

(*Paper No. 2447.*)

“Wire-Ropes.”

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THE experiments described in this Paper were undertaken with the object of discovering some practical means of selecting the best form of wire-rope to be employed in the erection of the Forth Bridge. When it is stated that upwards of 60 miles of wire-ropes were employed in connection with that undertaking, the importance of the investigation becomes obvious. At an early stage in these observations it became evident that by extending the tests a little much useful information might be gained, as to the behaviour of wire-ropes under varying conditions, and results of these experiments are now laid before the Institution.

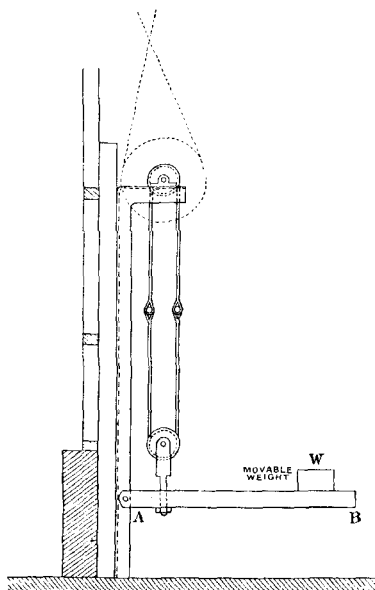
Wire-ropes are now put to various uses, and the work demanded from them differs to a wide extent. The form of the rope, therefore, must be suited to the purpose for which it is required. The principal causes which lead to the destruction of wire-ropes are: the wearing away of the outer surface of the outside wires, the rubbing of the wires against one another, and fatigue of the steel brought about when the rope is worked over a pulley relatively too small. A good example of ropes which give out by the wearing away of the outside wires is found in tramway cables, while deterioration of the last kind is seen in ropes working on crane barrels or in pulley blocks. In the case of tramway cables no practical consideration calls for small pulleys to guide the rope round street corners or similar leads. It is true that the carrying pulleys must be comparatively small; but these affect the life of the cable very little. Recognizing that the wear of the wires, due to the friction of the car-grippers, is in most instances very serious, while the stress due to bending the ropes round the pulleys is comparatively small, it is at once apparent that in this case a stiff rope may be used, having wires of a moderately large diameter, so as to allow of a sensible reduction in size, before the outer wires are worn completely away. On the other hand it will be observed that the conditions under which ropes work over small pulley blocks are the reverse of those in the case of tramway cables. Small pulleys are, for convenience, a practical necessity, and in con-

sequence the wires must be of a small diameter, so that the stress due to bending round the pulleys may be kept within moderate limits. Flexible ropes are in these instances a matter of absolute necessity, and the tabulated experiments in this Paper refer almost wholly to this class of wire ropes.

TESTING MACHINE.

The form of apparatus adopted in the tests was of the simplest kind, and was designed to wear out the ropes in a manner similar

Fig. 1.



to that which takes place in practice. On the testing machine were two pulleys, over which the wire-rope was stretched. The lower pulley was attached to a hinged lever *A B*, *Fig. 1*. This lever was loaded with a movable weight *W* to give the requisite tension. As the rope band was not long enough to allow of satisfactory splicing, and thus continuous running over the pulleys, it was made in two equal sections, joined together by eyes and shackles; a reciprocating motion was given to the rope thus strained, by an automatic arrangement (not shown) connected with

the upper pulley. A record was kept of the number of bends sustained by each rope put under test, thus affording means for comparison.

GENERAL CHARACTERISTICS.

In Table I, part 1, are detailed some of the general characteristics of different makes of wire-rope. In all cases the ropes were of flexible make, with the exception of those 3 inches and 4 inches in circumference. This stiffer type of rope was never called on to perform any other work than the carrying of dead loads, or acting as wind ties. It was ultimately discarded for the flexible ropes, which were as cheap, when allowance was made for the extra strength of the crucible steel and increased handiness.

A cross-section of the ropes presents a series of six circles clustered around a central one. Each of the six outer circles is in contact with the inner one and those on each side. The inner circle, or core, is generally wholly made of hemp, although in some instances several wires are placed in the heart of it, for the primary purpose of preventing the rope from twisting. The outer circles represent the strands, which are wound round the core, from left to right, at a slight angle. The strands, in some cases, have a hemp core, in others a wire one; but of whatever substance the core is, the wires of the strand are laid over it, sometimes from right to left, at other times from left to right.

It will be observed that the ideas of rope manufacturers as to the proper tensile strength of wire vary very much, ranging from 68 tons to 103 tons per square inch, in the same class of flexible rope.

A point of considerable importance is the difference between the aggregate strength of a number of steel wires, when tested singly, and that of the same wires when tested in the form of a rope. The loss of strength in the rope (although this cannot be stated with certainty, as the manufacture is in some cases more perfect than in others) seems to be about 10 per cent. The ropes tested were in short lengths, and as they were bent round a solid eye, and spliced at each end, it is probable that in ropes of the length usually employed this difference would be considerably reduced.

If the breaking-strength in direct tension of these steel-wire ropes is compared with that of hemp-ropes and chains, it will be found that to obtain equal strength, the weight of the hemp-rope must be about three times, and that of the chain five times the weight of the wire-rope.

The second part of Table I deals with the general features of ropes obtained for testing purposes. The results of running these ropes, and the individual wires of these ropes, over pulleys of various diameters, and the modulus, and limit of elasticity of the wires, are given in succeeding Tables. Special attention may, however, here be directed to Nos. 4 and 7 of Table I, part 2. No. 4 is a sample of Bessemer ingot wire of 45 tons, and No. 7 of steel wire of 163 tons ultimate tenacity per square inch.

WIRE.

The wire used in these flexible ropes was understood to be made from crucible steel. The tests adopted for determining the quality of the wire were those of tension and torsion.

The average tensional strength of the wire used, ascertained by direct pull on the individual wires, was from 80 tons to 90 tons per square inch.

The torsion, or ductile test, is the number of complete revolutions, or twists, which wire of a given length will stand before fracture. A piece of good wire, of 20 B. W. G. and 8 inches in length, should stand from seventy to eighty such turns. The mode of ascertaining this value is to place a piece of wire in an apparatus capable of gripping and rotating one end, while the other is held fixed to a point 8 inches distant, so that this length of 8 inches is the only free part of the wire where twisting can take place.

The variation in tensional strength of contiguous pieces of steel wire, both galvanized and ungalvanized, is very little (see Table II). In the case of galvanized the variation is only 3 per cent., while in the ungalvanized wire it is about 8 per cent.; in both cases not more than what may be looked for in any ordinary piece of steel.

The results of the tests of ductility on Table III are more striking. Contiguous pieces of six different series, representing three makes of ropes were tested. In the first series of six wires, all galvanized, the average was 68 twists, while the lowest was 31, and the highest 96. In series 2 of this Table it will be observed, that in one case the number of twists withstood by pieces taken within a few inches of each other, from the same wire, varies from 23 to 58. The average of this series is 62, the lowest being 23, and the highest 90. The last set of six wires, in this Table, shows an average of 92 turns, while the lowest gives 75, and the highest 103. In this case the wires were ungalvanized, which accounts for the greater ductility of the steel. Another

point brought out in this same Table, as also in Table II, is, that the results are practically uniform, whether the wire is, prior to twisting, put under a slight initial tension or left quite free. No appreciable difference is observed in the average result, whether the wires are twisted slowly, or so quickly as to become heated. Some interesting results of experiments with galvanized and ungalvanized wires, both annealed and unannealed, are brought out in Table II. In the case of galvanized wire, the loss in ductility, when annealed, is very marked. The average, when annealed, is 57·5 twists, against 85·5 when unannealed. The gain in ductility, in the case of ungalvanized wire when annealed, is, on the other hand, as striking. Thus the annealed ungalvanized wire shows an average of 178·5 twists, as against 101·5 when unannealed. The loss in tensional strength, due to annealing, in galvanized and ungalvanized wire, is practically the same; the galvanized falling from 207 lbs. to 118 lbs., and the ungalvanized from 217 lbs. to 120 lbs. in wire of 20 B. W. G. Experiments made to determine the modulus, and limit of elasticity, and the extension under direct pull, are recorded in Table IV. The results were ascertained on lengths of 100 inches. The modulus of elasticity is shown to vary from 22,400,000, in the case of the Bessemer iron wire, to 35,000,000 in piano steel wire. The ordinary crucible steel wire, shows a modulus of 33,000,000, the permanent set commencing at about half the ultimate tenacity. Permanent set took place in the case of Bessemer iron wire at about 12 tons per square inch, or about one quarter of the ultimate tenacity. No guide is furnished as to the point beyond which a permanent set takes place, by ascertaining the ultimate breaking-strength of a wire. Permanent set may take place at from 25 per cent. to 80 per cent., and even more, of the breaking strength. In galvanized and ungalvanized wire, the ratio of extension up to the elastic limit is practically the same. The extension at the breaking point, of good crucible steel wire, may be taken at about 3 per cent. in lengths of 100 inches.

PULLEY TESTS.

Reference has already been made to the series of experiments in which ropes were run over pulleys until destruction ensued.

The pulleys ranged from $5\frac{1}{4}$ to 24 inches in diameter, and flexible steel wire-ropes of $1\frac{3}{4}$ inch circumference were employed.

The results of the tests are given in Table V.

The failure of the ropes was in all cases occasioned by the

individual wires gradually giving way, one by one. In no case were the outside wires of the ropes severely worn away, although in a few instances, where the pulleys were large and the number of bends endured before breakage consequently greater, wearing away took place to a considerable extent. Before attempting to describe these experiments in detail, it will be well to examine, briefly, the conditions prevailing in the rope, while passing over the pulleys.

To bend a $1\frac{3}{4}$ -inch rope, composed of seventy-two wires, 20 B.W.G., over a small pulley, where the wires are free to move, is an easy matter. It will, nevertheless, take more than seventy-two times the power required to bend one of the wires to the same curve. If the wires composing the rope are soldered together at any point near to where the bend takes place, the power required to make the bend will be sensibly increased. The resistance may be thus augmented till it approaches that of a solid bar, as when the wires are all securely joined to one another along their entire length. The movement of the strands, as a rope is bent, is easily observed by the naked eye. If a rope be conceived straight, and under a longitudinal stress, it is apparent that the strands and wires will be held to one another by friction, due to the twisting around each other received during manufacture. The value of this friction may be illustrated by considering the strength of a splice. A splice of 40 feet in length will easily resist the full strength of an 80-ton tension steel wire, when in the form of a rope. A splice may thus give a resisting power of 2 tons per lineal foot.

If a rope, under tension, is bent round a pulley, the resistance will be that due to the bending of the individual wires, as beams, plus that due to the increased stiffness given to the wires, as a whole, on account of their being laid into one another.

The resistance to bending, on the part of the individual wires, is highest where small pulleys are employed, and bending in these cases is often the direct cause of by far the greatest separate longitudinal stress in the wires themselves.

If a wire is bent to a radius R , the bending moment at any point is, $M = \frac{EI}{R}$, where I is the moment of inertia of the section of the wire, and E is the modulus of elasticity. The stress consequently due to bending is $f = \frac{EI}{2R}$.

In Table V the stress due to bending a 20-B.W.G. wire, with E equal to 32,000,000, round pulleys of various sizes is given. It

will be observed that the stress, due to bending alone, in a wire 20 B. W. G. diameter, when bent round a pulley $10\frac{1}{2}$ inches diameter, is 50 tons. This at once shows that the usual ropemakers' allowance, in determining the size of the pulley as six circumferences of the rope, irrespective of the diameter of the wire, is beyond the limits of prudence, and if acted on will assuredly give a short life to a hard-wrought rope. It is evident that the diameter of the pulley should not be made to depend simply upon the circumference of the rope, but that the size of the component wires should also be taken into consideration.

Where small pulleys are employed, the principal stress in a rope, and the one to be kept most in view, is not that due to the uniform direct tension caused by the working load, but is the bending stress just referred to. Other stresses than those named are present in a rope, such as, the stress due to centrifugal force, that due to the bending of the wires while being laid on the strands, and also when the strands are being formed into the rope. These last stresses may be discarded, as they happen only once in the life of a rope. If, however, they were recurrent each time the rope passed over the pulley, they would be destructive ones, as they amount to that which produces a permanent set in the individual wires.

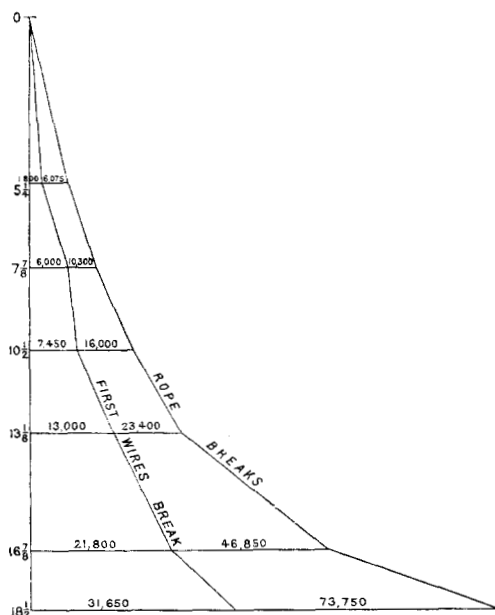
As will be observed from Table V, the full series of tests really begin with the $10\frac{1}{2}$ -inch pulley, although on each of the two smallest pulleys one test was made. In the case of these small pulleys the working stress in the wires was so far beyond the elastic limit that no appreciable length of life was obtained. The number of bends reached with the $10\frac{1}{2}$ -inch and $16\frac{1}{4}$ -inch pulleys respectively, shows no marked difference, although, in the case of the first, the working stress was beyond, while in that of the second it was practically within the limit of elasticity. The diagram given in *Fig. 2* shows, graphically, the increase in the life of the rope as the diameter of the pulleys is increased. No idea is furnished as to the point where the working stresses change from beyond to within the elastic limit, owing to the regularity of the increase. This may be partly accounted for by the fact that the wires, when running over comparatively small pulleys, get much cut up where they cross one another, owing to the longitudinal movement in the rope already referred to. This cutting action is easily observed in the wires, by examining a rope that has run for some time. The effects can be gauged, to a certain extent, by the torsion test; thus, a $1\frac{3}{4}$ -inch rope was run over a $10\frac{1}{2}$ -inch pulley 16,000 times, with a load equal to $\frac{1}{10}$ of its

breaking weight, when it was found the torsion test gave the following average results:—

Ductility of wires before running commenced	64
" " near fracture	6
" " at centre of wires not broken	3
" " midway between fracture and splice	30

No doubt much of the deterioration, in the rope referred to, was due to fatigue of the steel, but a large share must also be ascribed

Fig. 2.



to the cutting action of the wires against one another. It is worthy of note that, after having been run over the pulleys, the value of the part of the rope nearest the middle, where that cutting movement was greatest, was as 3 is to 30, compared with another part, where the bending was the same but the movement of the wires against each other less. This cutting action is also demonstrated by comparing the number of sustained bends, of a given rope, with the number borne in the case of individual wires, of a similar quality of steel. This same experiment may be

compared with experiment No. 1, on Table VIII, where 15,000 bends were given to wires of the same quality over a pulley of the same diameter. The result was to reduce the value of the steel from 77 to 32. The difference between 3, in the test above referred to, in which the rope stood 16,000 bends, and 32 in this one with the wire, is the loss due to the cutting action of the wires.

This cutting action may be modified to a very great extent by a judicious system of oiling. The oil should be capable of permeating the rope.

As is to be expected, the advantages due to oiling are more clearly marked when the ropes are worked within the elastic limit of the steel. For example (see Table V), Smith's ordinary rope, gave, on the 10½-inch pulley, when unoled, 16,000 bends before breaking, but when oiled, 38,700. This same make of rope when running over the 24-inch pulley, stood, when unoled, 74,000 bends against 386,000 when oiled. In this instance the movement of the wires would be less than in the case of the tests with the 10½-inch pulley. In these tests the wires composing the strands were laid from left to right, and the strands themselves, from right to left. The wires, as a consequence, cross one another rather severely.

In Table V are also the results of some experiments with a type of rope known as "Lang's lay," in which both the wires and the strands are laid from left to right. The result is that the wires composing a strand lie into the wires of the adjoining strands, against which they bear; thus, in a great measure, securing a longitudinal bearing surface throughout. A better bearing surface is also given the outside of the rope, and the cutting action is reduced to a minimum. This rope gave, on the 10½-inch pulley, when unoled, 53,000 revolutions, against 107,600 when oiled, and 38,700 for the first type of rope, when oiled also.

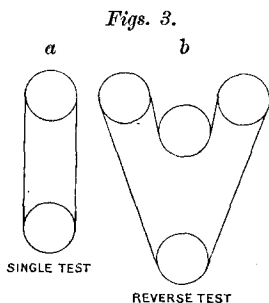
In connection with the bending of ropes over pulleys, experiments were also conducted to ascertain the difference between running over single pulleys, where the bending was all in one direction, (as in *Fig. 3, a*) and over pulleys placed as in *Fig. 3, b*, so that the rope, while running, was subjected to reverse stresses. The results are given in Table VI, and are instructive, as showing that generally the life of a rope, when bent in one direction only, is twice as long as when working under reverse stresses.

Other interesting points are brought out. For example, the longer life of No. 1 rope over No. 0, although the quality of the steel was the same. In the latter the wires cross one another

abruptly, while in the former the bearing is almost longitudinal.

The experiments in Table VII were undertaken for the purpose of comparing the life of single wires with that of ropes composed of similar wires. The general result is clearly this, that the life of the wire, when running alone over a pulley, is much greater than when in a rope, and running over the same pulley. Perhaps the most striking feature, in the results of the experiments recorded in this Table, is the failure of the wires in several cases, as the working stress was well within the elastic limit. In all cases failure was due to the fatigue of the steel, no appreciable wear being observable on the surface of the wires.

Test No. 4 is also remarkable. The wire was of a low quality of Bessemer iron, and worked beyond the elastic limit, yet the result attained was better than from any of the other wires, with



one exception. It even excelled high class plough steel, which in this Table bore a poor record.

The experiments on Table No. VIII reveal the effects of fatigue, or severe work, on a 20 B.W.G. wire running over a $10\frac{1}{2}$ -inch pulley. In every case the result is similar. The effects are: loss of tensional strength, loss of extension, and decrease in the value of the torsion test. In this Table, again, the Bessemer iron wire shows to advantage.

From the information gained by the foregoing experiments, some conclusions may be deduced as to the best type of rope to use under varying circumstances. Thus a $1\frac{3}{4}$ -inch flexible rope to run over, say, ordinary pulley blocks, should be made of ungalvanized steel wire, of about 20 B.W.G., with a tensional strength of about 80 tons per square inch. Hemp cores, oiled during manufacture, should be placed in the strands, as well as in the centre of the rope. The wires and strands ought to be laid

in the same direction. Further, when in use, the rope should be regularly oiled, to nullify as much as possible the cutting action of the wires, and at the same time prevent rusting. In a case such as that named, the diameter of the pulleys, will, owing to practical considerations, always be small, so that what is wanted is the best compromise. The user will be content to pay for a greater number of ropes, rather than have the pulleys made of such a diameter as theory and practice points out to be necessary for a long life; and in doing so he will be the gainer, as in almost all cases increased economy is obtained through the use of comparatively small pulleys.

Theoretical considerations would point to a 6-foot 6-inch pulley as a minimum, for a $1\frac{3}{4}$ -inch rope made of 20 B.W.G. wire. Allowance is here made for the effect of reverse stresses, which are always present in the case under consideration. While a general conclusion may be arrived at, such as that given, for a wire rope working over pulley blocks under certain conditions, it must be clearly seen that before determining what is the best form of rope for any given work, the conditions of economy under which it is to be used require to be clearly understood and provided for.

The Paper is accompanied by the diagrams, from which the *Figs.* in the text have been prepared.

APPENDICES.

TABLE I.—PART I.

Maker.	Circumference.	Quality of Steel.	Weight per Fathom.	Strands.						Breaking - Weight of Rope, average of two.	Breaking - Weight of 1 Wire, average of six.	Breaking - Weight of Wires per Square Inch.		No. of Wires multiplied by their Average Breaking-Weight.	Loss per cent.	Ductile Test.	Remarks.
				Number of Strands.	Number of Wires in one Strand.	Total Number of Wires.	Diameter and Area of Wires.		Tons.			Lbs.					
							Diameter.	B. W. G.					Inch.					Area.
T. & W. Smith	1 1/2	Crucible	Lbs. 2-05	6	12	72	0-036	20	0-0010	6-80	212	94-64	6-82	0-3	73	Ordinary flexible.	
"	1 3/4	"	2-55	6	24	144	0-036	20	0-0010	10-47	190	84-82	12-22	14-3	78	Special "	
"	1 3/4	"	2-10	6	12	72	0-036	20	0-0010	6-62	230	102-68	7-39	10-3	92	Ungalvanized.	
Bullivant & Co.	1 3/4	"	2-00	6	12	72	0-040	19	0-0013	5-85	200	68-68	6-43	9-0	66	{ Oiled in manu- facture.	
Dixon, Corbett, & Newall .	1 3/4	"	"	6	"	"	0-040	19	0-0013	9-85	228	78-29	"	"	46	Lang's patent lay.	
R. S. Newall .	1 3/4	"	"	6	19	114	0-036	20	0-0010	5-75	210	93-75	"	"	83	Ungalvanized.	
T. & W. Smith	2 1/4	"	4-55	6	24	144	0-040	19	0-0013	14-85	263	90-30	16-91	12-2	60	Ordinary flexible.	
"	2 3/4	"	6-80	6	24	144	0-048	18	0-0018	21-90	367	91-10	23-59	7-2	"	"	
"	3	Bessemer	"	6	7	42	0-110	11 1/2	0-0065	14-10	1,123	52-77	21-05	33-0	"	"	
"	4	"	"	6	7	42	0-144	9	0-0163	26-10	1,693	46-36	31-74	17-8	"	"	

TABLE I.—PART 2.—DESCRIPTION OF SPECIAL $1\frac{1}{4}$ -INCH ROPES SENT BY MESSRS. T. & W. SMITH FOR TESTING PURPOSES.

No.	Description.	Strands.	Total Number of Wires.	Wires.			Breaking-Weight of Wire, average of Six; Tons per Square Inch.	Torsion Test with 30 lbs. Initial Tension.		
				Diameter.	Wire Gauge.	Area.		Minimum.	Maximum.	Average of 30.
1	{Lay similar to Lang's; crucible steel . . .}	6	72	Inch. 0·036	20	Square Inch. 0·00100	100	27	86	71
2	{Patent improved steel wire}	6	72	0·036	20	0·00100	83	85	226	108
3	Plough steel wire . . .	6	72	0·036	20	0·00100	120	80	104	95
4	Iron wire	6	72	0·040	19	0·00130	45	4	210	69
5	Crucible steel	6	54	0·049	18	0·00188	86	43	62	54
6	" " " " " "	6	108	0·028	22	0·00060	92	73	120	99
7	Piano wire . . . . .	..	..	0·028	22	0·00060	163	16	107	69

TABLE II.—TESTS OF TWO SINGLE WIRES, ONE GALVANIZED AND ONE NOT GALVANIZED, BOTH BEFORE AND AFTER BEING ANNEALED.

The wires were supplied by Messrs. T. & W. Smith, and were of crucible steel, No. 20 B. W. G., similar to those used by them in their $1\frac{1}{4}$ -inch rope. In the torsion test the wires were fixed in the machine for twisting them with and without initial tension alternately.

No.	Not Annealed.						No.	Annealed.					
	Galvanized.			Ungalvanized.				Galvanized.			Ungalvanized.		
	30 lbs. Tension.	No Tension.	Breaking- Weight. ¹	30 lbs. Tension.	No Tension.	Breaking- Weight. ²		30 lbs. Tension.	No Tension.	Breaking- Weight.	30 lbs. Tension.	No Tension.	Breaking- Weight.
1	82	79	Lbs. 205	101	101	Lbs. 207	1	66	57	Lbs. 118	161	163	Lbs. 123
2	93	86	209	95	96	225	2	63	72	121	157	153	115
3	82	81	208	99	110	219	3	52	84	..	176	184	118
4	86	91	205	102	95	220	4	61	33	119	178	192	121
5	76	89	207	104	102	225	5	77	57	118	183	180	122
6	93	85	209	98	100	220	6	36	42	118	129	190	120
7	89	87	210	108	105	219	7	73	72	118	177	202	119
8	84	85	204	106	100	214	8	44	29	116	180	189	125
9	85	76	210	101	105	214	9	..	..	..	197	188	121
10	84	94	204	103	103	212	10	..	..	..	174	188	..
11	83	85	209	97	108	210	11	..	..	..	203	..	..
12	83	91	208	96	95	220	12	..	..	..	174	..	..
Average	85	86	207	101	102	217	Average	59	56	118	174	183	120
	Average 88·5			Average 101·5				Average 57·5			Average 178·5		

¹ Difference between highest and lowest 3 per cent. ² Difference between highest and lowest 8 per cent.

TABLE III.—VARIATION IN DUCTILITY OF ADJACENT LENGTHS OF SIX WIRES,
TAKEN FROM DIFFERENT ROPES $1\frac{3}{4}$ -INCH IN CIRCUMFERENCE.

The length of the part of the wire subjected to twisting was in all cases 8 inches, and the wires were tested with and without a tension of 30 lbs. per wire alternately.

Description.	First Wire.		Second Wire.		Third Wire.		Fourth Wire.		Fifth Wire.		Sixth Wire.		
	30 lbs. Tension.	No Tension.	30 lbs. Tension.	No Tension.	30 lbs. Tension.	No Tension.	30 lbs. Tension.	No Tension.	30 lbs. Tension.	No Tension.	30 lbs. Tension.	No Tension.	
(1.)													
Wires taken from	First length	50	..	60	..	86	..	62	..	84	..	86	
Messrs. T. & W.	Second "	..	35	..	66	..	86	..	59	..	76	..	76
Smith's ordinary	Third "	31	..	55	..	78	..	72	..	80	..	77	
flexible 1½-inch	Fourth "	..	50	..	66	..	96	..	65	..	70	..	83
rope. Galvan-	Fifth "	37	..	53	..	70	..	70	..	80	..	80	
ized wire, 20													
B. W. G. . . .													

Average with tension = 67.

Average without tension = 69.

(2.)													
Wires taken from Messrs. Bullivant & Co.'s flexible $1\frac{3}{4}$ -inch rope. Galvanized wire, 20 B. W. G. . . .	First length	39	..	70	..	64	..	77	..	70	..	90	
	Second "	..	42	..	70	..	63	..	66	..	62	..	87
	Third "	38	..	42	..	57	..	50	..	64	..	80	
	Fourth "	..	23	..	63	..	59	..	64	..	61	..	83
	Fifth "	57	..	61	..	43	..	58	..	63	..	89	
	Sixth "	..	58	..	60	..	63	..	45	..	59	..	90

Average with tension = 62.

Average without tension = 62.

(3.)													
Wires taken from Messrs. T. & W. Smith's ungalvanized $1\frac{3}{4}$ -inch rope. Galvanized wire, 20 B. W. G. . . .	First length	92	..	88	..	87	..	94	..	94	..	93	
	Second "	..	91	..	103	..	95	..	75	..	90	..	102
	Third "	89	..	97	..	91	..	88	..	91	..	96	
	Fourth "	..	87	..	98	..	87	..	97	..	91	..	95
	Fifth "	90	..	98	..	95	..	94	..	91	..	96	
	Sixth "	..	94	..	93	..	93	..	95	..	98	..	83

Average with tension = 92.

Average without tension = 92.

TABLE IV.

The limit and modulus of elasticity of—

1st. Galvanized crucible steel wire 20 B. W. G.

2nd. Iron wire 19 B. W. G.

Both supplied by Messrs. T. & W. Smith as being similar to those used in their ordinary $1\frac{3}{4}$ -inch ropes; also of—

3rd. Piano wire No. 22 B. W. G. = 0·028-inch diameter.

Each the average of two tests.

Length of wire experimented on = 100 inches.

Tension.	Crucible Steel.		Iron Wire (Bessemer).		Piano Wire (Ungalvanized).	
	Extension.	Permanent Set.	Extension.	Permanent Set.	Extension.	Permanent Set.
Lbs.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
10	0·03	Modulus of elasticity 33,000,000 lbs.	0·025	Modulus of elasticity 22,400,000 lbs.	0·025	Modulus of elasticity 35,000,000 lbs.
20	0·06		0·060		0·075	
30	0·09		0·100		0·125	
				Permanent set commences at 12 tons per square inch.		
40	0·12		0·130		0·150	
50	0·15		0·175		0·200	
60	0·18		0·220		0·275	
70	0·21		0·260		0·325	
80	0·24		0·310		0·375	
90	0·28		0·360		0·425	
100	0·32		0·420		0·500	
110	0·36	..	0·500	0·15	0·525	0·005
		Permanent set commences at 50 tons per square inch.				
120	0·39	0·05	0·600	0·20	0·580	0·01
130	0·43	0·01	0·800	0·36	0·640	0·02
140	0·46	0·02	134 lbs. = 46 tons	..	0·720	0·03
150	0·51	0·03		..	0·770	0·04
160	0·55	0·04		..	0·850	0·07
170	0·59	0·06	..	..	0·900	0·08
180	0·64	0·08	..	..	1·000	0·12
190	0·74	0·30	..	..	1·120	0·16
200	1·40	0·42	..	..	1·200	0·20
210	2·50	1·75	..	..	1·350	0·30
228 = 102 tons	5·50	..	..	..	220 = 1·60 225 = 1·75 = 163 tons	0·42 broke

TABLE V.—THE LIFE OF FLEXIBLE STEEL WIRE-ROPE WHEN RUNNING OVER IRON PULLEYS.

The figures in the Table give the number of times the rope passed over the various pulleys before breaking.

All ropes $1\frac{1}{2}$ inch in circumference. Load on rope, 14 cwt.

Maker.	Diameter of Pulleys in Inches.						
	$5\frac{1}{4}$	$7\frac{1}{4}$	$10\frac{1}{2}$	$13\frac{1}{2}$	$16\frac{1}{2}$	$18\frac{3}{4}$	24
	Rope breaks.	Rope breaks.	Rope breaks.	Rope breaks.	Rope breaks.	Rope breaks.	Rope breaks.
Messrs. T. & W. Smith's ordinary rope	6,075	10,300	16,000	23,400	46,800	72,700	74,100
Messrs. Bullivant & Co.'s	34,800	..	..	100,200	336,600
Lang's patent lay	53,100	85,200	..	392,500	
Messrs. T. & W. Smith's ordinary rope, oiled	38,700	37,300	..	163,200	386,100
Lang's patent lay, oiled	107,600	142,700			

CALCULATED STRESS IN TONS PER SQUARE INCH ON WIRES OF 20 B. W. G.
WHEN BENT OVER THE PULLEYS.

$$E = 14,700 \text{ tons.}$$

Diameter of Pulley.	Stress due to Bending.	Stress due to direct Tension.	Total Stress.
Inches.			
$5\frac{1}{4}$			
$7\frac{1}{4}$			
$10\frac{1}{2}$	50.0		
$13\frac{1}{2}$	40.0		
$16\frac{1}{2}$	31.4		
$18\frac{3}{4}$	28.2		
24	22.0		

In calculating the stress due to bending, no allowance has been made for the error in the ordinary formula when applied to solid sections.

TABLE VI.—LIFE OF ROPES WHEN RUNNING OVER 24-INCH DIAMETER PULLEYS.
Load on rope in all cases, 14 cwt.

Description of Rope.	Total Number of Bends before the Rope breaks when	
	Running over one 24-inch Pulley. (Fig. 3, a).	Running over three 24-inch Pulleys. (Fig. 3, b).
No. 0. Smith's ordinary crucible steel, wire and strands laid in opposite directions . . .	74,100	51,000
No. 1. Smith's rope, wire and strands laid in the same direction . . .	..	126,000
No. 2. Smith's patent improved steel, wire and strands laid in opposite directions . . .	96,000	57,000
No. 3. Smith's plough steel, wire and strands laid in opposite directions . . .	109,000	54,000
No. 4. Smith's iron wire, 19 B. W. G., wire and strands laid in opposite directions . . .	66,000	32,000
No. 5. Smith's crucible steel, 18 B. W. G., wire and strands laid in opposite directions . . .	87,000	47,400
No. 6. Smith's crucible steel, 22 B. W. G., wire and strands laid in opposite directions . . .	111,000	48,700

With the exception of Nos. 4, 5, and 6, the wires composing all ropes were 20 B. W. G.

TABLE VII.—LIFE OF SINGLE WIRES TAKEN FROM ROPES No. 2 TO No. 6, RUNNING OVER PULLEYS $5\frac{1}{4}$, $10\frac{1}{2}$, AND 24 INCHES DIAMETER, AND LOADED IN EACH CASE WITH ONE-TENTH OF THEIR BREAKING-WEIGHT.

Description.	Number of Bends before Breaking.			Calculated Stresses. ¹		
	Average of two Tests (Fig. 3, a).			Pulley.	Stress from Bending.	Stress from Direct Tension.
	Pulley $5\frac{1}{4}$ inches.	Pulley $10\frac{1}{2}$ inches.	Pulley 24 inches.			
No. 2. Improved steel; wires 20 B. W. G. }	15,200	104,000	453,000	Diameter inches. $5\frac{1}{4}$	50	8.3
				$10\frac{1}{2}$		
				24		
No. 3. Plough steel; wires, 20 B. W. G. }	22,000	128,700	181,300	$5\frac{1}{4}$	50	12
				$10\frac{1}{2}$		
				24		
No. 4. Iron wire; wires, 19 B. W. G. }	12,800	83,500	355,800	$5\frac{1}{4}$	38	4.5
				$10\frac{1}{2}$		
				24		
No. 5. Crucible steel; wires, 18 B. W. G. }	..	45,000	123,400	$5\frac{1}{4}$	70	8.6
				$10\frac{1}{2}$		
				24		
No. 6. Crucible steel; wires, 22 B. W. G. }	20,000	..	232,000	$5\frac{1}{4}$	40	9.2
				$10\frac{1}{2}$		
				24		

In the above Table the following values for E have been taken:—for steel wire, 14,700 for all ropes; for iron wire, 10,000.

¹ In calculating the stress due to bending, no allowance has been made for the error in the ordinary formula when applied to solid section.

TABLE VIII.—TEST OF SINGLE WIRES AFTER RUNNING OVER $10\frac{1}{2}$ INCH DIAMETER PULLEYS, AND LOADED IN EACH CASE WITH ONE-TENTH OF THEIR BREAKING-WEIGHT.

Wire, from—	Number of Bends.	Tensional Strength.		Ultimate Elongation per cent.		Torsional Test.	
		Before Running.	After Running.	Before Running.	After Running.	Before Running.	After Running.
No. 1. Smith's crucible steel, 20 B. W. G. . . .	5,000	Tons per Sq. Inch. 100	Tons per Sq. Inch. ..	Average of 2. ..	Average of 2. ..	Average of 36. 71	Average of 36. 77
	10,000	100	100	5.5	3.4	71	56
	15,000	100	98	5.5	3.0	71	32
No. 2. Improved steel (crucible) 20 B.W.G.	30,000	83	76	1.0	1.2	108	103
	60,000	83	..	..	..	108	69
	90,000	83	..	..	..	108	18
No. 3. Iron wire (Bessemer) 20 B. W. G.	15,000	45	45	0.75	1.75	69	29
	30,000	45	45	0.75	1.25	69	31
	45,000	45	42	0.75	0.75	69	18