a safety factor less than 4.5, more than 6 broken wires per lay, or the presence of marked corrosion.

Maximum safe life is obtained from hoisting ropes in installations where the ratio of drum or sheave diameter to rope diameter is at least 85 to 1 and the fatigue stress of the installation is not more than 25% of the ultimate strength of the rope. It is recommended that approval of future hoisting installations be made dependent upon careful consideration of these factors.

The committee recommends that section 173 (a) of the Regulations Governing the Operation of Mines be revised to make it compulsory for

the manufacturer to supply a certificate of Wire Rope Breaking Load from the Ontario Dept. of Mines.

The special tests of hoisting ropes performed so far by the Ontario Department of Mines Rope Testing Laboratory have been of great assistance to the individual mine operator in the development of improved rope practice. Still further benefit would be derived from the testing service if it were more generally utilized by the industry.

The committee recommends that the special rope testing service of the Ontario Department of Mines be expanded to allow a greater number of special tests of hoisting ropes to be made than is at present possible, and that the Department of Mines require such rope specimens to be sent to the laboratory for testing as experience indicates necessary.

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Part III

REPORT OF INSPECTOR OF MINES

on Accident at Paymaster Consolidated Mines, Ltd. on February 2nd, 1945

The hoisting rope on a double-deck cage lowering sixteen men at the No. 5 shaft of the Paymaster Consolidated mine broke at 7.55 a.m. on February 2. The safety dogs engaged the guides immediately, but they were torn out. They then worked ineffectively as the cage fell to the bottom of the shaft, a distance of more than 1700 feet. The cage stopped in the spill pocket about 19 feet above the shaft bottom. The impact resulted in instant death to all but two men. Only one man was reached while still alive, and he was unconscious when removed. He died en route to the South Porcupine General Hospital.

The Paymaster No. 5 shaft extends from surface to a depth of 2685 feet. The longitudinal axis of the shaft lies east and west. There are three compartments. The east compartment, or manway, is 5 feet long by 4.5 feet wide. The centre compartment, called the cage compartment, is 4 feet wide by 4.5 feet long. The west compartment, called the skip compartment, is 4 feet wide by 4.5 feet long. For a short distance above and below the 1200-foot level and from a short distance above the 2575-foot level to the bottom, there is a spillage-hoisting compartment, 3.7 feet wide by 4.5 feet long, east of the manway.

The levels served by the No. 5 shaft during the past two and a half years have been the 1050-, the 1200-, the 1575-, the 2075-, and the 2575-foot levels. All ore hoisted during this period has been hoisted in skips from pockets located below the 1050-, the 1575-, the 2075-, and the 2575-foot levels. The percentage of ore hoisted from the respective pockets during this period has been 28, 24, 43, and 5 per cent. The last pocket station is located 52 feet below the 2,575-foot level. The lip of this loading-pocket chute is 2635 feet below the shaft collar. A spillage pocket is located below the 2575 loading-pocket. The spill-chute bottom was made of 90-pound rails placed on a 40-degree slope under the two hoisting-compartments and the manway. The west or top side of the floor in the centre compartment where the cage first stuck is 31 feet below the lip of the 2575-foot loading-pocket chute, or 2666 feet below the shaft collar, or 19 feet above the shaft bottom.

Both hoisting-compartments of No. 5 shaft are flush, tight-lined. The guides were B.C. fir dressed exactly to 5 inches wide by 4 inches thick. The maintenance policy followed was to change guides when the face was reduced to 4½ inches in width. All the guides in the cage compartment, from 42 feet below the 1200-foot level, or from a point 1214 feet below the shaft collar to the bottom, were new and made of B.C. fir treated with creosote. The new guides had been in service only a month and a half and showed no appreciable wear. The guides above these were also of B.C. fir. They had been in service for some time and were worn to about 4⅝ inches in width.

The shaft conveyances consisted of two skips and a double-deck cage. The double-deck cage was used in the centre compartment in balance with a skip in the west compartment to hoist and lower the shifts and to handle material. It was interchangeable with the skip and when muck was hoisted it was replaced by a skip in the centre compartment. The skips weighed 3838 pounds each. The maximum weight carried in the skips was 6000 pounds. The double-deck cage weighed 4205 pounds. The hoisting rope used weighed 1.8 pounds per foot. The distance from the sheave to the lip of the loading-pocket was 2716 feet. The maximum weight of the rope was 4889 pounds. The safety factor based on a total load of 14,969.8 pounds was 6.8. The load carried was actually less than this. This figure takes into account 135 feet of rope not suspended in the shaft, and in addition to this the skip load was less than 6000 pounds, being reduced to 4500 pounds when hoisting from the lower pockets. The permissible man load, based on 85 per cent of maximum load of 14,969.8 pounds, was 12,700 pounds. Subtracting the weight of the cage, 4205 pounds, and the weight of the rope, 5132 pounds, as included in the maximum load, the permissible weight of men that might be carried was 3363 pounds. The combined weight of the sixteen men who were killed, as shown on their X-ray cards, was 2365 pounds.

The cage was manufactured by the Wabi Iron Works, of New Liskeard, in 1938. The over-all length of the cage was 15 feet 7 inches. The inside height of the lower deck was 6 feet 3-3/16 inches; that of the upper deck was 6 feet 4-7/16 inches. The safety dogs on the cage were the standard design supplied with all Wabi cages. The dogs were 4 inches wide; the biting width of the face teeth was 2-3/16 inches. The teeth, 5 in number, were designed to bite successively deeper into 5-inch guides up to a maximum depth of 13/16 inches on each side of the guide when fully engaged. The lower sides of the first 4 dog teeth were cut to meet the guides at right angles, the last tooth was cut to turn it slightly beyond a right angle to exert a compressive force on the guide when fully set. When fully set to engage a 5-inch guide to a depth of 13/16 inches, the dogs were held from rotating further by a shoulder on the drawbar, which came in contact with the top of the cage after the drawbar dropped 3½ inches. At the beginning of the movement the force of the springs pulling the drawbar down was supposed to be 3000 pounds. At the end of the movement the springs were supposed to exert 1000 pounds pressure.

The hoisting-rope was manufactured in February, 1941, by the B. Greening Wire Company. It was a "Special Green Strand," "Type B3," flattened Lang's lay rope, made of 6 strands of 27 wires, 12 over 12 over 3. The strands were wound around a Java core. The breaking-strength rating of the rope, as given by the manufacturer, was 51 tons. The rope was purchased by the Paymaster company in March, 1941. It was held in storage for seventeen months in a dry shed and was placed in service on August 5, 1942.

Using the manufacturer's breaking-strength figure of 102,000 pounds for the rope and a suspended load of 14,969 pounds, the static safety factor was 6.81. Based on the actual breaking strength obtained on tests made on February 4, 1943, September 13, 1943, March 2, 1944, and September 18, 1944, when breaking strengths of 100,700 pounds, 100,000 pounds, 101,000 pounds, and 98,700 pounds were obtained, the safety factors were 6.72,

6.68, 6.75, and 6.60. The extensions on the respective tests were 2.2, 2.1, 2.3, and 2.0 inches. In all the tests the lubrication of the core was found to be good. No unusual corrosion was evident.

The No. 5 shaft hoist is a double-drum Fullerton, Hodgart and Barclay hoist having a rated hoisting capacity of 11,450 pounds maximum unbalanced load, or 15,650 pounds balanced load, at a speed of 1200 feet per minute. Both drums are 60 inches in diameter and have 36-inch faces grooved for a 1-inch rope. The first winding takes 33 laps of rope; successive windings take 34 laps. When the cage is at the collar there are five layers of rope on the drum. The hoist has two caliper-type post brakes. They are raybestos-lined, oil-operated, and set by gravity. They are operated in case of emergency by a solenoid trip. Both drums have geared axial clutches. The interlocks between the brakes and clutches are mechanical. The hoist has two vertical-dial, gear-driven indicators and is equipped with a model "D" Lilly controller. There are two separate signal systems from the shaft to the hoist. One system serves the pockets only. A man safety is tied into the level-signal system in such a way that the return of any signal automatically sets a limit to prevent the conveyance going to the skip dump. Other safety controls include emergency switch, a circuit-breaker, a back-out switch, warning bells, and limit switches in the shaft.

The hoist is driven through a set of gears by a 350 h.p., A-C motor.

The acceleration and speed of the hoist motor is controlled automatically by 7 magnetic contacters connected to balanced steps of resistance in the motor secondary circuit.

The top speed of the motor is 750 r.p.m. The full load speed is 734 r.p.m. The pinion gear has 22 teeth; the drum gear has 220 teeth. The maximum speed obtainable on the 1st layer winding was 1177 feet per minute. The maximum speed attainable on the 4th layer winding was 1260 feet.

No. 5 shaft is operated on three shifts. J. E. Armstrong was hoistman on the graveyard shift from midnight to 8 a.m. on February 2. The graveyard shift hoists muck. This had ceased about 5.30 a.m., when the passes were emptied. C. Dukeshire relieved Armstrong about 7.30 a.m. Before commencing to load the 8 o'clock shift, Dukeshire ran the cage, empty, through the shaft and tested the Lilly controls. He then started to lower the day shift, lowering the men to the bottom level first. Two cage loads had been lowered and the third load was descending at 7.55 a.m. when the accident occurred. The third load had been rung to the 1050-foot level.

Dukeshire states that he was "feeling" the brakes, and the cage was at about the 900-foot level when the rope broke just outside the hoist-room, and the broken end fell back through the wall. He immediately applied the brakes and brought the ascending empty skip to a stop. Dukeshire is very positive that the brakes were not applied before the rope broke. When the hoist was stopped, there was about 25 feet of rope on the floor and about 11 laps of rope on the 4th layer of the drum, all of which had recoiled and loosened.

There was still a group of miners in the shaft-house. They heard the trailing end of the rope thrashing the roof and headframe as it was drawn down the shaft.

Three men, E. Tailifer, L. Bilodeau, and P. Stringer, on the 1575-foot level station saw the descending cage pass that point. They had gone down with the second cage load. They testified that the cage passed the 1575-

foot level at faster than normal speed. One man described its speed as fast but not as though it were falling free. One stated there was a tearing noise caused by the dogs working on the guides. They stated they could not see the trailing rope for dust. After it had passed, Stringer tried to telephone to the surface. The line was busy at first, but later he got F. Newman, mine superintendent. The three men then climbed down the manway to the 2000-foot level, from which point they again telephoned to Newman. From this station Bilodeau and Stringer went to the No. 3 winze to collect men to go down to the 2575-foot level by the No. 5 winze. Tailifer proceeded on down the manway of No. 5 shaft to the bottom. He was the first to arrive at the cage, which was at the floor of the spillage pocket. He states that he heard two of the men moaning. One of them, U. Legault, was conscious. Tailifer then went up to the 2575-foot level station and telephoned to Newman again.

It was arranged that a trial run of the empty skip would be made through the west compartment. Tailifer was to signal it back to surface if it reached the bottom. This was done, and the skip compartment was found to be clear.

Tailifer informed the mine superintendent that the cage would have to be burned to release the men.

After the trial run to the bottom, the mechanical department did not consider it safe to continue to operate the skip in the No. 2 compartment below the 1050-foot level until the two hoist drums could be clutched together. The acetylene burning-equipment was therefore dispatched to the bottom by way of No. 3 and No. 5 winzes, and all the rescue men going down from surface travelled this way. The local Mine Inspector was informed of the accident about 8.10 a.m. He arrived at the mine about 8.45 a.m. and examined the cage rope, which remained on the hoist, and then proceeded underground to the cage by way of the winzes. He arrived back at No. 5 shaft on the 2575-foot level just as the burner equipment arrived there at 9.55 a.m. Shortly after this, the removal of the broken rope from the No. 1 drum having been completed, the two drums were clutched together and the west skip was lowered to the bottom.

This compartment was then inspected by F. Newman, H. E. Rice, and M. Sura. It was found to be undamaged. The inspection was completed shortly before 11.00 a.m. Two doctors waiting at the shaft collar were then called down to the bottom as the removal of the first men from the upper deck was proceeding. U. Legault, the third man removed, the only man alive at this time, was found unconscious and in a dying condition. He was brought up the shaft accompanied by a doctor and then taken directly to the South Porcupine General Hospital, but died before reaching it.

The removal of the last man from the upper deck was accomplished about 4 p.m. The removal of the eight men from the lower deck was a much more difficult job than was the removal of the first eight from the upper deck. The upper deck was not as badly distorted as the lower. When the west side of the floor of the lower deck struck the sloping floor of the spill chute, the lower part of the cage was deflected 4 feet to the east, and the west edge of the floor was folded up to within 2 feet of the east wall. The walls were crumpled and torn, and the floor of the top deck was driven down within 3 feet of the high side of the lower-deck floor.

The immediate cause of this accident was the failure of the hoisting-

rope. The cause of the failure was the reduction in strength of the rope caused by internal wear and corrosion of the wires. The circumstances which resulted in this condition are obscure.

The rope failed at a point 1130 feet from the cage, leaving 1844 feet of rope on the hoist. The dogs contacted the guides first at 950.4 feet below the shaft collar. This point is 57.4 feet below the 900-foot level, or 95.9 feet above the 1050-foot level. There were 209 feet of rope between the hoist drum and the shaft collar. If the cage dogged the instant the rope broke, there would therefore have been 1159.4 feet of rope off the hoist and the break would have occurred 29.4 feet from the drum. The rope passes out through the wall of the hoist-room 17.5 feet from the drum, and the break would have then been 12 feet beyond the wall. It is reasonable to assume that the cage travelled some distance before the dogs turned into the guides and that the trailing rope, passing over the 7-foot sheave, to some extent retarded the setting of the dogs. It is further conceivable that the rope was near the point of failure when wound on the drum on the last ascending trip and that the failure occurred as the weakened point was unreeled from the drum. Both inspection and a calculation of where 1844 feet of rope, wound on the drum, would end shows that the rope broke on the layer about 12 laps from the face of the drum. There is no way of accounting for a particularly weak section at this point, which would come between the shaft collar and the sheave when hoisting from the 1050-foot loading-pocket at 1166 feet below the sheave. Only 28 per cent of the ore hoisted came from this point. When serving the 1050-foot level with the cage, a point on the rope 1130 feet above the cage would be between the sheave and the hoist.

After the accident the rope was cut up and tested at numerous points. Seven feet of rope showing the broken end and representative rope adjacent to the break was cut from the broken end at the hoist for an exhibit. The next 18 feet was cut into three test lengths. The rest of the 1844-foot section was tested at 150-foot intervals. The 1130 feet of rope that fell down the shaft was hauled up to the 2575-foot station in a tangled mass, a locomotive was hitched to loops in the rope, and it was dragged out on the level until the loops tightened. The rope was then cut and the ends of the pieces were tagged so that they could be correlated. The result was six pieces from which test pieces were cut at approximately 100-foot intervals. Twenty-six breaking tests in all were made by the Department of Mines. The usual test information was recorded, and in addition the diameters of each test piece were measured under no load, 3000-pounds load, and 6100-pounds load. The nature of the breaks of the wires was also recorded.

The tests showed that the upper section of the rope was in good condition except for the portion close to the break. Nine tests showed breaking loads greater than the manufacturer's rated strength of the rope, which was 51 tons (102,000 pounds). The highest of these was 104,750 pounds. For comparative purposes, 104,000 pounds was taken as 100 per cent of the strength of the rope. All test pieces above the break exceeded 90 per cent of this figure with the exception of the three taken from 7 feet to 25 feet above the break. The breaking load of the first piece above the break was 38,875 pounds, the second was 56,175 pounds, and the third was 59,445 pounds, or 37.4, 54.0, and 57.2 per cent of the original strength. The ex-

ternal condition of the whole upper section of the rope was described as "fair"; most of it was described as "worn"; the three weakest sections were recorded as having "slackness in the outer wires." The internal condition of the eight pieces nearest the drum end of the rope was described as "good, slight corrosion." Its lubrication inside the strands was described as "good" on these pieces. The internal condition of the next four pieces was described as "fair, some corrosion" and "fair lubrication inside strands." The internal condition of the three test pieces taken just above the break was described as "poor, badly corroded, no lubrication inside strands." Many inner wires broke off in brooming the ends when preparing them for socketing. The piece nearest the break had six broken outer wires, the next piece three, and the third piece two.

The strength of the test pieces cut from the 1130 feet of rope attached to the cage varied greatly. The weakest piece tested was cut from 219 to 225 feet above the cage. This piece broke at 52,000 pounds. The next weakest piece was the one cut nearest the break. It broke at 53,425 pounds. The best test was obtained on a piece taken from 728 to 734 feet above the cage. This piece broke at 102,500 pounds. The second best piece from this section was cut next to the socket attachment to the cage. This would have been the piece tested in March had the rope been left in service. This piece broke at 94,350 pounds. Its extension was 2.0 inches. It was described as being "fair, slight wear, corroded" externally. Internally it was described as "fair, some corrosion on inner wires, fair lubrication inside strands." With the exception of the piece cut next to the rope socket, all of the eleven pieces tested from the 1130-foot section of the rope showed from one to three slight kinks in each test piece. These kinks were not tight kinks, but in all cases they were enough to produce slackness in the outer wires, and in some cases broken inner wires protruded from the rope. With the exception of the two best pieces described above and the third best cut at 109 to 115 feet above the cage, all sections of the cage end of the rope were described as appearing "poor, worn and corroded" externally. The internal condition was described as "poor, badly corroded and no lubrication inside strands." This end of the rope was generally poorer than the drum end. Many inner wires broke off when the ends were being broomed preparatory to socketing the ends for testing. Generally the wires were drawn out in breaking if the remaining strength exceeded 90 per cent of the full strength. When strength was low the wires broke jaggedly, indicating brittleness and deterioration. It was noted that what was termed "external corrosion" was chiefly rust and that there was little pitting on the outer surface. The extension varied very uniformly with the breaking load; the lowest extension, 0.8 inches, was obtained on the weakest test piece, that nearest the break. The diameter of the rope was very uniform throughout. The variation between the full-sized rope on the drum, 64/64 of an inch, and the smallest diameter found on the weakest section was only 5/64 of an inch. The diameters of all six sections which broke at over 104,000 pounds was either 60/64 or 61/64 of an inch.

It should be mentioned that the general appearance of the cage end of the rope was changed by the accident and its subsequent treatment, when it was dragged out on the 2575-foot level. Most of the surface grease was whipped and scuffed off the rope. Water covered the rope for several hours in the shaft when the debris caused the pumping system to fail on

the night of February 3. The result was slime and wood fibre mixed with the remaining grease and a light coating of superficial rust where it otherwise would have been greasy or bright with surface wear.

No evidence was obtained in the investigation of work records that this rope had not received proper care and inspection. The fact was revealed that the Machinery Record Book recorded no inspection since the middle of June, 1944, but daily work-slips turned in by mechanics who inspected the rope at weekly intervals and greased it every two weeks were produced by the master mechanic to support his own evidence and the verbal evidence of the mechanics that the inspection and greasing of the cable had been done regularly. The master mechanic stated that the rope was first greased when it was put on.

The failure of the cage dogs to function properly has been cited as the second cause of the accident. The dogs, which have been described above, did not work effectively in this case. They took hold when the rope broke but they either bounced out or were whipped out by the trailing rope. At the first contact they cut into the guides for only a foot to a maximum depth of not more than 5/16 of an inch on each side of the guide. The teeth probably filled with wood at this point. The dogs on the east guide then cut out for two sets, and those on the west guide no more than scratched the guide. Then they gradually began to score deeper and from the top of the new guides to the bottom, they cut very uniformly to a combined depth of about 7/16 of an inch on each guide. The width of the cuts averaged about 2⅛ inches on the west guides and 1½ inches on the east guides.

It has been generally assumed that the dog teeth filled with wood and that they could not bite hard enough to roll in deeper. The uniform depth to which they cut seems to suggest that they were held by the linkage from rotating further and biting deeper. It has been suggested since the inquest that perhaps something got under the shoulder on the draw bar and thus prevented its full movement. This suggestion was investigated on March 2. On this date a small rock about ¾ of an inch in size was found under the shoulder on the skip draw bar. A similar rock might have been responsible for the failure of the cage dogs. This was not considered at the time of the accident, and there is no proof that this was the cause of their failure. Similar dogs have proved effective before. The last rope used in the same compartment was broken August 5, 1942, one hundred feet from the skip, when an overwind occurred, and on that occasion the dogs held the skip. Daily, usually between three and four o'clock in the afternoon, the cage dogs were lubricated, alternately with penetrating and lubricating oil. At the same time the top of the cage and the dogs were cleaned with a jet of compressed air. This had been done last on the afternoon preceding the day of the accident.

The injuries sustained by the various men were not enumerated at the inquest. It was simply stated that death was due to multiple injuries and shock. The injuries were so numerous that death was instantaneous in most cases. It is recorded that fourteen of the sixteen men suffered fractured necks.

The inquest was held before Coroner (Police Magistrate) E. R. Tucker, of Cochrane, in the Tisdale Township Hall at South Porcupine. The inquest was held on Russell Dillon, a resident of Tisdale township. The verdict in

his case applied also to all the other men who died at the same time, in the same place, and by the same means. Morning and afternoon sessions were held on February 26 and a morning session on February 27. The jury retired at 11.35 a.m. on February 27. They returned their verdict shortly before 1 p.m. It read as follows:—

We find that Russell Dillon came to his death at 8.00 a.m. on February 2, 1945, in No. 5 shaft in the Paymaster mine in the township of Tisdale through, first, by the breaking of the rope and secondly, through the failure of the safety dogs to function properly and stop the cage. From the evidence submitted the rope broke because of internal corrosion of which there was no indication from external examination. We consider the dogs faulty in design and operation and recommend that all safety dogs and attachments be approved by a competent authority appointed by the Department of Mines before permitting the use of the same. Also that a study be made on the prevention of internal deterioration of hoisting ropes by a Commission appointed by the Provincial Government, and every effort be made to prevent it. We strongly recommend that there be no delay by the said Commission in making investigation of all cables, safety devices, and hoisting equipment to prevent a recurrence of this serious and deplorable accident. We find that no blame can be attached to any one through carelessness or neglect.