

WIRE ROPES FOR LIFTING APPLIANCES,
AND SOME CONDITIONS THAT AFFECT
THEIR DURABILITY.

By DANIEL ADAMSON, *Member, OF HYDE.*

The question of the durability of the parts of mechanical structures seems to be strangely neglected by all authorities. A designer has generally the choice of several formulæ for calculating the mere strength of a given member, but usually he has to depend upon his own experience for the correctness of the proportions that will ensure for it a reasonable length of life. The durability of wire ropes in particular is of great importance to all engineers, whether engaged in the design and manufacture of lifting appliances, or in their care and management.

The two most important conditions appertaining to the manufacture and use of steel wire-ropes that affect their durability are:—

- (a) Quality of material and size of wire.
- (b) Diameter of pulleys and arrangement of ropes.

(a) *Quality of Material and Size of Wire.*—The wire used for lifting ropes is of steel having an ultimate tensile strength varying from 80 to 130 tons per square inch. Although ropes made from material having a high tensile strength are of smaller diameter, for a given load and a given factor of safety, yet this is not a great advantage to the crane designer because the stiffer character

of the wires makes larger drums desirable, if the durability of the rope is to be considered, notwithstanding that some rope-makers claim as an advantage for the stronger material that it does enable smaller pulleys to be used with a consequent lower cost of the working parts of the crane.

The ratio of the diameter of the individual wires to the diameter of the completed rope is an important factor. If the wires are too large they are stressed considerably when passing over the pulleys, and accordingly the material is quickly fatigued and the wires break. Smaller wires, on the other hand, are more quickly worn through by rubbing against the pulleys and against their neighbours in the body of the rope. The stress in a wire due to bending round a pulley is directly proportional to the modulus of elasticity and to the diameter of the wire, and inversely proportional to the radius of the pulley; therefore the radius of the pulley should be increased with an increase in the modulus of elasticity, if the same number of bends is to be endured by a stronger wire of the same diameter. Unfortunately a theoretical calculation of the stresses induced in the wires of a rope by being bent over a pulley does not alone afford a reliable guide to the length of life to be expected from the rope, for consideration must also be given to the mutual wear that takes place amongst the wires.

Assuming for the purpose of comparison that two ropes are constructed of equal size, one from wires half the diameter of those in the other, then for equal strength the one rope will have four times the number of wires and each of the wires will have one-quarter the cross sectional area. According to the usual formula, the stress due to bending will be half as severe in the smaller as in the larger wires, when the ropes are bent over pulleys of the same diameter. If it be allowed that a reasonable figure for the estimated stress due to bending an ordinary rope over a pulley of a size usually adopted in crane design be, say, 30 tons per square inch, and the stress due to the suspended load be 10 tons per square inch, there will be a range of stress of 40 tons per square inch in the material each time the maximum load is lifted and released, and the corresponding stresses in the rope of finer

wires will be 15 tons per square inch due to bending, and as before 10 tons per square inch due to the suspended load, or a total range of 25 tons per square inch.

Judging by the discussion that took place on Messrs. Eden, Rose and Cunningham's Paper before this Institution in November last on "The Endurance of Metals," there is, as yet, no agreement as to the exact effect upon the endurance of variations in the working stresses. It seems, however, to be reasonable to assume that a reduction in range of stress from 40 tons per square inch to 25 tons per square inch would increase the life of material, such as ropes are composed of, about 500 times. As no such improvement in the life of a rope has ever been experienced, or is to be reasonably expected, it must be taken for granted that abrasion is the principal factor in limiting the life of wire ropes, and therefore the effect of abrasion upon the suggested rope of finer wires may now be considered.

When the rope of finer wires is passing over the pulley, there being four times as many wires in it, the pressure at each point of contact between the rope and the pulley and between the individual wires of the rope may be assumed to be one-quarter of what it is in the rope of larger wires. The wires being of half the diameter the damage done to them by contact, even under this lower pressure, will be at least half as much as occurs to the coarser wires in the other rope, and this half damage done to a wire of one-quarter the sectional area will result in the cutting through of the wire in half the time, so that the effect of abrasion upon the rope of finer wires will be twice as great. If a smaller pulley be used for the rope of finer wires, as suggested by some authorities, the pressure at the points of contact and the stress due to bending will be proportionately increased, so that it may reasonably be expected that, with a pulley-diameter bearing the same proportion to the diameter of the wires, the life of the rope with fine wires will be one-quarter of that of the rope of coarser wires working over a pulley of correspondingly increased diameter.

A German investigator (Ernst Heckel) refers to the very great surface pressures on the wires at the place of contact with

the pulley (amounting in his opinion to as much as 12 tons per square inch) as a vital point in connection with the wear of wire ropes. This high pressure, accompanied as must be the case by relative movement even if quite small, readily accounts for the wear which takes place on the surface of the wires where they touch the pulleys or the other wires in the rope.

(b) *Diameter of Pulleys and Arrangement of Ropes.*—The lists issued by makers of wire ropes contain recommendations as to minimum sizes to be adopted, but no information is given as to the effect of using pulleys of different diameters. The author has felt for many years past the want of such information: the experience of users afforded no reliable guidance, presumably on account of the great difference in the conditions under which ropes work in different shops. Reference to a Paper read before the Manchester Association of Engineers by Mr. Matthews in 1902 brings to light one great difference in the working of cranes. Mr. Matthews, in his Paper, suggested that 400 to 1,700 lifts per crane per annum was the amount of duty required from certain cranes under his control, while the present author, in the discussion on Mr. Matthews' Paper, mentioned 32,400 to 43,200 lifts per crane per annum as representing his own experience in another class of work. Other important features that will affect the life of a crane rope are the average weight lifted and the average height of lift; cranes are generally occupied with loads much below their nominal capacity, but this will vary in different workshops as will the proportion between the maximum height of lift available and the height most frequently attained by the hook.

Inquiries addressed to the users of cranes elicited very various replies; ropes working upon cranes of the same general design were found to last for periods of from two years to ten years and upwards, and one correspondent suggested that 20 years might be expected from ropes on cranes (of from 5 to 20 tons capacity) if damage from accidental causes could be eliminated. As might be expected, the ropes on foundry cranes have not so long a life as in erecting shops, the relative difference being perhaps as three is to five.

The most reliable and consistent information that the author has been able to discover (with the assistance of numerous friends and correspondents, and also of the library staffs of the Institution of Mechanical Engineers in London and of the Engineering Library in New York, to all of whom his sincere thanks are due) is contained in a Paper by Mr. A. S. Biggart* published in 1890. The experiments to which this Paper refers were undertaken with the object of selecting the best form of rope to be employed in the construction of the Forth Bridge. A full description of the apparatus used and the details of the investigation will be found in the original Paper, and the present author will content himself with a short reference to the experiments and an abstract from the conclusions arrived at, adding some deductions he has made for his own guidance and for the purpose of this Paper. The apparatus used by Mr. Biggart contained two pulleys, round which the rope under trial was passed, the lower pulley being weighted to give the required tension on the rope. The experiments consisted in passing the ropes, under a normal working load, to and fro over the pulleys until breakage ensued. Experiments were repeated with different diameters of pulleys and different makes of rope, and the accompanying diagram, Fig. 1 (page 712), shows the life of different classes of rope as affected by the diameter of the pulleys.

The effect of oiling the ropes is shown by the diagram to be very beneficial, increasing the life of a given rope by two or three times. This is obviously due to the reduction of the cutting action of the wires upon each other. Experiments were also made to ascertain the effect on the life of a rope of running it over pulleys so arranged that the rope was subjected to reverse stresses, Fig. 4 (page 716). The results obtained from this series of experiments showed that generally the life of a rope working under such conditions was only one-half as long as a similar rope bent in one direction only.

* Proceedings, Inst. C.E., 1890, vol. ci, page 231.

FIG. 1.

Experiments on Durability of Wire Ropes as affected by Diameter of Pulley (1890).

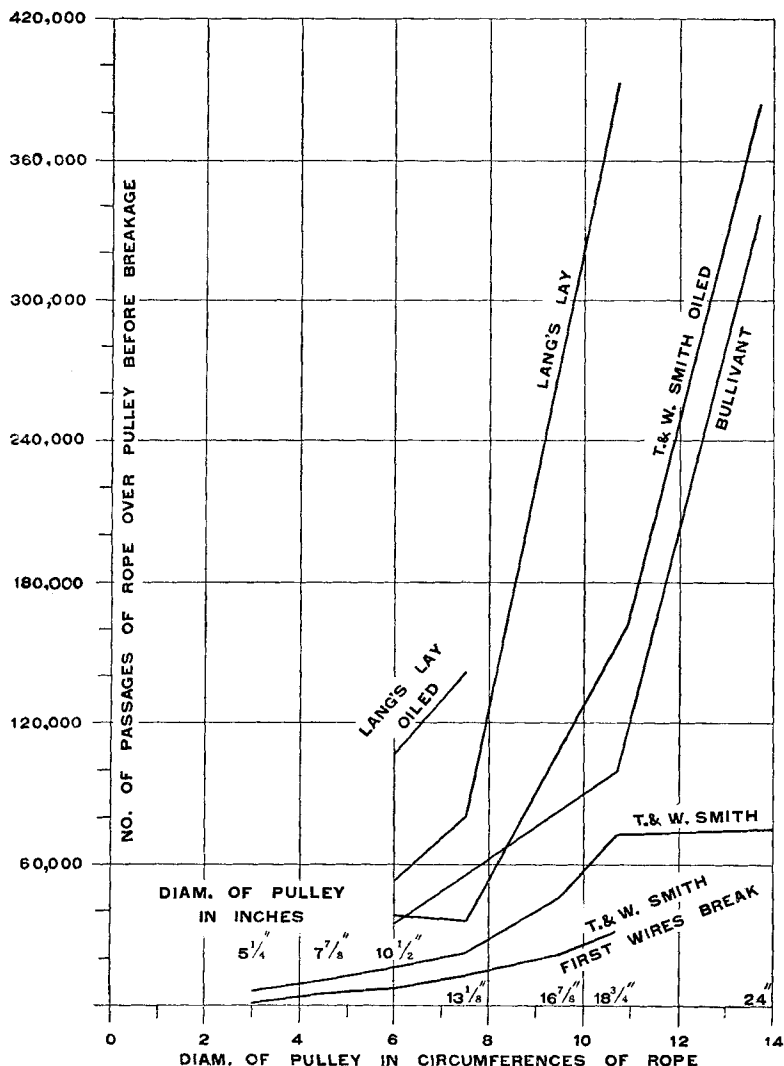


FIG. 2.—Regular Curves based on data in Fig. 1.

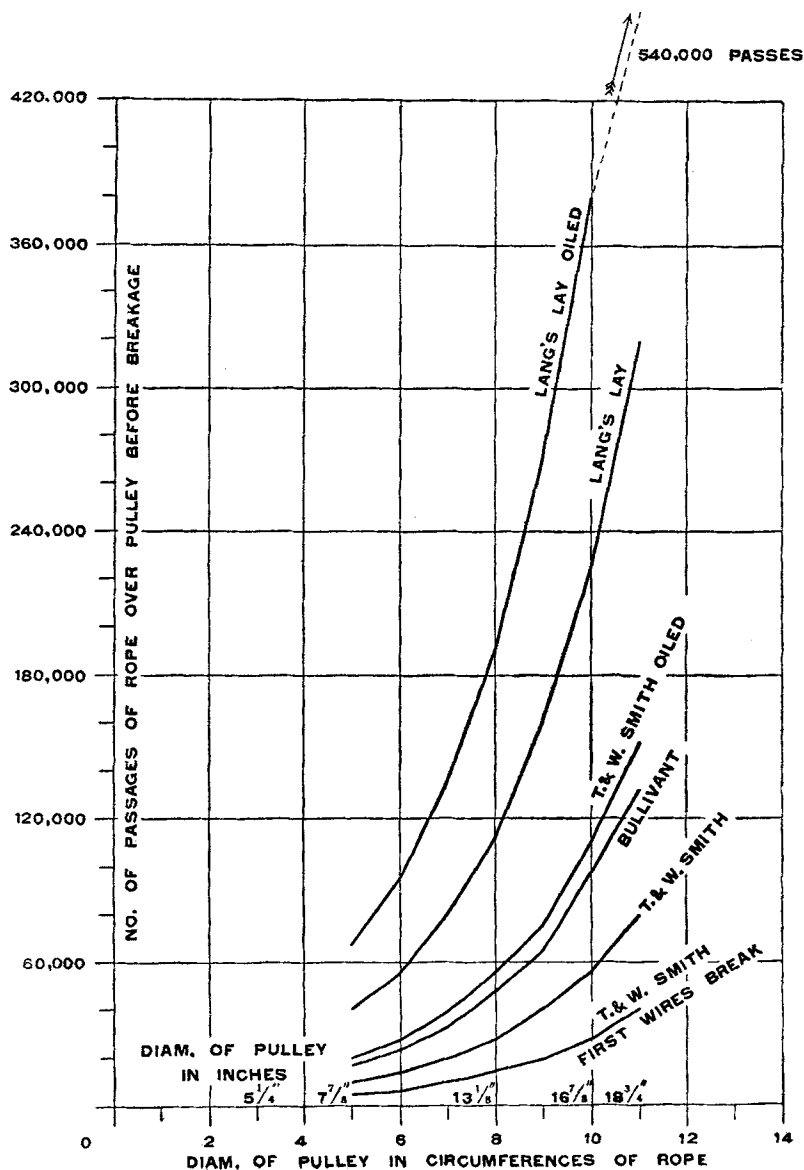
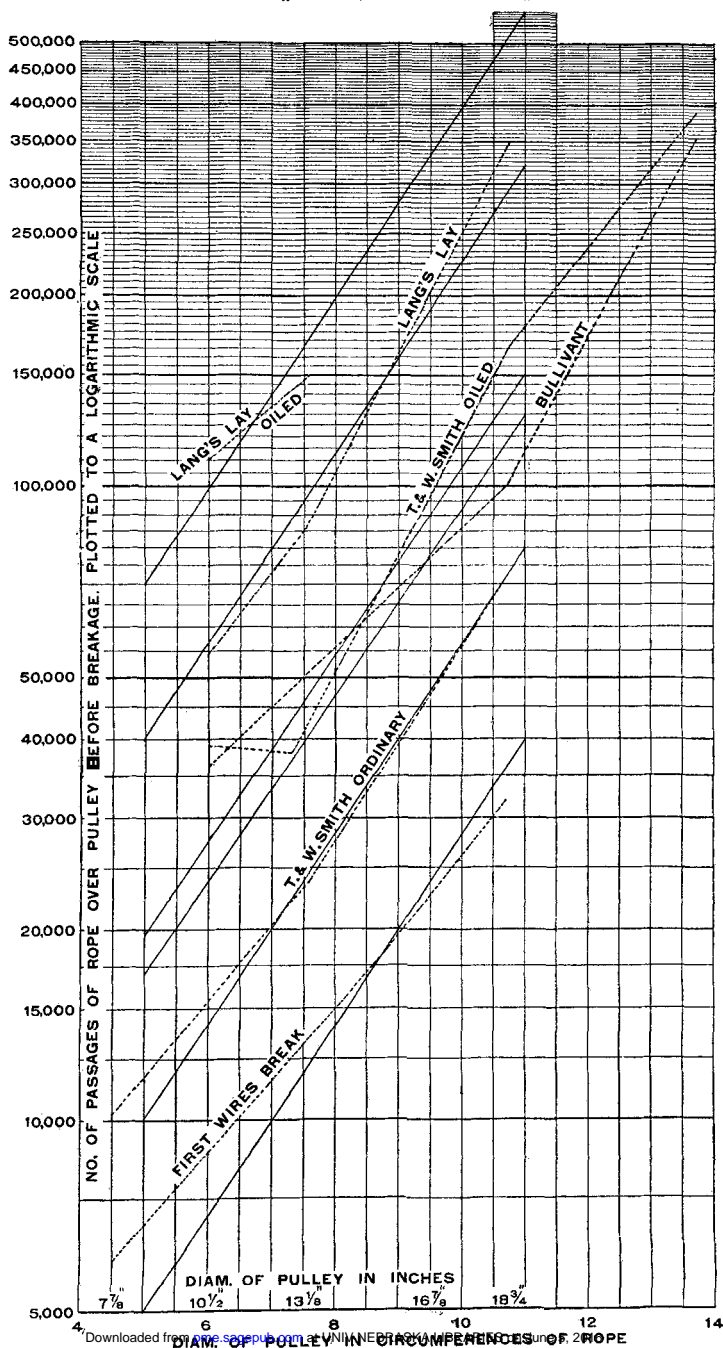


Fig. 1 is based upon the actual figures tabulated in Mr. Biggart's Paper, while Fig. 2 (page 713) shows the present author's approximations, as obtained by the simple method of drawing fair and regular curves through or near the points representing the results of Mr. Biggart's experiments over such a range of pulley diameters (measured in terms of the circumference of the ropes) as obtain in general overhead crane practice. Several interesting deductions may be drawn from a study of these figures. The time of breakage of the first wires of a rope in the lowest curve is only recorded for one make of rope, but comparing it with the second curve, which shows the time of breakage of whole ropes of the same make, it will be seen that when the first wire breaks the rope may be assumed to have passed through one-half of its life, and as no one knowingly works a rope until it breaks entirely, then the breakage of even a few wires is a sign that a rope should be carefully watched and replaced by a new one at an early opportunity.

The effect of varying the proportions of diameter of pulley to diameter of rope is one of the most important features to be noticed. Speaking generally, Mr. Biggart's experiments show that increasing the diameter of the pulleys by an amount equal to two circumferences of the rope will double the life of the rope. This is approximately correct for all the varieties of rope and conditions experimented with, and may therefore be taken as equally correct for all the varying conditions under which cranes are worked. It is very remarkable that so simple a rule should evolve from such numerous and varied experiments, and the author hopes that its statement in this form will be of some value to designers and other interested members. That it is sufficiently correct for all practical purposes may be readily seen by referring to Fig. 3 (page 715), where the ratios of pulley diameters to ropes are plotted as abscissæ to a linear scale, while the durability of the ropes is represented by ordinates drawn to a logarithmic scale.

These conclusions enable one to express a definite value for the effect upon the durability of ropes, of the various arrangements

FIG. 3.—Durability as Affected by Diameters of Rope and Pulley.



Various Arrangements in Lifting Appliances.

(See Table 1.)

FIG. 4.

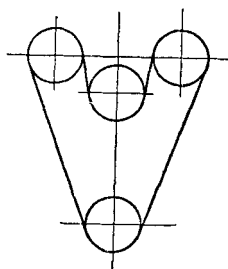


FIG. 5.

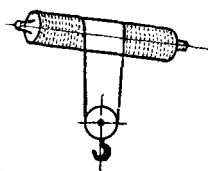
One Bend.

FIG. 6.

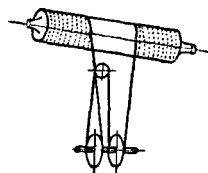
Three Bends.

FIG. 7.

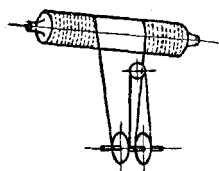
*Three Bends.
One Reverse.*

FIG. 8.

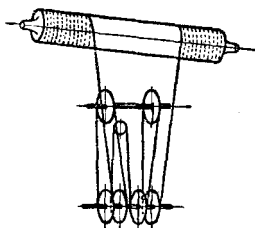
Seven Bends.

FIG. 9.

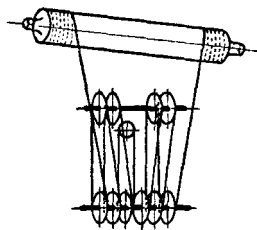
Eleven Bends.

FIG. 10.

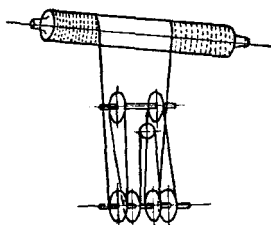
*Seven Bends.
One Reverse.*

FIG. 11.

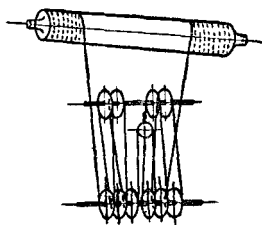
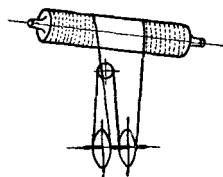
*Eleven Bends.
One Reverse.*

FIG. 12.

*Three Bends.
Large Bottom Pulleys.*

of pulleys that are commonly adopted in overhead cranes, some of which are illustrated in Figs. 5 to 11. Assuming that Fig. 6 in which the ropes make three bends in working, namely, one at

the upper drum and one on each side of the lower pulley, i.e., at entering and leaving) is the arrangement most frequently adopted in practice, and representing the anticipated life of the rope under these conditions by 100, then the relative lives of the ropes in each of the other arrangements indicated will be shown in Table 1.

TABLE 1.

Comparison of Anticipated Length of Life of Ropes arranged as shown in Figs. 5 to 11.

Fig. No.	Number of Bends.	Relative Life of Rope.
5	1	300
6	3	100
7	3*	75
8	7	43
9	11	27
10	7*	37½
11	11*	25

* Including one reverse bend which is twice as effective in wearing out the rope.

If it be desired to design each of the above arrangements of pulleys so that the ropes shall have equal durability, then the ratio of the drum diameters to rope circumference (if the law indicated by Figs. 2 and 3 is to be relied upon) must be increased as shown in Table 2 (page 718).

It is quite usual for purchasers to specify in their inquiries that the diameters of the pulleys and drums must bear a certain relation to the diameter of the rope, but the author wishes now to emphasize the point that this stipulation is not sufficient in itself,

TABLE 2.

Required increase in Diameters of Rope Drums (measured in terms of Circumference of Rope) required to give Equal Durability.

Fig. No.	Increase over Diameter called for by Fig. 6.
7	1 Circumference of Rope.
8	2½ Circumferences of Rope.
9	4 " "
10	3 " "
11	4 " "

without some consideration being also given to the arrangement of the rope and pulleys.

If the generally accepted ratio of seven circumferences, or twenty-two diameters, of the rope for the diameter of the barrel be assumed as suitable for the drum and pulleys arranged as in Fig. 6, then the diameters for the other figures, to give equal durability, should be as shown in Table 3.

TABLE 3.

Ratio of Diameter of Pulleys and Drums to Circumference of Rope to give Equal Durability.

Fig. No.	Ratio of Pulley and Drum Diameter to Rope Circumference.
5	4 to 1
6	7 to 1
7	8 to 1
8	9.5 to 1
9	11 to 1
10	10 to 1
11	11 to 1

To make the comparisons quite fair between the different arrangements, it must now be pointed out that, owing to the increased number of falls of rope adopted in Figs. 8 and 9, the size of the rope may be reduced as shown in Table 4 while retaining the same factor of safety.

TABLE 4.

Relative Rope Circumference allowing for Smaller Ropes due to increased number of Falls.

Fig. No.	Number of Falls.	Relative Rope Circumference.
5	2	140
6	4	100
7	4	100
8	8	70
9	12	57
10	8	70
11	12	57

Combining the figures given in Tables 3 and 4 will give drum and pulley diameters as shown in Table 5.

TABLE 5.

Drum and Pulley Diameters resulting from a combination of Tables 3 and 4, and still assuming that 100 represents the Condition in Fig. 6.

Fig. No.	Ratio of Pulley and Drum Diameter to Rope Circumference according to Table 3.	Relative Circumference of Rope as per Table 4.	Resultant Pulley and Drum Diameter assuming Fig. 6 = 100.
5	4	140	80
6	7	100	100
7	8	100	114
8	9½	70	95
9	11	57	90
10	10	70	100
11	11	57	90

The noticeable feature in the last Table is that whether two, four, or six falls are adopted, the diameter of the drum and pulleys should remain about the same, if the ropes are to have equal durability (compare Figs. 8 and 9 with Fig. 6). A recent text-book upon the subject of crane design states (as an advantage of a large number of falls of rope) that the proportionately larger

pulleys and barrel will ensure long life for the ropes, but the author hopes that he has made it clear that very large proportions are necessary to ensure a reasonable life for ropes on cranes with many falls of rope. Reference to Fig. No. 7 and Fig. No. 10 in Table 5 shows the increase that should be made in the diameter of the drum and pulleys if a reverse bend occurs in the run of the rope.

Another important detail in crane design may now be referred to. In Fig. 6, as already mentioned, the ropes make two bends at the lower pulleys to one at the drum, and therefore, if the lower pulleys are made of the same diameter as the drum, they will be responsible for two-thirds of the wear and tear of the rope. Now it is usually difficult to increase the diameter of the working barrel or drum of a crane, because to do so affects the ratio of the gearing and also requires a much larger framework with a correspondingly greatly increased cost of manufacture, but if it is agreed, as a result of Mr. Biggart's experiments, that increasing the diameter of the pulley, over which a loaded rope passes, by an amount equal to twice the circumference of the rope, reduces the evil effects of bending the rope round it to one-half, then a simple means of improving the durability of crane ropes is immediately at the disposal of the designer, namely, to increase the diameter of the pulleys in the blocks, leaving the drums of the original size, as indicated by Fig. 12 (page 716). This alteration can usually be effected without serious alteration of the design, and may even be carried out on existing cranes.

The result of increasing the diameter of the pulleys (as shown by Fig. 12) by an amount equal to two circumferences of the rope, will be that the effect of the double bend round the lower pulley is halved, and the resultant effect of the three bends will be equal to two only and the relative life of the rope will be increased by 50 per cent., or the drum diameter might be reduced by an amount equal to 1.2 times the circumference of the rope with a corresponding reduction in the size of the framework of the crab or winch, while still retaining a relative life for the rope equal to Fig. 6. In this case the diameter of the lower pulleys would only require to be about one circumference of the rope larger than the original size of Fig. 6.

In making the foregoing comparisons of diameters of drum and pulleys with different arrangements of rope, it has been assumed that the hook is raised to the full height available at each lift. This however is not the case in actual practice, the majority of loads not being raised one-half this height.

This consideration brings to light another great advantage of Fig. 12 as compared with any of the others. Where, as is usually the case, the average height of lift in a shop does not reach half the maximum available, then that portion of the rope which passes under the lower pulley does not reach the upper drum, and accordingly is only subject to the wearing action of the two bends at the lower pulley. If therefore the effect of the bends at the lower pulley is reduced to one-half, by the proposed increase in diameter of the pulley, then the actual life of the rope will be doubled, instead of only being increased by 50 per cent. as was first assumed.

Where there are more than two falls of rope, as in Figs. 8 and 9, the effect of increasing the diameter of the pulleys by an amount equal to two circumferences of the rope is also very marked, reducing the effect of the seven bends in Fig. 8 to four and a half, with corresponding increase in the lift of the ropes. This shows up the fault of those designers who adopt large drums (in order to obtain the great length of rope entailed by high lifts) and are yet content to make the pulleys of small sizes, when they could enormously increase the durability of the rope by the adoption of larger pulleys at little extra cost.

When the rope makes a reverse bend at the barrel as in Figs. 7, 10, and 11, the barrel ought to be increased in diameter to counteract the effect of the reverse bend. Thus, if in each of these cases the diameter of the drums were made larger by an amount equal to two circumferences of the rope, the durability of the rope would be equal to Figs. 6, 8, and 10 respectively.

Some Continental makers point out, very rightly, the desirability of making the compensating pulleys of reasonable size. The motion over such pulleys is apparently considered as negligible by some designers (judging by the forms of construction adopted), but

this point of view overlooks the movement of the rope due to the swinging of the load, and the repeated bending of the rope at the same place over a small radius has an appreciable effect upon the durability of the rope.

Although the deductions laid down here appear too simple to need elaboration, a glance at the designs of many modern cranes shows that neither the designers, nor the purchasers, are aware of the importance of the principles involved, otherwise we should not see modern cranes in this country with reverse bends in the ropes, and as many as eight plies of rope to carry the load on cranes of only 15 tons capacity, while at the recent Brussels Exhibition there were cranes exhibited by well-known Continental makers showing the same faults.

The author would like to add that while he is aware of many conditions affecting the durability of ropes other than those he has referred to, he regrets that want of first-hand experience prevents him from dealing with them as he would like, and he hopes that other members will help to make up the deficiency.

The qualities of wire used vary considerably, and this, together with the heat treatment in manufacture and the care taken by the makers in testing and examination, are questions that makers of ropes are in a better position to discuss than users.

The "lay" of the strands and the lubrication of the rope when in use have each a considerable effect upon durability, and some guidance on these points may be obtained from Fig. 3 (page 715), where "Lang's lay" is shown to have more than double the life of ropes of ordinary "lay," and ropes that are oiled last more than twice as long as when this precaution is neglected, as already mentioned on page 711. The superiority shown by "Lang's lay" naturally gives rise to the question as to why it is not exclusively used, and the answer the author has obtained from rope-makers is that such ropes must be very carefully handled to avoid "kinks," and also they are found to be more liable to "spin."

The Paper is illustrated by 12 Figs. in the letterpress.

Discussion.

The PRESIDENT, in moving a hearty vote of thanks to the author for his very excellent and valuable Paper, said it dealt with a subject which required a great deal more research on scientific lines than had been given to it in the past. Every one who had to do with the use of wire ropes for lifting appliances knew the great uncertainty attaching to their life. Personally, he felt that after an engineer had done all he could in the way of designing the pulleys, and carefully constructing ropes from proper material, it was necessary to rely eventually upon careful inspection during use. Every law that had so far been laid down, even including that of the author's, would be very uncertain in practice, though, of course, of very valuable assistance to the designer. He hoped the Meeting would, in the course of the discussion, hear some experiences of the different systems of using ropes and their manufacture.

The resolution of thanks was carried with acclamation.

MR. ROBERT MATTHEWS (Member of Council), in opening the discussion, said he desired first of all to render to his old friend and neighbour, Mr. Adamson, his hearty thanks for taking the trouble to write the Paper. The author had gathered together some valuable information, but he was afraid the conclusions arrived at did not convince him that they were correct. He alluded more particularly to the illustrations on page 716 and Table 1 (page 717). The members would notice that in Fig. 5 there was a drum with two bends on it, and the pulley down below, and the author described that as one bend. Then Fig. 6, with the same drum arrangement, and the ropes arranged with the addition of two pulleys, the author called three bends. That, to his mind, did not seem to be right, as with a compensating pulley of ample size there was very little wear and the system then became only a two-bend, and consequently, as those two Figures were the basis for

(Mr. Robert Matthews.)

what the author determined later on, he was afraid the results would be somewhat fallacious and misleading. In one part of the Paper the author said that the compensating pulley wore, and he took that into consideration to the same extent as one of the pulleys. If he did it there, he ought to do it also in Fig. 5, but he did not. The author called that one bend, and that was where he thought he was a little unreasonable. That being so, he felt compelled to disagree with the foundations of the whole of his deductions later on in the Paper. He thought most of the members recognized that Lang's wire ropes were the best crane ropes. Personally, he knew Mr. Lang very well and he had used Lang's wire ropes very largely throughout his works, and had always found them very satisfactory indeed.

There was one point dealt with in the Paper about which he felt a little bit hurt. The author had probably written what he had done in an unguarded moment. The statement was made (page 710) that he (Mr. Matthews) suggested, when he read his Paper in 1902 before the Manchester Association of Engineers, that 400 to 1,700 lifts per crane per annum was the amount of duty required from certain cranes under his control, while Mr. Adamson in the discussion on the Paper mentioned 32,400 to 43,200 lifts per crane per annum as representing his own experience in another class of work. It would be preposterous for an engineer to suggest that. What he did was to give the actual number of lifts in a large gun shop where very large tools were used, and where, in one lathe, there would be perhaps three lifts in three weeks. If an expensive electric-driven crane was standing idle for a considerable amount of its time, it was not always economical engineering to go in for such an expensive piece of machinery, and he was only showing from actual experience that he had done the wrong thing by putting in an electric crane. If he had kept to the old type of rope crane, it would have cost less money and would have been more economical. It was not because he recommended that type of crane; it was merely a statement of fact. In some of the other shops there were electric cranes working as quickly as ever they could both day and night. In the iron foundry they changed their old rope cranes to

electrical cranes, carrying out the work themselves. Good large pulleys were installed, and they had been working now for over seven years with continuous overtime without a single failure in the ropes. His firm generally carried out the practice that was recommended very largely by Newall. He thought it was better to use a larger size in the way of pulleys, and his own practice was to use from 20 to 25 times the size of the rope. If that proportion were used, fairly good working and a good life for the rope would be obtained. With the 50-ton cranes in the foundry to which he had already referred, very heavy castings were made. The cranes were low, because it was mostly bed work that was carried out. Consequently the crane was very near to the heat, and also to the sand and dust. Notwithstanding that, the cranes had been working for over seven years, very often with a load of 70 tons on a 50-ton crane when very large castings were being made.

One other remark made by the author which seemed to him a little illogical was, that a double bend in a rope shortened its life by one half. Personally, he thought it would be less than that, because bending in both directions was more injurious than bending in one direction and pulling out straight. He believed that if actual figures were taken, it would be found that it was less than a half. He was sorry he had not been able to study the Paper more closely, but if the Paper and its criticism helped the members in coming to a right conclusion in their use of wire ropes, he would be more than satisfied.

Mr. A. BASIL WILSON said that in listening to the Paper the point that struck him most forcibly was the comparatively small importance that the author attached to the question of reverse bends in ropes. Reverse bends did not, as a rule, occur in cranes used for foundry and other purposes where the direct load was immediately below the source of power, but wire ropes were used very extensively in connection with passenger and other lifts, in which it was quite a common practice for makers to pass their ropes round one if not two reverse bends. Such an example existed in the front passenger hoist of the building in which the

(Mr. A. Basil Wilson.)

Meeting was being held, and afforded an opportunity of estimating the effect on the rope. As originally put up, the hoist contained two reverse as well as three primary bends. The result was that the ropes lasted approximately not more than one session of about nine months, making 400 or 500 lifts a week. It was subsequently altered, and the lifting apparatus put at the top of the house, so that there was only one bend in the ropes and that a direct one. Since this was done no deterioration had occurred. The ropes had remained externally as they were, with practically no wear unless in the centre of the rope due to friction of the parts.

He would very much like to have the author's opinion, and the opinion also of the members, on the deterioration that might be expected to arise from a reverse half-bend. It might be assumed that it was 50 per cent. of that of a complete reverse bend, but he agreed with the last speaker that the effect of the half reverse-bend was much greater than a reduction of the life of the rope by 50 per cent. It was probably more in the neighbourhood of 70 per cent., especially if the reverse bend was one over which the rope passed for its entire length. If it was merely a reverse bend which was used for a compensating pulley, in which the travel of the rope round the pulley was small, then it might be almost neglected. Some years ago he had occasion to erect an engine of about 200 h.p. where it was desired to have brake efficiency records, and where a well-known system was adopted for the purpose in view. The ropes passed round two reverse pulleys, the intention being to ascertain the brake load on the engine continuously by the use of a recorder indicating the difference in the position of the reverse pulleys as they varied with the load. The apparatus worked well so far as ascertaining the brake horse-power was concerned, but was unsatisfactory with regard to the ropes. These ran at 4,000 feet per minute (there were eight of them), and began to show signs of deterioration in three weeks. Obviously that system had to be abandoned, and the ropes were taken direct, under which conditions they lasted about eight years, when the arrangement was changed and the rope drive abandoned.

The PRESIDENT inquired whether the ropes were of cotton.

Mr. BASIL WILSON replied that they were steel ropes of $\frac{3}{8}$ -inch diameter. But the special point he wished to emphasize was how far in the opinion of the members half-reverse bends influenced the life of a rope, which in many cases it was impossible to avoid.

Mr. J. HARTLEY WICKSTEED asked whether Mr. Basil Wilson meant by a half-reverse bend 90° instead of 180° .

Mr. BASIL WILSON replied in the affirmative.

Dr. WILLIAM H. MAW understood that Mr. Wilson meant in another plane.

Mr. BASIL WILSON replied that that was the case. Theoretically it might be assumed that the degree of the reversal would be the measure of the amount of wear in the rope, but it was a matter only experience could decide. He was sure the members of the Institution appreciated that the Paper was one of the most valuable character, since it dealt with a question which entered very largely into the everyday practice of the engineer.

Mr. J. HARTLEY WICKSTEED (Past-President) said the President had made the very significant remark that the safety of ropes could only be ensured by proper inspection. He himself thought there was everything in that remark, because people did not quite realize the fact that if one single wire was broken in a rope, it upset the whole structure and was the beginning of the end. If all the constituent wires had been bound together to pull parallel with each other in straight lines, then the breaking of one wire would only reduce the strength of the rope by an aliquot proportion; but in fact the wires were spirally wound into strands, each complete strand was built up round a core, and each constituent wire was restrained by all the other wires in that strand from altering its pitch. If a single wire broke in this

(Mr. J. Hartley Wicksteed.)

one strand, the original structure of that strand was impaired and as soon as the loose wire worked out of its position, the curves of the other spiral wires would tend to straighten and the whole of that strand to lengthen, and to leave off doing its share of the work with the other strands. And when that strand had lengthened and worked out of its original position, it, in its turn, left off restraining the other strands, and the whole rope must lose its symmetry and become deformed. In other words, when a single wire broke, the rapid destruction of the whole rope was assured, if it kept on working under the same conditions as had broken the first wire, when the structure of the rope was perfect as a whole. He had tested a few ropes, one of which had 364 wires. It was a rope of about 8 inches circumference. By very careful attachments, every wire was in an equal state of stress, the rope broke clear of the attachments with 280 tons load and with a sound like the report of a heavy pistol. Of course the element of wear did not come in, in that direct test; but in the direct testing of ropes which he had made, he had always found that the gripping of every single wire, without any disturbance of the structure by splicing or otherwise, was essential for ascertaining the veritable strength of any rope, whether of wire or of hemp. He had tested hemp ropes spliced with eyelets for attachment, and out of a large number of tests, very few gave more than 5 tons ultimate strength. By means of certain attachments, which did not involve splicing or disturbing the coil of the rope, and did not involve the cutting or wounding of a single fibre in the rope, the loads went up to the region of 7 tons. He did not think the same care had been taken in the attachment of ropes in actual practice as had been found necessary for the attachment of ropes in order to prove them to their full capacity.

No doubt in mines or cranes the bending of the rope would destroy it before the attachments were destroyed. In deep mines, however, such as there were in South Africa, which were getting on for nearly a mile deep, some important wear of the rope took place near the attachment, on account of a tendency in the long rope to twist one way and the other way as it lengthened and shortened.

He did not know whether he ought to go any further into the subject of testing, but he might just mention that a machine had been devised, and experimented with on a small scale, which would put, in ten minutes, as much wear upon a rope as it might take ten years of actual work to do. It seemed to him that a great deal of time was wasted in making investigations and in collating the experience resulting from accidents and failures, which might be profitably saved by the spending of a few hundred pounds on an efficient machine, by which experiments could be made in a short time and without accidents.

He had found in his experience that machines could make discoveries. He would not say that they could make inventions, but they certainly could make discoveries. A machine could make discoveries that clever men had spent years over in searching for without discovering. A machine that was so constructed as to make a mechanical record of everything that happened—a continuous automatic record—would, he thought, be competent to clear up any outstanding questions there might be as to the endurance of ropes of different constructions, both up to the point of the first wire breaking, and afterwards, up to the complete destruction of the rope under the same conditions of loading and bending as subsisted at the time of the first failure of a single wire.

Dr. WILLIAM H. MAW (Past-President) said the author had referred quite rightly to the unnecessary use of reverse bends in a number of cranes that were generally employed. He thought in a large number of instances this arose from retaining arrangements which were perfectly satisfactory with chains, but which were decidedly unsatisfactory with ropes. A very prominent case of that kind was in the arrangement of foundry cranes, and cranes serving steam-hammers. A very common arrangement in such cranes was to have chains led over the pulleys as shown in the sketch, Fig. 13 (page 730). There was in this arrangement a 90° bend in one direction, next a reverse bend of 180° , and finally a 90° bend in the same direction as the original bend. Some years ago, when he was going through Messrs. Tannett-Walker's Works at Leeds, Colonel

(Dr. William H. Maw.)

Tannett-Walker showed him a very simple alteration which he had made in the cranes of this class, which was deserving of being adopted more largely. With cranes using chains the original arrangement was quite satisfactory; when ropes were put in very severe wear was experienced. To reduce this, Colonel Tannett-Walker put two pulleys side by side on the same axis, as shown in

FIG. 13.

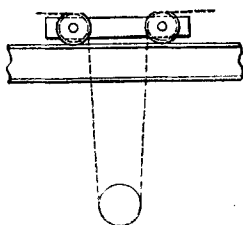


FIG. 14.

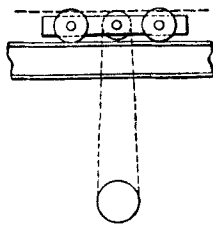


Fig. 14; he took the rope over one of these pulleys, then down to the hook pulley, round that pulley and then up over the second of the top pulleys. With that arrangement all the bends were in the same direction; and Colonel Tannett-Walker informed him that this simple alteration increased the life of the ropes, if he remembered rightly, about 50 per cent.

Mr. THOMAS JAMES said that one of the things which troubled him a little while ago was to what extent he could allow a rope on a crane to continue at work, assuming there were strands broken. He asked several engineers of experience what rule they followed in allowing a rope to continue at work after a certain number of strands had broken, presuming that very careful inspection was periodically made to see that there was no general deterioration in the rope; and he had some difficulty in getting any information from them. One engineer told him that he decided on the circumstances of the case at the time; another said that if it was not too bad, he would let it go on. Those seemed to him to be very unsatisfactory answers.

He had charge of a considerable amount of mechanical apparatus, and if he were asked why he allowed certain wire ropes

to continue working, he wanted to be in a position to give a satisfactory answer. He was able to refer to a few reliable tests, the results of which he would briefly quote to the Meeting. The first test was made on a rope of 2 inches circumference with six strands of 37 wires each, making 222 wires altogether, with hemp core. The basis upon which he set to work was that there should not be a factor of safety of less than 8 to 1. A rope, which had been in use for some time on that basis, was tested again and was found to be still within the margin, in fact it was rather curious that it came a decimal point or two over a piece of the same rope when new, namely, 8·23, as against 8·15, which was on record as its original factor of safety. Of that specimen two wires were subsequently broken, and the factor of safety still remained up to 8 to 1—actually 8·03, as compared with 8·23 with all the strands perfect. Continuing the experiment, 18 wires out of the 222 were cut through, and the factor of safety was then 7·5 to 1. Then an additional 20 wires were cut, that is, four in each of five strands, close together, in addition to 22 broken wires, and the factor of safety then fell to 7·42, that is, 42 wires cut or broken out of a total of 222, leaving the factor of safety 7·42 to 1. A piece out of the same length of rope was again tested, 72 of the wires being cut (12 in each strand) in addition to 1 wire already broken, the factor of safety falling to 7·125 to 1. One of the answers which he obtained from the engineers whom he consulted was that they would not let the rope be worked unless it appeared safe, and one would hardly let a rope go on working with 73 wires broken. As a final test, to bring it down to a much lower factor of safety, two out of the six strands were cut right through at opposite sides, in addition to 5 wires broken, making a total of 79 wires cut or broken, and a factor of safety was then obtained of only 5·34 to 1.

Those experiments led them to decide that the strength of the rope decreased proportionately with the number of broken wires, irrespective of whether the breaks occurred in the same strand, or were divided amongst the other strands. The object of the tests was to fix a necessary scrapping limit. It was rather a serious matter to scrap a rope too soon, and it was also a serious matter to

(Mr. Thomas James.)

see a rope working with certain of its strands broken, if one did not know exactly how it would stand. It was suggested that the results obtained from the experiments allowed a loss of 10 per cent. to be incurred, that is 22 wires cut still left 7·4 factor of safety against the original 8·2. That was without making any further allowance for margin of safety, or "so much for luck," an expression that an engineer ought hardly to use. But if 10 per cent. was allowed on figures from experiment, so much must be allowed for——

The PRESIDENT: The personal factor.

Mr. JAMES agreed with the President. So far as the experiments were concerned, the principle was adopted that wire ropes on cranes should not be worked when more than 4 per cent. of the wires were broken, all other things being satisfactory, with frequent periodical examinations to see that there was no general deterioration in the ropes.

The PRESIDENT inquired whether the rope on which the experiments were made was a new rope, or whether it had been already heavily worn.

Mr. JAMES replied that the rope had been in use for fifteen months, until two of the wires were broken.

Mr. THOMAS BURKE (Belfast Harbour Board) said that a good many wire ropes were used at the Belfast Harbour Works, in connection with which a system had been adopted whereby when the rope came from the crane-maker it received a number. It was put on the crane, and after a certain time it was taken off. No rope was allowed to work for longer than four months, if continuously working, or a certain number of turns. When a rope had lifted 10,000 tons, it was taken off. It was a 3-inch rope working over a 22-inch pulley with a straight lift where possible. The factor of safety used was not 8 to 1, but nothing less than 10 to 1.

The PRESIDENT inquired whether the rope was scrapped after it had lifted 10,000 tons.

Mr. BURKE replied in the affirmative. 10,000 tons was the maximum amount of work a rope was allowed to do. In the large 7-inch ropes a life of ten years was allowed.

Dr. H. S. HELE-SHAW (Member of Council) said there was one aspect of the question that had not been dealt with in the discussion, namely, the question of wear at the point of contact. If the ordinary lay was considered, in which the winding was taken across as in an ordinary rope, it would be seen that there was a great difference between the contact of the separate wires in this case and in the case in which Lang's lay was used. This resulted in a corresponding difference in the wear at the point of contact of a wire rope wound against the twist and a rope that was wound with the twist. It was known that Lang's lay gave trouble in connection with the rope as a whole, because it had not the property which kept the rope together, but it appeared to him to be a much better kind of rope from the point of view of contact wear. This was a point, however, on which some interesting questions arose. One thing was certain, that this contact wear for ropes running on pulleys needed investigation.

During the time that he was in South Africa a terrible accident occurred, in which forty Kaffirs were killed through the snapping of a rope, whereby they fell down the whole length of Robinson's deep mine—a distance of between three and four thousand feet. He was at the Technical Institute at Johannesburg then, and had the rope to examine. Taking a separate wire and stretching it out, he discovered that where it came in contact with the pulley it was worn through in many cases. All the wires that touched the pulley were worn at this point of contact. Why did that take place? There was no doubt, that what happened was that where the wire rope was bent round, the individual wire slipped on the pulley. There was not the slightest doubt that there must be a stretch on those large pulleys under the enormous strain, and

(Dr. H. S. Hele-Shaw.)

that the wire was not worn by pressing against the pulley but by slip in the actual take on and off owing to the stretch.

The accident in question practically led to the abandonment of the flat rope, though the flat rope appeared quite a feasible thing because it had so little bending strain. No doubt the reason why disasters occurred with flat ropes was because the ropes could not be inspected. The way to inspect an ordinary wire rope was to prise it open and examine the wires separately, but this could not be done with a flat rope. The suggestion he desired to make, in conclusion, was that the whole question of the wear of wire ropes over pulleys ought to be investigated by the Institution. He did not refer so much to the ropes that were used for direct pull, but to the ropes that were being put into use every day in ever-increasing numbers for driving over pulleys, and particularly in connection with lifts and hoists.

MR. DANIEL ADAMSON, in reply, in the first place thanked the President for pointing out the great importance of care and inspection in the use of wire ropes. The designer and the wire-rope maker might each do his best, but by negligent use afterwards the rope could very quickly be seriously damaged.

Mr. Robert Matthews (page 723) had criticized his method of comparing the number of bends to which the rope was subjected when working under the different arrangements indicated by Figs. 5-12 (page 716) and perhaps some explanation on this point was desirable. He (the author) took into consideration only the number of bends through which a given length of rope could pass while the load travelled from the lowest to the highest point; for example, in Fig. 5 (mentioned particularly by Mr. Matthews) the rope was certainly bent in more than one place, but as no portion of the rope could pass through more than one of the bends while at work he described this arrangement as including one bend. Turning to Fig. 6 (also quoted by Mr. Matthews), it would be quite in the ordinary course of events for one portion of the rope to pass under the bottom pulley (making a bend at entering and a second bend on leaving) and then on to the barrel (making a third

bend), and accordingly he had described this as a three-bend arrangement. The bend at the compensating pulley was not included in any example, because that portion of the rope did not pass any other pulleys and was therefore unaffected by the arrangement adopted for the drum and pulleys.

Mr. Matthews had quoted his reference to the compensating pulley at the foot of page 721. His intention in inserting that paragraph was to emphasize the importance of making the compensating pulley of reasonable size. Although it was not so important as the working pulleys, yet it was a point that must not be overlooked in the design. Mr. Matthews referred to Lang's lay as against the ordinary lay, and that had also been referred to by some of the other speakers; and it was also mentioned in the last few words of the Paper. The information he had from the rope makers was that the Lang's lay must be more carefully dealt with in putting on and in working than ropes with ordinary lay.

Mr. Matthews also took exception to the quotation of some figures given on page 710. It was perhaps not necessary to explain that he did not intend to imply that Mr. Matthews did not work his cranes efficiently, but he quoted those figures, as the only published figures with which he was acquainted, to show the great extremes that took place in the working of cranes. If there were any other authoritative figures available, he was sure all the members would be pleased to hear of them. Personally he was trying to emphasize the fact that some cranes worked hundreds of times and others only tens of times in the course of a week. He gathered from Mr. Matthews' remarks that he confirmed the accuracy of the figures, although he objected to the deductions which might be drawn from them. Mr. Matthews suggested that 20 to 25 times the diameter of the rope was suitable for barrels and pulleys. On page 718 of the Paper he had suggested that 7 circumferences, or say 22 diameters, was a reasonable figure. If Mr. Matthews would insist upon 25 diameters, or say 8 circumferences, for his barrels, and would make the bottom pulleys 2 circumferences larger, his (the author's) opinion was that the ropes would last twice as long as

(Mr. Daniel Adamson.)

they did at present. That was a point made in the Paper—that it was important to increase the diameters of the bottom pulleys.

Mr. Matthews also suggested that a double bend was worse than two ordinary bends. In making that statement he (the author) merely quoted from Mr. Biggart's results. If a reverse bend was worse than two ordinary bends, there was the greater reason for designing cranes and hoists so as to avoid them. There was one statement of Mr. Matthews with which he agreed, namely, that he hoped the discussion would help all the members to come to a right conclusion.

Mr. A. Basil Wilson also referred (page 725) to the disadvantage of reverse bends, and pointed out that, in the building in which the Meeting was being held, a hoist with two reverse bends and three primary bends lasted one session, whereas when an arrangement, including only one primary bend, was substituted very beneficial results followed. According to the Paper the rope should last seven times as long. Life was short, and it would be necessary to wait a little while to see whether that was the case, that is, that two reverse bends and three primary bends were seven times as destructive to the rope as the single bend now in use.

Mr. Wilson asked a question as to the effect of partial bends. His own opinion was that partial bends would be quite as objectionable as whole bends, if the loading was similar in the two cases. The opinion that had generally been held up to the present was that the life of a rope depended upon the stresses due to bending, but it depended very largely upon the amount of the abrasion that took place, and the amount of the abrasion depended certainly upon the loading between the rope and the pulley—exactly to what extent he had not been able to ascertain. As a rough approximation, a quarter of the wear and tear on a rope might be put down to the fatigue due to bending, and three-quarters of it to the abrasion which took place between the wires and the pulleys. That was a very rough approximation, but it showed the importance of considering abrasion when discussing the life of a rope. He suggested that with a partial bend the abrasion

might be proportionate to the angle included in the arc of contact with the pulley as compared with a 180° bend.

Mr. Wicksteed referred (page 727) to the difference between the strength of single wires and the aggregate strength of the same wires when built up into a rope. Ropes never quite attained the full strength of the aggregate wires in the rope, for the reason that Mr. Wicksteed explained, namely, the difficulty of equal loading of the wires. Mr. Wicksteed also emphasized the importance of the attachment of the wire rope to the hoisting appliance, and that was certainly a matter which deserved consideration under the heading of the Paper.

Another point Mr. Wicksteed mentioned was that in deep mines the effects of fatigue appeared to be shown at the attachment, presumably at the attachment to the cage rather than to the drum. Failures would generally occur at the attachment of the rope to the cage, if the breakage was due to the sudden starting of the load, for the reason that the effects of inertia were very much more severely felt at that point.

Mr. Wicksteed mentioned a testing machine for investigating the durability of ropes, and Dr. Hele-Shaw had suggested (page 734) that a Committee of the Institution should institute a research. The President had said the subject required research, and he would like personally to recommend the question of the durability of wire ropes to the consideration of the Council as a desirable object for investigation.

Dr. Maw referred (page 729) to the very frequent fault in human affairs of retaining old arrangements with new devices, until one found out the error and the mistake in so doing. Dr. Maw had given an example of an advantageous application of the common sense which engineers were to a smaller or greater extent endowed with, and it rather seemed to be a reflection upon Mr. Wicksteed's suggestion that a machine could find out such things. There was room both for the machine and for the brain power of the individual.

(Mr. Daniel Adamson.)

Mr. Thomas James gave some very interesting figures (page 731) obtained from the testing of ropes which had been in use about two years, and in which the strands were experimentally cut through, and suggested that when 4 per cent. of the wires were broken the life of the rope was ended. It was very difficult to count the number of wires broken in a rope unless they all happened to be in the same place, because if they were distributed along the whole length of the rope it might be thought that each wire was only one out of the 300 odd and that the other wires were intact near it. The suggestion was not original—it had been suggested to him during the Meeting—that the whole of the wires, or a very large number of the wires, might be broken in different parts of the same rope, the first intimation of which was that the rope pulled out; and, due to that element of luck which one speaker referred to, it frequently happened that the rope pulled out when under a very much smaller load than it had been previously carrying.

Communications.

Mr. H. LOWTHIAN BARGE wrote that, dealing with Section (a), quality of material and size of wire, the author remarked that some rope-makers claimed as an advantage for the stronger material that "it does enable smaller pulleys to be used." The writer would like to point out that what was claimed was not that smaller pulleys could be used, but that ropes of greater ultimate breaking stress might be used for pulleys of the same diameter.

With regard to paragraph 2 on page 709, it would appear that the author was assuming that, in increasing the number of wires, the additional wires were always added in the outer circumference of the strands, as he said that in a rope having four times as many wires in it, the pressure between the wires and the sheaves might be assumed to be one-quarter the pressure in the original case. As a matter of fact, when the number of wires in a rope was increased,

in almost all cases these wires were introduced in the centre of the strands. Fig. 15, Plate 39, showed ropes having various numbers of wires in each strand, which he hoped would make this point clear.

With regard to the internal abrasion (page 710), it was very desirable in ordering crane or other running rope that it should be specified that the individual wires should be thoroughly lubricated during manufacture. By this means a considerable amount of abrasion was avoided, as in oiling the outside of a rope it was by no means likely that the oil would percolate through to the inner wires of the multiple wire strands.

With regard to the last paragraph in the Paper (page 722), ropes made on the so-called Lang's lay principle should be used with both ends fixed or spliced into an endless band, otherwise they had a tendency to unlay. Undoubtedly ropes made on Lang's lay presented more wearing surface, as could be readily seen from the illustrations at the foot of Plate 39, but size for size with ropes of ordinary lay they were not so flexible, as well as having the disadvantages mentioned above. He thought the Paper was most interesting, and that it added considerably to the somewhat meagre amount of technical information available with regard to the working of wire ropes.

Mr. H. H. BROUGHTON wrote that he agreed, in the main, with many of the author's deductions. He was, however, of the opinion that numerical constants for the determination of the life of crane ropes based on Mr. Biggart's experiments were not as valuable to designers as they might have been, had the experiments taken into account several factors which had a far-reaching effect on the life of a rope. Three of the factors were:—(i) Frequency of starting and stopping; (ii) Effect of reversal; and (iii) Effect of impact. There were other factors that were not covered by Biggart's experiments.

He regarded with considerable suspicion the rule given in the Paper for doubling the life of a rope, and he would ask the author if his firm had succeeded in doubling the life of a rope in that way.

(Mr. H. H. Broughton.)

Perhaps he had drawn wrong conclusions, and to make certain he would like the author's opinion in a concrete case, namely:—that of a 50-ton crane with eight parts of rope, $3\frac{1}{8}$ inches in circumference, reeved double, and winding two parts on the barrel, block pulleys 22 inches in diameter. Was he correct in assuming that if the pulleys had been made $28\frac{1}{4}$ inches in diameter, the rope would have lasted twice as long?

It was his opinion that the author had not made it clear that very large proportions were necessary to ensure a reasonable life for ropes on cranes with many falls of rope. In the Table below he had set forth the summarized data for the lifting gears of five 50-ton cranes. The lifting speed was 10 feet per minute in each case, and the motors were each rated at 50 h.p. at 420 revolutions per minute.

	Number of parts of rope carrying the load.				
	4	6	8	10	12
Force on each rope . . . tons	$12\frac{1}{2}$	$8\frac{1}{3}$	$6\frac{1}{4}$	5	$4\frac{1}{6}$
Force acting on barrel . . . ,,	25	$16\frac{2}{3}$	$12\frac{1}{2}$	10	$8\frac{1}{3}$
Diameter of rope . . . inches	$1\frac{3}{8}$	$1\frac{1}{8}$	1	$\frac{7}{8}$	$\frac{3}{4}$
Circumference of rope . . . ,,	$4\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{1}{8}$	$2\frac{3}{4}$	$2\frac{3}{8}$
Diameter of barrel and sheaves ,,	33	27	24	21	18
Circumference of barrel and sheaves ft.	8.64	7.07	6.28	5.5	4.71
Speed of barrel . . . revs. per min.	2.32	4.25	6.37	9.1	12.74
Speed reduction	181	99	66	46.2	33

He would take the two extremes, namely, the cases where the load was supported by four parts of rope, and by twelve parts of rope. Neither was a freak arrangement. According to the author, the diameter of the barrel and sheaves for the small rope ($2\frac{3}{8}$ inches in circumference) should be made nearly equal to the diameter for the large rope ($4\frac{1}{4}$ inches in circumference) if the ropes had to be

equally durable. Did the author suggest that with a $\frac{3}{4}$ -inch rope and 18-inch sheaves, the rope would have only one-eighth the life of a $1\frac{3}{8}$ -inch rope on 33-inch sheaves? He considered a $\frac{3}{4}$ -inch rope and 18-inch sheaves to be a very liberal design, and with proper attention the rope would last for years.

On the question of rope lubrication he was in entire agreement with the author, and he thought that makers would be well advised to provide an appliance on the trolley for lubricating the rope. He agreed that compensating pulleys should be of large diameter, in order to minimize the effect of repeated bending of the rope at the same place due to the slight movement of the rope.

With regard to "Lang's lay" rope, his attention had recently been drawn to a rope in which the strands were double, one on the other, so arranged that each rope acted against the tendency of the other to twist, which ensured the rope remaining even without any tendency to spin.

As an advocate of the application of scientific principles to the design of crane mechanisms, he thought the Paper was a valuable addition to the literature on the subject. No one would deny that the question of rope life was important, but there were many other such questions which would have to be tackled before crane practice could be considered satisfactory.

Mr. GEORGE HUGHES (Member of Council) wrote that the Lancashire and Yorkshire Railway Company employed a large number of wire ropes, and the tabulated statement (pages 744-7) gave full particulars of some of them, of which he had every reason to believe that the observations were accurately made. He gave them as existing facts, leaving the members to conclude that the weak points would be rectified. These perhaps might be of greater service to the members than adopting a counsel of perfection.

On analysing the statement, it would be noted that the poorest life in number of lifts was Victoria Street Depot (Liverpool) goods lift, namely 9,396 lifts with a ratio of 36 and middle grade of steel and lowest flexibility, Lang's lay. The ratios of pulley diameters

(Mr. George Hughes.)

were good, namely, 36 and 47. On the face of it this should be one of the longest-lived ropes. The average lift was 13 cwt. against 30 cwt. capacity. This rope must have been injured although there was no record of it. The best life was Bolton goods hoist with 478,675 lifts. The pulley ratios were very good, namely, 36·5 and 47. Lang's lay, middle grade of steel and middle flexibility. It would be expected that this should also be good, but a lower grade of steel and a lower flexibility should suffice in the ordinary way. The next best was the fellow to this hoist on the other platform.

The next two examples were Liverpool, Victoria Street Depot, passenger hoist. Ratios 51 and 36. Lang's lay. Cheapest grade of steel. The next two were the ropes on the Halliwell electric 30-cwt. cranes. Ratios only 20·5. Middle grade steel, lowest flexibility, ordinary lay (old). The next two were cranes—one 5-ton at Newton Heath and the other 7-ton steam jib-crane at Wyre Dock. Neither of these was worn out yet. Ratios 24 and 14·5, the latter being very low indeed; it was a special compound rope known as "Nuflex." The Newton Heath crane is middle steel and lowest flexibility. The next three 9, 10, 11, are Newton Heath overhead cranes. Ratios 21 to 27. 3rd flexibility, middle steel. The average load per lift was very low indeed. Owing to their high flexibility the ropes were liable to injury.

Dealing with some of the others, namely, Werneth Cotton Shed overhead cranes, 15,794 and 23,700 lifts. These were low and their ratios were 19·8. Lowest grade steel. Ordinary lay and lowest flexibility. For this ratio and ordinary lay a higher flexibility and a middle grade steel should give a longer life. Wyre Dock transporter, Fig. 27 (page 743), 40,491 lifts, which was very poor. The ratio, 18·8, was bad, and there was a treble turn. The wear was excessive and new pulleys were being provided to overcome this trouble. Compound ropes. Lowest grade steel.

The two cranes in the heavy machine shop at Horwich gave a low life to their ropes. They had a middle flexibility and middle quality of steel, with 19·4 ratio, which was evidently the trouble. The ropes were large and should have 26–30 ratios. The top one in the list, namely, Horwich stores yard 30-cwt. electric crane, was bad

Examples of Pulley Arrangements for Wire Ropes on Cranes and Hoists of the Lancashire and Yorkshire Railway Company. (Figs. 18-31 are referred to in Table, pp. 744-7.)

FIG. 16.

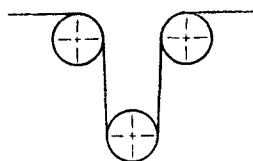


FIG. 19.

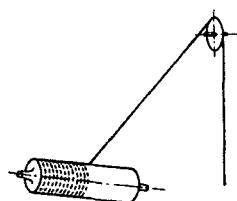


FIG. 22.

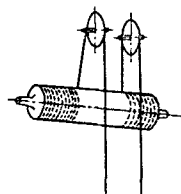


FIG. 26.

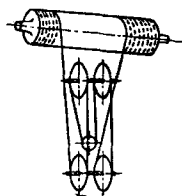


FIG. 29.

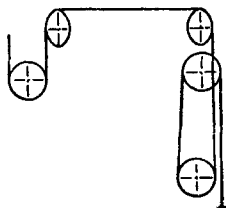


FIG. 17.

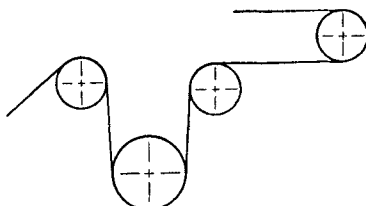


FIG. 20.

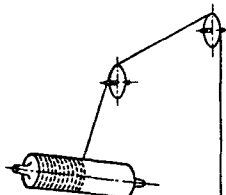


FIG. 23.

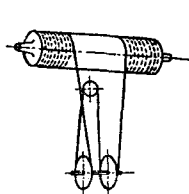


FIG. 27.

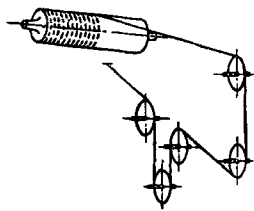


FIG. 30.

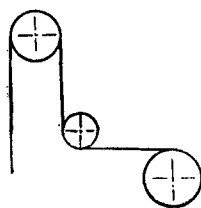


FIG. 18.

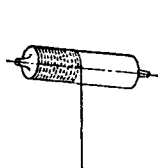


FIG. 21.

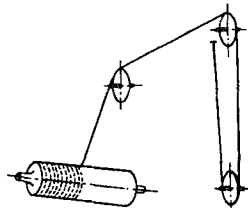


FIG. 25.

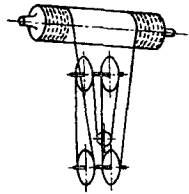


FIG. 28.

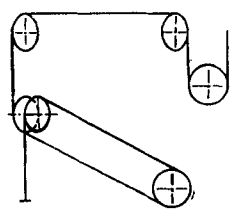
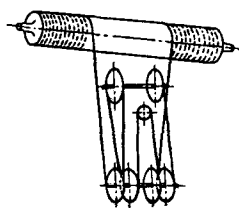


FIG. 31.



(Mr. George Hughes.)

TABLE 1 (continued on opposite page).

*Particulars of Work done by Wire Ropes on Specific Cranes and Hoists
on L. & Y. Railway during the month of May 1912.*

Arranged in Order of Merit.

Fig. (p. 743).		Place.	Appliance.	Registered Capacity.		Maker of Lifting Appliances.
				t.	c.	
1	19	Bolton Passenger, Down Platform	Electric Goods Hoist	1	10	Waygood
2	19	" " Up Platform	" " "	1	10	"
3	30	Liverpool, Victoria Street Depot	Electric Passenger Hoist	0	7	"
4	30	" " " "	" " "	0	7	"
5	18	Halliwell Goods Warehouse	Electric Overhead Crane	1	10	Crompton
6	18	" " " "	" " "	1	10	"
7	20	Wyre Dock	Steam Road Crane	4	0	Isles
8	24	Newton Heath Machine Shop	Electric Overhead Crane	5	0	Heywood & Co.
9	24	" " Lifting Shed, W.	" " "	10	0	J. Berry
10	24	" " " " E.	" " "	10	0	"
11	23	" " Saw Mill	" " "	5	0	Craven Bros.
12	19	Bolton Goods Warehouse	Electric Jib Crane	2	10	P. R. Jackson
13	19	" " " "	" " "	1	10	"
14	24	Horwich Millwrights' Shop	Electric Overhead Crane	10	0	J. Berry
15	26	Bolton Goods	Electric Goliath	40	0	A. Chaplin
16	24	Horwich Millwrights' Shop	Electric Overhead Crane	10	0	J. Berry
17	21	Wyre Dock	Steam Road Crane	7	0	Isles
18	23	North Mersey	Electric Cantilever Crane	10	0	Musker
19	26	Horwich Millwrights' Shop	Electric Overhead Crane	20	0	J. Berry
20	28	Goole Railway Dock	{ Hydraulic Coal Tip Table Tipping }	40	0	Tannett-Walker
21	27	Wyre Dock	Electric Transporter	1	5	Cowans Sheldon
22	23	Horwich Heavy Machine Shop	Electric Overhead Crane	10	0	Vaughan
23	20	Wyre Dock	Steam Road Crane	4	0	Isles
24	23	Horwich Heavy Machine Shop	Electric Overhead Crane	10	0	Vaughan
25	19	" Stores Yard	Electric Jib Crane	1	10	P. R. Jackson
26	18	Werneth Cotton Shed	Electric Overhead Crane	0	15	Spencer & Co.
27	31	Newton Heath Saw-Mill Gantry	" " "	7	10	Heywood & Co.
28	18	Werneth Cotton Shed	" " "	0	15	Spencer & Co.
29	22	Liverpool, Victoria Street Depot	Electric Goods Hoist	1	10	Waygood
30	25	Horwich Boiler Shop	Electric Gantry	15	heavy	L. & Y. Railway
31	29	Goole Railway Dock	{ Hydraulic Coal Tip (Hopper Tipping) }	40	0	Tannett-Walker
32	19	Bolton Goods Warehouse	Electric Goods Hoist	1	10	P. R. Jackson

(continued on next page) TABLE 1.

*Particulars of Work done by Wire Ropes on Specific Cranes and Hoists
on L. & Y. Railway during the month of May 1912.*

Arranged in Order of Merit.

	Circumference of Rope.	Class of Steel.	Construction.	No. of Strands, and Wires in each Strand.		Diameter of Barrel.	Diameter of Jib-Head Pulley.	Diameter of Bottom Pulley.
	inches.			strands.	wires.	inches.	inches.	inches.
1	2	Improved Plough	Lang's Lay	6	27	23 $\frac{1}{4}$	—	—
2	2	" "	"	6	27	23 $\frac{1}{4}$	—	—
3	2	Improved Crucible	"	6	12	32 $\frac{1}{2}$	—	—
4	2	" "	"	6	12	32 $\frac{1}{2}$	—	—
5	1 $\frac{3}{4}$	Improved Plough	old	6	19	11 $\frac{3}{8}$	—	—
6	1 $\frac{3}{4}$	" "	"	6	19	11 $\frac{3}{8}$	—	—
7	3 $\frac{1}{4}$	Improved Crucible	Compound	34	7	15	24	—
8	1 $\frac{1}{2}$	Improved Plough	Ordinary	6	19	11 $\frac{1}{2}$	—	14
9	2	" "	"	6	30	13	—	13
10	2	" "	"	6	30	13	—	13
11	1 $\frac{1}{4}$	" "	"	6	19	13 $\frac{1}{8}$	—	10 $\frac{1}{2}$
12	2 $\frac{1}{4}$	" "	old	6	37	14 $\frac{5}{8}$	14 $\frac{3}{8}$	—
13	1 $\frac{3}{8}$	" "	"	6	14	13 $\frac{1}{2}$	11 $\frac{3}{8}$	—
14	1 $\frac{7}{8}$	" "	Ordinary	6	19	13	—	13 $\frac{3}{4}$
15	3 $\frac{3}{8}$	" "	Lang's Lay	6	37	23	—	21
16	1 $\frac{7}{8}$	" "	Ordinary	6	19	13	—	13 $\frac{3}{4}$
17	2 $\frac{3}{4}$	" "	Compound	34	7	18	21	17
18	2 $\frac{1}{4}$	" "	Lang's Lay	6	27	17 $\frac{1}{4}$	—	17 $\frac{1}{2}$
19	2 $\frac{1}{4}$	" "	Ordinary	6	27	14 $\frac{1}{2}$	—	17 $\frac{7}{8}$
20	3 $\frac{3}{4}$	" "	Compound	34	7	36	—	—
21	2	Crucible	"	17	7	24	—	12
22	2	Improved Plough	Ordinary	6	27	15	—	12 $\frac{3}{8}$
23	3 $\frac{1}{4}$	Improved Crucible	"	34	7	15	24	—
24	2	Improved Plough	"	6	27	15	—	12 $\frac{3}{8}$
25	1 $\frac{5}{8}$	" "	"	6	19	11 $\frac{3}{4}$	12	—
26	1 $\frac{5}{8}$	Improved Crucible	old	6	14	10 $\frac{1}{4}$	—	—
27	1 $\frac{1}{4}$	Improved Plough	Ordinary	6	19	18	—	12
28	1 $\frac{5}{8}$	Improved Crucible	old	6	14	10 $\frac{1}{2}$	—	—
29	2	Improved Plough	Lang's Lay	6	19	23	—	—
30	2	" "	Ordinary	6	27	20 $\frac{3}{8}$	—	18 $\frac{1}{8}$
31	4 $\frac{1}{2}$	" "	Compound	34	7	42	—	—
32	2 $\frac{1}{4}$	" "	Lang's Lay	6	37	35 $\frac{1}{2}$	—	—

(Mr. George Hughes.)

TABLE 1 (continued from previous page).

*Particulars of Work done by Wire Ropes on Specific Cranes and Hoists
on L. & Y. Railway during the month of May 1912.*

Arranged in Order of Merit.

Fig. (p. 748).		Place.	Appliance.	Diameter of Guide or Jockey Pulley.	Days Worked.	Lifts Made. (a)
				inches.		
1	19	Bolton Passenger, Down Platform	Electric Goods Hoist	29 $\frac{3}{4}$	27	12,337
2	19	" " Up Platform	" " "	29 $\frac{3}{4}$	27	8,187
3	30	Liverpool, Victoria Street Depot	Electric Passenger Hoist	23	26	2,603
4	30	" " " "	" " "	23	26	2,563
5	18	Halliwell Goods Warehouse "	Electric Overhead Crane	—	27	9,450
6	18	" " " "	" " "	—	27	10,974
7	20	Wyre Dock	Steam Road Crane	21	17	6,475
8	24	Newton Heath Machine Shop .	Electric Overhead Crane	—	25	8,564
9	24	" " Lifting Shed, W.	" " "	—	26	3,341
10	24	" " " " E.	" " "	—	26	6,481
11	23	" " Saw Mill . . .	" " "	—	25	3,628
12	19	Bolton Goods Warehouse . .	Electric Jib Crane	—	27	2,972
13	19	" " " "	" " "	—	27	3,877
14	24	Horwich Millwrights' Shop .	Electric Overhead Crane	—	27	993
15	26	Bolton Goods	Electric Goliath	—	27	2,687
16	24	Horwich Millwrights' Shop .	Electric Overhead Crane	—	27	955
17	21	Wyre Dock	Steam Road Crane	17	13	1,422
18	23	North Mersey	Electric Cantilever Crane	—	26	2,422
19	26	Horwich Millwrights' Shop .	Electric Overhead Crane	—	27	650
20	28	Goole Railway Dock	Hydraulic Coal Tip	—	25	2,626
21	27	Wyre Dock	Electric Transporter	12	25	8,998
22	23	Horwich Heavy Machine Shop .	Electric Overhead Crane	—	27	4,016
23	20	Wyre Dock	Steam Road Crane	21	13	1,408
24	23	Horwich Heavy Machine Shop .	Electric Overhead Crane	—	27	1,880
25	19	" Stores Yard	Electric Jib Crane	—	27	527
26	18	Werneth Cotton Shed	Electric Overhead Crane	—	26	7,900
27	31	Newton Heath Saw Mill Gantry	" " "	—	24	3,251
28	18	Werneth Cotton Shed	" " "	—	26	7,897
29	22	Liverpool, Victoria Street Depot	Electric Goods Hoist	30	26	87
30	25	Horwich Boiler Shop	Electric Gantry	—	27	876
31	29	Goole Railway Dock	Hydraulic Coal Tip	—	20	50
32	19	Bolton Goods Warehouse . . .	Electric Goods Hoist	16	27	2,171

(concluded from page 744) TABLE 1.

*Particulars of Work done by Wire Ropes on Specific Cranes and Hoists
on L. & Y. Railway during the month of May 1912.*

Arranged in Order of Merit.

	Average Load per Lift. (b)	Average Height Lifted.	Maximum Load.	Minimum Load.	Life of Rope Already Renewed.	Life of Rope in Number Lifts of based on (a).	Life of Rope in Tons Handled per Rope.	Ratio of Barrel Diameter to Rope Diameter.	Ratio of Bottom of Jockey Pulley Diameter to Rope Diameter.
	t. c.	feet.	t. c.	t. c.	months.			diameters.	diameters.
1	0 4½	17.5	1 8	0 1	38.8	478,675	108,180	36.5	47
2	0 5.1	17.4	1 8	0 1	45.5	372,508	95,548	36.5	47
3	0 4½	90	0 7	0 1	27	304,551	68,521	51	36
4	0 4½	90	0 7	0 1	27	299,871	67,471	51	36
5	0 5.9	12	1 8	0 0¾	26.25	248,062	72,680	20.5	—
6	0 5.4	6.7	1 8	0 1	21	230,454	62,107	20.5	—
7	0 9.1	17.2	3 0	0 3	27*	174,825	79,545	14.5	23.2
8	0 6½	6	5 0	0 1	17*	145,588	48,962	24.1	29.4
9	0 7	5.1	5 0	0 1	42	140,322	49,604	21	20.4
10	1 11	10.3	10 0	0 1	18	116,658	123,135	21	20.4
11	0 12½	13.5	5 0	0 1	30	108,840	68,400	27.5	22
12	0 4.6	5.4	1 6	0 1	32.3	106,000	24,576	20.4	20
13	0 4.6	5.6	10 0	0 1	20.8	80,641	18,547	26	22
14	0 5	4	5 0	0 0½	74*	73,482	18,370	21.8	23
15	1 2	7.2	20 0	0 1	26.7	71,877	79,208	18.6	17
16	0 5½	4	5 0	0 0½	74*	70,670	18,551	21.8	23
17	0 17.1	15.5	6 0	0 4	48	68,256	58,700	20.6	19.5
18	1 9	5.7	9 15	0 2	24	58,128	84,285	24	24
19	0 5½	3.7	4 0	0 0½	74*	48,100	13,227	20.2	25
20	17 10	30	29 18	10 9	18	47,268	827,190	30	None
21	0 17½	21.5	1 5	0 0½	4.5	40,491	35,429	37.7	18.8
22	1 8	14	10 0	0 2¼	10	40,160	56,880	23.6	19.4
23	0 10.3	14	3 0	0 4	25*	35,200	18,128	14.5	23.2
24	0 19	14	10 0	0 2½	17	31,960	30,362	23.6	19.4
25	0 8	6	1 3	0 2	54	28,358	11,343	22.7	23.4
26	0 4½	12	0 6¾	0 3	3	23,700	5,334	19.8	None
27	0 7¾	6	5 0	0 1½	5*	16,255	6,397	33	25
28	0 4½	12	0 6¾	0 3	2	15,794	3,553	19.8	—
29	0 13	25	1 5	0 4	108	9,396	6,107	36	47
30	1 15	6	11 6	0 0½	6*	5,256	9,198	32	28.5
31	17 7	38	29 1	4 11	60	3,000	52,050	31	None
32	0 10.8	25	1 8	0 1	23.1	2,508	27,236	49.5	22.3

* First rope still in service.

(Mr. George Hughes.)

(28,358 lifts), for which there seemed no reason. Ratio 22·7, middle grade steel, lowest flexibility, ordinary lay. There should be a larger pulley and barrel. North Mersey cantilever was low lived. Ratio 24, middle flexibility, middle grade steel, Lang's lay. Wyre Dock steam cranes were bad. The ratio was low (14·5 and 20·6), although one crane was three and five times better than the other. They gave out where fastened to the socket with lead, owing to galvanic action.

All wire ropes were kept well greased or oiled, and galvanized ropes were not used. Their renewals were based upon the life of the rope preceding the present rope, except where the rope had had an accident. In a few cases it was the average of several renewals. Lang's lay could only be used in hoists where the ends were both fixed. Otherwise the ropes would unravel. Ordinary lay was less liable to unravel, but the wear on the rope was greater because a lesser surface of the wires lay upon the pulley. They tried to overcome this by using compound or "Nuflex" ropes, but the objection to these was their delicacy; they were easily injured by rubbing against anything, or a blow, or one coil lapping on another. The most surprising part of the report was the good work done by the Halliwell crane ropes, which were very hard worked and had a ratio of only 20·5 with a loose end.

The conclusions the writer drew were as follows:—

1. In general, use the lowest grade of steel.
2. In general, use the middle flexibility.
3. Use Lang's lay, if possible.
4. Ratio of pulley to rope diameter not less than 26.
5. 30 was better if it could be obtained.
6. If 30 to 40 could be got, use it and keep then to the lowest flexibility instead of middle flexibility.
7. Try to avoid special kinds of ropes.
8. If queer double turns were necessary like those shown in Fig. 17 (page 743), then let there be scarcely any limit to the pulley diameters, and have ratio to rope diameters, say 45 to 50, if at all possible. Only in this direction could reasonable length of life be secured.

Mr. C. HUMPHREY WINGFIELD wrote that, although much good work had been achieved in showing how experimental results applied to practical design, much still remained to be done. Mr. Adamson's Paper was a most valuable contribution to practical science in this respect. While fully agreeing with the emphasis which the author laid on the necessity for lubrication and the bad effect of reverse bends on wire ropes for cranes, he (Mr. Wingfield) found it difficult to follow the reasoning on pages 708-9, by which the author arrived at the result that of two ropes of equal diameter, sectional area, and load, one of which was made with wires half the diameter, and therefore four times as numerous as those in the other, the finer wires would wear out in half the time that the coarser ones would do if used on the same sized pulley, and in one quarter of the time if the diameter of the pulley bore the same proportion to that of the wires in each case. These ropes were usually made in six strands, and, if embraced by a closely fitting semicircular groove in a pulley, the maximum number of wires in contact with the groove at any section of an ordinary crane rope would be about six. Reference to the sectional views of flexible wire ropes given in certain makers' catalogues, indicated that with wires of half the usual diameter as many as nine might touch the pulley, if the diameter of the rope were the same as before. Thus the number of points of contact at a given section would be nine-sixths or only 50 per cent. more with the finer wire.

He (the writer) might be wrong, but he thought the author (page 709) had overlooked the fact that the pressure of individual wires on the pulley was not solely due to the tension in those particular wires, but also to the squeezing effect of the outer wires. Thus the total pressure on the pulley would be identical in the two cases, and the pressure per wire in the special rope would be six-ninths or two-thirds of that in the case of the ordinary rope. The author said it would be one-fourth. The pressure per square inch would vary inversely as the diameter of the wire and of the length in contact with the pulley (of which the latter's diameter was a measure). Hence, for the fine wires it would be $(\frac{2}{3} \div \frac{1}{2}) = \frac{4}{3}$ of that of the coarser wires if used on the large pulley and $\{\frac{2}{3} \div (\frac{1}{2} \times \frac{1}{2})\} = \frac{8}{3}$ in the case of the smaller pulley.

(Mr. C. Humphrey Wingfield.)

The rate of wear might reasonably be expected to bear some relation to the relative motion per inch of wires near the pulley, and, so far as bending alone was concerned, this would vary as the ratio of the diameter of the wire to that of the pulley.* Hence the rate of wear would perhaps be found to vary as this motion multiplied by the pressure per square inch against the sides of the wire, and the time required for the rope to wear out would then vary as the reciprocal of this multiplied by the diameter of the wire. If so, the fine wire on a larger pulley should last three-quarters as long as the coarser wire, and on a smaller pulley only three-sixteenths as long.

The following Table showed these calculations in detail.

Diameter of wire (d)	1	$\frac{1}{2}$	$\frac{1}{2}$
Diameter of pulley (D)	1	1	$\frac{1}{2}$
Total pressure on pulley P	1	1	1
No. of wires in contact with pulley. N	6	9	9
Pressure, per wire, on pulley $\left(\frac{6}{N}\right)$. . .	1	$\frac{2}{3}$	$\frac{2}{3}$
Pressure on wire per sq. in. $\frac{6}{dND}$. . . (p)	1	$\left(\frac{2}{3} \div \frac{1}{2}\right) = \frac{4}{3}$	$\left\{ \frac{2}{3} \div \left(\frac{1}{2} \times \frac{1}{2}\right) = \frac{8}{3} \right\}$
Amount of sliding per inch of wire $\frac{d}{D}$ (S)	1	$\frac{1}{2}$	1
†Rate of wear $\frac{6}{ND^2}$ (W)	1	$\frac{2}{3}$	$\left\{ \frac{2}{3} \div \left(\frac{1}{2} \times \frac{1}{2}\right) = \frac{8}{3} \right\}$
Time to wear to centre of wire $\left(\propto \frac{d}{W}\right)$ (T)	1	$\frac{1}{2} \div \frac{2}{3} = \frac{3}{4}$	$\frac{1}{2} \div \frac{8}{3} = \frac{3}{16}$

The writer did not put these figures forward as of any value beyond indicating the direction which further experiments should take. So far as possible he had taken the figures for the thicker wire as of unit value.

* The total relative movement, in one direction, between two contiguous wires at different radii was twice as great when two bends in opposite directions occurred as when the rope bent in one direction only.

$$\dagger p \times S = \left(\frac{6}{dND} \times \frac{d}{D} \right) = \frac{6}{ND^2}.$$

The author (page 709) rather despaired of any agreement being arrived at as to the effect of stress apart from wear, on the endurance by metals of repeated applications of load. During the discussion of Messrs. Eden, Rose, and Cunningham's Paper, the writer exhibited diagrams * which showed that, when allowance was made for the varying ultimate strengths of the materials, the experiments of different investigators were more consistent than might perhaps have been hoped for. He had been unable to conjecture why the author suggested that a reduction of from 40 to 25 tons range should increase the life 500 times. However, from Fig. 56 (in loc. cit.) he would have thought about $\frac{6000}{150}$, or say 40 times, would be a nearer approximation. He fully agreed, however, that even this figure was not likely to be approached in practice, and that abrasion was a more serious factor in the determination of the life of a rope.

The writer presumed the author did not attach much importance to Fig. 2 (page 713), as several of the lines seemed to depart rather widely from the dots through which the lines in Fig. 1 were drawn. He had checked several of the dotted lines in Fig. 3 (page 715), and found that they were accurately drawn through the experimental dots, so that the author's very simple and practical rule (page 714) was reliable to the extent shown by the divergence of the full and dotted lines in that Figure.

The question of the stress in a rope, subjected to bending as well as to tension, had not been satisfactorily determined. In Fig. 56 (already referred to) the writer had laid down the lowest line but one of the author's Fig. 1 (page 712), calculating the stress on the usual assumption; namely that the effect of bending in producing stress on the wire was the same as if it were parallel with the axis of the rope, and that the same applied to the effect of the longitudinal pull on the rope, the stresses given in the diagram being the sum of these two results. Obviously, owing to the twisted form of the rope, a torsional stress was produced on the wire by

* Proceedings 1911, Part 4, Figs. 55 and 56 (pages 905-6).

(Mr. C. Humphrey Wingfield.)

either bending or pulling the rope. Professor Unwin in his last edition of "Machine Design" had given, somewhat tentatively, a formula for making a correction on this account, but it was probably not worth while to complicate the calculations in this way when merely requiring relative results, as in this case. The friction on the pulley might very possibly have a still more serious effect, however, since instead of bending about its neutral axis there would be a tendency for the rope to bend about an axis nearer the pulley, as the sliding necessary for the first assumption to be true would be checked.

With regard to the last paragraph in the Paper (page 722), he understood that, for such purposes as hoisting men and material in the mines of the Transvaal, "Lang's lay" was used in preference to nearly every other make. Of course in such cases the cage was guided, which bore out what the author said as to this rope being most suitable in cases where spin was prevented.

The great importance of the points in design to which the author drew attention in Figs. 4 to 12 (page 716) and in the following pages, was very apparent after consideration of the facts which he demonstrated, and reference to catalogues of crane-makers showed that they had hitherto escaped notice. He trusted the discussion would be found worthy of the time and trouble such a Paper must obviously have taken to produce, and that the generosity with which Mr. Adamson had placed his results at the disposal of rival makers would be fully recognized. The writer wished to suggest that information should be given by rope-makers as to the behaviour of the hemp packing. To what extent was it efficient in preserving the strands in their original positions after a year or two of wear?

With regard to the suggestion made during the discussion that this subject was a matter well adapted for experimental examination, he (Mr. Wingfield) would like most heartily to support this proposal.

Mr. DANIEL ADAMSON wrote, in reply to Mr. H. Lowthian Barge (page 738) that he (the author) would quote the actual paragraph from a ropemaker's letter upon which the statement referred to

was based: "This wire (115 tons per square inch) allows of a fairly small rope being used, and the advantage of this is that the working parts of the crane can be made smaller, which decreases the cost of the crane, though perhaps the rope might be somewhat higher in price than if it were made from steel of 90 tons per square inch." Mr. Barge made what appeared to be the same claim in different words, in that he would use pulleys of the same diameter for ropes carrying greater loads. Whatever ropemakers might say, there was a very general feeling amongst rope-users that a low tensile strength was preferable (*see* Mr. Hughes' Communication, page 748).

Regarding the number of wires in contact with the pulley with ropes of fine wires, as compared with ropes of coarse wires, the author was aware that grave doubts existed as to his estimate of four times the number, but if the increase were less than this, then the pressure per wire would be increased and the rope of fine wires would be shown (as it was known to be) even less durable.

In reply to Mr. H. H. Broughton (page 739), the author was sorry he could not yet say that the life of any ropes had been doubled by increasing the diameter of the bottom pulleys, because of the length of time involved by the question, but he could say that since he had been acquainted with the deductions to be made from Mr. Biggart's experiments he had given his own designs the benefit of them. The concrete case stated by Mr. Broughton of a 50-ton crane with eight parts of $3\frac{1}{8}$ inches circumference, rope and block pulleys 22 inches diameter, seemed to provide for a very low factor of safety (only about 6.6 as compared with the usually accepted minimum of 8); the ratio of rope circumference to pulley diameter (seven to one) was therefore illusory. Assuming a reasonable factor of safety and accepting the conclusions in the Paper under discussion, the rope ought to be $3\frac{1}{2}$ inches circumference and the barrel and pulleys 30 to 33 inches diameter, to give a life equal to a four-part arrangement of 5 inches circumference rope as Fig. 6 (page 716), with barrel and pulleys of the same diameter, that is, 30 to 33 inches. Answering Mr. Broughton's direct question, the

(Mr. Daniel Adamson.)

author believed that increasing the diameter of the pulleys, Fig. 12 (page 716), would lengthen the life of the rope by 50 per cent. (as stated on page 720). Whether the life of the rope would be doubled depended upon the average height of lift (as explained on page 721).

Replying to Mr. Broughton's other question regarding the proportions given in the Table (page 740), the author considered that larger ropes should be adopted throughout, and further that the ratio of pulley to rope diameter—about 22 to 1 in the list—should be increased to 33 to 1 for the design with 12 parts of rope to ensure reasonable durability (*see* Table 3, page 718). If the ratio were retained at 22 to 1 throughout the series, the life of the rope with twelve parts would only be one-quarter of that of the rope with four parts, according to Table 1 (page 717).

Mr. Broughton asked whether the life of a $\frac{3}{4}$ -inch diameter rope on 18-inch sheaves would be one-eighth of that of a $1\frac{3}{8}$ -inch diameter rope on 33-inch sheaves, but such a suggestion was not contained in the Paper, and the author thought Mr. Broughton must have misread page 721 which referred to a special advantage of Fig. 12, where large pulleys were used on a four-part rope. This advantage would not apply to a twelve-part arrangement, because the portion of the rope which passed under the lower pulleys would in this case soon reach the upper drum and be subjected to the further bends there. The author quite agreed with Mr. Broughton's closing remarks as to the numerous questions in crane design that awaited ventilation, and hoped that other members would take them up in the near future.

The members generally would feel much indebted to Mr. George Hughes for the very complete tabulation of experiences with wire-lifting ropes that he had contributed to the discussion (pages 744-7). This showed the great variation that was found in the conditions under which wire ropes were used, and the extreme difficulty of arriving at any conclusions whatever under working conditions.

In reply to Mr. Wingfield (page 749), the author was quite prepared to accept the suggestion that the number of points of contact between the rope and pulley might only be 50 per cent.

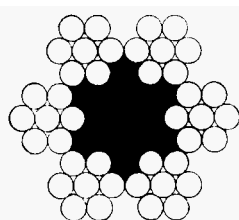
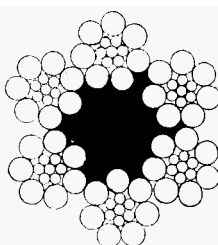
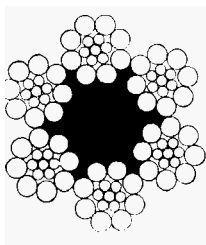
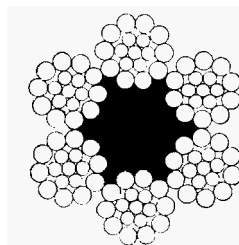
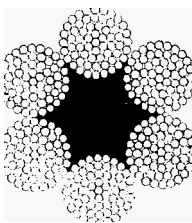
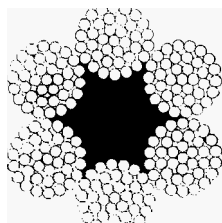
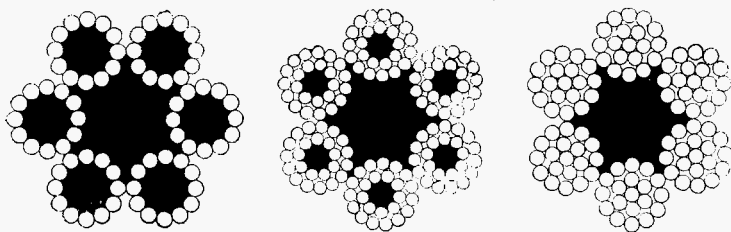
greater with the rope of finer wires suggested in the Paper, and accordingly the pressure per wire would be two-thirds as great as in the case of the ordinary rope instead of one-quarter as suggested in the Paper. This greater pressure would accentuate the wear and give even a shorter life than was suggested by the author, and accordingly the case of the rope of fine wires would be much worse than stated. Where the author differed from Mr. Wingfield was in estimating the rate of wear which Mr. Wingfield suggested would vary as the product of the pressure per square inch and the ratio of the diameter of the *wire* to that of the pulley. If this were the case, ropes of very fine wire would last longer than those of coarse wires, which was found not to be the case. However, all these imaginary discussions leading to different assumed results showed the desirability of having some reliable experiments carried out at the earliest opportunity.

The author's suggestion that a reduction from 40 tons to 25 tons range of stress would increase the life of materials subject to repeated applications of load by 500 times was only a very rough approximation from Fig. 56 of the discussion on Messrs. Eden, Rose and Cunningham's Paper.* Even if the increase were only 40 times, as suggested by Mr. Wingfield, it showed that the life of ropes was affected very much more by abrasion than by internal stresses.

* Proceedings, 1911, Part 4, Fig. 56 (page 906).

(Mr. H. Lochian Barge's communication.)

Fig. 15. Nine Ropes showing various numbers of wires in each strand.



Lang's lay Rope, New and Worn

