Th. Sect.

Some ~~Remarks~~ Researches

on the

Structure, Strength and

Commerical Testing of

Steel Ropes

-----

by

E. M. HORSBURGH.

Thesis presented for Degree of D.Sc.

Degree of D. Sc. conferred - 1918

April, 1918.

Table of Contents.

The Wire Rope

Historical and Introductory

Historical.

It has been stated that wire rope is a modern invention, brought about by the necessities of deep mining. It is claimed in Central Europe that wire ropes were first invented in Germany, in 1834, and that after 1837 their use spread to other countries.

Wire rope however is of great antiquity, as a specimen discovered in Pompeii is now on view in the Museum of Naples. [illegible]

Its re-invention in modern times dates from about the end of the first quarter of the nineteenth century.

In 1821 galvanised wire rope was used in the construction of the Geneva suspension bridge. This consisted of parallel wires, with a [illegible] to keep them together. Such ropes are rigid, non-elastic, and impossible to splice. Their strength however, if the rope be constructed properly, is equal to the sum of the strengths of the constituent wires. In 'formed' ropes on the other hand a considerable fraction of this may be lost, perhaps about 5% in small ropes but exceeding this considerably in large ones, and reaching sometimes 10% or 30%.

The first formed or stranded wire ropes manufactured in Germany were made by Councillor Albert of Clausthal, in the Hartz mining district, in 1834.

Mr. J. Wilson of Derby claims however to have made stranded wire ropes for the Haydock Collieries in Lancashire as early as 1832.

The ropes made in the Hartz district were not constructed by machinery, but were formed by hand, in a rope-walk, after the manner/

Historical.

It has been stated that wire rope is a modern invention, brought about by the necessities of deep mining. It is claimed in Central Europe that wire ropes were first invented in Germany, in 1834 and that after 1835 their use spread to other countries.

Wire rope however is of great antiquity, as a specimen discovered in Pompeii is now on view in the Museum of Naples. see footnote p.2

Its re-invention in modern times dates from about the end of the first quarter of the 19th century.

In 1821 selvagee wire rope was used in the construction of the Geneva suspension bridge. This consisted of parallel wires, with a serving to keep them together. Such ropes are rigid, non-elastic, and impossible to splice. Their strength however, if the rope be constructed properly, is equal to the sum of the strengths of the constituent wires. In 'formed' ropes on the other hand a considerable fraction of this may be lost, perhaps about 5% in small ropes but exceeding this considerably in large ones, and reaching sometimes 20% or 30%.

The first formed or stranded wire ropes manufactured in Germany were made by Councillor Albert of Clausthal, in the Hartz Mining district, in 1834.

Mr. J. Wilson of Derby claims however to have made stranded wire ropes for the Haydock Collieries in Lancashire as early as 1832.

The ropes made in the Hartz district were not constructed by machinery, but were formed by hand, in a rope-walk, after the manner/

Footnote, page 1.

"In the Musio Borbonico at Naples there is a piece of wire, rope excavated from the buried city of Pompeii.

The piece in question is 4½ metres long and has a circumference of about an inch. It is composed of three strands laid spirally together, each strand having fifteen wires also twisted together. The wires are of bronze.

Unfortunately, no record was made of the exact position in Pompeii where the rope was unearthed so it is useless to speculate as to the probable purpose to which it was applied by the Romans".

See p. 9. The Wire Rope and its applications: by W.E. Hipkins.

A photograph of this rope is shown on p. 8. It is regular in construction, of ordinary lay, and looks like a modern rope.

This book is the commercial catalogue of J + E. Wright Ltd. Universe Works Birmingham 1896.

manner of hemp ropes. They consisted at first of three strands, each of three wires (and later of four or more) of soft iron, 3.5 $^{m}/_{m}$ in diameter. The pitch was about one foot, and a permanent set was given to keep the rope together. The faulty construction caused them to wear out rapidly. In these early ropes the direction of the lay was the same in the strand as in the rope. This is spoken of in Central Europe as the Albert Lay. It soon went out of use, as it was unsuitable for early mining conditions.

A full description of the process of manufacture is quoted by Hrabak. In making a four wire strand, four wires were threaded through 30 or 40 four-holed wooden blocks, about a metre apart, in a rope-walk. They were also led through 4 holes in the centre of a double-handed wrench. This was held by the chief operator, the 'turner', who advanced along the walk, rotating the wrench by hand, and so twisting together the four wires. Some ten labourers advanced the blocks, as this became necessary. The turner was accompanied by a 'holder', who gripped with a hand-vice the end of the portion already formed, so as to enable the twist to be applied. The strands, after being formed, were in the same way fashioned into ropes. It took 13 workers one hour to complete about 15 metres of rope, and the cost was naturally excessive.

Count Augustus Brenner (Brit. Assocn 1838) describes the largest mining rope in use in the Hartz district about this date as consisting of 3 strands of 5 wires of diameter 1/6 ". The load raised was 1,000 lbs. and the winding drum was 8' in diameter. He further/

further states the gain in efficiency, as it was found that four horses working an iron wire rope did as much effective work as six on a flat hemp rope.

It seems doubtful who was the inventor of the first machine for making wire rope. Wurm, a Vienna mechanic, designed and made one about 1837, though the date is not certain. It contains the essential features of the modern machine. Prechtel's Technological Encyclopaedia says that machines of this pattern must have been in use since 1840.

In 1838, Mr. Newall of Dundee was advised by a friend, who was studying mining in Saxony, to design and construct a machine for making wire rope. This friend states that the German ropes consisted of 4,6, or 8 strands, each of 4 wires of $3/32$ of an inch in diameter. He then adds:- "Invent a machine for making them. It is very simply done here, as you can imagine, but slow and unscientific". Within a month Mr. Newall had completed the design of what was possibly the first rope-making machine. This was successful, and about 1841 he removed to Gateshead-on-Tyne and set up a ropery there. This firm still flourishes under the name of 'Dixon, Corbett & Newall.'

Even though the honour of making the first roping machine should not fall to Britain, yet British machines were soon established on the Continent, and took a pre-eminent place there. Thus in the St Egydy Works the Wurm design was used at first, but this was unable to cope with more than 42 wires. The speedy introduction of British machines made it possible to undertake all kinds of rope work. The St. Egydy Works are now said to be the largest and best of this nature/

nature in Austria-Hungary.

In Britain there was a special field for iron wire ropes, quite apart for mining. This was the rigging of the navy. The cost of this was halved about 1854 on the introduction of wire rope. These were the days of sailing ships, and the reduced cost of rigging the navy was £457,320. It was stated too that hemp rope had to be renewed in 3 years, while wire lasted for 16. This last estimate was over sanguine. It was stated that at this time there were 50 British firms engaged in making wire rope, which was being turned out at the rate of 100 tons daily, at a cost of £50 per ton. These were large quantities for those times.

In the primitive hand fashioned ropes of Albert of Clausthal, the handedness, or direction of lay, of the rope and the strand were the same. Owing to this, and to the fact that the load in mining was then merely suspended, it spun round incessantly in the shaft. In the case of miners being hoisted or lowered, this soon became unendurable, and the ordinary method of cross-braiding or opposite handedness came into general use. With this the spinning was not so troublesome.

With the introduction of machinery, wire rope making soon became a great industry. Many improvements in manufacture were gradually introduced. The six-bobbin machine, from its simplicity, became a useful standard, and the six-strand cross-braided rope became the most popular make, a position which it holds at the present day.

In the "cross-braid" the strand and rope are laid in opposite directions/

directions, so when hanging freely, and carrying a load, the strands and rope tend to untwist in opposite directions. These positive and negative rotations neutralise each other to some extent, so that such a rope may be used for hoisting a free load, as after a time it attains a fairly steady state, and does not impart much spin to the weight.

Long afterwards when great advances had been made both in mining and in rope-making, it was found of advantage in certain cases to have the same handed-ness in rope and strand. Thus, in 1880, G. Cradock patented the Lang Lay for modern ropes.

This is useful when the cages are guided, so that the spin is of little importance. It has advantages from the point of view of wear, as the "crowns" or "knuckles" of the wire are less pronounced, and there is a greater length of the wire in rubbing contact with the pulleys, so that, for a given amount of abrasion, the injury is not so local and deep as with the cross-braid. The cutting tendencies of the wires too are somewhat less.

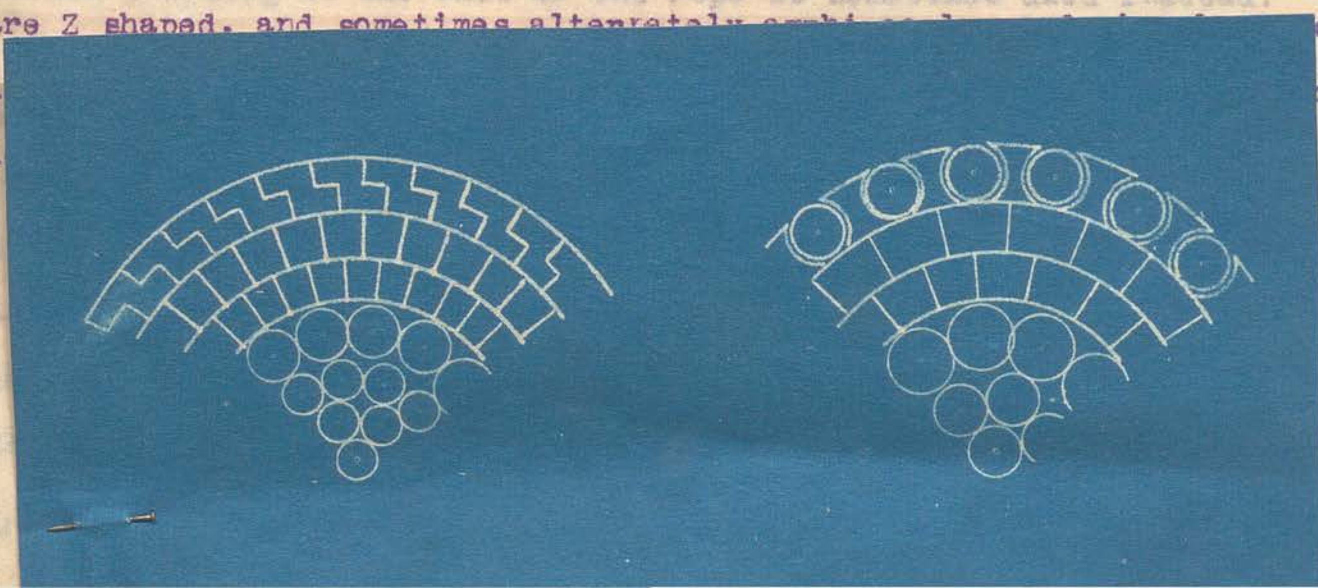
The greatest improvement in modern rope-making has been the introduction of steel to take the place of iron. This began in the sixties. Iron wire (or Bessemer steel) ropes were still used about 1890, but they are never used now for important work. It is agreed universally that it is better to pay the higher price and use a good quality of steel.

To illustrate the construction of ordinary ropes Bucknall Smith tabulates data from four typical ropes from $\frac{5}{8}$" to 2" in diameter/

diameter, and points out that "upon analysing this practice it will be noticed that the proportions the lays in the strands and ropes bear to the diameter of the roping range from about 3½ to 2½ and 6½ to 6 times the diameter respectively". As other writers have followed upon these lines of description, I venture to suggest that the introduction of the angle of the helix would lead to a simpler comparison, and to more comprehensive theory. The word 'lay' might be kept for the 'sense' or 'handed-ness' of the helix, i.e. whether right or left, so that it would not be confused with the 'pitch'.

Owing to the rotation of the rope, when under load, giving trouble, Newall introduced in 1876 a construction in which the constituent strands in the rope were alternately right and left handed. Various modifications of this method are in use at the present day for the formation of non-rotating ropes.

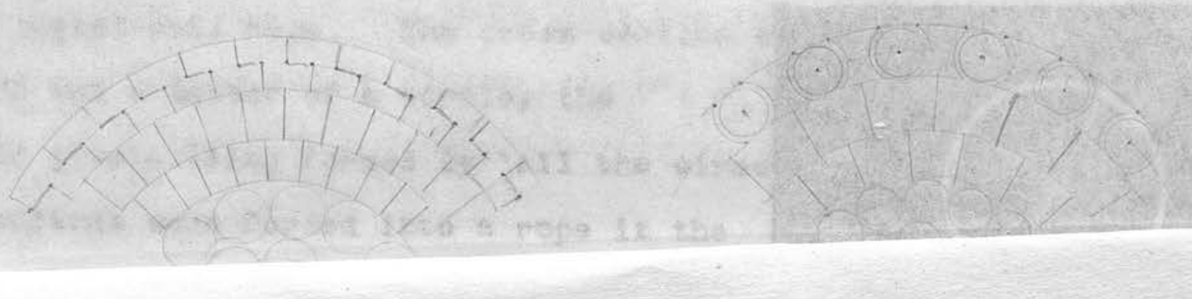
In 1884 Latch and Batchelor brought out the 'locked-coil' rope. This construction is claimed by the firm of Felten and Guilleaume of Mulheim In this there is usually a core in the form of an ordinary strand surrounded by layers of wires which are in cross-section truncated circular sectors. The distinguishing feature is that there is also a special locking layer on the outside. Sometimes the wires in this are Z shaped, and sometimes alternately [illegible]



diameter, and points out that "upon analysing this practice it will be noticed that the proportions the lays in the strands and ropes bear to the diameter of the roping range from about 3½ to 2½ and 6½ to 9 times the diameter respectively". As other writers have followed upon these lines of description, I venture to suggest that the introduction of the angle of the helix would lead to a simpler comparison, and to more comprehensive theory. The word 'lay' might be kept for the 'sense' or 'handed-ness' of the helix, i.e. whether right or left, so that it would not be confused with the 'pitch'.

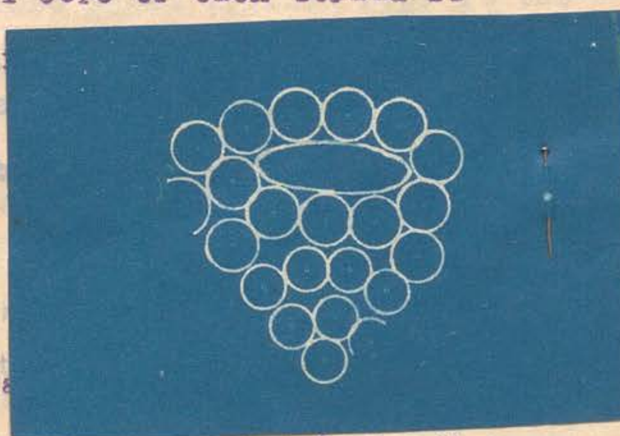
Owing to the rotation of the rope, when under load, giving trouble, Newall introduced in 1876 a construction in which the constituent strands in the rope were alternately right and left handed. Various modifications of this method are in use at the present day for the formation of non-rotating ropes.

In 1884 Latch and Batchelor brought out the 'locked-coil' rope. This construction is claimed by the firm of Felten and Guilleaume of Mülheim. In this there is usually a core in the form of an ordinary strand surrounded by layers of wires which are in cross-section truncated circular sectors. The distinguishing feature is that there is also a special locking layer on the outside. Sometimes the wires in this are Z shaped, and sometimes alternately amphi-coelus and circular, as in the accompanying figures. The various layers are wound right and left-handed alternately.



It is claimed that these ropes may be made of considerable flexibility, but those seen by the writer have been stiffer than ordinary ropes. In this construction, the internal wires when broken do not show, which is dangerous in practice, while the ropes are impossible to splice, though connections might be made by brazing or by special contrivances. They are almost perfectly cylindrical in form, and are admirably adapted to resist abrasion.

The flattened strand rope was also brought out by Messrs. Latch & Batchelor. In this the central core of each strand is metallic, and shaped in cross section l



The result of this is that the outer wires of this rope are in closer contact with the circum-cylinder than would be the ca thus the outer surface of the rope approaches more nearly to the smooth cylinder than does the rope with circular strands. The aim is to produce a larger wearing surface. A triangular core with the vertex pointing to the axis of the rope is sometimes used instead.

A large number of other constructions have been introduced, many of which have not obtained popularity.

The sectoral section, employed by Laidler, has been referred to in the locked-coil rope. The cross-sectiom o a strand was a sector of a circle, the complete circle being formed by all the wires These strands were formed into a rope in the

usual/

usual way. It shares with certain other forms the disadvantages of being stiff and impossible to splice.

An early form of locked rope was introduced by F.W. Scott of Reddish. In this the wires were clipped together in pairs before being laid into the strand.

A rope in which the strands consisted of parallel wires formed into a rope at one operation was introduced by Newell & Co. under the name of 'Ne plus ultra'. It has the advantage that the external wires would in theory be exposed to wear throughout the whole of their lengths, instead of receiving deep local damage at the crown. It is claimed that this form is simple to construct, and that the wires are of equal length and equally strained. Claims by patentees however are not always perfectly reliable.

In 1889 Messrs. Craven & Speeding of Sunderland manufactured a form of rope introduced by Westgarth, in which there were an equal number of twists in the strand and in the rope. Various advantages have been claimed for this also.

Between 1880 and 1886 there were 174 fatal accidents in Britain during winding. This led Armstrong & Co. to bring out a rope for combined winding and signalling. This was effected by placing insulated copper wires in the core.

As an attempt to reduce strains caused by bending the rope round a pulley, a yielding helical metallic core was introduced by Mr. Hodson. These strains due to bending are very important and lead to many difficulties. A design that has long been employed for haulage is to surround a standard one-strand rope by an extra layer, or/

or layers, of much thicker wires. This is useful in resisting the wear of a gripper, but it is not so flexible for passing over small pulleys as is a stranded rope.

Another formation which is frequently adopted is that by which the spaces, which would occur if wires of large diameter alone were used, are filled by wires of smaller diameter.

Many minor modifications of design might be enumerated, but the foregoing paragraphs indicate the usual lines of construction. It is almost needless to remark that no one type of rope is suitable for all conditions. The ordinary six stranded cross-braided rope is the one which is used most universally. Flexibility is obtained chiefly by increasing the number of strands, by reducing the diameter of the wire, by inserting fibre cores or hearts, and by decreasing the pitches of the helices.

The following extracts from tables of mining statistics dealing with the Dortmund district show the numbers and percentages of failures in various types of mining ropes between 1872 and 1905. In 33 years out of 9207 winding ropes discarded, 293 or 3.18% broke suddenly when in use. These are classified as follows:-

Type of Rope used in winding.	Number used	Number failed	Percentage of failures.
Aloe flat	97	7	7.22
Hemp flat	8	0	0.00
Iron flat	147	19	12.93
Iron round	881	105	11.92
Cast steel flat	1135	53	4.67
Cast steel round	6939	109	1.57
Totals	9207	293	3.18

These tables show the immense superiority of steel over iron for ropes. They also show the inferiority of the flat rope to the round one. The flat rope is rarely used now.

In 1872 the percentage of fractures was 19.30% while in 1905 it was only 1.52%. This shows the vast improvement in construction between these dates.

Considering the importance of steel rope in modern engineering, it is strange that so little in the way of producing a general theory has been attempted. The writer knows of no text books on wire ropes except Wire by Bucknall Smith and "Die Drahtseile" by Hrabrak. In the latter though Hrabrak claims with German modesty to have exhausted the subject, and to have produced a Thesaurus of Wire Ropes, reminiscent of a Treasury of Logarithms, others will not agree with him. The treatment of the subject is elementary, and almost without the aid of mathematics, while many of the methods and conclusions are, I venture to suggest, open to grave objections. He tabulates stresses obtained from very doubtful theory, but does not classify any large number of tests and exhibit and compare them graphically. This latter I have been able to do.

Buchnall Smith's admirable work covers a wide field, and gives apopular treatment of the subject.

Though many rope tests are published from time to time, the writer has unfortunately not been able to find any printed tests, which gave all the particulars which are required in attempting to examine what occurs in a wire rope.

A partial bibliography has been compiled, but many of the articles/

articles referred to have only been seen in the form of abstracts. Few or no writers attempt any general theory. Their conclusions, too, seem frequently contradictory, and are in consequence somewhat bewildering. Additional references are given throughout this paper.

The writer desires to express his grateful acknowledgement to Mr. J. D. Brunton (W.N. Brunton & Son, Wiremills, Musselburgh) and to the members of his staff, particularly to Mr. W. Kirkwood, head of the testing department, for his valuable practical help. Mr. Brunton gave the writer permission to work in his test rooms, which had been fitted up with the newest and finest machines specially designed for rope testing. It is a matter of profound regret that this magnificent department was completely destroyed in a great fire at the works in Oct - - - ,
Mr. Brunton also gave the writer access to the recorded tests of recent ropes constructed by the firm. Most of these were carried out in the test rooms at Musselburgh, but a large number were made by well known testing extablishments.

BIBLIOGRAPHY.

Textbooks and Pamphlets.

Wire by J. Bucknall Smith. 1891. Engineering

Die Drahstheile by Hrabak.

The following textbooks are mentioned in the Brit. Museum Catalogue.

The Known Forms and Developments of Wire Ropes by H. Cheesman.

How to test Wire.(19pp.) Peabody & Kennedy, Toronto 1909.

Tables of Breaking Weight of Wire in lbs.

Halifax 1888, F. Smith.

Wire Strength: 22 tables; Bulletin de la Société de l'Industrie Minerale 1880 IX 695-798.

The following reference are from the Proc. Inst. C.E.

Proc. Inst. C.E. 1879-94.

LXVII p.506-9.(Flat ropes; also tests of wire at various stages in manufacture; Also Revue Universelle des Mines 1881 Vol. IX.)

LXXXVIII p.538 (Taper)

XCVI p.169 (Durability.)

XC (Torsion Tests.)

Prov. Inst. C.E. 1894-1907.

CI

CXXVIII p.407 (Fibre Ropes.)

CLXVIII p.394 (Steel wire ropes; after Hrabak.)

CXXXV P.373 (A rope test d = $3\frac{1}{2}$")

CLXV P.144 (Widnes & Runcorn Bridge.)

CLX III P.418

CXXIV P.514 (Pribram: work done by a mining rope.)

The following references are Miscellaneous and foreign.

Oesterreichische Zeitschrift für Berg. und Huttenwesen,

XL CXXX p.331 1-594 J. Divis.

CL1X p.455 Number of bendings of a wire.

Glückauf XXXIX pp.318-321. O. Hoppe.

Proc. Mech. Eng. Oesterreichische Zeitschrift für Berg - und Hüttenwesen

pp.297-3 No references of any importance in this subject

Mines and Minerals Vol. XXIV. April 1904.

(Wire Rope: and includes partial bibliography)

Glückauf Vol. XL1 pp. 189-245. Rope Tests.

Engineering News Vol. L111 pp.87-88

Iron and Coal Trades Review. Vol. XX11 pp. 354-358

Oesterreichische Zeitschrift für Berg- und Hüttenwesen,

L111 pp.311-343.

Zeitschrift für physikalische Chemie 1912 Vol.LXXX11 P. 457

Journal de Physique 1912 Vol.11 p.399.

Transactions of the Institution of Mining Engineers. Vol.XXX1

pp. 443-450.

Dinglers Polytechnisches Journal 1906 pp. 161-279.

Trans. Inst. Mining Engineers Vol. XXIX pp. 525-526.

and XXX1 pp. 150-164.

Machinery Vol.X111 p.821, also pp. 569-570.

Zeitschrift des Vereines deutcher Ingenieure Vol. L1 pp. 652-657.

Mines and Minerals XXIV p. 403-459. Special number referred to already.

Journal of the Chemical and Metallurgical Society of South Africa, August

1909.

Engineering and Mining Journal LXXXIX pp. 278-80.

The following references are Miscellaneous and foreign.

Oesterreichische Zeitschrift für Berg- und Hüttenwesen, XLV111 pp. 561-594 J. Divis.

Engineer XC11 pp.35-98

Glückauf XXX1X pp.313-321, O. Hoppe.

Oesterreichische Zeitschrift für Berg - und Hüttenwesen pp.297-310.

Mines and Minerals Vol. XX1V. April 1904. (Wire Rope: and includes partial bibliography)

Glückauf Vol. XL1 pp. 188-345. Rope Tests.

Engineering News Vol. L111 pp.65-66

Iron and Coal Trades Review, Vol. XX11 pp. 354-355

Oesterreichische Zeitschrift für Berg-- und Hüttenwesen, L111 pp.311-343.

Zeitschrift für physikalische Chemie 1913 Vol.LXXX11 P. 457

Journal de Physique 1912 Vol.11 p.620.

Transactions of the Institution of Mining Engineers. Vol.XXX1 pp. 443-450.

Dinglers Polytechnisches Journal 1906 pp. 264-279.

Trans. Inst. Mining Engineers Vol. XX1X pp. 625-635. and XXX1 pp. 150-154.

Machinery Vol.X111 p.621, also pp. 569-570.

Zeitschrift des Vereines deutcher Ingènieure Vol. L1 pp. 652-657.

Mines and Minerals XX1V p. 405-459. Special number, referred to already.

Journal of the Chemical and Metallurgical Society of South Africa, August 1909.

Engineering and Mining Journal LXXX1X pp. 278-80.

Glückauf XLV pp. 1545 ... 1685. Bock. " XLV1 (Breakages.)

Oest. Zeit. f. B. und H. LV111 pp. 47-109. J. Divis.

Trans. American Instit. Mining Engineers August 1900.

Glückauf XXXV11 pp. 673-675. Statistics 1872-1900.

Winding ropes. Dortmund district & XXXV111 911-912.

Oest. Zeit. f. B. und H. XL1X pp. 272-273. Statistics.

Winding ropes Breslau district, also 455-458

also L, pp 539-541 & 315-316.

Comptes Rendus Mensuels de la Société de l'Industrie Minerale

1902. Statistics of winding ropes, in France Germany & Belgium.

Mines and Minerals XX11 pp. 316-7. Bending.

Annales des Mines XX pp. 143-198. E. Classen. Fatigue.

Revue Universelle des Mines LV111 pp. 1-34. Graphic statistics

for ropes. Dechamps.

Journal of the Canadian Mining Institute V pp. 33-41.

Glückauf XXXV111 p. 911-2.

Oester. Zeit. für B. und H. pp. 315-6. Both Statistical.

Bulletin de la Société de l'Industrie Minerale 1 (4th series)

pp. 709-15. Deverne.

Comptes rendus de la Société de l'Industrie Minerale 1902.
pp. 222-3. De Morgues.
pp. 223-4. Bouchard.

Glückauf XXX1X pp. 737-740. Statistics, Dortmund ropes.

Oester. Zeit. für B. und H. L,i pp. 591-594. & 624-626.

Statistical: also L, 111 pp. 41-45 & 59-61. Divis.

Berg. und Hüttenmannisches Jahrbuch L,11 pp. 1-84. E of ropes;

Divis.

Colliery Guardian Supplement L, XXX1X p.77 Vaughan & Epton.

Brit. Assoc.; Johannesburg, or Engineer C.p.223.

Proc. Engineers Society of W. Pennsylvania XXI pp. 26-39. Dieschey.

Comptes Rendus Mensuels de la Societé de l'Industrie Minerale

1905 pp. 162-170. Rodde.

Oester. Zeit. für B. und H. L111 pp. 271-4. & 290-2.

Schmid, & pp 413-418. Kroen.

Trans. Inst. Mining Engineers XX1X pp.173-186. Mitchell.
(capping locked coils)

Proc. S. Wales Inst. of Engineers XX1V pp. 151-157. Becker.

Transvaal Inst. Mining Engineers 1905. Vaughan and Epton.

Mining Journal L XX1X pp. 389-391.

Zeitschrift des Verbandes des Bergbau Betriebsleiter, 1906. pp.

145-154. Ryba.

Oester. Zeit. f. B. und H. L1V pp. 145-148. Kroen.

Engineer C11 189-213. Vaughan.

Glückauf XL111 pp. 1376-1378. Statistics.

Trans. Inst. Mining Engineers XXX1V. pp. 140-148. Routledge.

Midland Inst. Min. Civ & Mech Engineers, 22/7/09, and Colliery

Guardian XCV111 p. 231. Elce.

Zeit. fur das Berg Hütten und Salinenwesen. LV11 Wagner.

Engineering and Mining Journal XXXV111 pp. 362-3. Beers.

Oest. Zeit. fur B. und H. LV11 419-474. Stör.

Electrical Magazine X11 pp. 129-131.

Journal of the Chemical and Metallurgical Society of South Africa

August 1909. Murray.

Engineering and Mining Journal LXXX1X pp. 278-280. Rowland.

Glückauf XLV pp. 1545-1685. Bock.

Oester. Zeit. für B und H. LV111 pp. 47 ....109. Divis.

Glückauf XLV1 pp.11-13. Statistics, breaks.

Internat. Congress of Mining; Iron and Coal Trades Review

LXXX pp. 1004-1005. Louis (report).

Glückauf XLVl pp. 1521-1525. Baumann.

also pp. 785-838. Speer.

Mining and Metallurgical Society of America Bulletin No. 33,

Caldecott; or,

Mining World XXXlV p. 735. Caldecott.

Glückauf XLVll pp. 264-267. Baumann.

(Baumann recommends for deep winding, steel for ropes at 180-250

Kilog. □ m/m)

Oester. Zeit LlX pp. 471-494. Horel.

Iron and Coal Trades Review. LXXXlll p. 651. Baird.

Proc. Roy. Soc. Ed. (A LXXXll pp. 546-559.
(A LXXXVl pp. 534-561. Poynting.

Glückauf XLVlll pp. 737-829 Speer also 897-908. Herbst.

Iron and Coal Trades Review LXXXV p. 596. Lloyd.

Glückauf 1912 XLVlll pp. 2021-2024. Baumann.

also 1913 XLlX pp. 117- 120. Baumann.

Glückauf 1913 XLlX pp. 520-526, 557-565. Bürklein.

Statistics, ropes, Dortmund, etc.

Ironmonger 1913 Vol. LXl pp. 379-384 and 393-396. Scheifenbaum.

Glückauf 1913 XLlX pp. 1328-1330. Benoít.

Bergbau 1913. XXVl p. 531. Speer.

Revue de Metallurgie, Memoires 1913 X pp. 206-210. Fremont.

Colliery Engineer 1913. XXXlll pp. 578-579. Lloyd.

Glückauf 1913. pp. 1646-1652. Baumann; and,

pp. 1936-1940. Herbst; and,

pp. 1727-1734. Speer.

Trans. American Foundrymens Assoc. 1913 XX11

pp. 169-200. Tinsley.

Glückauf 1914. pp. 1293-1298. Baumann.

1915 pp. 1-6 and 29-37. Herbst.

Trans. Inst. Mining Engineers 1915. XL1X pp. 557-627.

Blast Furnace and Steel Plant 1915. pp. 1031-1034. Lewis.

Chapter I

Notation and Cross Section

Notation.

Before an attempt is made to classify ropes, some formula for denoting them is required. [illegible] does not give a general formula and hence his classification is somewhat confusing.

We may distinguish between one-strand ropes, stranded ropes, and cables. The six strand rope is the most usual.

Following the analogy with fibre ropes, we see that a number of wires may be layed into a strand, a number of strands formed into a rope, and a number of ropes closed into a cable.

The formula should indicate as simply as possible the number of strands, and their arrangement, the number of wires in each strand and their relative positions, the diameters of the wires and the material of the cores.

When the specimen is sent from the winding shop to the test room, this formula should be attached, and also a copy of the tests of the constituent wires should be provided with it. As these tests were taken on the original straight wires, they should be compared with the further tests on the constituent wires after winding, which are made in the test room after the specimen has been broken.

Taking the simplest case of a single strand, or a one-strand rope, the formula is required to give the number of wires in the various layers, their diameters, and the material of the core. We may write the numbers of wires in the various layers in a vertical column, the outer layer being the first entry; then follows the diameter of the wire, and a notice of the core.

Thus $\frac{18}{12}$/.092) or $\frac{18}{12}$/.092 | denotes a single strand with two layers of wires, the outer consisting of 18, and the inner of 12 wires/

Notation.

Before an attempt is made to classify ropes, some formula for denoting them is required. Hrabak does not give a general formula and hence his classification is somewhat confusing.

We may distinguish between one-strand ropes, stranded ropes, and cables. The six strand rope is the most usual.

Following the analogy with fibre ropes, we see that a number of wires may be layed into a strand, a number of strands formed into a rope, and a number of ropes closed into a cable.

The formula should indicate as simply as possible the number of strands, and their arrangement, the number of wires in each strand and their relative positions, the diameters of the wires, and the material of the cores.

When the specimen is sent from the winding shop to the test room, this formula should be attached, and also a copy of the tests of the constituent wires should be provided with it. As these tests were taken on the original straight wires, they should be compared with the further tests on the constituent wires after winding, which are made in the test room after the specimen has been broken.

Taking the simplest case of a single strand, or a one-strand rope, the formula is required to give the number of wires in the various layers, their diameters, and the material of the core. We may write the numbers of wires in the various layers in a vertical column, the outer layer being the first entry; then follows the diameter of the wire, and a notice of the core.

Thus $\frac{18}{12}$/.072 j or $\frac{18}{\frac{12}{j}}$/.072 j denotes a single strand with two layers of wires, the outer consisting of 18, and the inner of 12 wires/

wires. These are all .072" in diameter, and are laid round a jute core.

In the same way 37/.054 or $\left.\begin{matrix}18\\12\\6\\1\end{matrix}\right|$ .054 denotes a strand of 37 wires, each .054" in diameter arranged in layers containing respectively 18, 12, 6, 1 wires, the core being in this case a single wire. This arrangement is a standard winding. The letters l or r are used to denote left or right handedness of the helix. If we wish to denote a rope formed of six of the latter strands round a hemp core we may write 6/37/.054 h or more fully $6\left|\begin{matrix}18\\12\\6\\1\end{matrix}\right|$ .054 h.

If the rope is wound righthandedly and the outer wires of the strands are lefthanded, and the layers left and right handed alternately, and we wish to emphasise this, we may represent it by the formula

$$6\ r\left|\begin{matrix}18 & l\\12 & r\\6 & l\\1 & \end{matrix}\right| .054\ h.$$

More generally we may denote a rope of a layer of S strands, each consisting of layers of wire $N_1\ N_2\ N_3 \cdots$ in number round a jute core, the main core being of hemp, by the formula,

$$S\left|\begin{matrix}N_1\\N_2\\N_3\end{matrix}\right|\ d\quad jh$$ Where d is the diameter of the wire.

If we desire at any time to emphasise that we are using a one strand rope we might write it as 1/n/d.

It is easy to generalise this:-

As an example the rope

$$\begin{array}{c|c|c}
A & a_1 & d_1 \quad h \\
 & a_2 & d_2 \\
\hline
 & b_1 & d_3 \\
B & b_2 & d_4 \quad h \\
 & b_3 & d_5
\end{array}\ j$$

denotes one in which there are two layers of strands, the outer A in number, and the inner B. Each strand of the outer layer consists of two layers of wires round a hemp core. The outer layer contains a_1 wires/

wires of diameter d_1 the inner a_2 wires of diameter d_2. Each strand of the innerset is built up of three layers of wires, the outer one containing b_1 wires of diameter d_3, the middle one b_2 wires of diameter d_4 and the inner of b_3 wires of diameter d_5. This strand has a hemp core. The inner set of strands is formed round a jute core.

Thus the formula is simple, comprehensive, and gives a large amount of information in a very small space.

If N such ropes were closed into a cable with a jute core we should merely write as the formula for the cable

$$N \left| \begin{array}{c|c|c} A & \begin{matrix} a_1 \\ a_2 \end{matrix} & \begin{matrix} d_1 \\ d_2 \end{matrix} \\ \hline B & \begin{matrix} b_1 \\ b_2 \\ b_3 \end{matrix} & \begin{matrix} d_3 \\ d_4 \\ d_5 \end{matrix} \end{array} \right. \begin{matrix} h \\ jj \\ h \end{matrix}$$

The number of wires in such a cable is $\left\{(a_1 + a_2)A + (b_1 + b_2 + b_3)B\right\} N$

The orthogonal area of the steel for each diameter of wire is

$N.A.\ a_1 \pi \frac{d_1{}^2}{4}$, $NA\ a_2 \ \pi \frac{d_2{}^2}{4}$, &c.

Some geometrical properties of the rope will now be given, beginning with the cross-section.

Cross-section of a standard Strand

This is looked on, so far as the writer has seen, as if the cross-sections of the wires were circles. Attention is devoted naturally to the case where all the wires are of the same gauge.

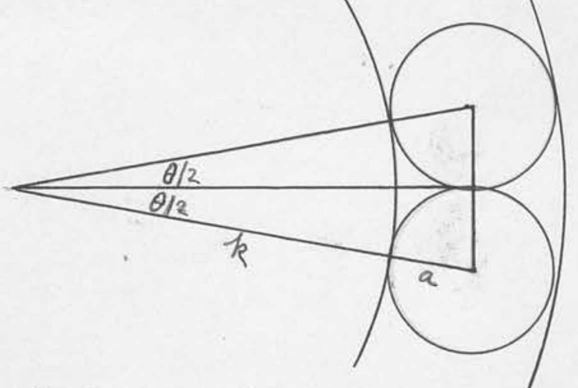
In the standard case, the numbers of the wires in the successive layers are assumed (presumably by drawing) to be 1, 6, 12, 18, &c. The sum of this series to r terms is $3r^2-3r+1$. Thus if r be the number of layers, and n the number of wires in the rope, we have the table

r	1	2	3	4	5	. . .	r
n	1	7	19	37	61		$3r^2-3r+1$

General Formula for the Cross-Section of a Strand

Suppose that in the right section of a

strand, the cross-sections of the wires are circles. This will be very closely what occurs in most cases in practice, since the angle of the helix approaches or may exceed 75°. Let all the wires be of the same diameter. Let k be the radius of the core or heart, a that of the wire, and suppose ~~that~~ N wires fit exactly into the layer.



Then $\sin\frac{\pi}{N} = \frac{a}{k+a}$

$$\therefore N = \frac{\pi}{\sin^{-1}\frac{a}{a+k}}$$

This gives the value of N for any course, and from this all cross sections may be derived

In the following example the suffix denotes the layer.

1. Let k = a This gives the standard section

		Differences
$N_1 = \frac{\pi}{\sin^{-1}\frac{1}{2}} =$	6·00	
		6·43
$N_2 = \frac{\pi}{\sin^{-1}\frac{1}{4}} =$	12·43	
		6·34
$N_3 = \frac{\pi}{\sin^{-1}\frac{1}{6}} =$	18·77	
		6·29
$N_4 = \frac{\pi}{\sin^{-1}\frac{1}{8}} =$	25·06	
		6·29
$N_5 = \frac{\pi}{\sin^{-1}\frac{1}{10}} =$	31·4	
		6·28
$N_{10} = \frac{\pi}{\sin^{-1}\frac{1}{20}} =$	62·8	
		6·28 = 2π
$N_{100} = \frac{\pi}{\sin^{-1}\frac{1}{200}} =$	628.	

as $\lim_{\theta \to 0} \frac{\sin\theta}{\theta} = 1$ so in the case of windings derived from this formula the n^{th} term becomes in the limit $\frac{(2n-1)a + k}{a} . \pi$.

So that the series approximates to an arithmetical progression, whose common difference is 2π.

In practice the numbers taken for the standard strand are 1, 6, 12, 18, 24, &c to allow for the angle of the helix and ~~for~~ the fact ~~that the~~ section is not exactly circular. One may observe too. by looking at a 1/6/1 .125 "aerial" that the fit is not perfect, even if the angle of the helix is over 80°

2. Let $k = 2a$

$N_1 = \frac{\pi}{\sin^{-1}\frac{2}{3}} = 9.2$

$N_2 = \frac{\pi}{\sin^{-1}\frac{2}{5}} = 15.6$

$N_3 = \frac{\pi}{\sin^{-1}\frac{2}{7}} = 21.9$

$N_4 = \frac{\pi}{\sin^{-1}\frac{2}{9}} = 28.2$

$N_5 = \frac{\pi}{\sin^{-1}\frac{2}{11}} = 34.6$

$N_{10} = \frac{\pi}{\sin^{-1}\frac{2}{21}} = 66.$

$N_{100} = \frac{\pi}{\sin^{-1}\frac{2}{201}} = 630$

Let $k = \frac{2\sqrt{3} - 3}{3} a$

$$N_1 = \frac{\pi}{\sin^{-1} \frac{\sqrt{3}}{2}} = 3 \cdot 0$$

$$N_2 = \frac{\pi}{\sin^{-1} \frac{\sqrt{3}}{2 + 2\sqrt{3}}} = 9 \cdot 8$$

$$N_3 = \frac{\pi}{\sin^{-1} \frac{\sqrt{3}}{2 + 4\sqrt{3}}} = 16 \cdot 1$$

$$N_4 = \frac{\pi}{\sin^{-1} \frac{\sqrt{3}}{2 + 6\sqrt{3}}} = 22 \cdot 4$$

$$N_5 = \frac{\pi}{\sin^{-1} \frac{\sqrt{3}}{2 + 8\sqrt{3}}} = 28 \cdot 7$$

4. Let $k = 2 \cdot 864\, a \;=\; a\,(1 - \sin 15^\circ) / \sin 15^\circ$

$$N_1 = \frac{\pi}{\sin^{-1} .2588} = 12$$

$$N_2 = \frac{\pi}{\sin^{-1} .1705} = 18 \cdot 3$$

$$N_3 = \frac{\pi}{\sin^{-1} .1272} = 24 \cdot 6$$

$$N_4 = \frac{\pi}{\sin^{-1} .1014} = 31 \cdot 0$$

$$N_5 = \frac{\pi}{\sin^{-1} .08432} = 37 \cdot 2$$

Thus in all cases of this sort, whenever k is given, the cross section of the rope can at once be determined, and all forms of strand section can be designed.

The Effective Cross-Sectional Area of a Strand, and its Limiting Value.

Let there be N wires, each of radius a, and let them be arranged in n layers in the standard form 1, 6, 12, 18, &c.

$\therefore N = 1 + 6 + 12 + 18 + \cdots + 6(n-1). = 3n^2 - 3n + 1.$

$\therefore$ the effective area of the cross section is

$\pi(3n^2 - 3n + 1)a^2.$

If there be n layers the radius of the circum-circle is $(2n-1)a$

$\therefore$ Efficiency ratio of section $= \dfrac{\text{Effective area}}{\text{Circum - area}} =$

$= \dfrac{3n^2 - 3n + 1}{4n^2 - 4n + 1}$. When $n \to \infty$ this becomes ultimately $\frac{3}{4}$. i.e. three quarters of the possible space is occupied.

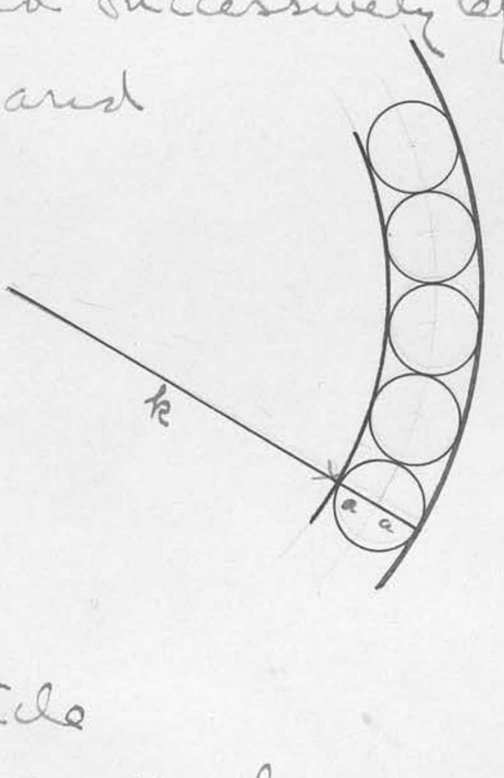
Writing $U = \dfrac{3n^2 - 3n + 1}{4n^2 - 4n + 1}$ and putting $\dfrac{dU}{dn} = 0$ for maximum efficiency, we have $U' = -\dfrac{1}{(2n-1)^3}$

Thus there is no maximum efficiency within our range for finite integral values of n, but the value of U diminishes constantly from $.78$ when $n = 2$ to $.75$ when $n \to \infty$ excluding the trivial case $U = 1$ when $n = 0$.

So in large strands the effective area, which we identify later with the orthogonal area, is very closely ·75 of the circum-area.
The circum-area may be obtained from taping the circumference of the strand or rope. In certain cases a considerable amount of error may be thus introduced necessitating a correction diagram which has been constructed.

Efficiency of an Orthogonal layer of the Cross-Sectional Area.

Since the layers are wound successively left & right, we may take the in- and circum-circles as the bounding lines.



Let k be the radius of the core, or in-circle,
a the radius of the wire
$\therefore k + a =$ radius of centre-circle
Let N be the number of wires in the layer

$$\therefore N = \frac{\pi}{\sin^{-1}\frac{a}{a+k}}$$

$$\therefore \text{Efficiency of Layer} = \frac{N\pi a^2}{\pi(k+2a)^2 - \pi k^2} = \frac{Na}{4(k+a)}$$

$$= \frac{a}{4(k+a)} \cdot \frac{\pi}{\sin^{-1}\frac{a}{a+k}}.$$

If the number of wires be large

$$\text{Efficiency} = \frac{\pi a}{4(k+a)} \frac{1}{\left\{\frac{a}{a+k} + \frac{1}{6}\left(\frac{a}{a+k}\right)^3 + \right\}}$$

$$= \frac{\pi}{4}\left\{1 - \frac{1}{6}\left(\frac{a}{a+k}\right)^2\right\} \text{ approximately.}$$

If $k = a$ this has the value $.78$ approximately, but the series is not sufficiently rapidly convergent for this approximation unless k have a more reasonable value.

Diameter of a strand

We may find the diameter approximately of a standard strand in terms of the diameter of the wire, and the number of wires. The rope is supposed to have a wire core. Let N be the number of wires, δ the diameter of a wire, D the diameter of the strand.

$$\therefore .78 \frac{\pi D^2}{4} > N \frac{\pi \delta^2}{4} > .75 \frac{\pi D^2}{4}$$

$$\therefore 1.13\,\delta\sqrt{N} < D < 1.16\,\delta\sqrt{N}$$

Diameter of a Rope

If ~~the suffix~~ s be used to denote a strand

∴ $D_s \doteq 1.16\ \delta\sqrt{N_s}$. Then for a standard rope

6|n|d we have $D \doteq 3.3 D_s$, $N = 7N_s$

∴ $D = 1.45\ \delta\sqrt{N}$ on elimination.

Strabok quotes the formula $D = 1.7\ \delta\sqrt{N}$ without giving any indication of how it has been established. He attributes it to Professor Rziha

As an example. Consider the rope $\frac{6}{7}\left|\begin{matrix}18\\12\\6\\1\end{matrix}\right|.084$.

Rziha's formula gives $D = 1.7 \times .084 \times 14.9''$

∴ the circumference $= 6.67''$

My formula gives $D = 1.45 \times .084 \times 14.9''$

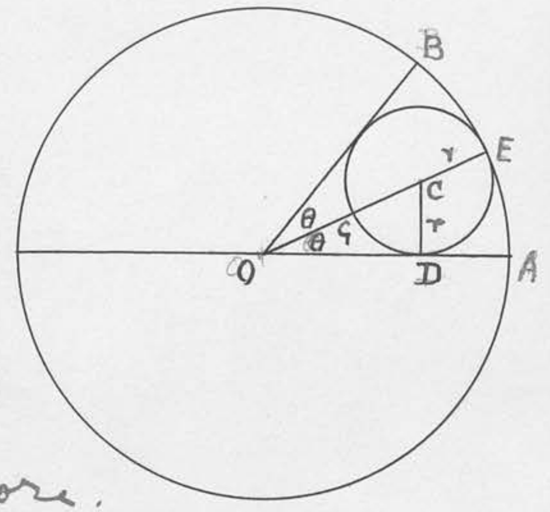
∴ circumference $= 5.66''$.

The catalogue gives the circumference of this rope as $5\frac{1}{2}''$, a taped value, I presume. If so, on adding 3% (see diagram) for the 6 circumferential strands we get 5.66" which checks with my result.

For a given circum-circle of Radius R, and a given number of strands S, there is:—

(i) a definite size of strand

(ii) a definite size of core



Let there be s strands. The central angle is $\frac{2\pi}{s}$

$\therefore AOE = \frac{\pi}{s} = \theta$

Let $OG = r_1$ be the radius of the core.

Let R be the circum-radius, and r the radius of the strand. Then θ and R are given and we require r & r_1

$$\therefore r = \frac{R \sin\theta}{1+\sin\theta} = \frac{2R\tan\frac{\theta}{2}}{(1+\tan\frac{\theta}{2})^2}$$

$$\text{Also } r_1 = R - 2r = R\,\frac{1-\sin\theta}{1+\sin\theta}$$

Thus r and r_1 are completely determined

If we put $r_1 = \mu r$ then $\sin\theta = \frac{1}{1+\mu}$

and μ may have any positive value. Hence we have the following table, which gives the range of values for the variables

S	θ	r	r_1
2	$\frac{\pi}{2}$	$\frac{R}{2}$	0
∞	0	0	R.

If R be the circum-radius of a layer of the strand (or rope) and r the radius of a wire (or strand) then $r(1 + \sin\frac{\pi}{n}) = R \sin\frac{\pi}{n}$

$\therefore D = d(1 + \operatorname{cosec}\frac{\pi}{n})$

where D and d are the diameters of the strand (or rope) and the wire (or strand) respectively.

Tabulating the values we have

n	θ°	$1 + \operatorname{cosec}\theta$
3	60	2.1547
4	45	2.4142
5	36	2.7013
6	30	3.
7	25°43′	3.3046
8	$22\frac{1}{2}$	3.6131
9	20	3.9238
10	18	4.2360
12	15	4.8637
15	12	5.8097
18	10	6.7588
20	9	7.3925
24	7°30′	8.6613
30	6	10.5668
45	4	15.335
60	3	20.107
90	2	29.654
180	1	58.3

From the above values a diagram has been prepared from which D may be read by inspection within the ranges $30 > n > 3$ and $.1 > d > 0$

(see Diagram)

As a wire in a strand is not — owing to its thickness — a line drawn on the circum-cylinder, a correction is made to deduce the circumference of the centre cylinder of a layer of wires from ~~that~~ of its circum-cylinder

Suppose the cross sectional area of the strand is formed by s layers of wire of circular section and radius a, about a central wire of radius a. Let C be the circumference of the circum-circle.

Then $C = 2\pi(2s+1)a$.

$\therefore$ the required circumference $C_1 = 2\pi\{(2s+1)-1\}a$

$\therefore C_1 = 4\pi s a$

If $C_1 = \lambda C \quad \therefore 4\pi s a = \lambda \cdot 2\pi(2s+1)a$

$\therefore \lambda = \frac{2s}{2s+1}$

Thus λ is the factor by which C is to be multiplied for determining C_1. Its values are given in the following table

s	1	2	3	4	5	. . . . .	∞
λ	$\frac{2}{3}$	$\frac{4}{5}$	$\frac{6}{7}$	$\frac{8}{9}$	$\frac{10}{11}$	. . . . .	1

Thus for the strand $\left|\begin{matrix}6\\1\end{matrix}\right| d$ $\lambda = \frac{2}{3}$

If a layer of wires of radius a surround a core of radius c

$\therefore C = 2\pi(c+2a)$ and $C_1 = 2\pi(c+a)$

$\therefore \lambda = \frac{c+a}{c+2a}$. where λ is the multiplying factor as before.

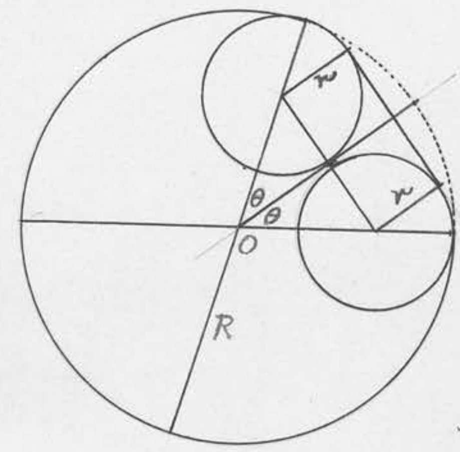
If s layers of wire of radius a surround a core of radius c

$\therefore C = 2\pi(c+2sa)$ $C_1 = 2\pi(c+\overline{2s-1}\,a)$

$\therefore \lambda = \frac{c+(2s-1)a}{c+2sa}$.

The Taped Circumference and its correction for strands in a rope. (or wires in a strand.)

Let R & r be the radii of the rope and the strand, s the number of strands.



$\therefore \theta = \frac{\pi}{s}$. Let T be the taped perimeter

$\therefore T = s(2r\theta + 2r)$

When s and T are known, R and r are required

$\therefore r = \frac{T}{2s(1+\theta)} = \frac{T}{2(\pi + s)}$

$R = \frac{1+\sin\theta}{\sin\theta} \cdot r = \frac{T(1+\operatorname{cosec}\theta)}{2(\pi+s)}$

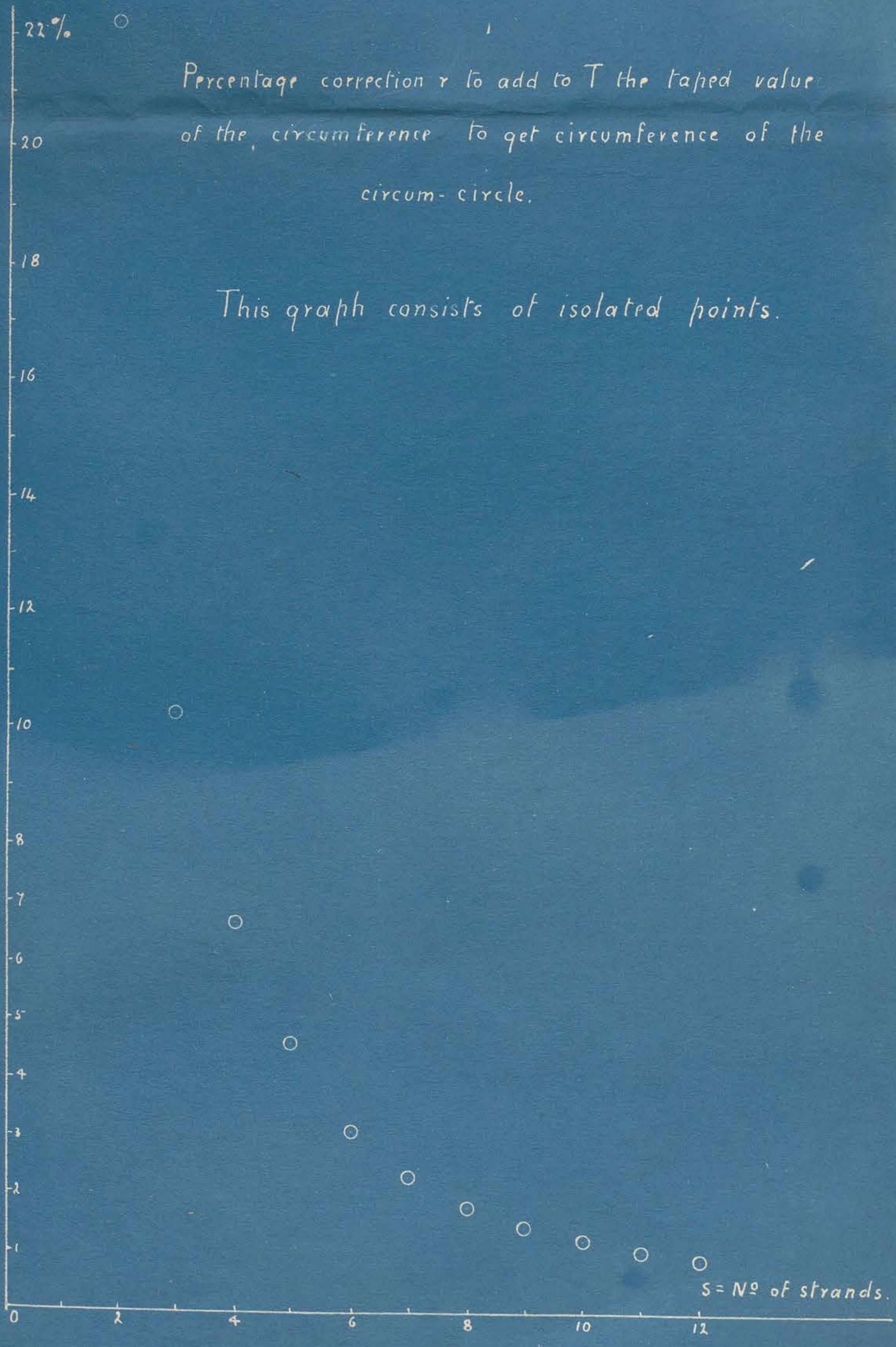
Thus the correction, additive to the taped value T, is $2\pi R - T$

$= T\left\{\frac{1+\sin\theta}{\sin\theta} \cdot \frac{\theta}{1+\theta} - 1\right\} = T \cdot \frac{\theta - \sin\theta}{\sin\theta(1+\theta)}$

Thus if $s = 6$

Error on taped value for circumference of circumcircle is $T \cdot \frac{2\pi - 6}{\pi + 6} = \cdot 03098\, T$

ie add 3.1%.


22 %
Percentage correction r to add to T the taped value of the circumference to get circumference of the circum-circle.
This graph consists of isolated points.
20
18
16
14
12
10
8
7
6
5
4
3
2
1
0
2
4
6
8
10
12
S = Nº of strands.

a diagram was constructed giving this correction for any given number of strands.

The last equation $R = (1 + \operatorname{cosec}\theta)\, r$ also gives the circum-radius R in terms of the taped circumference T

$$D. = 2R = \frac{T(1+\operatorname{cosec}\theta)}{(\pi + s)}$$

with The writer learnt that one of the practical rules used in rope construction was as follows. For a strand 1" in circumference add 3 to the number of the outer wires: the reciprocal of this shall be the diameter of the wire in inches. This is the actual rule by which the wire is selected.

On page 34 I have established this in a much more general form viz:

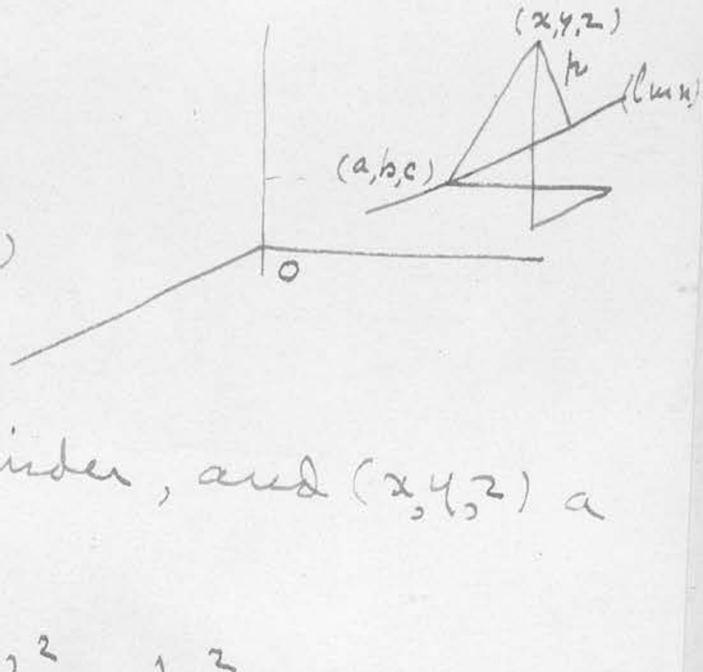
$$2r = \frac{T}{\pi + s}$$

where T is the taped circumference and s the number of the wires in the outer layer. Thus instead of 3 the value taken should be π

Elliptic Cross Section of the Wire.

So far in considering the cross-section of a strand the sections of the wires have been assumed to be circles. This of course is only approximately correct, though near enough for most cases in practice.

Assume first that the wire wrapped round a core cylinder may be represented in the neighbourhood of a particular point on the core by a cylinder A touching the core cylinder C.



Let l, m, n be the direction cosines of the axis of A, (a, b, c) a point upon the axis, p the radius of the cylinder, and (x, y, z) a point upon it.

$$\therefore \Sigma (x-a)^2 - \{ \Sigma l (x-a) \}^2 - p^2 = 0$$

An elliptic section is formed by any plane $l'x + m'y + n'z - p' = 0$.

In particular if the axis of A meet the plane $Z=0$ in the point $(h, k, 0)$ and (a, b, c) be taken as $(h, k, 0)$ $\therefore$ $(x-h)^2+(y-k)^2-\{l(x-h)+m(y-k)\}^2-p^2=0$

is the equation of the elliptic section

or $(1-l^2)(x-h)^2-2lm(x-h)(y-k)+(1-m^2)(y-k)^2-p^2=0$

Simplifying this by rotating the axes of reference so as to make the axis of the cylinder through the point $(c+a, 0, 0)$ (c) and a being the radii (? respectively) of the core and wire cylinders, α the angle of the helix, in this case the angle between the axes of the two cylinders,

then since $\cos\theta = ll'+mm'+nn'$ $\left\{\begin{matrix} l & m & n \\ 0 & 0 & 1 \\ l' & m' & n' \\ 0 & \cos\alpha & \sin\alpha \end{matrix}\right.$

the equation of the section becomes

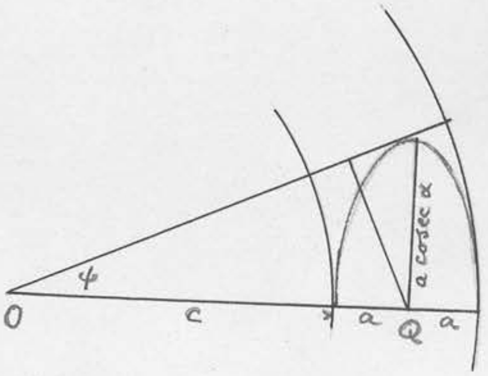
$$\left\{\frac{x-\overline{c+a}}{a}\right\}^2+\frac{y^2}{(a\operatorname{cosec}\alpha)^2}=1$$

For a definite size of core and of wire there would be a definite angle of lay with a given number of wires in any particular layer.

The advantage of a fibre core is

partly from its adaptability to the above requirement, and also to its flexibility under bending. There are various other practical advantages, since it may be impregnated with anti-rust and anti corrosion material, a consideration of extreme importance under most conditions of working

To find the central angle ϕ in the case of the elliptic section.



The ellipse is

$$\frac{(x - \overline{c+a})^2}{a^2} + \frac{y^2}{a^2 \operatorname{cosec}^2 \alpha} = 1$$

If $y = mx$ be the tangent

then by the condition for tangency

$$m^2 = \frac{a^2 \operatorname{cosec}^2 \alpha}{c^2 + 2ac}$$

$\therefore$ the double tangents through the origin are

$$y = \pm \frac{a \operatorname{cosec} \alpha}{\sqrt{c^2 + 2ac}}\, x$$

For the point of contact with the upper tangent we have on solving

$$(c^2+2ac)\{x^2-2(c+a)x+(c+a)^2\}+a^2x^2-a^2(c^2+2ac)=0$$

$$\therefore \{x(c+a)-(c^2+2ac)\}^2=0$$

$$\therefore x=\frac{c(c+2a)}{c+a} \qquad y=\frac{a\operatorname{cosec}\alpha}{c+a}\sqrt{c(c+2a)}$$

Shifting the origin from O to Q

$$x=c+a+\xi \qquad y=\eta$$

$$\therefore \frac{\xi^2}{a^2}+\frac{\eta^2}{a^2\operatorname{cosec}^2\alpha}=1$$ The tangent at (ξ_1,η_1) is

$$\frac{\xi\xi_1}{a^2}+\frac{\eta\eta_1}{a^2\operatorname{cosec}^2\alpha}=1$$ $\therefore$ the perpendicular from Q

on this is $$p=\frac{a^2}{\sqrt{\xi_1^2+\eta_1^2\sin^4\alpha}}=\frac{a(c+a)}{\sqrt{a^2+(c^2+2ac)\operatorname{cosec}^2\alpha}}$$

$$\therefore \sin\phi=\frac{p}{c+a}=\frac{a\operatorname{cosec}\alpha}{\sqrt{c^2+2ac+a^2\operatorname{cosec}^2\alpha}}$$ hence ϕ.

If $c+a$ is large as compared with a

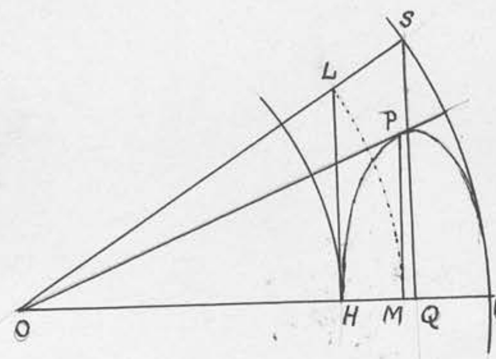
$$\therefore \tan\phi=\frac{a\operatorname{cosec}\alpha}{c+a}\left\{1+\frac{1}{2}\frac{a^2}{(c+a)^2}-\&c\right\}$$

So the error in taking $\tan\phi=\frac{a\operatorname{cosec}\alpha}{c+a}$

is approximately $\frac{1}{2}\frac{a^3\operatorname{cosec}\alpha}{(c+a)^3}$

We have also a simple construction for the point of contact.

Since $x = \frac{c(c+2a)}{c+a}$, at Q raise a perpendicular to the line OQ, cutting the outer circle in S. Join OS.



Draw a perpendicular through H to meet OS in L.

With centre O and radius OL draw a circular arc to cut OQ in M. M is the abscissa of the point required. The proof is simple.

The point P, which is required, is got by drawing a perpendicular to OQ through M to cut the line OS. The point is thus determined graphically without constructing the ellipse.

The angle of the lay may be found by determining the next ellipse. This also must touch the line $y = mx$. Hence by the condition of tangency $\sin^2\alpha = \dfrac{a^2}{m^2(c^2+2ac)}$

Thus when any three of the four quantities a, c, α, ϕ be given the fourth may be found.

When c is large, $\sin\alpha = \dfrac{a}{c+a}\cot\phi$, very nearly.

Examples.

i Standard $\frac{6}{1}$ strand or rope.

$$\therefore \sin\alpha = \frac{a\sqrt{3}}{\pm\sqrt{c^2+2ac}}$$

There is no ambiguity, as α is an acute angle and the +ve sign alone is taken; the change of sign merely denoting a right or left handed helix

If $c = a$ $\therefore \sin\alpha = 1$ $\alpha = \frac{\pi}{2}$

This is the case of the selvagee rope

If $c < a$ the construction is impossible as we should have $\sin\alpha > 1$

If $c > a$ the construction is possible

Hence, in the case of a standard strand, the centre wires should be thicker than the others, the value being given by the above equation. (See diagram) — which -

ii If $\alpha = 70^\circ$, $n = 3$, $\psi = 60^\circ = \frac{\pi}{3}$

$$\therefore \left(\frac{c}{a}+1\right)^2 = 1 + \frac{L}{m^2}\operatorname{cosec}^2\alpha$$

$$\therefore \frac{c}{a} = -1 + \sqrt{1.3773} = .174.$$

(See diagram) which

iii If we take α small, from the point of view of roping, say $\alpha = 45^\circ$, $n = 3$, $\psi = 60^\circ$

$$\therefore \frac{c}{a} = -1 + \sqrt{\frac{5}{3}} = .291$$

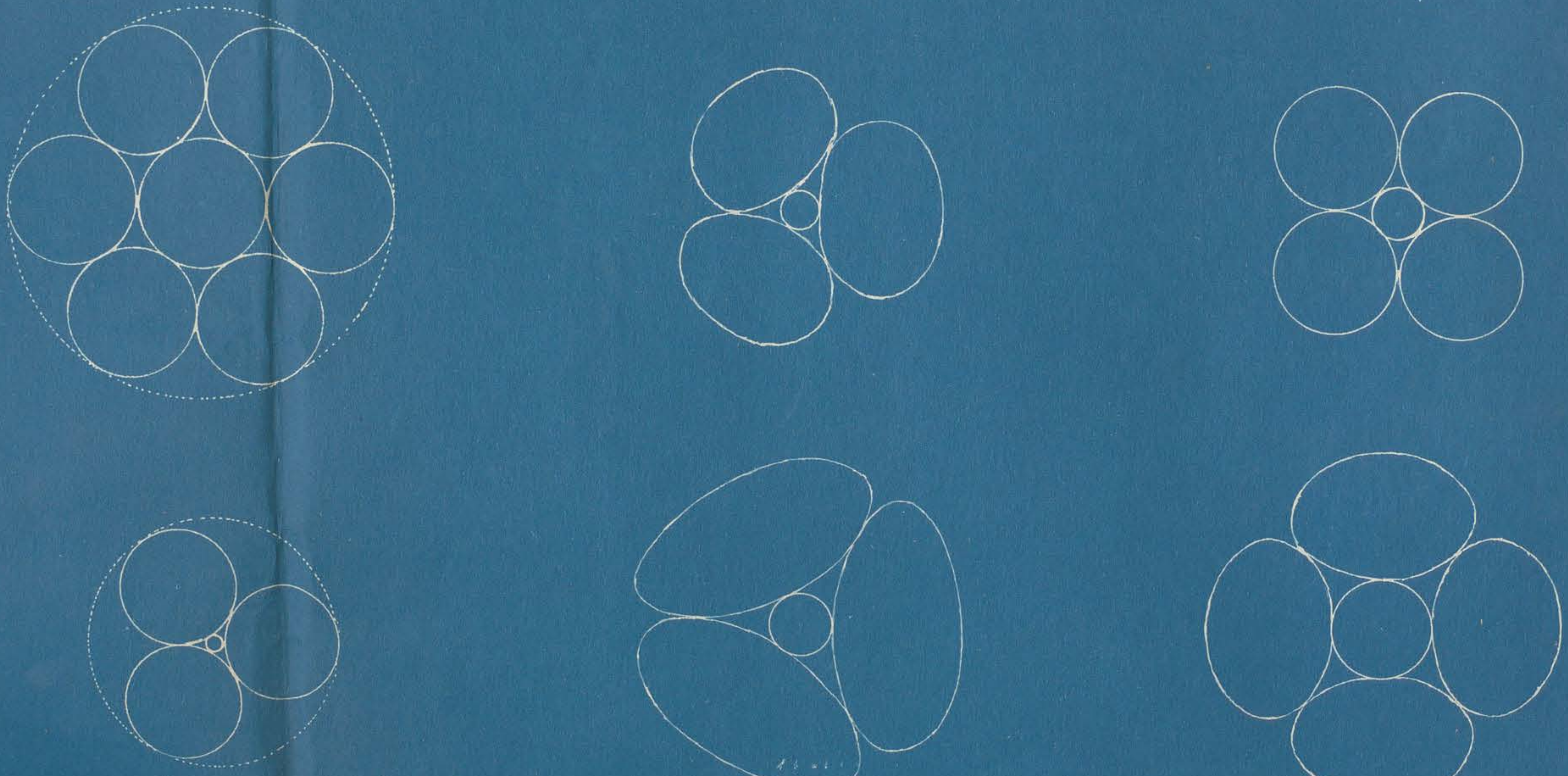
(See diagram)

iv If $\alpha = 30^\circ$, the other values being as before

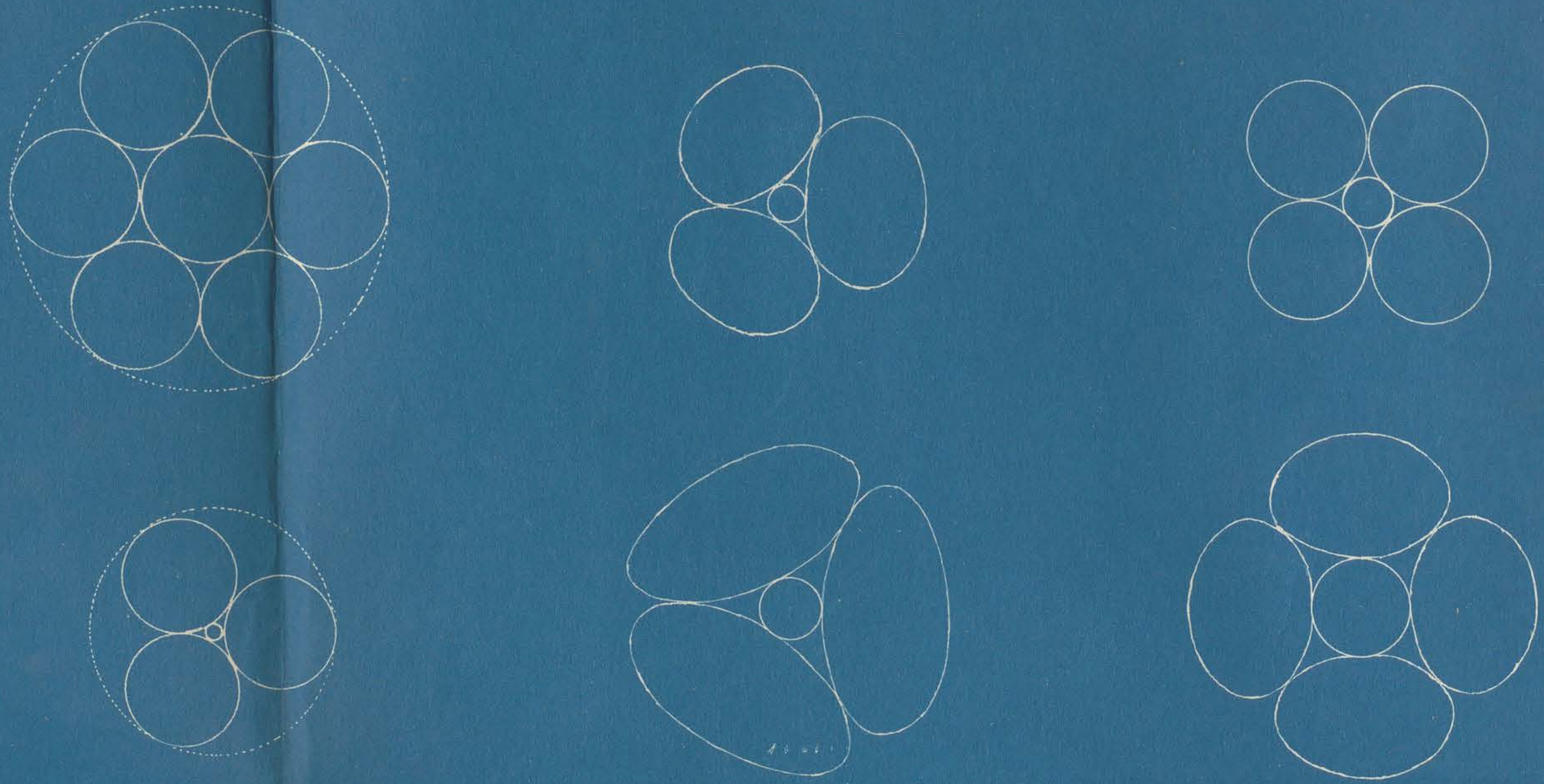
$$\therefore \frac{c}{a} = -1 + \sqrt{\frac{7}{3}} = .528$$

(See diagram.)

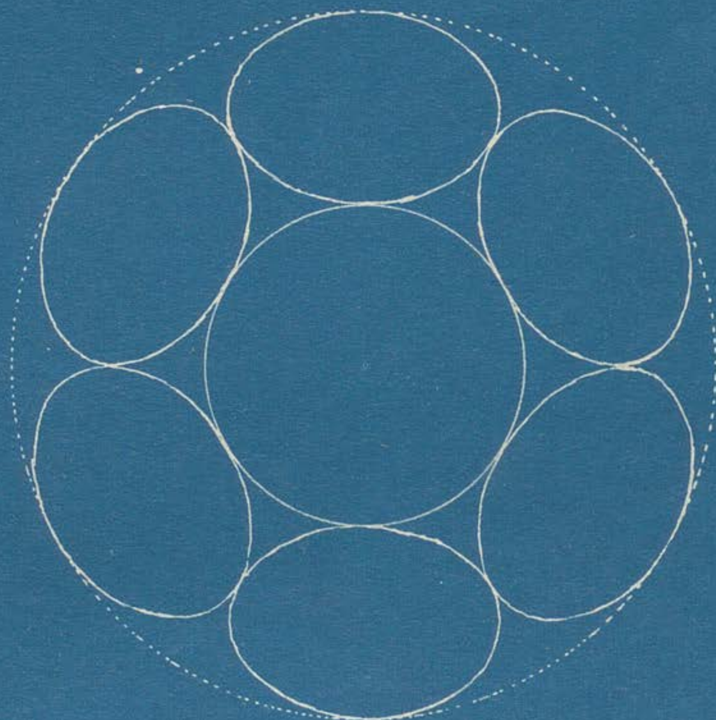
Sections



Sections



Section. No. 8



v If $n = 4 \therefore \psi = \frac{\pi}{4}$ $\alpha = 70°$

$\therefore \frac{c}{a} = -1 + \sqrt{1 + \operatorname{cosec}^2 \alpha} = -1 + \sqrt{2.132} = .460$

(See diagram) ?

vi If $\alpha = 45°$ the other conditions as in v

$\therefore \frac{c}{a} = -1 + \sqrt{3} = .732$

(See diagram) which ?

vii For a normal 6/1 strand or rope say $\alpha = 80°$. Then $\psi = 30°$

$\therefore \frac{c}{a} = -1 + \sqrt{1 + 3\,(1.0302)} = 1.0225.$

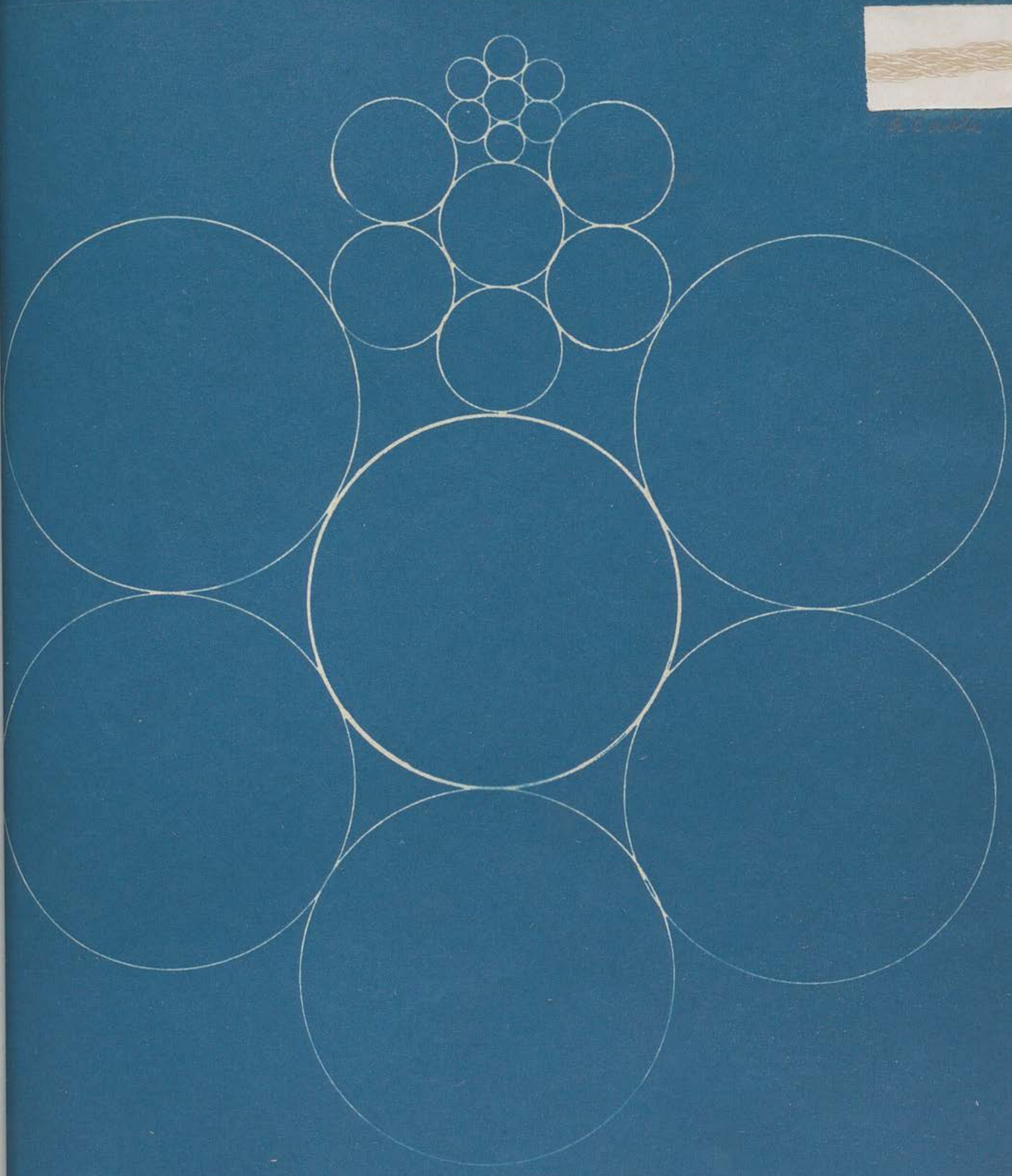
(See diagram)

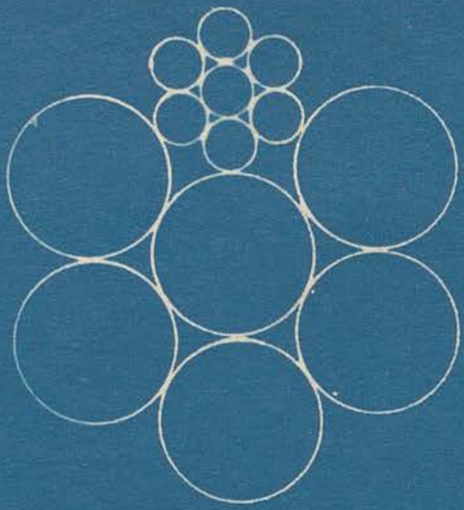
viii For a normal 6/1 strand or rope with $\alpha = 45°$

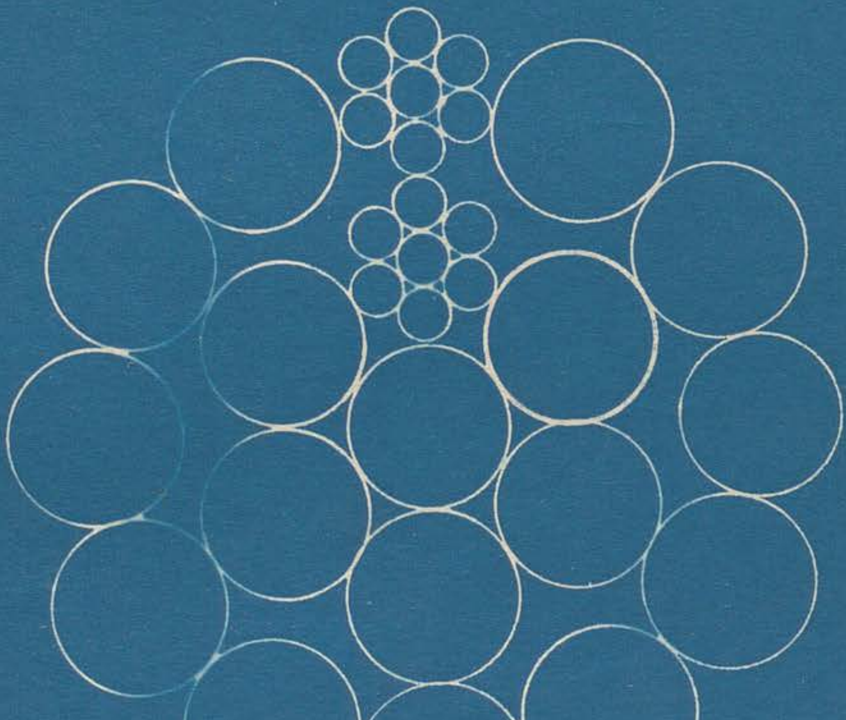
$\therefore \frac{c}{a} = -1 + \sqrt{1 + 3 \times 2} = 1.646$

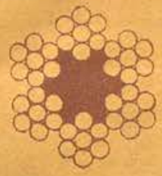
(See diagram.)

After the wires have been formed into strands, the strands are laid into ropes, or the ropes closed into cables in the same way. Diagrams are given showing typical sections of ropes and cables.

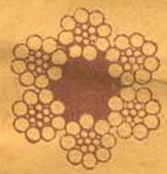




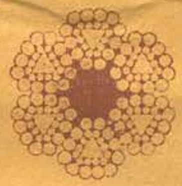




6 strands, 7 wires.



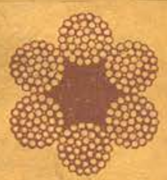
6 strands, 15 wires.



6 strand, 25 wires.

Whole Closed Section.

6 strands, 19 wires



6 strands, 37 wire

The stranded ropes of the largest sectional area which the writer has noticed, are those for the Widnes and Runcorn transporter bridge (Proc. Inst. C.E. CLXV. p144. 1906) The section may be represented by the formula

	36	
12	·30	
6	24	
1	18	·1624"
	12	
	6	
	1	

The wire strength was 94 tons □" and the orthogonal area of the rope was 50□". The elastic limit of the wire was said to be from 85% to 95% of the ultimate strength. The wires in the strand were parallel.

In the discussion that followed this paper, one criticism, directed against the rope, stated ~~that~~ the cable form would have been better. With this the writer does not agree, for reasons indicated in a later chapter of this paper.

Locked coil ropes of large section were used in the Emperor Franz Josef Bridge at Prague. These though much smaller than those used at the Widnes & Runcorn bridge, were 9.2 Cm in diameter.

One great objection to the use of ropes in Suspension bridges is the chance ~~that~~ rain or moisture may collect in the interior of the ropes, and cause decay by corrosion. This disadvantage is of much lesser importance in mining, haulage, and naval ropes, as these are frequently renewed.

The writer adds a copy of the tables prepared by him for obtaining rapidly the orthogonal area of steel in a rope.

See. Tables. A.

Winding.

Chapter II

Structure of the Strand and Rope

In making a strand, which is the first step in forming a [...]nded rope, concentric [...] wires are wound in helices round a [...]ral core. To ensure this it is necessary that any point on a [...]ated wire shall have a uniform rotation about a fixed axis and a [...]orm translation parallel to that axis. These combined motions [...] be given to each of the wires. In winding a strand of [...] α ($\alpha = \tan^{-1}\frac{p}{2\pi a}$) the velocity parallel to the axis bears [...]stant ratio to the velocity of rotation.

$$x = a\cos\omega t$$

$$y = a\sin\omega t$$

$$z = \frac{p}{2\pi}\,\omega t$$

[...] the equations of the helix, where x, y, z are the coordinates [...]he point, a the radius of the cylinder, $\omega = 2\pi n$ the angular [...]city, p the pitch, t the time at any instant, and n the frequency. [...]g the fluxional notation for differentiating, the ratio of the [...] velocities of translation and rotation is $\frac{\dot z}{\dot s} = \frac{pn}{a\omega} = \frac{p}{2\pi a} = \tan\alpha$

[...]f the ratio of the two velocities is constant α is constant.

A mechanism is employed to maintain this constant ratio when [...]ding a strand. To alter the pitch, or the angle of the helix, [...]e method adopted in practice is to vary the velocity $\dot z$ by means [...] change-wheels.

When the strands have been wound in a stranding machine, they [...] be formed in precisely the same fashion into a rope, by a closing [...]chine.

Winding.

In making a strand, which is the first step in forming a stranded rope, concentric layers of wires are wound in helices round a central core. To ensure this it is necessary that any point on a selected wire shall have a uniform rotation about a fixed axis and a uniform translation parallel to that axis. These combined motions must be given to each of the wires. In winding a strand of angle α ($\alpha = \tan^{-1}\frac{p}{2\pi a}$) the velocity parallel to the axis bears a constant ratio to the velocity of rotation.

Thus $x = a\cos\omega t$

$y = a.\sin\omega t$

$z = \frac{p}{2\pi}\omega t$

are the equations of the helix, where x, y, z are the coordinates of the point, a the radius of the cylinder, $\omega = 2\pi n$ the angular velocity, p the pitch, t the time at any instant, and n the frequency. Using the fluxional notation for differentiating, the ratio of the two velocities of translation and rotation is $\frac{\dot{z}}{\dot{s}} = \frac{pn}{a\omega} = \frac{p}{2\pi a} = \tan\alpha$

So if the ratio of the two velocities is constant α is constant.

A mechanism is employed to maintain this constant ratio when winding a strand. To alter the pitch, or the angle of the helix, the method adopted in practice is to vary the velocity $\dot{z}$ by means of change-wheels.

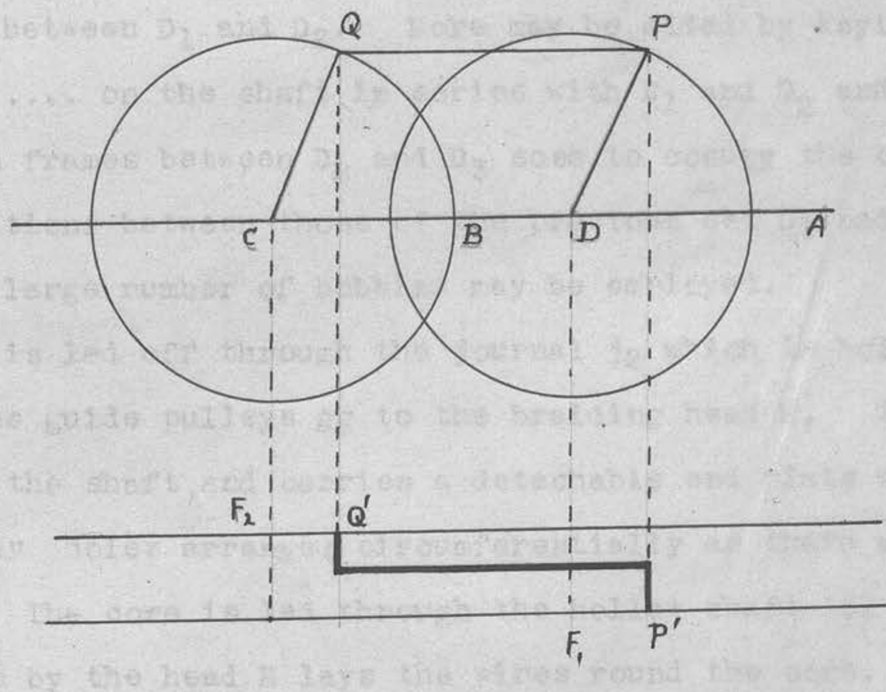
When the strands have been wound in a stranding-machine, they may be formed in precisely the same fashion into a rope, by a roping machine.

These two machines are practically identical in design, and details regarding them may be obtained in any makers catalogue. In view however of certain misunderstandings of their principles, by some who have worked with them, a brief indication of their action may be given.

The following is a purely diagrammatic sketch of the ordinary type of winding machine. The hollow shaft S revolves in bearings carried by the frame A,A, and is driven through belting by the pulley P. Two wheels or discs D_1, and D_2 are keyed to the shaft S and revolve with it. These carry by means of journals the arrangement for holding the wire bobbins. At j_1 and j_2 are these bearings, in which the crank-piece c_1 c_2 c_3 c_4 can rotate relatively to D_1 and D_2. Between C_2 and C_3 is attached rigidly the frame which carries the bobbin B on which the wire is wound. Owing to its weight this would assume the hanging position shown in the figure while the shaft rotates. In the earliest type of machine this arrangement was thought to be sufficient, but there was apt to be 'hunting', and any possible seizing of the axle would have been disasterous. Thus it was found necessary to add a guide-ring L. In this there is a journal at E into which the crank-piece passes. The ring is free to rotate about its centre as in the figure, but in order to obtain the smoothest running its inner periphery is supported against two friction wheels. This arrangement holds the bobbin frame so that it hangs suspended when the shaft rotates.

The foregoing mechanism is analogous with the ordinary locomotive coupler, a simple case of the four bar chain. C and D are the centres of/

of two equal circles, of radius a;



CD = ℓ, DP and CQ are two parallel radii so that QP = CD = ℓ. If ADP be the crank angle θ, and if PD revolve uniformly, the coupler PQ drives the wheel CQ uniformly also. Actually the two wheels are not in the same plane, like the coupled wheels of a locomotive, but are in parallel planes, as indicated in the lower part of the diagram. Conversely, as the two wheels revolve, QP is unchanged in direction though it is displaced in position. Thus the crank piece, though rotating relatively to the wheel, is unchanged in direction relatively to the frame, that is to say the bobbin frame in the machine remains hanging vertically during the revolution of the shaft. Though this arrangement/

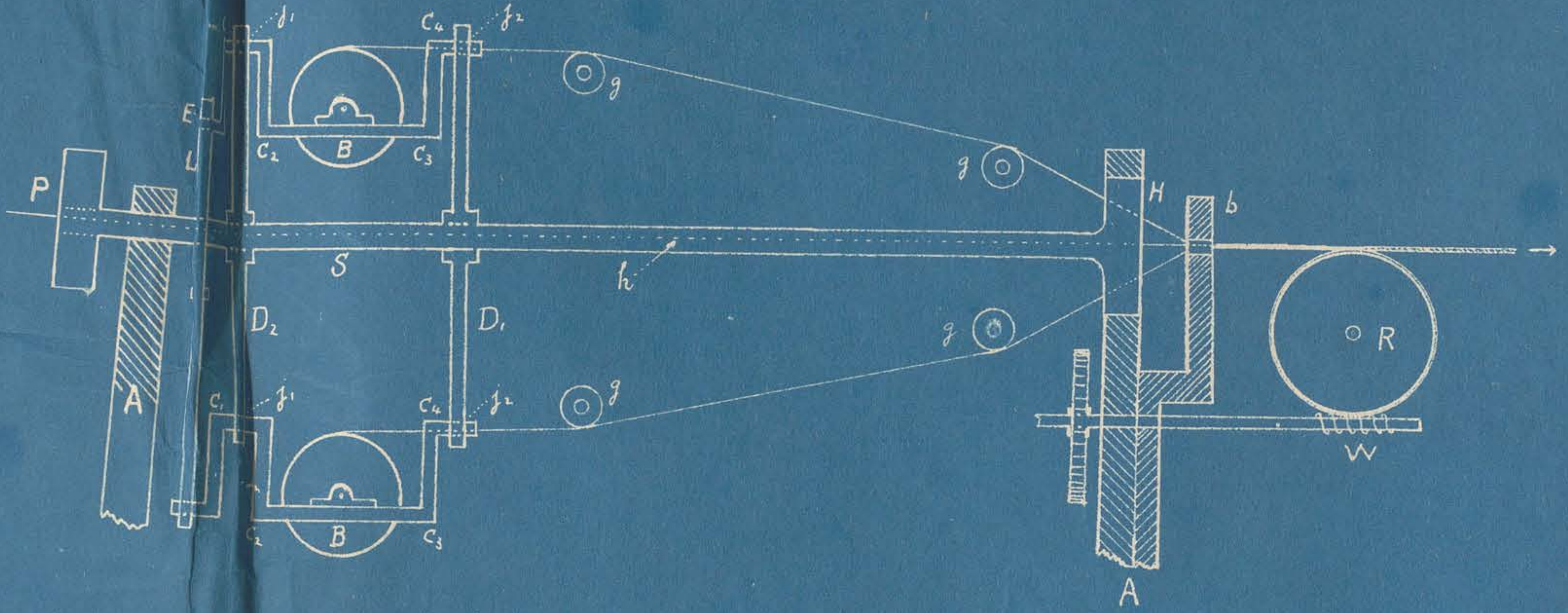
arrangement is not a sun and planet motion, it receives this name among many wire engineers.

In the usual type of winding machine there may be 6 or 12 bobbin frames between D_1 and D_2. More may be added by keying more wheels D_3, D_4 .... on the shaft in series with D_1 and D_2 and spacing the new bobbin frames between D_2 and D_3 so as to occupy the circumferential positions between those of the previous set D_1 and D_2. In this way a large number of bobbins may be employed.

The wire is led off through the journal j_2 which is hollow, and passes over the guide pulleys gg to the braiding head H. This revolves with the shaft, and carries a detachable end plate which employs as many holes arranged circumferentially as there are wires being wound. The core is led through the hollow shaft S, and the rotation given by the head H lays the wires round the core. These are at the same time drawn forward so as to form the helices. In larger machines two or three layers may be laid at once. There is a braking arrangement at b to control the wires which are being wound into the strand. The strand, as it is formed, is led forward by the removal disc R. This is driven by a worm gear W from toothed wheels driven from the main shaft, so that R is rotated a definite amount by each rotation of S. The strand is passed round the periphery of R, and the frictional grip so obtained advances the constructed strand the requisite amount so as to ensure the required angle α . To obtain a different value, α', change wheels are employed, as in a lathe, for driving W at a rate such as will give this new angle. As $\frac{\dot{z}}{\dot{S}} = \frac{h}{2\pi a} = \tan\alpha$

so/

so by altering the value of the velocity $\dot{z}$ by the change wheels the required value is obtained.


P
A
E
L
j1
j2
C1
C2
C3
C4
B
D2
D1
S
h
g
H
b
A
R
W

Snake Machine.

This machine is the most recent for wire strand winding, and was largely employed at Bruntons. It presents scarcely the least resemblance to the older type of machine, yet it is kinematically equivalent to it. It resembles a long hollow horizontal cylinder, and consists actually of two hollow co-axal cylinders with portions removed longitudinally. The bobbins are arranged in their frames axially inside the central cylinder, their axes being horizontal diameters of the cylinder. The cylinder sustaining the bobbins remains at rest while the outer cylinder rotates relatively to it. The wires are threaded through small guides on the surface of the inner cylinder and pass along its generating lines to the braiding head, the rotation being given by the outer cylinder. This is light and of small radius, consequently its moment of inertia is kept low, and hence it may be run at a very high speed.

The 'snake' accomplishes a great deal of work in a given time, but it takes rather longer to set than the ordinary machine.

From the fact that the bobbin-frames remain with the same orientation throughout the revolution of the shaft, one finds a universal agreement that there is no twist in the wire when laid into the helix. In fact it seems very difficult to convince wire workers on this subject, yet, though the torsional strain of the wound wire is not apparent in a rope, if a locked coil rope be unwound, the torsion of any non-cylindrical wire is at once apparent. One can also verify this experimentally by marking a generating line on a straight flexible cylinder, which is then laid round another cylinder, when the line is seen to be deformed into a helix.

If the material were perfectly elastic the rope-wire would spring back to its original straight state when unwound, but, as it has been strained far beyond the elastic limit, much of the deformation is permanent. The total strain should be one twist per convolution. This may be explained by noting that since the bobbin-frame maintains the same orientation, and the wire gets say a +ve lay in the helix, it must get an equal and opposite rotation on its own axis, so that the sum of these two rotations may be zero. Thus there is a torsional strain in the wire, though this has been usually denied by wire-workers. (see specimens), or photograph.
The torsion cannot be detected in photos 1 & 2 of cylindrical wire, but is is plain in photos 3, 4, & 5 wh are non-cylindrical.

In connection with the subject of winding, when the writer began his researches, he wanted to borrow a machine for winding small experimental strands. This he could not get so he was obliged finally to design and make one.

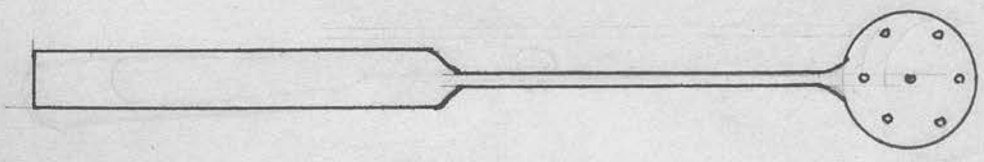
In case any of his experimental machines, which are described later/

later, may seem a little crude he begs to mention that he asked for no financial grant, and himself paid all expenses. Consequently the machines had to be constructed cheaply, as otherwise the expense would have been prohibitive.

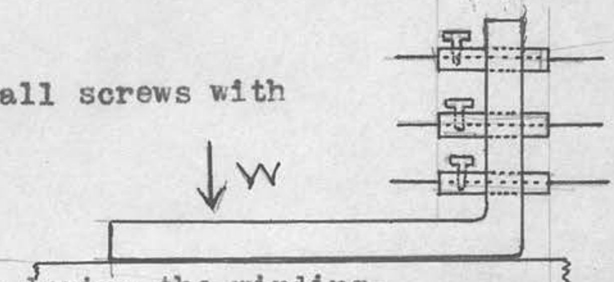
His winding machine worked excellently. It was an adaptation of a lathe, and as some experimenters may desire to know of a simple method of forming experimental strands, he adds a brief description.

He fitted up his small back geared foot-lathe so that the wires to be wound had their extremities held in the chuck. From that they were passed through a 'stranding-tool', and these were taken as nearly parallel to each other and to the lathe centres as possible, and fastened to attachments on a sliding carriage placed beyond the lathe bed, and able to move parallel to it.

The stranding tool was a hand tool, having at its extremity a circular disc, with holes for the wires to pass through.



The sliding carriage was made of wood and in the shape of a simple angle section. Corresponding with the holes in the stranding tool were small brass hollow tubes set in the vertical face of the carriage.

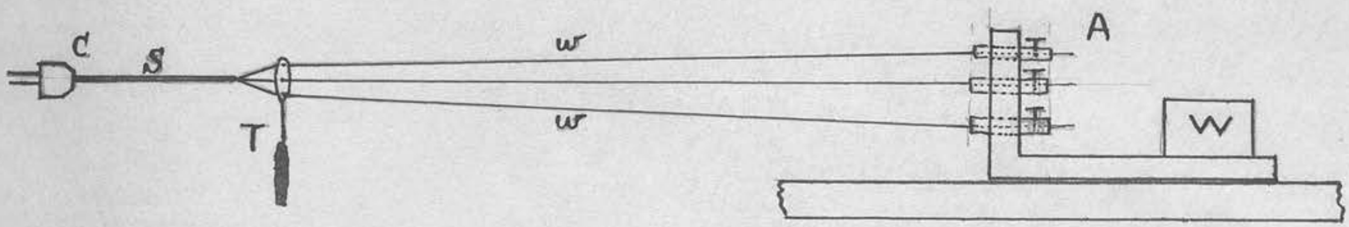


The wires passed through these and were pinched in position by small screws with milled heads. A heavy weight was used to hold the sliding carriage upright. The carriage advances slightly during the winding.

In/

In order to wind the strand the rotation was obtained by revolving the mandrel by the treadle and wheel, while the horizontal motion was obtained by moving the stranding tool parallel to the centres like the feed of a slide-rest from its leading screw.

A diagram of the arrangement is given



C is the chuck, S the formed strand, T the stranding tool, w the wires, A the sliding carriage, and W the weight.

As with all hand lathe work it required a small amount of practice before perfectly regular strands could be spun. Short lengths only could be made, say about 3' in length, but these were sufficient for the purpose in view.

The Lay

The helically laid wires in any layer of a strand tend to produce a rotation under load as has already been mentioned. To reduce this in amount, the successive layers are laid alternately right- and left-handedly. This produces also a more perfectly cylindrical strand. When the strands are formed into an ordinary stranded rope, the lay of the strand in the rope is opposite to that of the outer wires of the strand. Most frequently the lay of the strand in the rope is right, and that of the outer layer in the strand is left. An arrangement such as this is called "crossed" or "ordinary" lay, to distinguish it from Lang's or Albert's lay, in which both are in the same sense.

If one takes, say, a left handed strand, and winds it right-handedly round a core, the strand is tightened up, and the angle of its helix reduced, while if it be wound round a core left-handedly it receives a certain amount of untwisting, and the angle of its helix in increased. Thus in the ordinary, or cross braid, one notices that the crowns or knuckles of the wires are pronounced, i.e. where the wire touches the circum-cylinder of the rope, it bends sharply from it, forming a sharply curved portion. In cable construction, a cable being formed of N ropes, this is particularly pronounced, (See specimens) and is one of the causes of the inefficiency of the cable. (Photographs are shown)

If the angle of the helix of the tightened strand be equal to that of the strand in the rope, the tangent to the wire at the crown will be parallel to the axis of the rope. In this case the wire in the strand, at the point diametral to a crown, is inclined at an angle 2ω to the axis of the rope, where $\omega = \frac{\pi}{2} - \alpha$ is the angle of the lay, and α the angle of the helix in both cases.

In Lang's Lay the crown is less pronounced, owing both to the untwisting effect, and also to the tangent at the crown making the angle 2ω with the axis of the rope. The tangent at the point in the strand diametral to the crown

the rope, ω being the angle of t

Owing to this prominence of

effect of abrasion is to remove m

the outer wires of a rope, and as th

the circum-cylinder, i.e. in all

the rope is greatly weakened. S

nounced in Lang's Lay, the latter

abrasion is considerable.

(See illustrations). From B

Thus in the standard rope $6 \left| \begin{matrix} 12 \\ 6 \\ 1 \end{matrix} \right.$

would be injured seriously by abr

were wound so that if of the wires i

only two touched the circum-cylin

employed) then only twelve wires

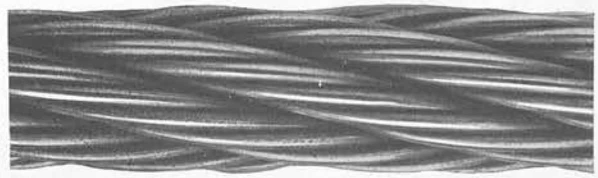
seriously compared with the depth

adjustment however would be diffi

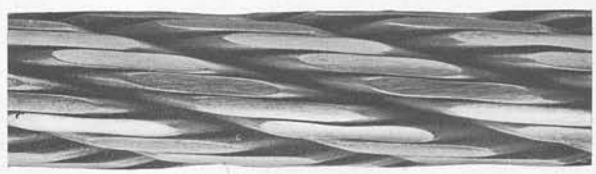
An/

14 W. N. Brunton & Son, Musselburgh, Scotland.

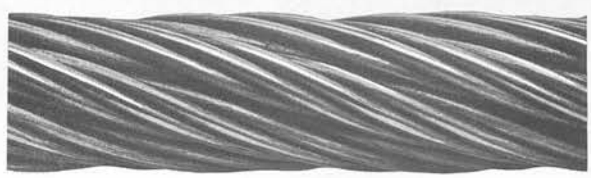
ILLUSTRATIONS OF WIRE ROPES.



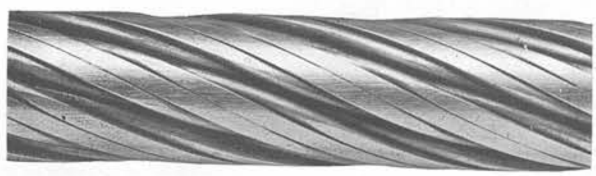
Cross or Ordinary Laid Rope. New.



Cross or Ordinary Laid Rope. Worn.



Lang's Lay Rope. New.



Lang's Lay Rope. Worn.

ALL CONSTRUCTIONS KEPT IN STOCK.

An average value of the braiding angle $\omega = \frac{\pi}{2} - \alpha$ is about 16°, though it ranges roughly from 8° to 24°. The higher values give more flexibility with a slight loss of strength. If we seek for the best value of α as regards strength the stress q may be written in the form.

$$q = A \operatorname{cosec} \alpha + H \cos \alpha + K \cos^2 \alpha$$

Where the three terms indicate the effects due to tension, torsion, and bending of the wire in the straight loaded strand. Since $\alpha \ngtr \frac{\pi}{2}$, q has its least value for this range when $\alpha = \pi/2$. This would mean the selvagee rope, but owing to its disadvantages of construction, and splicing, and its stiffness under an external serving, it is never used now.

Actually α is usually taken at about 74° as already mentioned.

The following graphs are plotted from values given by Bucknall Smith and give a fair indication of the values of α and p.

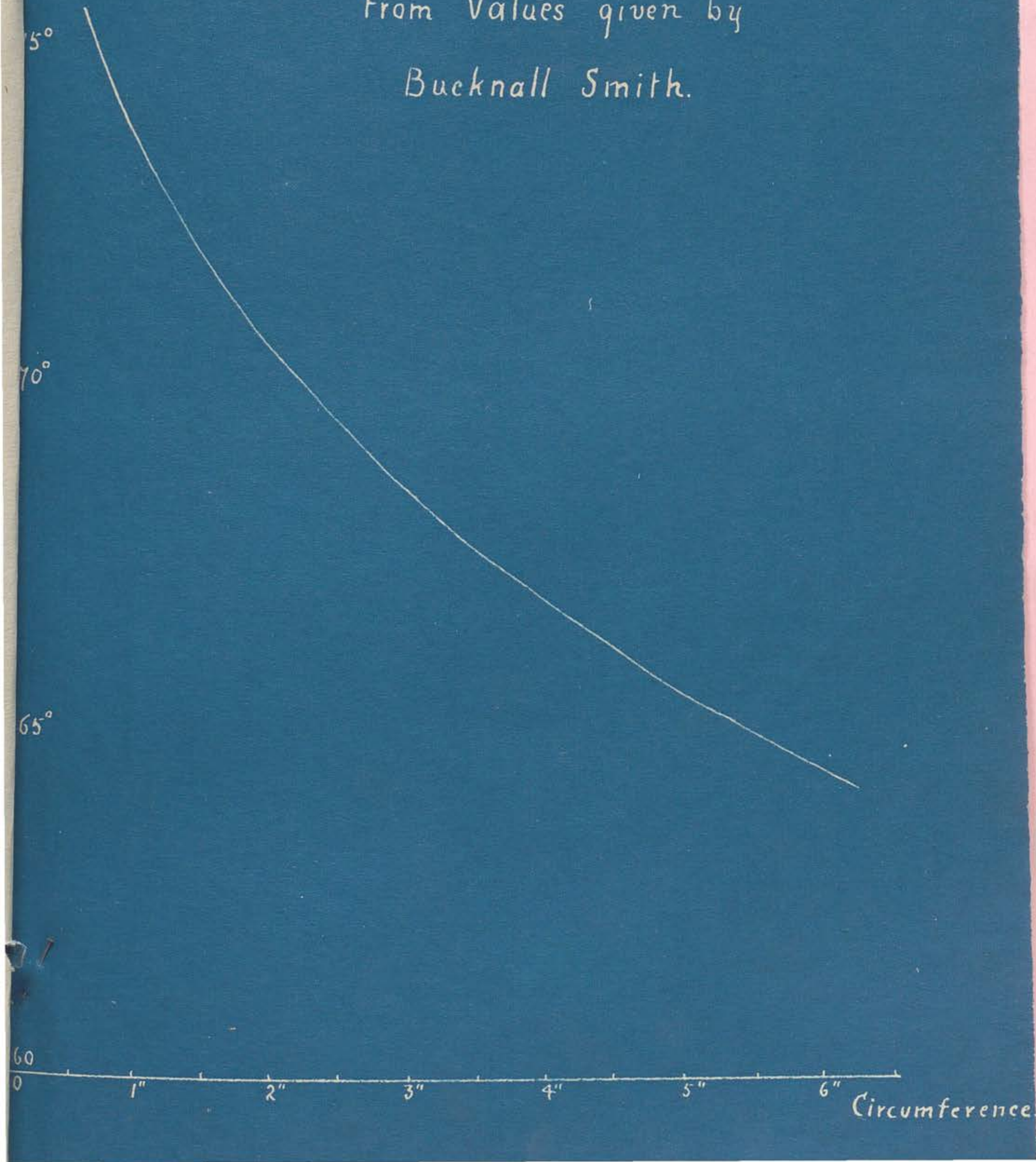
Pitch and Diameter.

From Values given by

Bucknall Smith.

Angle of Helix α, and Circumference C.

From Values given by Bucknall Smith.



The angle α

The angle of the helix is denoted by α in this paper. This is the complement of ω, the angle of the lay. In a straight one-strand rope ω is the angle between the wire and the axis of the rope. In an ordinary stranded rope the lays of the rope and of the strand are equal, or very nearly so. In the case either of the rope, or of the strand, it is difficult to measure the angle directly.

It is well known that the use of the protractor even in the simplest cases of determination of angles in plane geometry is most unsatisfactory. Even with a first class instrument – costing anything over £3 – the result is rarely as good as one would wish; while with the small cheap ones so much used at the present day in schools and actually advised and relied upon the error is enormous. Even students who come to a University require almost invariably to be broken of the habit of using unsatisfactory protractors for the accurate measurement of angles.

To measure an angle accurately in geometrical drawing its tangent should be scaled as accurately as possible – taking the abscissa and ordinate as large as is convenient. The angle is then read from a table of natural tangents. Conversely, to set out an angle accurately a table of natural tangents should be used, and needless to say the drawing should be on as large a scale as possible.

In the case of the wire-strand, where the lines are not only short, but also possess curvature and torsion, the use of the protractor would be out of place. The angle should be determined from its tangent. For this the pitches and circumferences of the strand and rope require to be measured.

Thus let r and R be the radii of the strand and rope, p and P their pitches referring to the outer wires α and A the angles of the helices. Then $A \simeq \alpha$ in the formed rope, $\tan A = \frac{P}{2\pi R}$, $\tan \alpha = \frac{p}{2\pi r}$ where R and r are corrected values, R being measured to the centre of a strand and r to the centre of an outerwire.

In a standard rope such as $6/n/d$, $R \simeq 2r$ and hence $P \simeq 2p$. This cannot be verified on dissecting the rope since on ~~the~~ strand being set free its pitch increases owing to untwisting.

Curvature and Torsion of the Helix.

A well known property of the helix may be recalled. Let ~~the~~ curve be $x = a\cos\theta$, $y = a\sin\theta$, $z = a\tan\alpha.\theta$. Denoting differentiation with respect to s by a dash we have

$$x''^2 + y''^2 + z''^2 = \frac{1}{\rho^2} = \frac{1}{a^2}\cos^4\alpha$$

$$\therefore \rho = a\sec^2\alpha.$$

$$\text{Also } \frac{1}{\rho^2\sigma} = \begin{vmatrix} -\sin\theta\cos\alpha & \cos\theta\cos\alpha & \sin\alpha \\ -\frac{1}{a}\cos\theta\cos^2\alpha & -\frac{1}{a}\sin\theta\cos^2\alpha & 0 \\ \frac{1}{a^2}\sin\theta\cos^3\alpha & -\frac{1}{a^2}\cos\theta\cos^3\alpha & 0 \end{vmatrix}$$

$$= \frac{1}{a^3}\cos^5\alpha\sin\alpha$$

$$\therefore \sigma = \frac{a}{\sin\alpha\cos\alpha}.$$

where ρ and σ are the radii of curvature and torsion.

Writing down the equation of the principal normal

$$\frac{x - a\cos\theta}{\cos\theta} = \frac{y - a\sin\theta}{\sin\theta} = \frac{z - a\tan\alpha.\theta}{0}$$

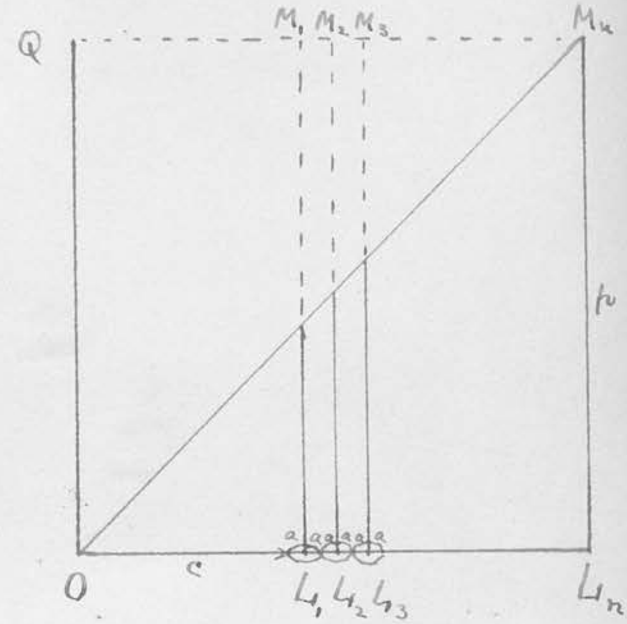
we see ~~that~~ it intersects the axis of the cylinder perpendicularly

A diagram has been constructed from which the value of ρ may be read for any values of a and α within the roping range. This is useful as it shows by inspection the radius of curvature to which any wire is bent when it has been formed into a strand. It is unnecessary to give the calculations.

(See Diagram.)

Length of a wire in a strand. The Uptake.

Let c be the radius of the core, a that of ~~the~~ wire, p the pitch of the outermost wires, α the angle of ~~the~~ helix, and n the number of layers of wire. Then for the length p of the strand the length of any of the outermost wires is



$$l = \sqrt{p^2 + \{2\pi(c + \overline{2n-1}\,a)\}^2}$$

But if the angle of the helix be constant throughout ~~the strand~~ then this is also the length of wire in any layer. The pitch of course alters from layer to layer being $2\pi(c + \overline{2r-1}\,a)\tan\alpha$ for the r^{th} layer

For a length of strand P where $P = kp$ k being a known constant the corresponding length of the wire is

$$T_1 = kl = \frac{P}{p}\sqrt{p^2 + \{2\pi(c + \overline{2n-1}\,a)\}^2}$$

$$= P\sqrt{1 + \left\{\frac{2\pi(c + \overline{2n-1}\,a)}{p}\right\}^2}$$

The uptake or extra allowance of wire required for winding a length P of strand is

$$P\left\{\sqrt{1+\left\{\frac{2\pi(c+\overline{2n-1}a)}{p}\right\}^2}-1\right\}$$

Under working conditions where p is large compared with a and c and n is a small integer, its value is approximately $P\left\{\frac{\pi(c+\overline{2n-1}a)}{p}\right\}^2$

If α be not constant throughout ~~the strand~~ draw the radial line through O at the angle α_r for the layer $L_r M_r$. Its pitch is determined by the height of the ordinate from L_r to this line.

If the radial line cut QM_n in N_n then ON_n is the length of wire in ~~that~~ layer.

The effect of keeping α constant from layer to layer of a straight strand would be that the helical wires would all be of equal length. Thus excluding considerations of bending and torsion, and assuming no yielding of the core, ~~the~~ strains due to extension would be equal in all the curved wires for a given elongation of ~~the~~ strand.

This equality of strains throughout the rope is what is aimed at but owing to various causes it is not obtained exactly

Convolutions on a strand.

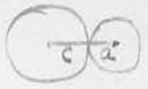
To find the number of convolutions on the corresponding length of a standard strand for a given pitch p of the rope.

Consider a rope 6/N/d. of pitch p and standard section. Let a be the radius of ~~the~~ strand.

For the length p of the rope the length of a strand is $l = p \operatorname{cosec}\alpha$ or $l = 4\pi a \sec\alpha$. If the angle of the rope equals the angle of ~~the~~ strand then the number of convolutions in ~~the strand~~ to one in the rope is $\dfrac{l}{2\pi a \tan\alpha} = \dfrac{4\pi a \sec\alpha}{2\pi a \tan\alpha} = 2\operatorname{cosec}\alpha = N$

Generalising this :—

Let α and a be the angle & radius of the strand, respectively; β the angle of the rope, c the radius of the core and let p be the pitch of the rope.

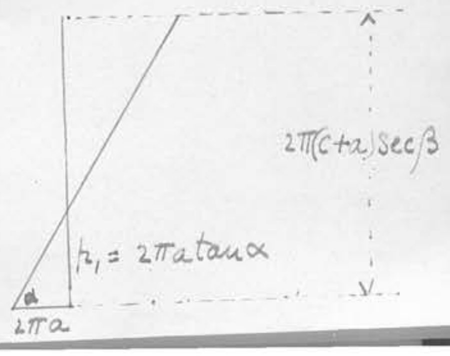


Then l the corresponding length of ~~the strand~~ is

$p \operatorname{cosec}\beta$ or $2\pi(c+a)\sec\beta$.

∴ the number of convolutions N in this length of strand is

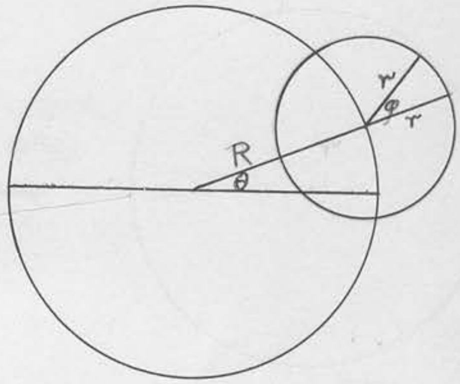
$$\frac{2\pi(c+a)\sec\beta}{2\pi a \tan\alpha} = \left(1+\frac{c}{a}\right)\sec\beta\cot\alpha = N$$



If $c = a$ and $\beta = \alpha$ as in the normal rope 66

$N = 2 \operatorname{cosec} \alpha$ as above.

An approximation to the length of a wire in a rope by integration.



We may write down equations which represent approximately the wire curve in a rope; viz:—

$x = R\cos\theta + r\cos(\theta+\varphi)$

$y = R\sin\theta + r\sin(\theta+\varphi)$

$z = R\tan\alpha . \theta$

Set $\varphi = n\theta$

$\therefore x = R\cos\theta + r\cos\theta(1+n)$

$y = R\sin\theta + r\sin\theta(1+n)$

$z = R\tan\alpha . \theta$.

$\therefore \dfrac{dx}{d\theta} = -R\sin\theta - r(1+n)\sin\theta(1+n)$

$\dfrac{dy}{d\theta} = R\cos\theta + r(1+n)\cos\theta(1+n)$

$\dfrac{dz}{d\theta} = R\tan\alpha$.

$$\therefore \left(\frac{ds}{d\theta}\right)^2 = R^2\sin^2\theta + r^2(1+n)^2\sin^2\theta(1+n) + 2Rr(1+n)\sin\theta\sin(1+n)\theta$$
$$+ R^2\cos^2\theta + r^2(1+n)^2\cos^2\theta(1+n) + 2Rr(1+n)\cos\theta\cos(1+n)\theta$$
$$+ R^2\tan^2\alpha$$

$$\therefore \frac{ds}{d\theta} = \sqrt{R^2 \sec^2\alpha + r^2(1+n)^2 + 2Rr(1+n)\cos n\theta}$$

$$= \sqrt{R^2\tan^2\alpha + \{R + r(1+n)\}^2 - 4Rr(1+n)\sin^2\frac{n\theta}{2}}$$

Putting $\phi = n\theta/2$

$$S = \frac{2}{n}\sqrt{R^2\tan^2\alpha + \{R + r(1+n)\}^2}\int d\varphi\sqrt{1 - \frac{4Rr(1+n)}{R^2\tan^2\alpha + \{R+r(1+n)\}^2}\sin^2\varphi}.$$

This integral is elliptic of ~~the~~ species 2nd, $\{E(k,\varphi)\}$

$\int d\varphi\sqrt{1-e^2\sin^2\varphi}$ where $e^2 >< 1$ as

$$4Rr(1+n) >< R^2\tan^2\alpha + \{R + r(1+n)\}^2$$

as $0 >< R^2\tan^2\alpha + \{R - r(1+n)\}^2$

But this is always positive

$\therefore e^2 < 1$. as required.

Hence we have the approximate value also of the inclination of a wire in the rope to its axis in the form

$$\cos\gamma = \frac{dz}{ds} = \frac{R\tan\alpha}{\sqrt{R^2\sec^2\alpha + r^2(1+n)^2 + 2Rr(1+n)\cos n\theta}}$$

Now the denominator is +ve and never zero, so max & min values of $\cos\gamma$ occur when

$\cos n\theta = \pm 1$

These give a minimum when $\cos n\theta = +1$

$\therefore \theta = \frac{2k\pi}{n}$

and a maximum when $\cos n\theta = -1$

$\therefore \theta = \frac{(2k'+1)\pi}{k}$

In particular, in the Lang's lay when $k=0$, $\theta=0$
$\therefore \gamma$ is a maximum ie the outer wire of ~~the~~ strand makes the greatest angle with ~~the~~ core of the rope and ~~the~~ this case ~~the~~ inner wire is parallel to the axis of the rope.
In the ordinary lay this is reversed.

Equations to the axis of a wire in a rope.

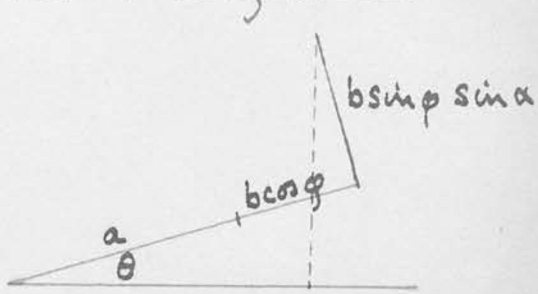
Let a be the radius from centre of rope to centre of strand: let b be the radius of the strand. Then the centre of the strand lies on the helix.

$$\begin{cases} x = a\cos\theta \\ y = a\sin\theta \\ z = \frac{p}{2\pi}\theta \end{cases}$$

where $p = 2\pi a \tan\alpha$, α being the angle of the helix and p ~~the~~ pitch.

Then the axis of ~~the~~ wire is obtained by taking a circle of radius b, whose centre lies on the above helix and whose plane is perpendicular to it. Let this circle revolve uniformly in its plane about its centre and at ~~the~~ same time let the centre move uniformly along the helix. A point P on the circumference will trace the axis of a wire. Consider the wire passing through the point $(a+b, 0, 0)$ and suppose the circles of radii b and a to have their initial radii drawn in the same direction & sense.

Then from the point Q on the helix $(a\cos\theta, a\sin\theta, \frac{p}{2\pi}\theta)$ the point P on the axis of the wire is obtained by revolving the circle of radius b through the angle $\pm\varphi$, the sign of φ giving the handedness, where $\varphi = n\theta$. Taking φ positive and projecting on the horizontal plane through P we have the figure shown.



The equations of the wire axis become

$$\begin{cases} x = a\cos\theta + b\cos\varphi\cos\theta - b\sin\varphi\sin\alpha\sin\theta \\ y = a\sin\theta + b\cos\varphi\sin\theta + b\sin\varphi\sin\alpha\cos\theta \\ z = \frac{p}{2\pi}\theta - b\sin\varphi\cos\alpha \end{cases}$$

or

$$\begin{cases} x = a\cos\theta + b\cos\theta\cos n\theta - b\sin\theta\sin n\theta\sin\alpha \\ y = a\sin\theta + b\sin\theta\sin n\theta + b\cos\theta\sin n\theta\sin\alpha \\ z = \frac{p}{2\pi}\theta - b\sin n\theta\cos\alpha. \end{cases}$$

To determine by integration the length of an arc of this curve we have

$$\frac{dx}{d\theta} = -a\sin\theta + b\{\cos\theta(-)n\sin n\theta - \cos n\theta\sin\theta\}$$
$$-b\sin\alpha\{\sin\theta\, n\cos n\theta + \sin n\theta\cos\theta\}$$

$$\frac{dy}{d\theta} = a\cos\theta + b\{\sin\theta(-)n\sin n\theta + \cos n\theta\cos\theta\}$$
$$+b\sin\alpha\{\cos\theta\, n\cos n\theta + \sin n\theta(-)\sin\theta\}$$

$$\frac{dz}{d\theta} = \frac{k}{2\pi} - b\cos\alpha.\, n.\, \cos n\theta.$$

$$\therefore\left(\frac{ds}{d\theta}\right)^2 = \Big[a^2\sin^2\theta + b^2\{\cos^2\theta\sin^2 n\theta.\, n^2 +$$
$$\cos^2 n\theta.\sin^2\theta + 2n\cos\theta\sin n\theta\sin\theta\cos n\theta\} + b^2\sin^2\alpha\{\sin^2\theta\times$$
$$n^2\cos^2 n\theta + \sin^2 n\theta\cos^2\theta + 2n\sin\theta\cos\theta\sin n\theta\cos n\theta\}$$
$$+2ab\sin\theta\{n\cos\theta\sin n\theta + \sin\theta\cos n\theta\} + 2ab\sin\alpha\sin\theta\times$$
$$\{n\sin\theta\cos n\theta + \sin n\theta\cos\theta\} + 2b^2\sin\alpha\{n^2\sin\theta\times$$
$$\cos\theta\sin n\theta\cos n\theta + n\cos^2\theta\sin^2 n\theta + n\sin^2\theta\cos^2 n\theta$$
$$+\sin\theta\cos\theta\sin n\theta\cos n\theta\}\Big] + \Big[a^2\cos^2\theta + b^2\{$$
$$n^2\sin^2\theta\sin^2 n\theta + \cos^2 n\theta\cos^2\theta - 2n\sin\theta\cos\theta\sin n\theta$$
$$\cos n\theta\} + b^2\sin^2\alpha\{n^2\cos^2\theta\cos^2 n\theta + \sin^2\theta\sin^2 n\theta$$
$$-2n\sin\theta\cos\theta\sin n\theta\cos n\theta\} + 2ab\cos\theta\{(-n)\sin\theta\sin n\theta$$
$$+\cos\theta\cos n\theta\} + 2ab\sin\alpha\cos\theta\{n\cos\theta\cos n\theta$$
$$-\sin\theta\sin n\theta\} + 2b^2\sin\alpha\{(-)n^2\sin\theta\cos\theta\sin n\theta\cos n\theta +$$

$+ n^2 \sin^2\theta \sin^2 n\theta + n \cos^2\theta \cos^2 n\theta - \sin\theta\cos\theta \times$ 71

$\sin n\theta \cos n\theta \}] + \frac{k^2}{2^2\pi^2} - \frac{k}{\pi} b n \cos\alpha \cos n\theta +$

$b^2 n^2 \cos^2\alpha \cos^2 n\theta.$

After a considerable amount of simplification these 33 terms reduce to

$$\left(\frac{ds}{d\theta}\right)^2 = a^2 \sec^2\alpha + b^2\{n + \sin\alpha\}^2 + 2ab\cos n\theta$$
$$+ b^2 \cos^2\alpha \cos^2 n\theta$$

Tests

(i) Set $b = 0$ $\therefore \frac{ds}{d\theta} = a \sec\alpha$ $\therefore l_1 = 2\pi a \sec\alpha$

which is true

(ii) Set $n = 0$ $\therefore \frac{ds}{d\theta} = \sqrt{(a+b)^2 + a^2\tan^2\alpha}$

$\therefore l_2 = 2\pi\sqrt{(a+b)^2 + a^2\tan^2\alpha}$

which is true.

$$\therefore s = \int d\theta \sqrt{b^2(n+\sin\alpha)^2 + (a\sec\alpha + b\cos\alpha\cos n\theta)^2}$$

This gives the length of a wire.

Also the angle between the wire and the axis of the rope being ν

$$\cos\nu = \frac{dz}{ds} = \frac{a\tan\alpha - bn\cos\alpha\cos n\theta}{\sqrt{b^2(n+\sin\alpha)^2 + (a\sec\alpha + b\cos\alpha\cos n\theta)^2}}$$

If we write this in the form

$$\nu = \cos^{-1} \frac{a \tan\alpha - bn\cos\alpha\cos n\theta}{\sqrt{b^2(n+\sin\alpha)^2 + (a\sec\alpha + b\cos\alpha\cos n\theta)^2}} -$$

or $\nu = \cos^{-1} \dfrac{A - B\cos n\theta}{\sqrt{C^2 + (D + E\cos n\theta)^2}}$ for shortness.

$$\therefore \frac{d\nu}{d\theta} = (-) \frac{\sqrt{C^2 + (D + E\cos n\theta)^2}}{\sqrt{C^2 + (D+E\cos n\theta)^2 - (A - B\cos n\theta)^2}} \cdot \frac{d}{d\theta} \cdot \frac{A - B\cos n\theta}{\sqrt{C^2 + (D+E\cos n\theta)^2}}$$

$$= - \frac{1}{\sqrt{C^2 + (D+E\cos n\theta)^2 - (A - B\cos n\theta)^2}} \times \frac{1}{\{C^2 + (D+E\cos n\theta)^2\}} \times$$

$$\times \left[\{C^2 + (D+E\cos n\theta)^2\} Bn\sin n\theta + En(A - B\cos n\theta) \times \right.$$

$$\left.(D + E\cos n\theta) . \sin n\theta\right] = 0$$

Denom^r $\neq 0$ hence we have.

$$n\sin n\theta \left[B\{C^2 + (D+E\cos n\theta)^2\} + E(A - B\cos n\theta)(D + E\cos n\theta)\right] = 0$$

$\therefore \sin n\theta = 0$ and

$$BC^2 + BD^2 + 2BED\cos n\theta + BE^2\cos^2 n\theta + AED + AE^2\cos n\theta$$
$$- BED\cos n\theta - BE^2\cos^2 n\theta = 0$$

$$\therefore \cos n\theta = - \frac{BC^2 + BD^2 + AED}{BED + AE^2}$$

$$= - \left\{ \frac{D}{E} + \frac{BC^2}{E(BD + AE)} \right\}$$

Hence on substituting $A = a\tan\alpha$, $B = nb\cos\alpha$

$C = b(n + \sin\alpha)$ $D = a\sec\alpha$ $E = b\cos\alpha$

$$\therefore \cos n\theta = - \frac{a\sec^2\alpha}{b} - \frac{nb}{a}(n + \sin\alpha)$$

but $a > b$ and $\sec^2\alpha > 1$

so this equation gives no real value for θ

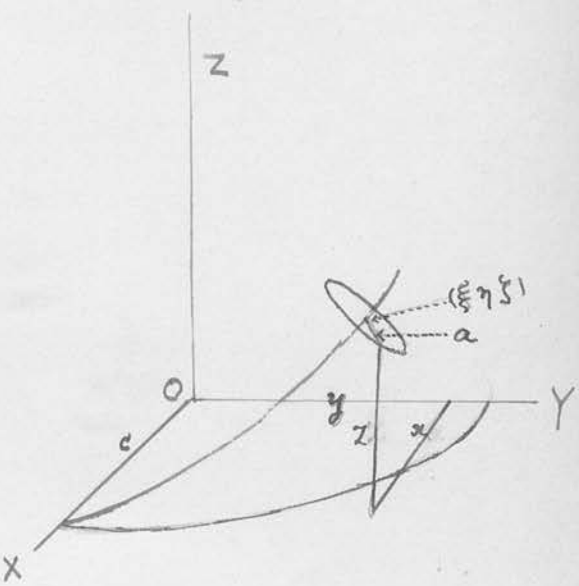
hence the only factor to be considered is $\sin n\theta = 0$

ie $n\theta = r\pi$ or $\theta = \frac{r\pi}{n}$

ie at the outside of the strand in ordinary lay & the inside of the strand in Lang's lay.

The wire-strand surface

Equations may be found to represent the wire-strand surface.



Let c be the radius of the core and a that of the wire. Let (ξ, η, ζ) be a point on the helix and centre of the generating circle.

$\therefore\ \xi = c\cos\theta$

$\eta = c\sin\theta$

$\zeta = c\tan\alpha . \theta$.

Let (x, y, z) be a point on the wire surface. Then the tangent to the helix at the point $(\xi\,\eta\,\zeta)$ is perpendicular to the plane of the generating circle.

$$\therefore (x - c\cos\theta)^2 + (y - c\sin\theta)^2 + (z - c\tan\alpha.\theta)^2 = a^2$$

and also

$$(x - c\cos\theta)(-c\sin\theta) + (y - c\sin\theta)(c\cos\theta) + (z - c\tan\alpha.\theta)(c\tan\alpha) = 0$$

the latter being the condition of perpendicularity. The θ-eliminant between these two equations is the equation of the surface required.

The same result is obtained by considering the surface as the envelope of the onefold infinity of spheres given above.

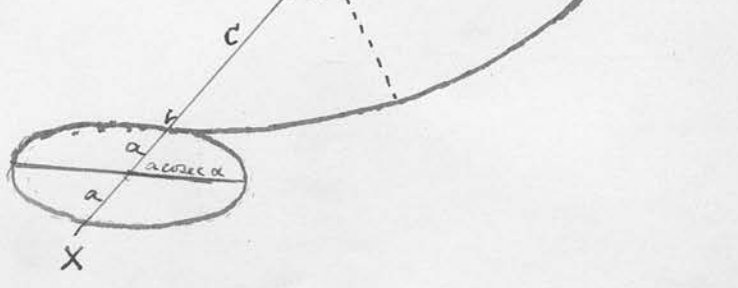
viz $(x - c\cos\theta)^2 + (y - c\sin\theta)^2 + (z - c\tan\alpha.\,\theta)^2 = a^2$.
For this, differentiate with respect to θ and form the eliminant.

As a particular case consider the surface when $c = a$. Putting $x = y = 0$ the two equations reduce so as to give the z-axis. Thus in winding one-layer strands without a core (twin wires) ~~the surfaces~~ have the z-axis as a single ruled line upon them.

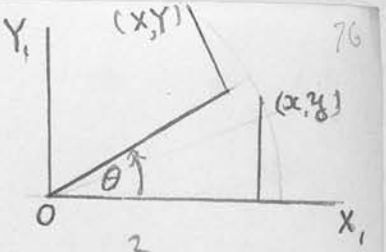
The equations given for the wire-strand surface are in parametric form. A constraint equation may be found as follows which represents closely the surface.

Suppose the wire to have the elliptic section

$$\begin{cases} z = 0 \\ \dfrac{(x - \overline{c + a})^2}{a^2} + \dfrac{y^2}{a^2\csc^2\alpha} = 1 \end{cases}$$



Then if the ellipse be rotated through the angle Θ in the XY plane, so ~~that~~ the point (x, y) is rotated to (X, Y) we have the equations of rotation



$$\begin{cases} x = X\cos\theta + Y\sin\theta \\ y = Y\cos\theta - X\sin\theta \end{cases}$$ and hence

$$\frac{\{x\cos\theta + y\sin\theta - (c+a)\}^2}{a^2} + \frac{(y\cos\theta - x\sin\theta)^2}{a^2\operatorname{cosec}^2\alpha} = 1.$$

If, at ~~the same~~ time it be elevated through the distance $z = a\tan\alpha\,\theta$. ~~the equation~~ of the surface so formed is

$$\{x\cos(\tfrac{z}{a}\cot\alpha) + y\sin(\tfrac{z}{a}\cot\alpha) - (c+a)\}^2 + \sin^2\alpha\,\{y(\cos\tfrac{z}{a}\cot\alpha)$$

$$- x\sin(\tfrac{z}{a}\cot\alpha)\}^2 = a^2$$

Section of the wire for a right section of the strand.

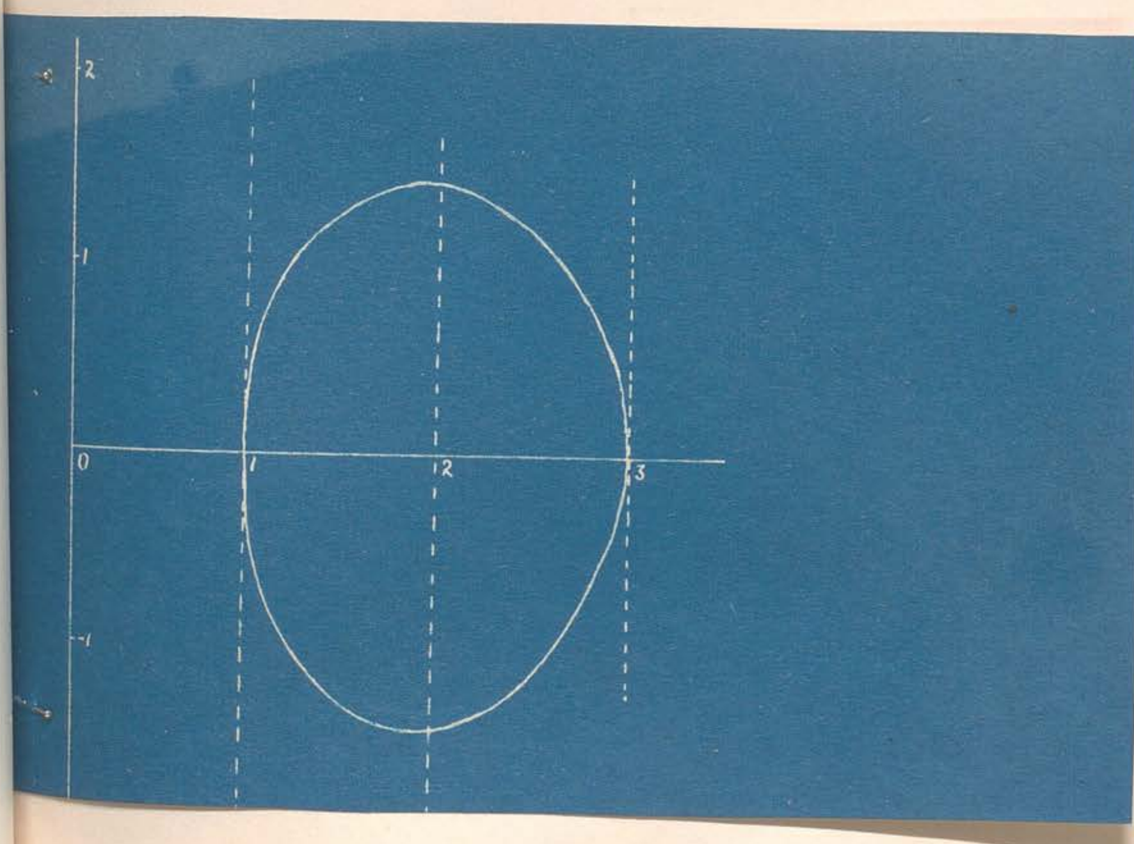
So far we have assumed ~~the section~~ to be elliptic, though actually it is a transcendental curve.

If we put $z =$ ~~constant~~ or in particular $z = 0$ we get ~~the contour~~ section required in the form of the θ-eliminant between the equations

$$\begin{cases} (x - c\cos\theta)^2 + (y - c\sin\theta)^2 + c^2\tan^2\alpha\,\theta^2 = a^2 \\ (x - c\cos\theta)(-c\sin\theta) + (y - c\sin\theta)(c\cos\theta) - c^2\tan^2\alpha.\,\theta = 0 \end{cases}$$

In order to show the shape of ~~the section~~

as distinguished from that of the ellipse an extreme case – from the roping point of view – has been drawn in which $\alpha = \frac{\pi}{4}$ and $c = a = 1$. It will be noticed ~~that~~ this curve bends more rapidly from the circum-circle and approaches more closely to the core-circle than an ellipse would do.



Chapter III

TESTING MACHINES.

The Wire

The testing machines in Brunton's main test room included a 100-ton machine, a 15-ton machine and a 10,000 lb. machine. There were also a Brinell tester for hardness, an Avery pendulum impact machine, and a torsion tester. The machines were all of the latest and most improved types.

The large machines were by the firm of Tinius Olsen, U.S.A. As full details may be obtained from the makers' catalogue, a few words of description will suffice.

The two large machines were of the long horizontal type and were designed specially for tensile and particularly for rope tests. Power was applied in each case by an electric motor driving a Hele-Shaw pump, which forced oil under pressure into a strong steel cylinder. A piston moved in the cylinder and was guided by a tail-rod. To the other end of the piston-rod was attached one end of a connecting-rod while the other end drove a strong carriage which moved on rollers along the frame. It will be seen that the mechanism is like that of a horizontal stationary engine, in which the carriage running on its rollers along the frame corresponds with the motion of the crank-pin. The carriage was formed so as to take one pair of the grips for holding one end of the specimen. A similar holder /

T E S T I N G   M A C H I N E S.

The testing machines in Brunton's main test room included a 100-ton machine, a 15-ton machine and a 10,000-lb. machine. There were also a Brinell tester for hardness, an Avory pendulum impact machine, and a torsion tester. The machines were all of the latest and most improved types.

The large machines were by the firm of Tinius Olsen, U.S.A. As full details may be obtained from the makers' catalogue, a few words of description will suffice.

The two large machines were of the long horizontal type and were designed specially for tensile, and particularly for rope tests. Power was applied in each case by an electric motor driving a Hele-Shaw pump, which forced oil under pressure into a strong steel cylinder. A piston moved in the cylinder and was guided by a tail-rod. To the other end of the piston-rod was attached one end of a connecting-rod, while the other end drove a strong carriage which moved on rollers along the frame. It will be seen that the mechanism is like that of a horizontal stationary engine, in which the carriage, running on its rollers along the frame, corresponds with the motion of the crank-pin. The carriage was formed so as to take one pair of the grips for holding one end of the specimen. A similar holder /

holder, which was stationary, took the other end of the specimen, and there was an arrangement to ensure that the pull was axial.

In the 15-ton machine the balance weight was run out by means of a hand-wheel, but in the 100 ton machine it was moved by another electric motor. The machines were easy to adjust, rapid in working, reliable and delightful to control. The long holders employed were highly satisfactory for rope work.

The 10,000 lb. machine was vertical in type and was worked by hand. It was used for wires and for small strands. Our chief criticism was that the return stroke of the ram was rather slow, and this lost time when one was breaking a large number of wires.

The other machines, viz:- the Impact, the Brinell, and the Torsion-tester were of well known standard types.

AN EXTENSOMETER.

The extension of a new rope under load is comparatively large, and so is much easier to measure than the elongation of a steel bar.

Its measurement requires preferably some form of extensometer. The types which are suitable for bars cannot readily be used for ropes, since in the first place there are no /

no suitable points on the specimen where the binding screws may hold, and secondly, even if there were such points, yet as the rope contracts appreciably in diameter, the instrument would not retain its position during the test.

The extensions in the case of automatic diagrams are frequently taken by means of a rod or cord attached to a crosshead of the machine, instead of between two points on the specimen. This of course is faulty, and vitiates the diagram, as there is always some slip of the rope or parts relatively to the crosshead, and frequently this is a large amount. Another method is to chalk two areas on the rope and scribe marks upon them with lead pencil. Then the extension between these marks may be measured by beam compasses. This method is somewhat rough.

The writer designed and got constructed a simple extensometer for this work. The aims were these:-

(1) Rapid attachment and detachment.

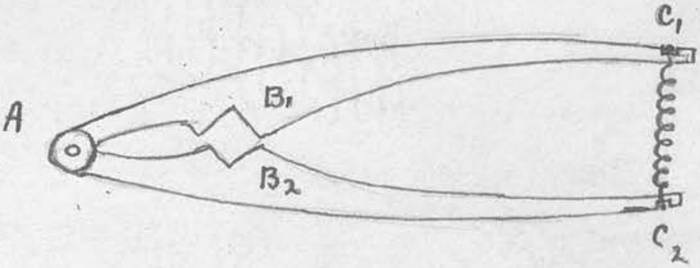
(2) A hold which should not have the disadvantages of a conical point boring its way between the wires, or slipping off the convex surface of a small wire.

(3) Cheapness and simplicity, so that it might be left attached till the specimen began to break, and also so that it could not be much damaged even when fragments of the wires began to fly.

An /

An arrangement that encircled the rope permanently was tried and abandoned, as when wires spring out at fracture, the instrument could not be removed. When the broken fragments of the rope are removed from the testing machine such a type of instrument would be undetachable.

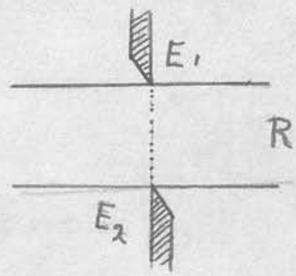
The method adopted suggested to some extent the appearance of two pairs of nut-crackers. These were formed of thin sheet steel and of the shape shown.



A. is the fulcrum.

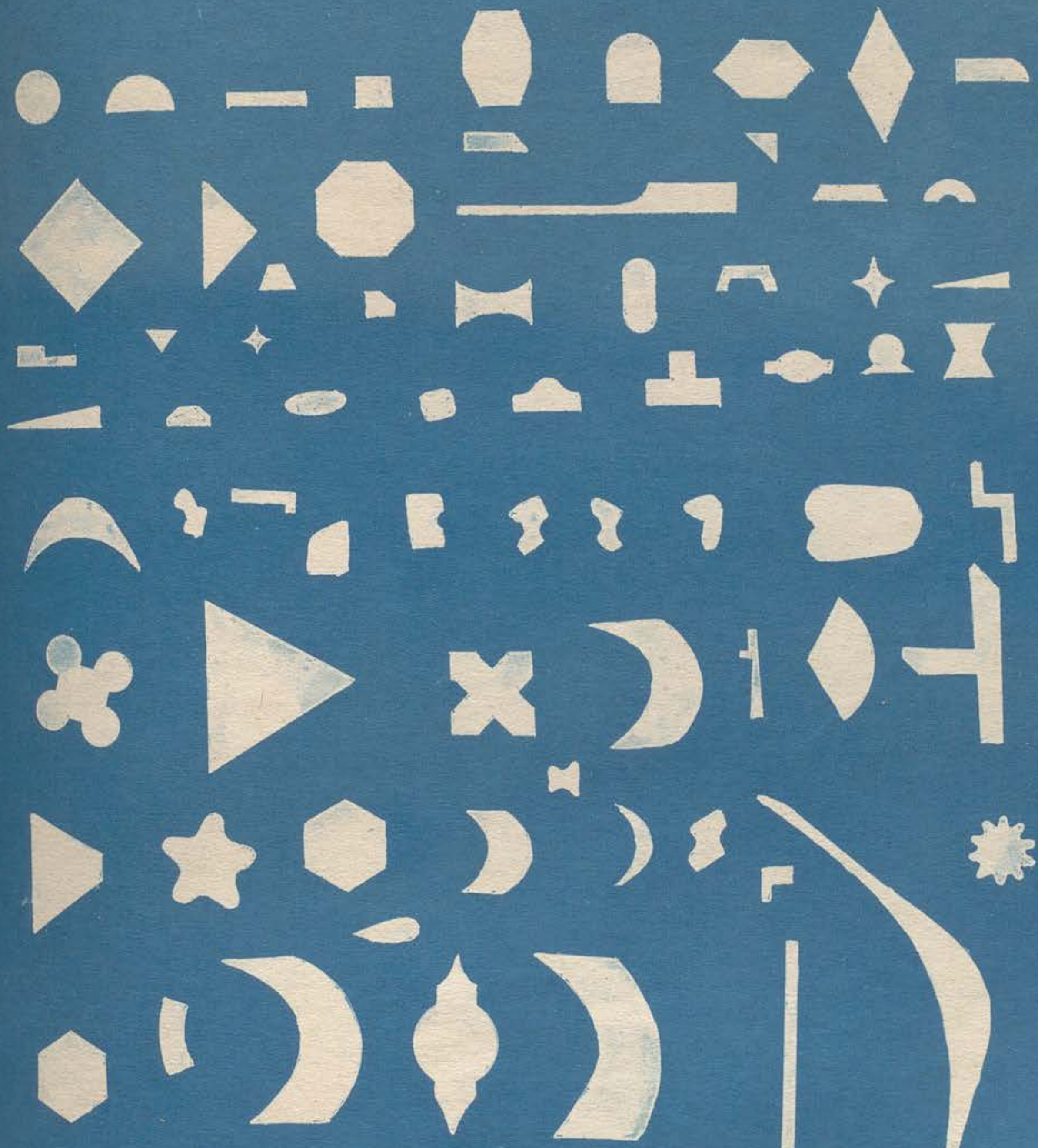
AC_1 and AC_2 the two arms. These are so shaped that when the two arms came close together they formed a square at B_1 and B_2 as shown in the figure. The arms could slide over each other as in a pair of shears. When the rope was in position in the testing-machine the "nut-crackers" were opened, and the square made to surround the rope so that the cross section of the rope was inscribed in this square, and the instrument was supported at the four points of contact. The square naturally becomes deformed when the arms are opened or closed. A strong helical spring attached at C_1 was clipped over the end of C_2. This could be put on instantly, and it held the "nut-cracker" firmly in position since the leverage was considerable. Further, when /

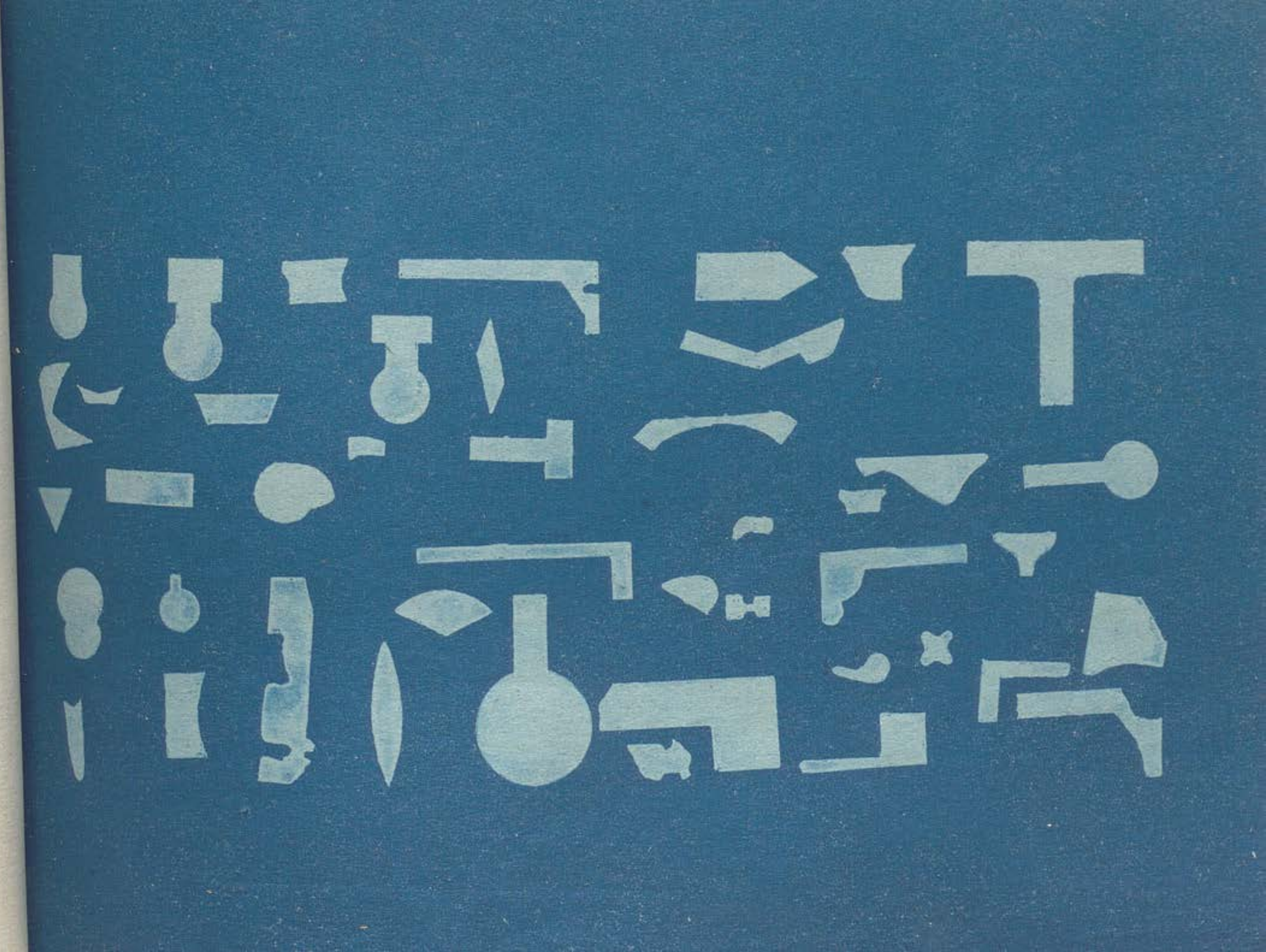
when the diameter of the rope contracted, the helical spring made the two arms follow on, and so maintained the same contact with the rope. Thus the two nut-crackers were set instantly at whatever distance or position might be desired. One of them carried a scale and a guide, the other, an attachment for a light wire carrying a pointer. The wire was passed through the guide on the one and fastened by a pinching screw to the attachment on the other. Its pointer was adjusted to the zero on the scale and everything was then ready for measuring the extension. In order to get contact in one (vertical) plane between the nut-cracker and the rope, the two arms AC_1 and AC_2 which slide over one another, had their rubbing surfaces round the edges of the square bevelled or ground to knife edges as shown in the diagram.



This was quite satisfactory.
In the figure R is the rope and E_1 and E_2 the edges referred to.

Shaped Wire.





THE STRAIGHT STEEL WIRE.

In speaking of wire one thinks usually of the cylindrical form. Many kinds of shaped wire, however, are also drawn. A few of these are illustrated by sectional diagrams, and it will be seen that some of these are of intricate design. Examples, which will occur to everyone, are turbine blades, pinion wire for wheels of cheap clocks, locked coil sections, and hexagonal wire. The last is turned out in enormous quantities up to 1" or more in diameter, for the rapid manufacture of hexagonal nuts. For ropes, however, excluding locked coils and special cores, the wires are cylindrical. A large number of wire gauges have been used from time to time. Mr Thomas Hughes in his pamphlet "The English Wire Gauge" gives particulars of 52 different ones proposed or in use, 43 of which relate to this country. Fortunately, these have been superseded by the Imperial Standard gauge.

Originally the number of the wire denoted the number of passes, but this is no longer the case. The reduction of area for small wires is about 25% at each pass.

There is still a great diversity of opinion as to what kind of steel is best for ropes. All strengths from crucible /

crucible steel at 70 tons □" or lower to special plough at 200 tons □" are used, and have their enthusiastic advocates. Nickel steel is unsuitable, but the high tensile steels have been much recommended lately for deep winding. Recent observations, however, show that these are frequently unsatisfactory.

The compositions of two typical steels for rope making are given later. The effect of annealing below the critical temperature is to modify and rearrange the previous crystalline structure of the metal, while if above the critical temperature, a new structure is formed. In the patented process, the steel wire is heated above the critical temperature by passing through a muffle, and is cooled and hardened by an oil bath or by air, and then tempered frequently by melted lead, at about 700° F. These processes are continuous and close together so as to ensure uniform treatment.

After from three to six or more passes the steel becomes brittle and is then annealed. The speed of drawing is from 100 to 400 feet per minute for large wires, and about 1000' per minute for small ones, but this varies very greatly with different machines and various materials.

The dies resemble white cast iron in composition, but differ from it by being malleable when hot. They have usually /

usually a high percentage of manganese. The value of Young's modulus varies considerably with different kinds of steel. Biggart's tests gave a value of E for ordinary galvanised crucible steel wire as 33×10^6 lbs. and a permanent set at about half the breaking load. These values are probably too high at the present day. Goodman's tests (Mechanics applied to Engineering) give a value of about 25×10^6 for E for steel wire, and show that the affect of annealing in raising its value is about 8%.

It is accepted generally that structural steel when well cared for has an almost indefinitely long life. Even when steel is subjected to violent alternating stresses, as in the connecting rod of a reciprocating engine, we observe that it may nevertheless be perfectly reliable after the lapse of many years. In view of this, it comes as a surprise to find that in the case of a steel winding rope, formed from the best materials, well treated, and not overloaded, with a factor of safety as high as 10, its life may be only a matter of a few months. This is an interesting problem to which we shall attempt to give an answer later. Further, in view of the high cost of steel ropes, anything which may tend to improve their duration and strength, or to add to our knowledge of their behaviour, should be of importance in the industries of this country.

With structural design in steel, the stresses in the

various /

various members must not exceed the elastic limit. This is axiomatic, since it is only when working below the elastic limit, and on the rectilinear portion of the stress-strain diagram, that permanent deformation is avoided, and that the metal can recuperate from the loads which it has sustained. In fact the engineer designs his structure as if the elastic limit were to all intents and purposes the breaking point.

It is instructive to glance at the treatment of steel in the drawing of wire for a wire rope. Mr Brunton, in his paper on the heat treatment of wire (Journal of the Iron and Steel Inst. No. II. for 1906), describes the changes which take place in the strength and micro-structure of commercial steel, when being drawn down into the form of wire. The following is a brief summary of some of the particulars. Two ordinary commercial steels, such as are used for drawing wires for wire ropes, were taken. These were received from the rolling mills in the form of wire rods in coils.

The analysis showed:-

	I. Per cent.	II. Per cent.
Combined Carbon	.750	.830
Graphite	.000	.000
Silicon	.100	.084
Manganese	.640	.710
Sulphur	.025	.025
Phosphorus	.031	.042
Iron (by difference)	98.454	98.309

I /

I is an acid open hearth Swedish steel, and II a similar steel of British make. Specimens were tested with and without a preliminary annealing of the bars.

Tables were prepared showing the result of drawing these down cold through 17 passes. The quantities tabulated were as follows:- number of passes, reduction per cent, maximum stress, elongations % in 8", torsion in 100 diameters, specific gravity, rate of reduction in feet per minute.

After the usual preliminary treatment and the first pass, it was found that a sample which had received the preliminary annealing was mechanically indistinguishable from one that had not. The reduction per cent increased from about 5.5% at the 1st pass to 20% at the 16th pass, while the maximum stress increased steadily to more than double its original value. The elongations did not decrease continually, but fluctuated to some extent. The figures given in these tables suggest a law such as $y = Ae^{-Bx} \cos(Cx + D)$, but the writer only suggests this tentatively, assuming the values given. The torsions are irregular, as in our usual experience, but increase to about the 6th pass, remain fairly constant till about the 13th pass, and fall off rapidly after that. The specific gravity increased slightly till about the 16th pass. At this stage the wire was seen to be overdrawn and brittle. After /

After a rise from the first to the 13th or 14th pass, the tension began to fall off rapidly, showing that this was the upper limit for the use of this steel in rope making. The lower limit was about the 4th or 5th pass, as the material had then become sufficiently homogeneous and tough, as was also shown by the micro-structure. Two of the tables are reproduced:-

TABLE I /

T A B L E I. S A M P L E I.

No. of Passes	Reduction per cent.	Max. Stress.	Elongation % in 8".	Torsion in 100 diameters.	Specific Gravity.	Rate of Reduction in feet per minute.	Remarks.
1.	5.5	68.4	7	33	7.768	142	
2.	4.7	72.1	6¼	38	7.779	142	
3.	5.5	75.0	4½	23	7.795	142	unequal torsion.
4.	5.3	77.5	4½	28	7.812	142	"
5.	6.2	80.	6¼	41	7.819	142	
6.	7.2	83.	5	37	7.841	142	
7.	7.1	85.5	4	44	7.853	142	
8.	7.7	89.5	4½	40½	7.872	142	9 bends.
9.	7.5	90.5	4	44½	7.888	142	9
10.	10.0	96.0	3½	40	7.893	142	12
11.	10.0	99.0	6½	42½	7.916	142	15
12.	10.0	104.0	6	42½	7.933	142	19
13.	12.	115.0	3	41	7.950	332	22
14.	13.9	121.0	3	32	7.972	225	32
15.	16.	136.0	3½	37½	7.991	225	35 unequal)
16.	20.	165.0	2.8	21	7.998	225	36 torsion)
17.	10.	152.0	3.1	14	7.997	225	35

TABLE IV. SAMPLE 2.

No. of Passes	Reduction per cent.	Maximum Stress.	Elongation % in 8".	Torsion in 100 diameters.	Specific Gravity.	Rate of Reduction in ft. per minute.	Remarks
1.	5.5	81	7	$16\frac{1}{2}$	7.771	142	
2.	4.7	83	$5\frac{1}{2}$	11	7.784	142	
3.	5.5	83	6	15	7.792	142	
4.	5.3	91	$6\frac{1}{2}$	14	7.807	142	
5.	6.2	92.5	$4\frac{1}{2}$	45	7.822	142	
6.	7.2	93	$4\frac{1}{2}$	23	7.845	168	
7.	7.1	98	$4\frac{1}{2}$	34	7.859	157	
8.	7.7	99	4	37	7.871	142	7 bends.
9.	7.5	101	$4\frac{1}{2}$	37	7.891	131	$9\frac{1}{2}$
10.	10.	109	$3\frac{3}{4}$	$37\frac{1}{2}$	7.907	142	10
11.	10.	110	$3\frac{3}{4}$	37	7.919	142	12
12.	10.	117	$3\frac{1}{2}$	36	7.938	142	16
13.	12.	126	3	$35\frac{1}{2}$	7.957	332	14
14.	13.9	140	3	17	7.975	225	18
15.	16.	166	$2\frac{1}{2}$	24	7.994	225	(18 unequal (
16.	20.	169	3	9	7.988	225	(23 torsion
17.	10.	157	$1\frac{3}{4}$	0	7.971	225	18

Judging by these tables the specimens examined were at their best in the neighbourhood of the 10th pass, when the stress and torsions were in round numbers 100 and 40 respectively. In view, however, of the behaviour of ropes under working conditions, to be referred to later, the writer suggests that values before the maximum should be taken.

A set of photo-micro-graphs accompanies this paper, showing the structure of the rod both when annealed, and unannealed, and of the wire at various stages of the drawing. The fibre is very distinct at the 5th pass, while at the 15th it is seen to be so excessive, that the internal strains must be very great, and fracture may occur easily. The effect of annealing is also shown, but it should not be assumed that annealing gives complete recuperation after wire-drawing.

As is well known, drawing hardens a wire, but it may not be desirable to use a wire at the maximum point as in the tables referred to, since the duration of life of a rope is all important, and ropes which are made of extra strong and hard steel are found to deteriorate more rapidly than those formed from apparently an inferior steel. Thus the winding difficulties, at at least one of the great South African mines, were only overcome by substituting finally for plough steel ropes some of a milder steel of less high quality. /

quality.

It is difficult to give a visible verification - apart from microscopic examination - that in the extension, compression, and torsion of metals there is shear or slipping of the elementary crystals within the crystalline grains of the metal. The writer, however, has been able to get some specimens which he thinks illustrate this conclusively. One of these is a cylindrical gun metal bar of composition 88% Cu. 10% Sn, 2% Zn. It broke at 19.0 tons $\square$", 32.2 extension on $\ell = 4\sqrt{area}$, reduced area 33.6. The test piece was cylindrical and had its surface very bright, and carefully finished. After being broken in tension it showed clearly by the surface elevations and depressions the outlines of the crystalline grains, in a way that almost certainly implies shearing within the grains. Another specimen shows the same shearing phenomena set up by torsion. [Owing to the cylindrical surface, these specimens would not give satisfactory photographs.]

When a mild steel bar is tested to destruction in tension, there are the well known phenomena of the plastic state and the contracted area. Goodman (Mechanics for Engineers) points out that the condition of the bar at the contracted area is analogous to what happens in wire drawing, and that the apparent increase in strength of a wire due to successive passes is /

is similar to the actual rise of the stress-strain curve of a tensile specimen, when the contracted area is taken into account.

In wire drawing, the permanent deformation of the material has been so great that a recovery to the original condition of the steel seems unlikely. We know that strain somewhat beyond the elastic limit raises the elastic limit; also that rest promotes partial recovery, also that annealing enlarges the grain, and produces an approach to the original state. Further, we know that the elastic limit should be determined not merely by considering the straight portion of the stress-strain diagram, but by noting how far there is no permanent deformation on removing the load. The more delicate the instruments of measurement become, the more does it appear that permanent deformation occurs at lower loads than was formerly suspected, so that the recuperability of steel in the form of wire when strained by even its working conditions is probably far from perfect.

No doubt annealing and heat treatment, by enlarging the grain, and reducing the internal strains, bring the material partly back to its former state, but even this under commercial conditions can scarcely be expected to give perfect recuperation at high working loads. The effects of annealing and galvanising /

galvanising in reducing the apparent and actual strengths of steel wire are illustrated by some values given by Biggart. (Proc. Inst. C.E. C i.)

Crucible Steel Wire	20 B.W.G.	Breaking Load.
	In Tension.	
Unannealed	ungalvanised	217 lbs.
Unannealed	galvanised	207 lbs.
Annealed	ungalvanised	120 lbs.
Annealed	galvanised	118 lbs.

This shows the advantage of the unannealed ungalvanised wire.

In Torsion.

		Twists before breaking.
Annealed	ungalvanised	178.5
Unannealed	ungalvanised	101.5
Unannealed	galvanised	88.5
Annealed	galvanised	57.5

The failure in torsion due to galvanising is clearly marked. The outer fibres are weakened by the formation of the alloy, and as these are the most important in resisting torsion, the reduction in value is very distinct. Goodman's experiments on wires drawn from the same billet of steel show the /

the effect of annealing in raising the value of E, in increasing the extension, and in reducing the maximum stress and the elastic limit. (Mechanics applied to Engineering).

The lack of perfect homogeneity even in steel wire seems to account for some unexpected failures. Fremont goes so far as to say that many premature failures which have been put down to fatigue are really due to enclosed slag. (Revue de Metallurgie 1913, 206-210). Torsion tests frequently show remarkable discrepancies. Even with the most careful treatment of wire for ropemaking, there is bound to be some weak spot in a wire 6000' in length; and the strength at the weakest spot determines the strength of the wire. The writer has an interesting mild steel specimen in the form of a piece of wire 8" long, and approximately $\frac{5}{32}$" in diameter, It had received a permanent deformation under torsion of 7 complete twists, but six of these had taken place in a length of an inch and a quarter. Another specimen in the writer's possession is a "wire" approximately $\frac{3}{4}$" in diameter which broke in tension orthogonally to the axis, with practically no reduction of area. I was able to break this again within a distance of 9 inches of the above break and get the perfect cup and cone fracture of mild steel. The "wire" had not been subject to any specialising treatment and was supposed to be perfectly /

perfectly homogeneous.

These two cases illustrate the unexpected lack of homogeneity quite apart from any considerations of enclosed slag.

The efficient joining of two wires in the constructionoof a rope is a matter of considerable difficulty. The junction should be no thicker than the rest of the wire. It is desirable that each wire should be continuous throughout the length of the rope, but this is by no means always possible in very long ropes. The new wire should be brazed to the end of the last one. It is manifestly incorrect to butt together the ends of two wires - say of a strength of 100 tons □" - and braze them with a brass at 12 tons □". If, however, they are scarfed to an elliptic section, whereof the major axis is 10 times the diameter of the wire, then the joint should be stronger than the rest of the wire, provided the heating has not reduced the strength of the steel. Such a joint however is troublesome to make satisfactorily.

Even the joining of two high-class steel wires efficiently by twisting, without any restriction on the diameter of the junction, is an exceedingly difficult matter; particularly when the diameter of the wire is greater than .15". This subject has been investigated recently in the U.S.A. aeroplane department.

and diagrams of a large number of joints are shown with their efficiencies, and it is remarkable that even in the best cases it rarely rises above 90% of the strength of the wire. No one would believe the difficulty of making this junction till he has experimented in this matter.

FURTHER NEW TABLES.

Continental engineers express the stresses in wires or wire ropes in kilogrammes per square millimetre, while in British measures, tons per square inch are used. The writer made recently a conversion diagram for use at Brunton's. He judged, however, that it would be better to make also conversion tables from tons □ " to kilogrammes □ m/ms., and conversely, as he did not know of any in existence; e.g. the metric tables by Molesworth convert lbs. □ " or lbs. □ ' to kilogs. □ c/m. or □ m/m. He accordingly constructed the following tables for the usual range of working stresses.

(See Tables B & C.)

He also constructed - for use in the wire works - tables giving the strength of wires for all diameters from .000" to .210" and for steels whose breaking stresses ranged from 80 tons □ " increasing by increments of 5 tons to 120 tons tons □ ". (A copy of this is shown). (See Table D.)

This /

This table is useful in selecting out of store the coils of wire for constructing a particular rope, or conversely for checking the tests of individual wires made of steels of known strengths.

WIRE TESTS.

As regards the testing of a wire in direct tension there seems little new to say. When metal is drawn into wire, a hoop tensile stress is produced apparently in the outer fibres, which compresses the inner fibres. Any cut in the outer skin leaves the wire in an unstable condition, so that it is likely to break at this point. This is further intensified by bending. Thus any damage to the skin of a wire reduces its strength more than the reduction of area implies. In this way the tensile strength of a wire differs from that of a bar.

Since there are a large number of wires in any rope the tensile testing of these takes considerable time, and after a little becomes purely mechanical. For the investigator a quick acting testing machine is essential. The small Olsen machine used in the test rooms at Brunton's has been referred to already, and on this the writer used to test the individual wires and smaller strands in great quantity after the rope had been broken. It acted admirably, the grips were automatic and worked instantly. The wire-store and the drawing mills too were well supplied with testing machines, and on these the wires were tested before winding. A sample wire table is shown and a few typical tables are given later illustrating

the /

Wire tests (2)

the selection of wires for inclusion in a rope. The leading columns give the breaking load in lbs., and the two last columns show the complete twists in an 8" length. The figures are self explanatory. The two columns of zeros are due to my tabulating by means of the Burroughs Adding and Printing machine in the E. U. Mathematical Laboratory.

Test H. 502 d = ·082"

i

lbs	twists
97,000	40
99,000	42
96,000	38
98,000	40
99,000	38
97,000	38
98,000	38
100,000	40
98,000	38
97,000	36
98,000	34
100,000	39
99,000	38
100,500	40
100,000	38
98,000	42
98,000	44
97,000	40
98,000	38
101,000	38
97,000	41
98,000	39
110,000	3[illegible]
98,000	3[illegible]
98,000	3[illegible]
2,469,50/9.65	

ii

lbs	twists
96,000	40
95,000	42
97,000	40
95,000	38
98,000	41
98,500	37
97,000	40
98,000	41
95,000	34
99,000	34
101,000	36
106,000	42
97,500	40
144,000	34
99,500	35
100,000	38
101,000	42
103,000	40
98,000	37
98,000	34
100,000	38
97,000	40
98,000	42
103,000	42
99,000	42
2,473,509.69	

iii

lbs	twists
98,000	40
101,000	42
97,000	42
98,000	40
99,500	40
100,000	38
98,000	36
99,000	40
100,000	38
99,500	40
98,000	41
101,000	39
99,000	42
99,500	38
101,000	40
99,500	38
100,000	38
99,000	42
98,500	40
101,000	40
99,500	42
101,000	38
99,000	41
98,500	40
99,000	39
2,433,509.94	

iv

lbs	twists
112,000	38
112,000	37
116,000	36
112,000	36
112,000	37
111,000	35
115,000	36

Totals

lbs.

246950
247350
248350
79000

821650 / 82 = 1002 lbs Average

Twists = 3183 / 82

Average = 38·82.

		lbs
Highest	Tensile	950
Lowest		1100

Highest	Twists	44
Lowest		35.

Wire Tests (3)

One of the subjects which the writer attempted to investigate, was to compare the strengths of the wires before winding with their strengths after the test piece, of which they had formed part, had been broken. This could only be carried out in a wire mill, but even there it was a matter of extreme difficulty. One cannot stop the working of a mill to get specimens of the wires before or during winding, particularly in works which have been turning out munitions at high pressure since the beginning of the War. For these values one must rely on the figures supplied by the foreman. These however are taken with care and are most probably correct.

The conclusion I came to, after taking a large number of the broken test pieces of rope, untwisting them and then testing the individual wires, was that though there was little difference between the two cases as regards tensile strength, yet that the twisted wires were slightly weaker and more uncertain than the unstrained wires. I expected that since the wires in the rope were strained so much beyond the elastic limit, and then tested to destruction under tension with the incidental twist and bend, that they would have been greatly inferior to the values of the unstrained wires. This was not the case, as the difference was small, and later the reason for this became clearer.

A /

Wire Tests (4)

A recent Austrian investigator* has stated that the strength of a rope equals very closely the sum of the strengths of the constituent wires. The results which I have given in this paper do not bear this out, as the efficiency of the rope will be seen later to be less than that of its component wires.

Some matters of interest follow from a table such as that given above. We observe that though the material and diameter are supposed to be the same, yet the strength of the wires may vary a good deal (5.2 and 9.8%). But it does not follow

---

* Oesterr. Zeitschr. für Berg-und Huttenwesen, XLVIII.

Wire Tests (5)

that putting in the lower valued wires would mean a corresponding reduction in the strength of the rope, though this is sometimes believed. Also it would not be correct to employ the law of errors for deducing from these tables the probable error in determining the strength of the rope. There may be quite a large variation in breaking load from wire to wire, even with the same material, but the rope may be quite efficient, as the stress on each wire may be practically the same. Applying this idea we see that ropes may be designed effectively though formed of wires of different gauges.

The torsion test is of great importance in grouping and selecting wires for a rope. It is a more sensitive test than tension for determining homogeneity and predicting duration. Various observations have shown that towards the end of the life of a rope, while the tension of the wires is not greatly reduced, the reduction of their resistance to torsion is great, and this shews that they are becoming exhausted and that they will soon fail.

The following tests (Proc. Inst. C.E. Ci ; p. 248) of single wires 20 B.W.G., loaded to one-tenth of their breaking load, and run over a 10½" diameter pulley illustrate this.

Table /

Wire Tests (6)

Wire	No. of Bends.	Tensile Strength Before running tons □"	Tensile Strength After running tons □"	Ultimate Elongation Before running	Ultimate Elongation After running	Torsional Twists Before running	Torsional Twists After running
Crucible	5,000	100	100	5.5		71	77
Steel.	10,000		100		3.4		56
	15,000		98		3		32
Improved Crucible	30,000	83	76	1.	1.2	108	103
Steel.	60,000						69
	90,000						18
(Bessemer) Iron.	15,000	45	45	.75	1.75	69	29
	30,000		45		1.25		31
	45,000		42		.75		18

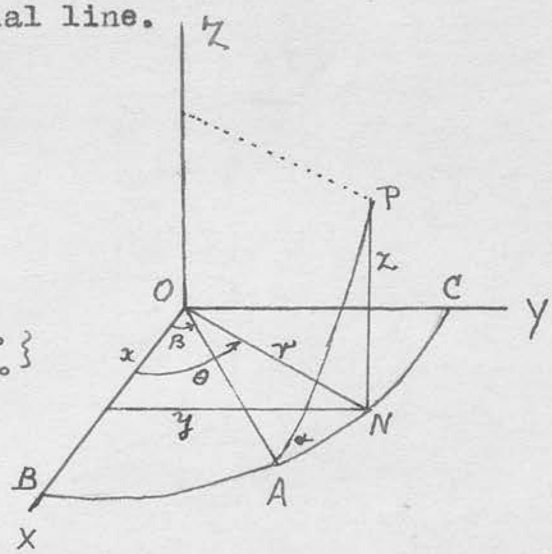
Thus it will be seen that the torsion tests indicated in a marked way the deterioration which had been produced in the material by the work accomplished. Tests of this nature should be of the greatest value for showing the reliability of ropes at work in winding or hauling.

THE SLIP SURFACE.

When a mild steel bar is broken in tension we get the well known cone and cup fracture. The writer suggests the following as a possible mathematical explanation of what has happened:--

Slip Surface (2)

If we assume that the lines of slip or shear in a cylindrical rod or wire are helices and that the angle of the helix is constant, say , then to estimate the effect of this doubly infinite system we may consider a slip surface generated by such helices passing through a radial line.



Let AP be one of the helices,
NP the ordinate of P, BOA = β
ON = r; P (x,y,z)
then NP = z = AN $\tan\alpha$

$\therefore z = \tan\alpha \cdot r(\theta - \beta)$, or

$z^2 = \tan^2\alpha \cdot (x^2+y^2)\{\tan^{-1}\frac{y}{x} - \tan^{-1}\frac{y_0}{x_0}\}$

A being the point $(x_0, y_0, 0)$

If $\beta = 0$

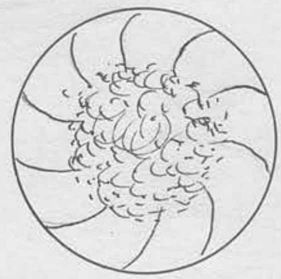
$\therefore z^2 = \tan^2\alpha \, (x^2+y^2)(\tan^{-1}\frac{y}{x})^2$

Then for α = constant the pitch of each helix is proportional to r, i.e. the pitch increases in passing radially outwards.

It is not difficult to make a model of this surface. The contours parallel to the xy-plane are seen to be hyperbolic spirals, in which any particular convolution increases in magnitude as one moves away from the origin along the z-axis.

Slip Surface (3)

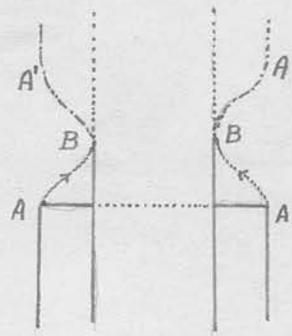
By rotating the ray O A through all positions successively up to 2π, we take into account all the possible shear lines which start from the particular xy-plane selected.
We thus get a diagram like what is indicated in the figure.



In this the central portion forms a 'jabble' where one would expect the material to break off flat, and there is a well defined shear (owing to the double system of surfaces) in the outer layers, corresponding with the typical formation which one sees on breaking a mild steel rod or wire in tension, viz. the flat or cup-shaped central portion where the jabble occurs, and a coned portion on the outside.
The same type of fracture is seen if the wire or bar be not cylindrical.

Slip Surface (4)

When breaking a steel rod we should have one cylinder deformed into another of lesser radius and equal volume. But as the deformation is continuous, and sharp edges do not occur, the outer particle has to travel along the dotted line from A to B, a greater displacement than that suffered by the particles nearer the axis. This further tends to produce the well known conical form in the breaking under tension of a ductile material such as steel.



With the hard types of steel wire or rod this effect is very much less marked as the drawing-down is slight.

As this movement of the particles is what occurs in wire-drawing, we see that it indicates the existence of a normal pressure (as shown in the figure) and the consequent hoop tension in the outer fibres of a drawn wire which has been referred to already.

COMBINED STRESSES IN A WIRE.

With a view to examining the complicated system of forces which occurs in a steel rope, the writer made some experiments on steel wires subject to compound stresses. These were,--

(i) Combined tension and bending;

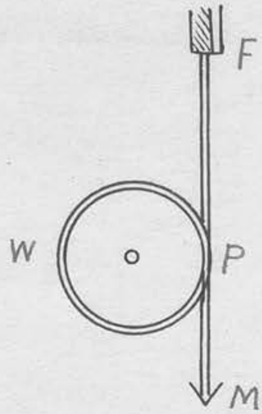
(ii) Combined tension and torsion.

Combined Tension and Bending.

A wire in a straight loaded rope sustains tension, and is also bent to various curvatures. Now when a rod of length l and radius r is bent to a radius of curvature R, the elongation of the outer fibres is δl so that $\frac{\delta l}{l} = \frac{r}{R}$ Thus is a measure of the strain, and in the theory of structures it is assumed that the elastic limit is not passed. Now if the radius of curvature of a wire in a strand or rope be calculated, it will be seen that under ordinary working conditions this limit is far exceeded, in fact that a large permanent deformation is produced in the wire, even when the rope is straight. Accordingly it appears unreasonable to apply equations such as the ordinary Reuleaux bending equation deduced for elastic material to this case, and to say that the stress in the outer fibres of a wire in a straight rope would be of the form $\frac{w \operatorname{cosec} \alpha}{\pi r^2} \pm \frac{Er}{\rho}$ where w is the load on the wire, ρ the radius of curvature at the point considered, and $\frac{\pi}{2} - \alpha$ the angle of the lay. It might be permissible however to multiply the second term by μ in order to attempt to allow for the relative movements of the wires, where μ is a factor to be determined by experiment, and whose value is less than unity.

The writer carried out a number of what he called 'wheel tests' of wire to discover the effect due to the curvature, but unfortunately this was stopped by the complete destruction of the machines and instruments in the great fire already referred to. The instrument made was an addition to the ordinary testing machine. He got a number of cast-iron wheels of various radii, got a shallow flat groove turned on the rim of each, and made the surface of the groove as smooth as possible. The circumferences were measured, and the radii found. The wheels could be slipped on a spindle on which they were free to turn. This was bolted to a flat steel holder. The wheels were rapidly interchangeable, so as to vary the radius of curvature at will. A frame was attached to the uprights of the small vertical Olsen testing machine, and on this a vice was fastened. The holder was put into this, so that the wheel was vertical in position, and also tangential to the axis of a straight specimen in the machine. The wire to be tested had one end F held in the upper fixed jaws of the machine and was taken round the wheel W and had the other end held in the

jaws /



jaws attached to the ram M. A diagrammatic view of the arrangement is shown:

When the load was put on, the specimen was in tension, but the curved part had also the strain due to curvature, similar to what would occur even in a straight rope.

The forces introduced are of course quite distinct from those considered in the frictional effect of coiling a rope or wire round a post, which gives rise to the well known equation $T = T_0 e^{\mu\theta}$ since the wheel is free to turn.

The writer found that the wire broke on nearly all occasions at the point P where the curvature began; but, unless the curvature were great, at a load little if at all less than that of the straight wire. Sometimes when ρ had its larger values the wire broke in the straight portion instead of at the beginning of the curve, showing that the introduction of theoretically high bending stresses had little effect on the ultimate strength.

We may take $e = \cdot 001''$ as a high strain in structural steel, but I found that in wire ropes unless e has a very much greater value say $e = r/R \doteq \cdot 02''$ failure in the wire may occur on the straight part, and not where the extra

stresses /

Wheel tests for Curvature Effects.

lack wire for haulage. $d = .0515''$ $a = .00208 \square''$

traight wire broke at 416; 404; 416; 416 lbs.

ρ radius of curvature 1.95'' 1.435'' .955'' .238''

Breaking Load: lbs. 414 396 396 372

The curved portion was re-broken: the original

trength was obtained if $\frac{r}{\rho} < .01$

Black wire for haulage $d = .0555''$

Straight wire broke at 550, 566, 552, 560 lbs. [557]

hen $\rho = 1.71''$ the wire broke at 562, 522,

545, 548 lbs. [544] ie 2.3% weakening

Black wire. $d = .0483''$

Straight wire broke at 382, 381, 383 lbs. [382]

$\rho = 1.92''$ BL = 376 lbs: curved part rebroken at 382, & 384 lbs.

$\rho = 1.44''$ BL = 374 lbs. " " " 378 & 374 lbs.

$\rho = .95''$ BL = 360 " " " " 364 lbs.

If $\frac{r}{\rho} < .01$ the curved part still gives the

original strength approximately of the wire.

Black wire $d = .0808$. BL on straight is
1278, 1285, 1276 lbs. mean 1280

$\rho = 3.16''$ BL = 1280 lbs : curved part rebroke at 1330, 1260.

$\rho = 1.92''$ " 1250 & curved part at 1240 in grips.

$\rho = 1.44''$ " 1258 " " 1270
1264 " " 1250

$\rho = 1.19''$ 1210 " " 1210

$\rho = .95$ wheel broke at 1160 lbs.

If $\frac{a}{\rho} < .02$ the curved part gives approximately the original strength of the wire.

Black wire $d = .052''$
For BL. 473, 473, 480, 472, 484, 484.
$\rho = 1.67''$ BL = 469, ... rebroke curved part at
473, 475, 480, 480.

$\rho = 1.92''$ BL = 463. 479 : rebroke curved part at
481, 490, 483, 480, 479.

Black Wire $d = .054''$ BL = 443.

$\rho = 1.19$. Broke at 450, 437, 442 438 [442]

The curved parts rebroke at the values
432, 428, 520, 428.

Excluding {520 lbs / 450} the mean is 439 & 429 lbs.

stresses due to bending are introduced. This is interesting, and I think very important, particularly when we compare it with results deduced from the accepted theory of bending. Some six values from actual tests are given. (See 'Wheel Tests')

One conclusion is that a prolonged effect of this nature, especially when accompanied by shock and repeated stresses, would be very weakening, particularly if the material be such that it cannot recuperate perfectly: in fact that a tensile test of a new rope is unsatisfactory, since it gives no direct indication of the durability.

Some experiments by Mr Brunton in the pamphlet already quoted lead to the same conclusion. He led a wire, clamped so as to be endless, round two pulleys, the lower one being suspended, free, and loaded with a weight equal to half the breaking load of the wire. The top pulley was driven from a shaft. The diameters of the pulleys were such that the ratio d/D was constant $= 1/100$. The following table gives the results of the experiments.

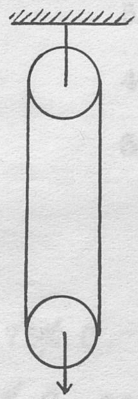


Table III./

Combined stress (5)

Table III.

Size of sample	Passes Sample had.	Feet travelled by sample. 1	A1	2	A2	Rate per minute.
.140	6	4490	8460	8861	8514	168
.130	7	8560	7527	8140	8290	157
.121	8	3937	6783	7088	5801	147
.111	9	8000	7933	8521	7879	131
.101	10	6096	8623	8025	7702	115
.090	11	8184	8230	6239	7726	105
.081	12	3337	3116	2465	3024	84
.070	13	5854	4630	5229	4666	73
.061	14	2237	4247	2229	2249	63
.050	15	2096	2111	1602	1607	52
.040	16	2000	2100	1536	1560	40
.036	17	1897	1900	1420	1460	36

From this he concludes that a steel having .75% C is best drawn to stand 95 tons □ ", and one containing·85% C to stand 100 tons □ ".

Further, however, I noticed that on tabulating the lives of the wires - obtained by taking the quotients of $\frac{\text{space}}{\text{velocity}}$ - these have nearly the constant value 50.

Now the strains are constant, and hence it seems that the dura-

tion /

tion of a wire under roping conditions would terminate after accomplishing a certain amount of work. And this again is the conclusion to which the recent observations of Mining engineers on steel winding ropes seem to point.

Combined Tension and Torsion.

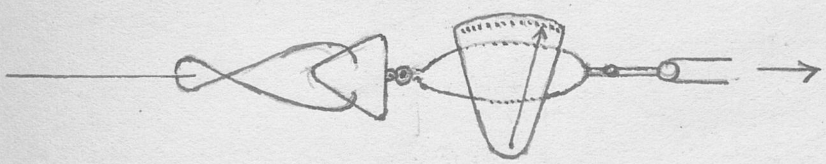
The writer also made some experiments on combined tension and torsion. These were on mild steel galvanised wires of small diameter ($d \ngtr \cdot 1''$). He designed and constructed a machine on the following lines. A lathe was dismantled, and its bed extended to about 10'. The movable headstock was set at the far end, and the hand wheel operating the barrel was used to give extension to the specimen. To the barrel and to the end of the mandrel were fitted strong isosceles triangular frames, attached by the bases, and with the vertices pointing outwards towards each other :

Two wire-drawers grippers were obtained, and the ends of the handles softened and bent into hooks, suitable to slip into the triangular attachments. The arrangement is shown diagrammatically:

On /

Combined stress (7)

On revolving the hand wheel, and so retracting the barrel, the triangular attachments compressed the handles, and so gripped firmly the wire specimen. Arrangements had to be made for measuring the tension, and for floating the specimen, so that the heavy vertical loads due to the grippers should be removed. These were arranged in the following way: Between the movable headstock and its gripper was inserted a spring dynamometer for measuring the load. Thus when the handwheel was rotated, and the barrel moved in the direction of the arrow, the load was applied through the dynamometer to the specimen. Hence the



tensile strain in the specimen was obtained. In order to relieve the wire from the weight of the grippers and connecting links, an overhead frame was made, parallel to the lathe bed. On this frame little carriages could slide with cord attachments and counter weights to balance exactly the weights of the hanging parts. These were thus floated, and the specimen relieved from their weights. The torsion was applied to the specimen by revolving the mandrel, and graduations on it allowed the angle of twist to be read.

Combined stress (8)

The first time the machine was used some wires were tested in torsion, and the machine showed at once that they were shortened in length by the torsional strain. This was indicated by the pointer going back on the dial. To be certain however that this was not due to any slipping of the specimen in the grips, screw clamps were obtained and applied, and by closing the arms of the grippers by means of them, there was no possibility of slip occurring. Thus it was shown that the effect was not due to slipping at the grippers but that the torsion had produced shortening of the wire. This result had however been published by Poynting in Proc. R.S.Ed. A. LXXXVI, pp. 534-561.

The combined stress was applied by putting on a load through the hand-wheel to any desired amount, as read on the dynamometer, and then rotating the mandrel through any desired angle. When a load was taken approaching half the breaking load, a small torsional strain produced fracture. This took place suddenly, though the material was ductile. The fracture showed nothing of the 'cup and cone' of mild steel in tension, but was square across the specimen.

The direct tension had of course extended the specimen, but the torsional strain reduced this to an appreciable extent. The result of these experiments was to show that even a small torsion combined with or superimposed on tension had a decidedly weakening effect, and was apt to produce sudden rupture even in a ductile material.

THE FORCES ACTING IN A ROPE.

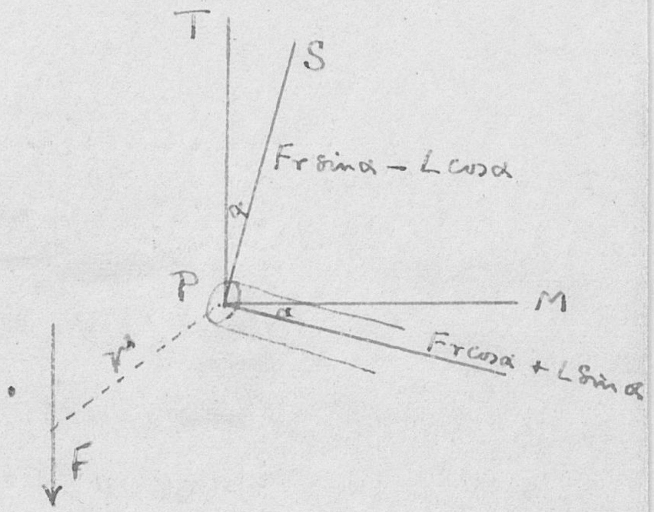
The system of forces acting in a loaded rope is of a complicated nature. A single wire lies in a helix, simple or compound. The simple helix is the only form in which a wire can lie when held by terminal couples, if the two principal flexional rigidities of the wire be equal. It is possible for the wire to be held in a helix by forces alone, or by a couple alone or by a wrench of given pitch, but in each case the twist must be properly adjusted. "A wire cannot be held in the form of a given curve unless either a certain torsional couple be applied to it directly at each section, or the wire have a given twist. This twist is indeterminate to the extent of a certain arbitrary constant, so that if a wire be held in a given curve with a certain twist it can still be so held when the twist is increased uniformly".-- Love, Theory of Elasticity, vol. II., ch. xiv.

If the pull in a rope be axial, due to an axial load, the system of forces acting at a point on the helical wire may be considered as a tensile pull, and a couple, acting as in the case of an open helical spring, i.e. in producing combined torsion and bending.

If we consider a helical spring under an axial load F at the radius r, producing the moment $M_1 = Fr$ with a twisting

moment /

Forces (2)



moment L about the axis PT we have (see Perry, Mechanics, p. 637, or Andrews, The Strength of Materials, ch. xii.).

$$Fr\sin\alpha\cos\alpha\left(\frac{1}{A}-\frac{1}{B}\right)+L\left(\frac{\sin^2\alpha}{A}+\frac{\cos^2\alpha}{B}\right)$$

as the axial rotation per unit length of wire, about the direction PT where A and B are respectively the torsional and flexional rigidities of the wire. If φ be the total amount of the rotation and l the length of the wire

$$\frac{\varphi}{l}=Fr\sin\alpha\cos\alpha\left(\frac{1}{A}-\frac{1}{B}\right)+L\left(\frac{\sin^2\alpha}{A}+\frac{\cos^2\alpha}{B}\right)$$

In the same way the rotation per unit length about P M is

$$Fr\left(\frac{\cos^2\alpha}{A}+\frac{\sin^2\alpha}{B}\right)+L\sin\alpha\cos\alpha\left(\frac{1}{A}-\frac{1}{B}\right)$$

so the downward displacement of a point on the axis of the spring due to this is r times the above expression. Thus the amount of the downward displacement of a point on the axis of the spring due to this (torsional) rotation of the whole length l of the wire is $lr \times$ (above expression). Calling this, which is the extension of the spring, x we have

$$\frac{x}{lr}=Fr\left(\frac{\cos^2\alpha}{A}+\frac{\sin^2\alpha}{B}\right)+L\sin\alpha\cos\alpha\left(\frac{1}{A}-\frac{1}{B}\right)$$

This however only holds for small values of x and φ .

Forces (3)

In the case of a rope the ends are most frequently fastened in practice, the cross section of the wire is rarely other than circular, L is small, and r which varies from layer to layer is very small compared with l , even in test piece lengths. These equations show the amounts of the torsional and bending strains in the wires. As a rope is very different from a free suspended helical spring under load, since there are great frictional forces between the layers, these equations are not of much practical help in the treatment of ropes.

It is more important to consider the effect of the resultant force. If T be the tension of a wire, w the load it sustains, and α the angle of the helix, we have the three (component) forces $T \sin\alpha = w$, $T \cos\alpha$ the untwisting force, and T/ρ the normal force due to the radius of curvature, and compressing the layers upon the core. That the effect of the $T\cos\alpha$ component is very considerable may be seen on watching the rotation of a new crane rope at work.

Though the force T/ρ is large toward the breaking point of the rope, yet the alteration of diameter even of a fibre-cored rope when tested to destruction is surprisingly small.

Incidentally, if the fibre core be used as a reservoir for an anti-acid preservative and lubricant, the pressure squeezes this out among the wires, and so tends to prevent their deterioration. The effect of good lubrication, especially in mining

ropes /

ropes affected by acid water, is of great importance in prolonging their lives; and further it minimizes the local abrasions of the wires due to friction between the layers, which is essential for the duration of the rope.

The Core and Strands: Strains.

A rope and its constituent strands have cores or hearts which may be of metal or fibre. The size of the cross-section necessary has been already discussed. A fibre core is usually of jute, hemp, manilla, or cotton. It gives greater flexibility than a metal one.

It is accepted generally that the metal core is always absolutely inefficient. This is not quite true, since at first, at least, even a solid metal core contributes its share to the strength of the rope. A wound core is much more efficient than a solid one.

The effect of a solid core in a strand.

Let c_r be the radius of any layer of wires, and p_r the corresponding pitch. Let α be the angle of the helix. Consider the length p_r of the strand, and suppose it to be extended — due to a load — by the small amount $d\,p_r$. Let l_r be the length of a wire in the layer

$$\therefore l_r^2 = p_r^2 + (2\pi c_r)^2$$

$$\therefore 2 \log l_r = \log \{ p_r^2 + (2\pi c_r)^2 \}$$

$$\therefore 2 \frac{dl_r}{l_r} = \frac{p_r}{p_r^2 + 2^2\pi^2 c_r^2} \cdot dp_r$$

$$= \frac{p_r^2}{p_r^2 + 2^2\pi^2 c_r^2} \frac{dp_r}{p_r}$$

Now $\frac{dl_r}{l_r}$ and $\frac{dp_r}{p_r}$ are the respective tensile strains in the wire and in the core

Also $\frac{p_r^2}{p_r^2 + 2^2\pi^2 c_r^2} < 1$

$\therefore \frac{dl_r}{l_r} < \frac{dp_r}{p_r}$. Thus in all cases the strain in the core wire is greater than ~~that~~ in ~~any~~ one of the other wires.

The above equation may also be written

$$\frac{dl_r}{l_r} = \sin^2 \alpha \frac{dp_r}{p_r}$$

So whatever be the angle of ~~the~~ helix the solid core is overstrained before the other wires are strained up to the elastic limit.

Also if α be constant from layer to layer $\frac{dl_r}{l_r}$ is constant from layer to layer, ie all the wires undergo the same strain in the strand. Hence for the maximum efficiency of a given cross-sectional area of steel two of the conditions are, for a strand,

(i) that ~~the~~ core should not be of solid steel

(ii) ~~that~~ the angle of the helix should be constant, if the effects of torsion and bending are excluded.

If e_ω and e_c denote the strains in a wire and in the core respectively we have the following table

α	50°	55°	60°	65°	70°	75°	80°	85°
$\frac{e_c}{e_\omega}$	1.703	1.491	1.334	1.217	1.132	1.071	1.030	1.008

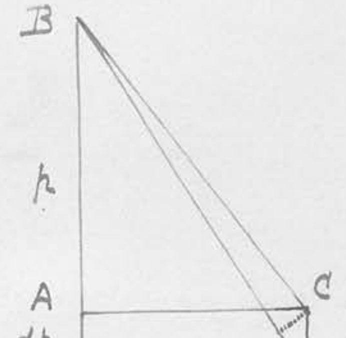
The inefficiency of a core wire shows itself in a curious way. If a new rope be tested to destruction, the core wire bears very closely its proportional share of the load. But as it is more heavily strained than the outer wires during its working life it becomes more heavily fatigued and so deteriorates in time.

The value of the strain may also be established as follows.

Let k be the radius of the incircle of the layer considered, a the radius of the wire

Consider a length of strand equal to the pitch p of the outer wires, and let dp be its extension

Then ~~the strain~~ in the core wire is $\frac{dp}{p}$



The circumference of the centre-circle is $C = 2\pi(a+K)$

$$\therefore BC = \sqrt{p^2 + 2^2\pi^2(a+K)^2}$$

$$BC' = \sqrt{(p+dp)^2 + 2^2\pi^2(a+K)^2}$$

Since $AC = A'C'$, i.e. neglecting compression of ~~the~~ core, or assuming it to be undeformable metal.

$\therefore$ ~~the~~ strain in ~~the~~ wire BC is

$$\frac{\sqrt{(p+dp)^2 + 2^2\pi^2(a+K)^2} - \sqrt{p^2 + 2^2\pi^2(a+K)^2}}{\sqrt{p^2 + 2^2\pi^2(a+K)^2}}$$

$$= \frac{\sqrt{p^2+2^2\pi^2(a+K)^2}\left\{1 + \frac{p\,dk}{p^2+2^2\pi^2(a+K)^2} + \quad\right\} - \sqrt{p^2+2^2\pi^2(a+K)^2}}{\sqrt{p^2+2^2\pi^2(a+K)^2}}$$

or on neglecting values of dp above the first

$$= \frac{p\,dp}{p^2 + 2^2\pi^2(a+K)^2} = \frac{dp}{p + \frac{2^2\pi^2(a+K)^2}{p^2}}$$

i.e. is less than $\frac{dp}{p}$, ~~the~~ strain in the core-wire. As k increases this value becomes less so that ~~the~~ strain in the wires decreases continually as we pass outward from the axis.

When $K \to \infty$ ~~the~~ strain in the outer wires becomes zero.

<u>The effect of a fibrous or deformable core in a strand.</u>

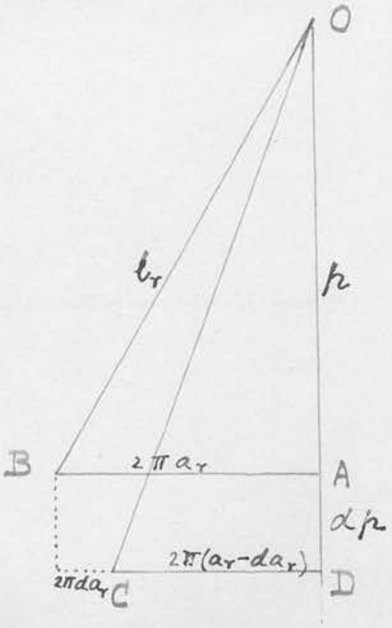
Under load, owing to the curvature of the wires, normal pressure is introduced. This compresses the core when it is of fibrous or soft material.

Let the radius be decreased from a_r to $a_r - da_r$ when the length of the strand p is increased under load to $p + dp$. Thus ~~the~~ point B is displaced to C and we have

$$(l_r + dl_r)^2 - (p+dp)^2 = \{2\pi(a_r - da_r)\}^2$$

$$\therefore l_r\,dl_r - p\,dp + 2^2\pi^2 a_r\,da_r = 0$$

$$\therefore \frac{dl_r}{l_r} - \frac{p}{l_r^2}dp + \frac{2^2\pi^2 a_r}{l_r^2}da_r = 0$$



$$\therefore \frac{dl_r}{l_r} = \sin^2\alpha \frac{dp}{p} - \cos^2\alpha \frac{da_r}{a_r}$$

So for any value in the core-wire of ~~the~~ strain $\frac{dp}{p}$, we find ~~that~~ the corresponding strain in the layers of wire is lessened by the use of a compressible core.

For ~~the case~~ of a rope the treatment is similar. Consider the standard rope 6/1/n/d. Let L be the pitch of the rope, r the circum-radius and α the angle of ~~the helix~~

$$\therefore \cot\alpha = \frac{2\pi.\frac{2}{3}r}{L}$$

The length of the core of a strand for ~~the~~ length L of the rope is $\sqrt{(2\pi\frac{2}{3}r)^2 + L^2} = L' = L\,\text{cosec}\,\alpha$

Let N be the number of convolutions in the strand for one in the rope ∴ the length of a wire in ~~the~~ strand is $\sqrt{\{2\pi(\frac{1}{3}r)N\}^2 + L'^2}$

& $N = \frac{L'}{p'}$, where p' is ~~the~~ pitch of ~~the~~ strand

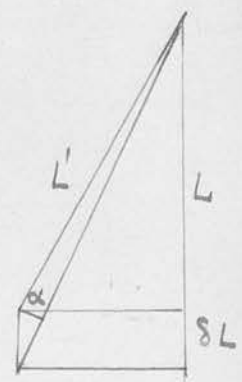
$$\therefore N = \left(2\pi\frac{2}{3}r\sec\alpha\right) \Big/ \left(2\pi\frac{1}{3}r\tan\alpha\right) = 2\,\text{cosec}\,\alpha$$

If $\omega = 18^\circ$ $N = 2.1$ $N \simeq 3$ when the rope is opened up.

If δL be the extension of the length L of the rope and $\delta L'$ the extension of the axis of the strand

$\therefore \delta L' = \delta L \sin\alpha$.

The wire length in ~~the~~ strand is $L' \operatorname{cosec}\alpha$ ie $L \operatorname{cosec}^2\alpha$ and the extension of the wire $\delta L' \sin\alpha$ ie $\delta L \sin^2\alpha$



$\therefore$ ~~the~~ strain in the wire is

$$\frac{\delta L \sin^2\alpha}{L \operatorname{cosec}^2\alpha} = \frac{\delta L}{L} \sin^4\alpha$$

If $\alpha = 70^\circ$ ~~the~~ strain in the helical wire is only ·78 times ~~that~~ in ~~the~~ straight core-wire of the rope. Thus in general the straight central wire gets overstrained compared with the helical wires.

A core could be formed however in which this overstrain does not occur. Let it be a strand and let β be the angle of its helix. Then the strain in a wire is $\frac{\delta L}{L} \sin^2\beta$.

Equating this to the strain in the outer wires we have $\sin\beta = \sin^2\alpha$ Thus if $\alpha = 72^\circ$, $\beta = 64^\circ 45'$.

If however a single wire be used as a core it is frequently taken of softer material than the other wires but this does not get rid of the defect. It reduces the efficiency of the rope ~~to~~ use such a wire merely as a distance piece, and in long winding-ropes every little disadvantage tells. It looks as if the difficulty would be met best by using a fine strand of ~~the same~~ sectional area as ~~the straight~~ core and the proper angle.

An interesting illustration of the subject of the above paragraphs was seen recently by the writer. Two specimens of winding rope which had been in use for some considerable time were sent to be tested. They stood the tensile tests well. On opening up the strands the central core-wire of each was seen to be triangular. They had been twisted into a helix by the lay of their surrounding wires and so far as I could see there was not the least tendency for the wires to cross the sharp edges. This is noteworthy since cautions have been given against the use of the sharp-edged core from the point of view that the wires would cross the edges and be cut by them. Also it was curious to notice that scarcely half an inch in length of the triangular core-wire remained unbroken. Even allowing that too hard a wire had been chosen as core, which undoubtedly was the case, one would have expected some occasional breaks but nothing like the array of minute fragments which was seen.

Evidently when the rope was loaded the helical wires produced their normal pressure all along the core, and as this was great the frictional grip was powerful. A relative movement takes place between the wires and the core and a wrench is set up about the core. In the present case owing to the evident hardness of the triangular wire it had effected this shattering aided of course by the bending round the winding drum.

Since a strand may be looked on as a one-strand rope with the notation 1/n/d, its strength may be considered among the rope ~~tests~~. It will there be seen ~~that~~ it is more efficient than the stranded rope.

Hrabak in chapter IX advances the peculiar theory that the effect of ~~the~~ pressure of the circumferential wires on the core-wire permits the latter to be stressed far beyond the breaking stage without rupture, but that without this lateral pressure it would have broken long before. He compares it with the 'boiling delay' of 'overheated water'. I confess that I do not see ~~that~~ the hypothesis of this explosive state is necessary.

Commercial testing is naturally not so elaborate as laboratory investigation. When a large number of specimens require to be tested daily, there is no time for anything more than the essentials. From every rope which is constructed, a special machine in the ropery cuts off the required length of the test specimen. This has been duly served with marlin for two or three feet at each end. It is brought to the testroom and the breaking loads and twists of the wires (in the straight) should be supplied with it.

Procedure in Commercial Testing.

The great difficulty in rope testing is of course the holding of the rope. A machine which may be excellent for testing bars, is frequently useless for testing ropes; since the comparatively short grips used for bars would nick or injure a rope and give a result which would be quite unreliable. Some of the requirements of suitable grips for ropes are as follows:-

(1) Great length is needed, so that the rope may be held firmly and without injury. Thus in the 100-ton machine referred to the grips were about 18" in length.

(2) The edge at the extremity where the rope issues should be rounded carefully so that the rope may not be nicked or damaged. It is just at this place that the specimen is so apt to fail, and any extra strain at this position has a seriously weakening effect. Also the hold should increase gradually from the anterior to the posterior part. This may be attained by making the channel in which the rope lies change gradually from circular to an elliptic iron section, or, what amounts to the same

Commercial testing is, naturally, not so elaborate as laboratory investigation. When a large number of specimens require to be examined daily, there is no time for anything more than the essentials. From every rope which is constructed, a special machine in the ropery cuts off the required length of the test specimen. This has been duly served with marlin for two or three feet at each end. It is brought to the test-room and the breaking loads and twists of the wires (in the straight) should be supplied with it.

The great difficulty in rope testing is of course the holding of the rope. A machine which may be excellent for testing bars, is frequently useless for testing ropes; since the comparatively short grips used for bars would nick or injure a rope, and give a result which would be quite unreliable. Some of the requirements of suitable grips for ropes are as follows:-

(1) Great length is needed, so that the rope may be held firmly, and without injury. Thus in the 100-ton machine referred to, the grips were about 18" in length.

(2) The edge at the extremity where the rope issues should be rounded carefully so that the rope may not be nicked or damaged. It is just at this place that the specimen is so apt to fail, and any extra strain at this position has a seriously weakening effect. Also the hold should increase gradually from the anterior to the posterior part. This may be attained by making the channel in which the rope lies change gradually from a circular to an elliptic iron section, or, what amounts to the same/

same thing, by flattening slightly the back part of the channel.

(3) The grips should be easy to change, and the boxes or cross-heads in which they are carried should be self-adjusting in direction, so as to obtain an axial pull.

One of the few criticisms which I felt inclined to make with regard to the two large machines referred to was that a slight enlargement of the cross-head end of the connecting rod would have given more room for tucking away the end of the test piece, and so would save trouble in rope-testing.

With reference to the failing of mining ropes, I was anxious to test the side-gripping effect of wires in a rope by cutting certain of the outer wires, each a definite length in advance of the other. This would necessitate testing a specimen from 20 to 50 feet in length, but there was no possibility of doing so even with these machines. Perhaps it might be worth while for makers of testing-machines to contemplate the possibility of making a supplementary part to some of the high class machines, that would allow such experiments to be carried out.

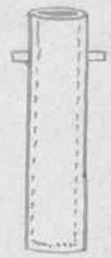
In preparing a specimen for laboratory testing, one is advised to clean the ends of the rope very thoroughly, untwist the wires, lay them back, place them in end-boxes and fill in the whole end solid with white metal. But though this gives an excellent way of holding the test piece, yet it takes a long time to prepare a specimen in this manner, and in commercial testing it would be unprofitable to adopt it always.

If spelter is used instead of white metal, and large end-blocks/

blocks be formed, the higher temperature of the zinc may possibly weaken the rope at the point where it meets the end-block. It will be remembered that the critical point Ar_1 for steel is about 660C°, while the melting point of zinc is 736°F or 391°C. Still it is not impossible that some weakening may be produced in this fashion. According to the experiments of Arnold (see Engineering 64.49. 1897 and Oswald (see Metallographist 2.80. 1899) it does not very much matter from what temperature the cooling of mild steel begins, provided it is above the critical range 720° (Mellor p. 58 Crystallisation of Iron and Steel). At the same time I have assisted in testing modern heat-treated steel rods which were markedly altered and reduced in strength by a treatment below the temperature of melting zinc.

There is a further matter for consideration, if one examines the sudden transition from the flexible wires of the rope to the rigid end-pieces, which probably leads to a certain amount of weakening, which is indicated by many specimens, prepared in the way referred to above, failing just at this point. Compare this too with the failures of mining ropes referred to under 'Working Conditions'.

When testing some small rope specimens in Edinburgh University Engineering Laboratory, I used to prepare the ends as follows:- I removed the fibre core at both ends and replaced it by a piece of wire of the same size, served it roughly with tinned iron wire, rubbed in fluxite, and dipped the two ends in a bath of solder. This/



This gave excellent results. The vessel containing the solder was made from a piece of cast iron pipe plugged at one end and with trunnions attached near the other end. This was held upright on a triangular support and heated by a bunsen flame.

Tests could be carried out very rapidly at Bruntons Laboratory owing to the excellent design of the machines. During a rope test observations could be taken of extension and change of circumference, though this was a dangerous amusement near breaking point. Sometimes autographic records were taken. The details of the tests were of course duly entered in the books.

I devoted a good deal of time to breaking the constituent strands and wires of the large tested ropes. The former gave a very great deal of trouble, and there were in fact comparatively few tests of this sort that were quite satisfactory. The reason for this was that the strand, being in the form of a helix, was most refractory to work with. To grip it in any fashion was almost an impossibility owing to its shape, strength, and springiness, and it took a great deal of time and of humouring before one of these helical strands could be held and broken. There seems to me no satisfactory way of getting over this difficulty. I concluded that a new strand, or one-strand rope, when broken in the testing machine, was less efficient than the sum of the strengths of the straight wires, chiefly owing to the effect of the equation $T \operatorname{cosec} x = W$, already referred to, and that the rope was less efficient than the sum of the strengths of its constituent straight strands owing to the same reason. Also that the duration/

duration of the life of the rope or strand was chiefly affected by the combined stresses already referred to, particularly when accentuated by shock.

Finally there was the testing of the individual wires. This was a simple though laborious matter. The little vertical Olsen machine was admirably adapted to this work. It could be balanced exactly and the grips worked instantly and automatically.

It is desirable to keep all details dealing with the test of one rope together, so that they may be compared. These amount to a considerable number, and in commercial testing it may be difficult to get them all.

The rope has its wire number, its commercial number, and its test number. Its construction is denoted by its formula, lay and angle. The weight should be quoted. The wire tests, noting whether it be galvanised or black, should be filed with the rope test. If possible tests of the straight strands should be included.

The circumference and pitch of the rope and the circumference and pitch of the strand should be noted. These are best measured by a steel tape graduated decimally. Details of the steel should be given. Data for the load-extension curve should be observed. Attention should be paid to whether the rope fails at the grips or not, and how failure occurs.

Chapter V

The Rope.

Rope Tests.

ROPE TESTS.

In classifying any large number of tests, the first consideration is naturally to obtain the best method of grouping and representing the results, so as to obtain from them such general principles as may govern the subject of the investigation.

The number of variables unfortunately is considerable. These include the different diameters of wires, sizes of strands and ropes, types of construction, lay, and angle of helix or pitch, both in strand and rope, metal or fibre core, and differences in grade of steel.

Through the kindness of Mr J. D. Brunton, I am able to quote the results of the determinations of the breaking loads (B.L.) of some 700 of the firm's recently constructed ropes. Nearly half of these had been made since the beginning of the War, and this, which represents only part of the activities of Brunton & Son's undertakings, gives some indication of the great amount of munition work which has been carried out by the firm. Throughout a considerable portion of this time I had the privilege of experimenting in the test-room.

I have grouped these tests under the headings M and S, indicating different sets of testing machines and testers. Then I classified the results according to the constructions of

Rope Tests (2)

the ropes, and tabulated them in the following forms :--

No.	Formula	Diam. Wire	B. Load	Remarks. M.
06	7/12/d	·019	2·24	
19b		"	2·89	
13		·020	3·0	g c = $\frac{3}{4}$" BQSWR.
		·0135	1·18	GWR.
		·009	·54	
		·0084	·50 } ·55 }	
44	7/37/d	·015	5·0	
281	7/19/d	·0092	·885	
		"	·911	
		·01	1·12	
281		·011	·93	
177		·020	4·5	
225	6/6/d_1 6/d_2 1/d_3	·062 ·045 ·058	20·25	
233	6/15/·036 9 3	·036	18·16	g c = 2$\frac{3}{8}$ BQSpF SWR.
307	6/9/d_1 6/d_2 1	·072 ·056	12·7	

II Formula of Rope.	III Diam^r of Wire."	IV Break^g Load Tons	V Remarks.
6/6/1/d	·041	5·95	107 t□" orthog area of steel
	·052	8·18	92 t□"
	·053/6	9·65	104 t□"
	·053	8·82	
	·070	16·4	102 t□"
	·071	16·4	99 t□"
	·072	15·7	92 t□"
	·072/3	17·05	
	·072	14·8	
	·072	16·95	
	·072/5	14·93	
	·073	16·3	
	·081	21·13	98 t□"
	·081	19·4	
	·081	18·4	
	·081	19·1	
	·081	21·6	
	081	23·45	
	081	19·46	

II	III	IV	V
6 6/1 d	·081	19·5	
	·081	20·3	
	·081	20·95	
	·082	19·25	
	·082	17·6	
	·082	19·43	
	"	19·1	
	·082 } 79 }	18·53	
	·082	19·1	
	·082	18·6	
	·082	18·92	
	·082	19·4	
	·082	22·5	
	"	22·85	
	·082	15·8	
	·082	18·8	
	·082	18·4	
	·082	17·65	
	·082	19·70	
	·082	20	
	·083	18·6	
	·083	20·5	
	·083	18·52	
	·083	18·8	
	·083	18·55	
	·083	19·05	
	·083	19·62	
	·083 } 4 }	23·2	
	·083	23·	

II	III	IV	V
6/⁶⁄₁/d	·081	19·05	
	·091	25·93	95 t□"
	·094	25·72	88·5 t□"
	·095	25·05	84·5 t□"
	·095	26·55	
	·095	27·05	
	·095	26	
	·096	23·50	77·5 t□"
	·096	26·38	
	·098	26	
	·096	29·3	
	·109	33·25	85 t□"
	·109 } ·111 }	35·80	
	·108 } ·110 }	35·70	
	·109	42·58	
	·109 } ·110 }	42	
	·108 } ·109 }	41·09	
	·108 } ·109 }	42·60	
	·112	37·48	90·5 t□"
	·123	47·03	94·3 t□"
	·123	49·45	
	·123	47·3	
	·124	49·3	97·5 t□"
	"	51·1	100 t□"
	·125	51·7	
	"	51·5	99·5 t□"
		51·1	

II	III	IV	V
6/19/d	diam wire	B. Load	Remarks.
"	·020	3·35	93·5 t □"
6/12/6/1/d	·030	6·95	86·2 t □"
	·031	8·02	93·5 t □"
	"	6·0	
	"	8·35	
	"	7·64	
	"	7·38	
	·034	8·7	84·5 t □"
	"	9·7	
	·035	10·53	96 t □"
	"	9·50	
	·036	10·25	
	·041	13·55	90 t □"
	·042	16·6	105 t □"
	"	16·48	
	·043	15·21	92 t □"
	·047	17·63	89·5 t □"
	"	17	
	"	19·7	
	·049	19·42	91 t □"
	·050	20·92	94 t □"
	"	20·4	
	"	21·37	
	"	21·24	
	"	21·7	
	·052	21·53	
	"	21·85	
	"	21·35	

II	III	IV	V
6/6²/1 d	·052	21·78	
"	·054	26·75	103 t□"
6/19 d	·056	30·75	109 t□"
	·057	19·42	67 t□" doubtful
	·058	27·42	
	"	31·6	
	"	25·39	84 t□"
	·059	25·60	82·5 t□"
	·064	34·8	95 t□"
	·066	36·2	
	"	38·4	
	"	29·58	76 t□"
	·067	34·33	85·5 t□"
	·085	53·5	83 t□"
	·0945	96·32?	
	·094	67.	85 t□"
	·095	67·8	84 t□"
	"	68·5	
	·100	73·55	82·5 t□"
	"	76·62	86 t□"
	·106	96	99 t□"
6/18/12/6/1 d	·017	5·8	116 t□"
	·023	8·60	93·5 t□"
	"	9	
	"	8·8	
	"	8·95	
	"	8·42	
	·021	12·18	96 t□"

II	III	IV	V
6 / 18 12 6 1 / d	·030	14·02	90 t□"
	·031	14·02	84 t□"
	·032	16·9	95 t□"
	·033	22·35	118 t□"
	"	22·9	
	·036 } ·035 }	21·46	98 t□"
	·035 } ·036 }	22·5	
	"	19·68	
	·038	21·45	85·5 t□"
	"	23·9	
	"	21·95	
	"	20·3	81 t□"
	·0385	23·9	
	·038	21·12	
	"	23·75	
	·039	21·12	
	·042	29·25	95·3 t□"
	"	29·8	
	·045	36·25	102·5 t□"
	"	33·7	
	"	34·81	
	·045 } ·047 }	34·4	
	·046	35·5	96·5 t□"
	"	39·	
	·045	37·	
	·046	34·70	

II	III	IV	V
6 / 18, 12, 6, 1 / d	·047	40·8	106 t □"
	·048	39·42	98·5 t □"
	·048	35·2	
	"	40·25	
	·048 / 9 / 50 }	43·6	103 t □"
	·053	54	105 t □"
	·053 / 4 }	44·65	88 t □"
	·054	41·4	
	"	46·8	
	·055	54	102·5 t □"
	·055	48·4	
	"	47·6	
	·056	57	104 t □"
	·057	56·4	100 t □"
	"	54·65	
	·058	52·80	90 t □"
	·061	62·7	97 t □".
	"	57·55	
	·0615	61·8	
	·070	82·75	96·5 t □"
	"	76·35	
	"	75·5	
	·071	79·25	90·5 t □"
	·072	72·5	80·5 t □"
	·071 / 2 }	80·7	89·5 t □"
	·073	109·8	117 t □"

II	III	IV	V
6 | 18, 12, 6, 1 | d	·075	91·35	93·5 t □"
	·076	96·6	96·5 t □"
	·084	88·3	72 t □"
	·089	112·7	82 t □"
	·082	99·8	79·8 t □"
	·113		no fracture at 200 tons
6 | 12 | d	·030	5·2, 5·02	
		5·1,	
	·031	5·25, 5·1	
		4·72, 5·28	
		5·32, 5·28	
		5·16, 5·15	
		5·4, 5·05	
		5·1, 5·22	
		5·35, 5·0	
		5·3, 5·09	
		5·29, 5·28	
		5·3, 5·5	
		5·32, 5·6	
		5·32, 5·45	
		5·52, 5·71	
		5·69	
	·032	5·2	90 t □"
	·035	6·6	95·5 t □"
	·036	6·82	93·5 t □"
	"	6·80	
		6·63	
	·041	9·88	104 t □"
	"	9·93	
	"	10·05, 10·	
		10·10	

Formula	Diam. Wire	Br. Load	Remarks
6/18/12/d	·090	105·10	92 t □"
"	·099} ·098}	130·	95 t □"
6/6/d	·070	12·55	90·5 t □"
"	"	13·18	
"	·071	13·62	
"	"	14·88	
"	·072	13·	89 t □"
"	"	15·15	
"	"	15·30	
	·083	18·5	95·5 t □"
6/1/d	·041	5·68	
"	·116	7·48	
18/12/6/1/d	·055	9·32	106 t □"
	·058	(6) 9·51	97·5 t □"
	"	(6) 9·83	101 t □"
	·061	(6) 11·04	102·5 t □"
	·070	14·57	102·5 t □"
	·089	(6) 22·46	97·5 t □"
	·113	(6) 38·64	104 t □"

Formula	Diam. Wire	B. Load	Remarks
6/15/9/d	·021	5·47 lb 5·55	109 t □" 111 t □"
	·022	5·35, 5·52	
		5·38, 5·6	
		5·55, 5·60	
		5·12, 5·20	
		5·33, 5·38	
		5·28, 5·05	
		4·98, 4·55	
		4·86, 4·82	
		5·0, 4·95	
		5·10 5·02	
		4·98, 5·20	
		4·76, 5·0	
		5·02,	
"	·025	6·52	
	·028	9·25	105 t □"
	·031	11·1	103 t □"
	·035	13·88	100 t □"
	·036	11·85	81·5 t □"
	·042	18·25	91·5 t □"
	·043	21·40	102·5 t □"
	·096} ·097}	89·82	86·4 t □"
6/15/9/3/d	·027	9·03	98 t □"
	·036	15·66	95 t □"
	"	16·42	
	"	15·22	
	·063	47·3	94 t □"
6/9/3/d	·026	3·21	84 t □"
	·031	5·00	92 t □"

Formula	Diam. Wire	B. Load	Remarks
6/10/6/1 d_1 d_2 d_3	·136 ·103 ·104	125	
"	·135 ·103 ·103	118·8	
"	·135 ·104 ·104	122·9	
6/24/18/12/6/1 d	·0545	86·15	101 t □"
	·056	94·75	105 t □"
6/9/9/1 d_1 d_2 d_3	·079 ·043 ·087	31·66	
6/7/1 ·082	·082	25·15	
6/17/11/5 ·041 1 ·030	·041	23·12	
6/7 ·072 6/1 ·032	·072 ·032	20·62	
"	·064 ·028	16·35	
6/11 ·058	·058	14·65 14·34	
/8 ·104 7 ·060	·104 ·060	59·8	

Formula	Diam Wire	B Load	Remarks
6/8/d_1 6/d_2 1/d_3	·102 ·05·6	5·0	100 t □"
	·104 ·05·9 ·062	61	
	·10·2 ·05·7 ·05·9	51·05	
	·104 ·05·9 ·062	60·6	
	·104 ·060 ·060	59·8	
6/9/d_1 6/d_2 1/d_3	·116 ·076 ·081	80·2	
6/10/d_1 6/d_2 1/d_3	·135 ·104 ·103	124,05 122·30 125·90 125·00	
	·135 ·104 ·103	122·3	
	·133 ·101 ·101	127·4	
	134·5 104 104	118·8, 122·9 124·95, 124·9 123·5, 127·25 128·4, 124·05 122·3, 125·9 125, 124·9	
	134 [illegible] [illegible]	124·9, 123·5 127·3 128·4	

Formula	Diam. Wire	B. Load	Remarks
6/9/·116 6/·076 1/·081	·116 ·076 ·081	80 t.	
7/15/d 9 3	·063 4 5	47·3	
"	·076	79·2	61·6 t □"
"	·079 ·081	125·05	96·2 t □"
7/19/·115	·115	132·8	96·5 t □"
7/7/·169	·169	96·5	88
5/12/·032 6 1	·032 1 1	7·30	Martine covered wire rope.
11/6/082	·082	18·7	
5/15/·022 1/9 15 8	·022	5·35	
6/15/·022 7	·0225	5·48	
6/12/d_1 12/d_2 1/△	·054 ·033 △	20·22	
6/24/·05	·05	27·05	
6/61/·054	·054	86·15	
6/15/— 1/9 3	·062 ·061		

	Formula	Diam WIRE.	B. Load.	Remarks. M.
1	6/7/d.	·044	6·4.	B.P.Cr
.5'		·052	8·9	
1		·072	14·95	c = 2"
3		"	14·4; 13·14	g; cl.
4		"	15·2	Tn Tn. B.P.Cr. gr.
5'		"	16·2	
9		"	15·3	S.I.G.W.R.
7		·074	13·5	Worn out rope. c = 2 5/8"
49.		·082	18·4	c = 2 3/8. 1g. B.P.Cr
51		"	18·75	g BPCr.
82		"	19·9	Tn Tn. B.P.C.
89		"	20	LL. BPC
		"	19	gr.
98		"	19	2 3/8 = c. B.P.C. gr.
34		·082	22·2	Tn Tn B.m.plo.
13		"	22·2	plo.
18		"	24·6	B.plo. g
13A		"	17·9	Worn out rope: Δ core.
13B		"	21·6	" " " Δ much fract[d].
46		"	19·3	B. M. plo. Tn Tn
10		"	19·3	Tn Tn g.
63		"	20; 19.	90·3 & 86 t □"
02		·086	21; 20·6	86·5 t □" & 84·5 t □"
17		·096	26·1	cl. B.Q.S.W.R c = 2 3/4
5'		"	24·1	gr. G.W.R. 79·5 t □"
12		"	25·2	BPCr SWR. (H,W core) 83·5.
32		·109	35.	cl Sp Imp. P.C. 89·5 t □"

No.	Formula	Diam. Wire	B. Load.	Remarks M.
69	6/19/d	·020	4·2	117·3 t□" Ex. Flex.
16		"	7·4 ?	1½ c. Sp. Imp. Pat. Ex Flex.
47		·023	3·75	g 79·3 t□" 1"c. M. plo
09		·024	4·5	g 87·5 t□" S. Imp Pat. Ex Fl.
70		·025	5·2	g 93·2 t□" Sp Ex fl.
40		·026	6·3	2d. c = 1¼" F.G.S W R 104 t□"
79		"	5·4	3 " 89·3 t□"
01		"	5·4	G. F. S. W. R.
41.		·030	7·3	FSWR. 90·8 t□"
54		"	6·65	[Sp 8] 82·6 t□"
84		·032	8·7	FSWR.
71		·034	[9·6]	FSWR
53		·036	9·9	g " 85·2 t□"
40 B		"	10·8; 10·9; 10; 11.	all g. 92·3 t□" FGSWR.
36 B		"	10·1	87·2 t□" "
04		·037	10; 9·7; 10·4	GSWR. gr. 84·2 t□"
01		"	9·1; 9·9; 10·4; 10·0; 10·4; 10·2; 10·4	9 tons specd. all gr. 82·1 t□" GFSWR.
60		"	10·3; 9·96	gr. FGSWR 94·5 t□"
55 A		"	10·25, 10·3, 10·3	g FGSWR. 84·4 t□"
79		·038	9·7; 10·2, 10	g 88 t□" c = 2"
L1		·042	14·3	g. 90·5 t□"
6		"	14·6	g 92·5 t□"
55		"	14·1	g 89·5 t□"
			14·3	BQSWR.
54		"	14·2	g ~~F.G.~~ S W R 2" 90 t□"

No.		Formula.	Diam. Wire	B. Load	Remarks. M.
50		6/19/d	·042	15.	g 7.G. SWR. 95.5 t□"
40			"	14·3; 14·7	" 92 t□"
36			"	14·5; 14·3 15.1	g.c.g. G F SWR. 92.5 t□"
73			"	13·5	g 85.5. B pat Cr.
79			·049	19.1	B P Cr. SWR. 89.2 t□"
24.			·050	18·2	g SWR. 2 3/8" 81.5 t□"
97			·050	19·8	88.8 t□" G SWR.
95			"	17·3	(16 sp) 77·2 t□". BQSWR.
75.			·052	19·85	G.F. c = 2 1/2
02			"	20·2; 19·8 21; 20·2	} 83 t□" FSWR. 2 3/8" = c
			"	19·9; 19 20·1; 19·4 }	g
				19·8; 19·4 19·7. }	g.
31			"	20	g. BQSWR 83 t□"
81.			"	19·55; 19·3	80·5 t□"
80			"	19·45; 19·8	81·3 t□"
68			"	20·3	84·1 t□" free.
96			·064	34·4	c = 3". F. Plo. 93·6 t□"
02			·066	35·3	1 g. 90·8 t□" FSWR.
04			·095	68·2	1 g c = 4 1/2 Sp Ex F. m. plo galv. 84·8 t□"

No.	Formula	Diam. Wire	B. Load	Remarks. M.
19	6/18/12/6/1/d	·018	8·6	g
12		"	6·3	111 t□"
14		"	5·6	99·3 t□" GFSWR
56		·022	8·25	97·8 t□" "
76		"	8·3	98·7 "
19		"	8·2	g 97·7 g plo
2		"	7·3	GPSWR
03		"	7·3	
12A		·024	10·1	101 t□"
14			9·9	[8] 99 t□"
06		"	6·3?	
17		"	9·8	98 t□"
35			9·2	92 t□"
3.		·030	15·3	97·5 t□" Ex F.G.M plo
1		"	13·8	g
85		·035	23·5	111 t□"
9a		"	18	84·6 t□"
10		"	17·1	80·3 t□"
		·036	18·56	g BQFS (Wire core)
		"	23·6	g plo
58		"	21·8	96·5 t□"
11 6		"	20; 19·3	
13.		"	19·3.	89 t□"
48		·038	25·7	c=2½"
89		"	24·7	1g 98·5 t□"
48		"	23·9	g 95·2 t□" BQF1 Pl
93		·039	23·2	g 87·3 t□"
14		·040	23·5	84·5 t□"
20		·042	30·57	99·7 t□"
16		"	23·7	77·3 t□"

No.	Formula.	Diam. Wire	B. Load	Remarks. M.
20	6 / 18, 12, 6, 1 / d	·042	30·57	Fl. G.S.W.R. 99·7 t □"
16		"	23·7	77·3 t □"
34		·044	33·6	Ex Fl. SWR. 100 t □" (thimbles)
69		·047	31·8	E. Fl.
88		·048	35·1	g EFSWR 87·6 t □"
14		"	33·5	g Pl. S.W.R. c = 3 5/8 83·5 t □"
37		"	31·3	BQFSWR 78 t □"
109		·048	30	E.F.SWR. 75 t □"
78		·049	32·24	B.Q.F. SWR 77·3 t □"
44		"	33	E.F. 79 t □"
75		·050	43·9	BQ 101 t □"
62		"	40	g 92·1 t
87		"	36·8	FP. 84·7 t □" c = 3 1/4"
208		"	35·1	BQP. 80·5 t □"
19		"	33·5	S.I. Pat. E.Fl 77 t □"
270 B		"		Repeated order.
		·052	39·7; 36·8	84 & 78·3 t □" c = 3 1/2"
27		·054	45·1	BQSWR.
319		·060	58·26	" broke dies; Cl. rope not broken.
87		"	65	103·7 t □"
13		"	53·6	1g. 85·5 t □" c = 4"
310		"	48·95	g (56) 78·6 t □"
78		·064	69·5	97·1 t □" B.F.I.P.
200		·074	86·5	low Pl. SWR. [re-tested]
295		·076	81·3	g 85·3 t □"

Formula	Diam. Wire	B. Load	Remarks M.
6/12/d	·016	1·3	
	·018	2·0	
	·020	2·7	
	"	2·72	c = 1"
	"	2·7	
	·026	3·9; 3·9; 3·9	c = $1\frac{1}{4}$" G S W.R.
	·032	5·1	c = $1\frac{1}{2}$
	"	5·3 }	g FGSWR
	"	4·95 }	c
	"	5·6	g 7 Bk M Pl. SWR
	·036	7·7	
	·042	9·3; 9·1	GSW.R.
	"	9·47	c = 2" GFSWR.
	"	9·3	" "
	·052	12·9	
	"	14·4	c = $2\frac{1}{2}$
	"	12·4	" GFSWR.
	"	13·1	" "
	"	13·3	" "
	"	13; 13·4	f " "
	·060	19·8	c = 3"
	"	"	" 99t□"
	·064	21·6	FSWR.
	"	18·9	
	·074	27·6	c = $3\frac{1}{2}$" F.G. S.W.R.
	"	26·4	" "
	·086	37·7	c = 4" "
	·094	48·3	c = $4\frac{1}{2}$" "
	·098	43·7	c = 4·5"

Nº	Formula	Diam Wire	B. Load.	Remarks. M.
216	1/7/d	·128	6·5; 6·7; 6·4 6·25; 6·5	15·0 t□" Trial.. G. S.W.
286		"	7; 6·7; 6·7; 6·75; 6·65; 6·7	15·6 t□" Trial "
242		"	6·4; 6·5; 6·5; 6·4; 6·6;	15·0 t□" Trial. "
268		"	5·5; 6·7 6·4; 6·8 6·4; 6·5 6·6.	149·5 t□" " "
293		"	6·5.	150·2 t□" " "
	1/19/d.	·035	2·4	
238 B		·032	2·03	133 t□"
254 B.		·028	1·59; 1·83; 1·84	150 t□"
254 A.		"	1·54	132 t□"
231 B		·026	1·88	
		·025	1·098	
		·0195	·75	
231		·018	·685	141 t□". G S W R: broke in socket.
		·017	·536	124 t□"
		·015	·513	153 t□"
	1/37/d			
293		·019	1·283	122·5 t□"
		"	1·4	133·6 t□"
		·023	2·1	FSWR. 136·6 t□"
		·026	2·365	120 t□"
236 C		·028	2·9	127·5 t□"

No	Formula.	Diam. Wire	B. Load.	Remarks. M.
74.	$6 / \substack{9 \\ 3} / d$	·026	3·2	B. P. Cr
"		·032	4·7	B. P. Cr
00		"	5·2	Sp I. P. G.W.R.
212	$6 \Big/ \substack{16 \\ 10 \\ 4} \Big/ d$	·018	4·5	$c = 1\frac{1}{16}''$
212	$6 / \substack{15 \\ 9} / d$	·018	4·2	g $c = 1''$
221		·032		$c = 1\frac{3}{4}$ Ex. F.
218		·036		Ex F. Plo $c = 2\frac{3}{8}$
285		·086	66·2	$c = 5''$ Ex Sp Plo. in thimbles
		·093	68·2 70·1 84·3	g $c = 5''$.
	$6 / \substack{24 \\ 12} / d$	·022	8·7	g
94	$6 / \substack{18 \\ 12} / d$	·030	13·3	Th Th $c = 2''$ 104·5 t□"
80		·046	27	Th Th. 90·5 t□"
65		"	25·4	G F S W R
		·050	33·1	93·3 t□" E. F. M. Plo $c = 3·25''$
10	3/3/3/·1	·1	13·7	$c = 2\frac{1}{2}''$
08	Locked Coil		27·7	7 rail 70 upon 7 round ·136" ·176"

No.	Formula	Diam. Wire	B. Load.	Remarks.	M.
90	6/6/d	·072	12·5	BQSWR.	c = 2"
		"	12·9	d = 5/8 "	"
12		"	"	BPCr SWR.	"
5·2		"	11·8	g	"
5·9			11·5		"
57.	12/6 / 19/d	·044.	39·5	G.P.C. Kilindo c = 3½" 76 t □ "	
05	9/6 / 7/ ·06/·04	·06 ·04	20·5	Imp. Pat. Kilindo c = 2¼"	
	18/7/·028	·028	9·5		
28	7/14/d	·0084	·5·6		
			·5·6; ·5·8		
			·5·8; ·5·7		
	7/7/d	·0084	·4065		
35		·0092	5·5 cwts	In thimbles: broke at splice	
7/16		·0165	1·34		
11		·018	1·71; 1·74	GFSWR.	
			1·72; 1·54		
			1·49; 1·65		
06		"	1·79; 1·67		
01			1·71		
		"	1·57		
293		"	1·49; 1·51		

Rope Tests (3)

If we merely plot such results so as to get curved line graphs, e.g. F (breaking load, diameter of wire) = o, then remembering that we should get families of curves owing to the presence of various distinct grades of steel, we see that the diagrams would be so confused that they would give little information. Thus it is necessary to introduce if possible the linear law, so as to check errors and 'equalise up' graphically. This may be done fairly well within the roping range, by plotting the orthogonal area of the steel as abscissa, and the breaking load (B.L.) as ordinate.

Incidentally it will be noticed how the normal construction dominates the situation, and how completely it has swamped the fancy forms of construction.

As it is difficult to draw conclusions from tables of statistics, I plotted graphs for all the more important constructions. In these each test is represented by a small circle. From these diagrams, copies of which are exhibited as blue prints, the strength of practically any rope may be read. It will be noticed that by taking the orthogonal area of the steel as abscissa, the linear law is followed closely. Taking into account the different qualities of steel represented, the points plotted lie fairly well on radial lines. Actually they should lie on curves to which the straight lines should be close approximations.

See Groups of Diagrams of Rope Tests (Thirteen Sheets)

From /

Rope Tests (4)

From the diagrams an equation expressing the breaking load as a (linear) function of the orthogonal section of the wire may be written down by inspection if required. The straight line drawn is usually for good crucible steel; inferior and superior (plough) qualities would be indicated by radial lines of slightly lesser and greater slopes respectively.

It is better perhaps to rely on the diagrams instead of formulae, as the former show in addition the effects due to the different qualities of steel, and also the extent to which uncertainty comes in. A formula may be applied without discrimination. To give the fundamental formula for the strength would necessitate so many variables - as has been indicated already - that its complication would be considerable.

With the large number of constructions in use, one would naturally expect great differences in strength according to the method employed. This however is not the case. The type of construction is by no means immaterial, but it may be altered a good deal without affecting appreciably the strength, as shown by the test.

Between strands, ropes, and cables of the same orthogonal area there are naturally considerable differences in strength, the efficiency of the strand being greater than that of the rope, and the efficiency of the rope greater than that of the cable. The considerations on which this is based have been already given.

Rope Tests (5)

Diagrams have been drawn showing the comparative load-extension curves of some typical ropes in 50" lengths, and also the comparative curves for sets of strands. It will be seen that all these curves are of a similar type. Even in the case of ropes with metal cores there is a considerable variation in the extension. This depends on the construction, hearting, and material employed, a ductile steel giving, of course, a greater extension.

Selections are given from the results of plotting some three dozen graphs for normal wire cored ropes (See Load-Extension Diagrams. 4 sheets.). From these it will be seen that the average extension in a destruction test was about 1.5" in a rope length of 50" or .03 per unit length. In the case of fibre cores, the extension was greater, viz. about 2.5", or roughly .05 per unit length. A few of these curves are shown.
(See Stress-Strain Diagrams [illegible] sheet)

The curves were not recorded automatically, but were plotted from a few corresponding observations of load and extension. As far as one can judge, however, there is no distinct yield point, as in the stress-strain diagram of a steel bar. In the latter the diagram is the straight line $y = Ex$ up to the elastic limit, then there is a distinct discontinuity at the yield point, and after that a curve is obtained convex upward and terminating at the breaking point. If the correction for

reduction /

reduction of area be allowed for it resembles an arc of the upper branch of the parabola $y^2 = Ax + B$

In the case of a rope there is no distinct discontinuity, and the graph might be represented approximately by a single equation instead of two. This might be taken as $y = Ax - Bx^3$ from the origin to the breaking point. These curves may be fitted to any actual set of observations by writing down normal equations for A and B.

The load-extension curves are modified easily to stress-strain diagrams, by plotting the stress per □" orthogonal area of steel as ordinate, and the strain per 1" length of rope as abscissa. A set of these is drawn from some of the load-extension curves given already, the accented and unaccented letters showing the corresponding curves.
(See Stress-Strain Diagrams; 1 sheet)

A good deal has been written about the elastic modulus of ropes, and it is looked on as if it corresponded with the Young's (elastic) modulus of material. Hrabak in fact has deduced the elastic modulus of the strand, rope, and cable by resolving it in a manner which seems to me quite unjustifiable.

Young's modulus in the stress-strain diagram of a bar only holds for that linear segment between the origin and the elastic limit, i.e. throughout the range of recuperability of the

material./

material. It deals with material independently of the shape into which it has been manufactured. It would be incorrect to use the same term to denote an extension co-efficient, or function, for a manufactured article, when the value depended on the form into which the article was made. In addition to this the stress-strain curve of a rope is not a definite straight line to a discontinuity at an elastic limit, and recuperation does not occur. Thus the term 'elastic modulus, E' of a rope is apt to cause confusion, particularly when the theory of bending is introduced, and 'extension coefficient' might be substituted instead.

In the following pages the wire tables are given together with the corresponding tests of the ropes. The latter are given under the two groups M and S which indicate different machines and testers. From these wire tables which give the strengths of the wires before winding the efficiencies of the ropes have been calculated and plotted. The strengths are in lbs and the two last columns give the total number of twists in a length of 8" before breaking.

6/37/035

16240
·034 g 95/100

19,000.60
19,000.66
19,500.00
19,000.61
19,200.00
19,500.66
19,000.00
19,500.00
19,500.70
19,800.00
19,000.00
20,000.68
20,500.00
21,000.00
20,500.74
20,000.00
19,500.00
19,000.79
20,000.00

372,505.44

$\frac{3725·0}{19} = 196·05$

5·44 - [illegible]

16485 ·05·0
125/130 [illegible].

55,000.57
55,000.55
55,000.54
57,400.52
56,000.54

278,402.72

$\bar{w} = 556·8$

6/37/035

16240

·034 g 95/100

19,000.60
19,000.66
19,500.00
19,000.61
19,200.00
19,500.66
19,000.00
19,500.00
19,500.70
19,800.00
19,000.00
20,000.68
20,500.00
21,000.00
20,500.74
20,000.00
19,500.00
19,000.79
20,000.00

372,505.44

$\frac{37250}{19} = 196.05$

5.44 [illegible] lbs

16485 ·050

125/130 l.

55,000.57
55,000.55
55,000.54
57,400.52
56,000.54

278,402.72

$\bar{w} = 556.8$

16535 ·060

63,500.31
65,000.59
63,000.40
66,000.58
64,000.00
67,000.00
68,000.00
66,500.41
64,500.00
67,000.00
65,000.00

719,501.89

60,500.38
60,500.00
61,500.00
60,000.00
61,000.00
61,500.42

365,000.80

16[illegible]

1[illegible]
1[illegible]
1[illegible]
1[illegible]
1[illegible]
1[illegible]
1[illegible]
1[illegible]
1[illegible]
1[illegible]
1[illegible]
118,500.00
129,000.27

1,581,501.84

16892 [illegible]·086

121,000.25
125,500.25
121,000.25
124,000.26
122,000.30
117,000.32
125,000.30
120,000.27
122,000.28
120,500.31
119,000.30
124,000.29
123,000.26
122,000.34
120,000.28
119,500.31
121,000.30
126,000.25
124,000.00
119,500.00
122,000.28
118,000.00
129,000.00
124,000.00
118,500.30
121,000.25
120,000.26
120,000.00
120,000.00
124,000.32
126,500.00
119,500.00
126,000.27
124,000.00
130,000.28
120,000.00
119,500.00

4,518,007.08

$\frac{609950}{50} = 1219.9$ lbs

i ii
2

16863. ·072
85/90t.

88,000.42
87,000.44
86,000.41
85,000.40
87,000.44
86,000.45
85,000.42
86,000.47
84,000.41
86,000.45
85,000.46
82,000.42
86,500.45
87,000.43
88,000.40
86,000.43
87,000.44
85,000.45
86,000.41
85,000.42
84,000.43
86,000.45
79,000.45
80,000.44
81,000.42

2,127,510.81

16863 ·072 iii iv 30

81,000.44
80,000.42
78,000.45
78,000.41
76,000.46
78,000.43
76,000.42
77,000.44
79,000.42
78,000.46
75,000.45
79,000.44
80,000.42
78,000.45
79,000.42
78,000.41
79,000.45
76,000.44
76,500.41
79,000.43
80,000.44
81,000.41
80,000.45

1,801,509.97

2,122,411.86

i ii 30 iii

000.74
500.82
000.00
300.81
000.00
500.00
900.74
500.00
000.00
000.80
500.00
000.00
000.00
000.77
500.00
000.82
000.00
500.00
000.94
000.89
500.00
000.98
200.00
500.90
000.00

40921

4?040
41930
42350
129920
71 = 182.986

16725 · ·046

171

34,000.39
33,500.52
35,000.61
34,000.50
35,000.61
34,500.65
34,500.66
34,000.59
34,000.61
34,500.54
35,000.49
34,500.62
33,500.50
33,000.61
33,500.60
33,500.57
33,000.50
34,000.62
35,000.49
33,000.49
33,000.55
33,500.62
34,000.53
35,000.61
34,500.00
36,000.00
34000.59

6892

12 | ·086 H $n = 72$ $\bar{w} =$ 7 lbs $\Sigma w = 41\,t.$

$BL = 37{\cdot}7$ $Ef = \frac{37{\cdot}7}{41}$ % dep = 8 %

11 271

6 | $\frac{6}{1}$ | ·072 b.p.c. 2" = c $\bar{w} = 804{:}3.4$ $\Sigma w = 15{\cdot}1\,t$

$BL = 14{\cdot}95$ $Ef = 98{\cdot}7\%$ dep = 1·3 %

16725 294

6 | 18 12 j. | ·030 2" = c $BL = 13{\cdot}3\,t.$ $\bar{w} = 182{\cdot}986$

$\Sigma w = 14{\cdot}7\,t$ $Ef = \frac{13{\cdot}3}{14{\cdot}7} = 90{\cdot}5\%$ dep = 9·5 %

16725 280

6 | 18 12 j. | ·046 J.J. T.T. = 27 $\bar{w} = 349{\cdot}52$

$\Sigma w = 28\,t$ $Ef = \frac{27}{28} = 96{\cdot}5$ dep = 3·5 %

270. 16240.

6/37/.035 $BL = 17.1\,t$ $n = 222$ $\bar{w} = 196.05$

$\Sigma w = 19.4\,t$ $Ef = \frac{17.1}{19.4} = 88.3\%$ dep = 11.7%

62. 16485.

/37/.050 $3\frac{1}{4}'' = c$ $BL = 44\,t$. $\bar{w} = 556.8$ lbs

$\Sigma w = 55.3\,t$. $Ef = \frac{44}{55.3} = 79.6\%$ dep = 20.4%

270. 16240.

6/37/.050 (38.7 t) $\bar{w} = 451.67$ lbs $\Sigma w = 44.7\,t$

$Ef = \frac{38.7}{44.7} = 87\%$ dep = 13%

278. 16751

6/37/.064 $BL = 69.5\,t$. Best Flex imp? plo. c = 4"

$\bar{w} = 861$ lbs $\Sigma w = 85.5\,t$.

$Ef = \frac{69.5}{85.5} = 81.5\%$ dep = 18.5%

273 16535

6/37/.060 m. plo. 4" $BL = 53.6\,t$ $\bar{w} = 640$ lbs

$\Sigma w = 63.5\,t$. $Ef = \frac{53.6}{63.5} = 84.5\%$ dep = 15.5%

5217 Kirk.

42 HMC

·105

K1010

$\frac{12}{6}\big|\frac{6}{6}\big|$ ·105

.076

lbs.	Twists
88,500	.44
88,000	.44
89,500	.44
90,000	.40
91,000	.42
89,000	.42
91,500	.40
89,500	.40
90,000	.43
89,000	.43
90,500	.40
90,000	.42
88,500	.42
90,000	.42
88,000	.40
89,500	.37
90,000	.38
89,000	.39
89,000	.38
89,000	.37
91,000	.39

1,880,508.56

146,000
147,000
149,000
148,000
159,000
152,000
153,000
141,000
140,000
138,000
140,000
139,000
141,000.
136,000.
140,000.
139,000.
141,000.
150,000.
150,000.
150,000.
148,000.
147,000.
140,000.
141,000.

14,139,035.

·9 $\frac{3517}{100}$ = 35·17

237,000.27
241,000.29
241,000.26
239,000.25
241,000.29
236,000.24
237,000.30
236,000.31
235,000.26
233,000.27
237,000.30
233,000.28
233,000.23
234000.31
232,500.29
237,000.29
238,000.25
241,000.32
236,000.25
236,000.29
237,000.30
233,000.30
236,000.30
238,000.30
238,000.29
233,000.29
233,500.28
234000.24
233,000.30
236,000.25

~~7322,003.67~~

7085 00 840

$\frac{840}{30}$ = 28 tw

$\frac{70850}{30}$ = 2361.66 lbs

176 2

L11.5-9

.049

505,000.40
495,000.41
525,000.47
520,000.49
520,000.47
515,000.33
490,000.46
500,000.50
510,000.56
495,000.44
495,000.54
490,000.53

~~6,041.1~~ 5 6.80

6050

= 504.17 lbs.

.022 g 115-120. L1160

950,000.00
970,000.00
960,000.00
960,000.00
970,000.00
990,000.00
920,000.00
970,000.00
960,000.00
990,000.00
950,000.00

~~1,1~~30,000.00

1058

= 961.8 lbs.

270,000.30
274,000.31
261,000.31
270,000.29
258,000.29
271,000.29
271,000.30
279,000.27
269,000.25
282,000.22
283,000.23
264,000.28
274,000.27
293,000.22
261,000.29
265,000.29
280,000.25
279,000.25
272,000.31
273,000.27
266,000.30
260,000.29
263,000.26
271,000.29
270,000.24
273,000.30
261,000.28
263,000.32
271,000.28
263,000.28
260,000.30
275,000.30
269,000.29
261,000.29
273,000.25
263,000.30
262,000.28
260,000.27
260,000.28
258,000.31
259,000.29

1105

11,010,0/11.49

26.13

263,000.24
259,000.28
257,000.31
257,000.30
260,000.28
268,000.23
263,000.28
261,000.26
256,000.28
257,000.30
260,000.27
256,000.30
260,000.32
271,000.27
256,000.26
262,000.24
270,000.29
273,000.28
278,000.27
261,000.29
255,000.23
1,000.00
256,000.26
258,000.28
262,000.24
256,000.24
263,000.32
263,000.27
271,000.29
265,000.27
262,0 0.28
261,000.27
264,000.31
269,000.23
260,000.31
272,000.31
263,000.30
274,000.24
273,000.32
276,000.24
275,000.30

0547,0/11.06

26.13

268,000.28
275,000.27
273,000.30
264,000.30
275,000.21
268,000.30
271,000.23
272,000.28
282,000.30
270,000.30
274,000.20
282,000.22
258,000.21
260,000.30
265,000.24
274,000.21
282,000.22
274,000.22
271,000.22
263,000.22
269,000.21
259,000.22
270,000.23
269,000.22
262,000.22
280,000.22
277,000.22
282,000.21
278,000.22
259,000.27
278,000.30
265,000.33
273,000.34
266,0 0.27
269,000.32
269,000.22
268,000.28
258,000.27
260,000.20
256,000.27
262,000.22
259,000.30
260,000.30
263,000.30

830/11.19

1149
1106
1119

1152 ·112.
to
·090
·090".

52.
0/110.

5000.29	176,000.36	217 000 30	223,000.29
5000.34	178,000.38	220,000.32	218,000.27
2000.37	181,000.33	220,000.30	219,000.29
3000.28	173,000.35	218,000.31	217,000.29
8000.37	179,000.36	219,000.32	220,000.28
4000.40	193,000.36	218,000.30	217,000.30
2000.30	192,000.37	215,000.31	221,000.29
6000.37	190,000.35	210,000.30	214,000.30
3000.37	176,000.36	229,000.27	218,000.29
8000.38	175,000.35	276,000.28	215,000.31
7000.39	178,000.36	219,000.29	215,000.30
8000.33	170,000.34	216,000.29	217,000.30
6000.37	171,000.36	219,000.28	218,000.29
7000.35	173,000.37	221,000.27	213,000.28
5000.38	173,000.37	213,000.27	217,000.29
1000.37	167,000.38	219,000.28	217,000.31
3000.35	170,000.33	2 210,000.30	218,000.30
4000.39	172,000.35	224000.29	214000.27
1000.35	178,000.40	218,000.28	227,000.30
5000.38	178,000.37	221,000.29	220,000.29
0000.38	174000.36	215,000.29	214000.29
0000.37	177,000.30	216,000.29	215,000.30
0000.37	172,000.37	221,000.27	217,000.30
0000.38	171,000.38	213,000.28	216,000.29
0000.36	171,000.38	220,000.29	218,000.30
0000.33	172,000.40	213,000.29	217,000.28
0000.32	166,000.34	221,000.27	219,000.30
0000.35	17435000	215,000.27	214000.29
0000.29	168,000.36	223,000.29	215,000.30
0000.33	174,000.41	219,000.27	217,000.29
0000.36	175,000.39	217,000.28	220,000.33
0000.34	174,000.38	221,000.28	214000.30
0000.37	172,000.38	218,000.28	218,000.31
0000.30	171,000.36	219,0 0.29	217,000.29
0000.31	168,000.33	218,000.27	
0000.36	180,000.37	213,000.29	
0000.35	166,000.36	219,000.28	
0000.35	172,000.36	216,000.28	
0000.37	175,000.35	212,500.29	
	179,000.38	223,000.31	
	173,000.38	221,000.28	
	174000.38		

01372

7.321,5/4 492

89 555,5/1149

7.399,01001

61970
73214
142384 / 81 = 1757·8 lb

2864 / 81 = 35·36 tw.

55
90
45 = 2179·37

1001
2180 / 75 = 29·07

178

" imp plo. steel galv

lbs. tw. 8"

209,000.24
205,500.25
205,500.25
205,000.27
205,000.25
213,000.26
209,000.24
210,000.24
213,000.24
210,000.26
219,000.24
206,000.24
210,000.27

22 ·034 Bl 95/100

184/15 = 199.

20,000.84
19,500.80
20,500.86
19,500.78

·05-4

55,000.55
57,500.55
57,000.46
58,500.48
57,000.50

285,000.252

lbs.

8-21. ·036"

26,000.86
26,000.87
26,000.69
25,500.71
25,500.73
26,500.77
26,000.70
26,400.70
26,000.72
25,000.74
24,500.72
26,500.72
24,800.68
27,000.68
25,000.82
26,000.86
27,000.68

Q 1338 ·031 Bl.

15,500.68
18,500.44
16,000.81
15,600.88
19,500.84
16,500.69
17,300.91
17,000.58
17,000.74
17,200.78
17,300.69
16,500.60
17,300.76
17,600.70
16,500.76
15,500.64

Q1866 ·032 g 95/100

185,000.44
195,000.84
173,000.91
170,000.58
170,000.74
172,000.78
173,000.69
173,000.76
176,000.70
173,000.86
170,000.63
175,000.88
179,000.95
175,000.68

Bl 105/110

1-21

73,600.40 (6 over 7, 3 over 6)
73,500.46
76,000.49
72,500.46
78,000.44
74,500.49
73,000.44
73,500.50
73,000.46
77,000.48

744,60462 (7 over 4, 3 over 4)

418-421 ·030"

132,000.90
170,001.02
169,000.94
170,000.96
168,000.92
172,000.92
169,000.92
168,000.94
170,001.10
170,001.02

1,708,009.64

Q1865.

·026 g 95/100

132,000.85
113,000.88
112,000.84
113,000.89
133,000.83
132,000.85
115,000.87
123,000.89
124,000.92
132,000.86
140,000.83
130,000.87
137,000.85
130,000.81

1,774,01204

47-3 $\overline{tw}$ = 46.2

= 170.8 $\overline{tw}$ = 96.4

= 126.714

$\frac{1204}{14}$ = 86.

.44. ·045 Bl. 105/110

405,000.62
410,000.62
405,000.62
410,000.70
395,000.64
403,000.72
395,000.58
405,000.60
400,000.66
404,000.58
410,000.62
400,000.68
415,000.64
420,000.58
415,000.60
415,000.58
410,000.62

6,917,010.66

:406.88 $\frac{1066}{17} = 62.706$ tw.

620,000.48
595,000.48
600,000.46
620,000.47
620,000.48

5,495,004.23

= 610.5'5' $\frac{423}{9} = 47$

U1679 ·112

on 8"

214,000.29
213,000.25
216,000.25
219,000.27
216,000.27
217,000.28
217,000.28
213,000.29
213,000.30
219,000.28

2,157,002.76

215.7. $\overline{tw} = 27.6$

U.2138.
·1 galv.

153,000.21
162,500.25
165,000.22
160,000.23
160,000.23
165,000.25
157,500.23
157,000.23
158,000.22
160,000.25
159,500.24
164,000.22
158,500.23
161,000.21
160,000.22
159,500.20
157,500.23
157,000.24
159,000.25
162,500.23
162,000.22
160,000.21
164,500.24
160,000.23
158,500.22
157,000.23
159,500.22
163,000.25
160,000.27
158,500.24
160,000.22

4,959,507.14

15'99.84 $\frac{714}{31} = 23.03$.

V218 ·036 g 105/110 179

239,000.85
250,000.40
240,000.41
240,000.38
250,000.38
250,000.40
245,000.40
250,000.38
260,000.38
255,000.40
240,000.38
240,000.36
240,000.37
240,000.36
250,000.32
250,000.40
250,000.30
240,000.36
260,000.35
270,000.40
241,000.35
252,000.35
245,000.37
260,000.37
249,000.40
245,000.39
247,000.36
243,000.37
262,000.40
241,000.40
234,000.42
270,000.40
239,000.42
234,000.39
234,000.40
266,000.40
250,000.37
245,000.36
250,000.43
265,000.40

9,931,015.73

$\frac{99310}{40} = 248.275$ $\frac{15.73}{40} = 39.33$

M'. ·105 g 105/110.

210,000.25
207,000.24
204000.20
210,000.25
214000.25
209,000.19
207,000.23
210,000.20
208,000.25
210,000.26
208,000.21
207,000.24
204000.25
206,000.23
204000.25
204000.25
1
209,000.26
205,000.25
210,000.20
205,000.21
204000.25
209,000.24
207,000.24
206,000.23
207,000.21
206,000.23
205,000.17
206,000.25
210,000.24
205,000.19
204500.17

6,420,507.10

·1 lbs 22·9 tw.

X 1746

tw. on 8"

143,000.25
151,000.27
159,000.25
147,000.27
146,000.27
155,000.27
148000.26
158,000.25
158,500.27
158,000.27
159,000.25
154500.24
158000.27
150,000.25
148000.26
150,000.26
150,000.27
145,000.28
153,000.25
154000.27
147,000.25
153,000.27
160,000.26
156,000.24
152,000.24
156,500.27
159,000.25
157,000.27
154000.26
158,000.24
155,000.27
155,000.25
162,000.26
154500.27
150,000.27

5,374009.10

$\frac{53740}{35} = 1535·43.$ $\frac{910}{35} = 26·$

G648 180
·072 Bl 100/110

94000.44
98,000.42
97,500.46
94,500.40
98,000.42
96,500.44
98,000.44
98,000.46
98000.44
92,000.46
93,000.46
98,000.44
97,500.42
94,000.44
95,500.42
95000.40
95,000.42
96,500.42
96,000.41
94000.44
95,000.44
105,000.41
104000.40
106,000.37
106,000.36
102,500.40
105,000.35
103,000.38
105,000.38
100,000.39
103,500.40
102,000.38
104000.36

3,265,013.67

$\frac{3265·0}{33} = 989·4$

i

2610 89/90
.096.
5· 6.93 lbs per 6′

6/.096. 23.5°C.
2.02″

```
30,000.34
32,000.32
31,000.34
32,000.32
31,000.34
30,000.34
31,000.32
30,000.32
30,000.32
30,000.36
30,000.34
32,000.34
34000.32
33,000.34
31,000.32
31,000.32
35,000.34
33,000.32
32,000.36
31,000.36
34000.34
36000.34
32,000.35
31,000.34
31,000.34

93,008.39
```

ii

G2610
.096

```
132,000.34
133,000.32
131,000.33
132,000.34
131,000.36
130,000.35
130,000.36
130,000.35
133,000.32
132,000.34
133,000.35
132,000.34
134000.33
134000.34
135,000.36
133,000.34
130,000.34
133,000.32
130,000.34
132,000.36
131,000.34
131,000.32
133,000.36
130,000.34
132,000.32

297,008.51
```

iii

G2610
.096

```
133,000.32
133,000.32
131,000.35
130,000.33
133,000.34
130.000.36
130,000.34
131,000.34
130,000.34
132,000.31
132,000.36
130,000.34
131,000.37
132,000.36
130,000.34
134000.33
132,000.34
133,000.36
131,000.34
130,000.33
131.000.35
134000.34
132,000.36
130,000.34

3155,008.21
```

iv

G2610
.096

```
130,000.34
132,000.32
131,000.33
132,000.34
134000.33
130,000.32
130,000.33
158000.28
160,000.34
143,000.36
145,000.36
158000.32
158000.34
156,000.32
156,000.34
145,000.36
154000.32
155,000.34
131,000.38
148,000.34
140,000.34
143,000.32
145,000.36
143,000.32
145,000.32

3,602,008.37
```

```
1460   34
1440   34
2900   68
```

mean value 1350.2

```
32930    25
32970    25
31550    24
36020    25
 2900     2
136370   101
```

```
101)13637(135.02
    101
     353
     303
      507
      505
       200
```

1350.2

F157
.082 Bl 80/90
1077.95 = [illegible]

11,9000.36
11,9000.36
120,000.38
122,000.40
122,000.38
116,000.38
120,000.40
114000.42
122,000.38
120,000.39
123,000.37
119,000.38
120,000.40
120,000.41
9,000.42
8000.38
00,000.38
8000.42
00,000.40
9,000.38
01,000.40
03,000.40
9,000.42
02000.38
8000.40
04000.39
01,000.40
8000.38
9,000.40
0,000.40
9,000.42
2000.39

F2620
.082 Bl 80/90

110,000.36
119,000.34
119,000.35
120,000.35
121,000.37
117,000.38
119,000.35
121,000.35
120,000.33
115,000.32
118,000.38
118,000.37
118,000.36
121,000.36
120,000.34
121,000.36
120,000.37
120,000.36
119,000.35
121,000.36
122,000.34
122,000.35
122,000.36
119,000.33
122,000.36
121,000.34
122,000.33
122,000.34
121,000.34

3,47

H 15.2 i
.072 90/100

94000.38
98,000.38
93,500.40
94000.38
93,000.44
95,000.38
96,000.40
94,000.44
94,000.46
94000.22
93,500.44
95,000.46
94000.44
90,000.40
91,000.42
93,000.40
92,500.40
94000.38
94000.46
93,500.44
95,500.36
96,000.38
91,000.44
94,500.42
94000.36

2,335,010.08

182 iii
H 15.2
.072

91,500.32
93,000.36
84,000.42
91,000.44
96,000.42
96,000.44
92,000.42
92,500.40
91,000.40
90,000.42
89,000.41
90,000.40
94,000.41
90,500.39
89,000.38
93,000.40
92,000.40
92,000.39
91,000.38
90,000.42
92,000.40
92,000.39
91,0 0.40
940 0.37
87,000.38

2,283,509.96

H . 15.2 IV
.072

96,000.42
93,000.40

H 701 ·116 plo. 115/120 i

26,400.24
26,800.28
26,000.24
26,400.26
26,200.24
26,400.24
26,600.25
26,100.22
26,800.26
26,200.23
26,100.25
26,000.24
26,600.26
26,500.22
26,200.28
26,400.24
26,000.22
26,400.26
26,500.22
26,300.24
27,000.25
25,800.25
26,400.28
25,900.26
26,300.26

65831619

25,900.23
26,000.22
25,900.24
26,600.23
{25,000.23
1,000.00}
25,800.24
26,400.23
26,200.23
26,600.22
26,100.24
26,400.24

655,506.03

H 701 ·116 plo iii

26,400.24
26,200.24
26,300.23
26,000.26
26,000.25
26,200.26
26,700.24
26,200.22
26,400.23
27,000.24
26,200.23
26,400.22
26,200.23
25,800.27
26,200.24
25,900.24
26,200.24
26,100.23
26,400.23
26,000.23
26,2 0.21
26,400.26
25,900.22
26,100.25
26,200.25
26,000.25

6[illegible]1,606.2[illegible]

27,000.24
26,900.22
26,400.22
25,800.22
25,800.23
26,100.26
26,200.24
26,100.22

263,502.29

30	25
50	25
60	26
0	10
10	86

2626.6

H 5·02 183 i ·082 80/90 pal.

97,000.40
99,000.42
96,000.38
98,000.40
99,000.38
97,000.38
98,000.38
100,000.40
98,000.38
97,000.36
98,000.34
100,000.39
99,000.38
100,500.40
100,000.38
98,000.42
98,000.44
97,000.40
98,000.38
101,000.38
97,000.41
98,000.39
110,000.37
98,000.36
98,000.34

2,469,509.66

(077?)

…02 ii
… 89/90. pat.

…6,000.40
…5,000.42
…7,000.40
…5,000.38
…8,000.41
…8,500.37
…7,000.40
…8,000.41
…5,000.34
…9,000.34
…1,000.36
…6,000.42
…7,500.40
…4,000.34
…9,500.35
…0,000.38
…1,000.42
…3,000.40
…8,000.37
…8,000.34
…0,000.38
…7,000.40
…8,000.42
…3,000.42
…3,000.42

…3,509.69

…150
…350
…350
…000
…1650

…650 / 2 = 1002

H 502 iii
·082 88/90 pat.

98,000.00
101,000.42
97,000.42
98,000.40
99,500.40
100,000.38
98,000.36
99,000.40
100,000.38
99,500.40
98,000.41
101,000.39
99,000.42
99,500.38
101,000.40
99,500.38
100,000.38
99,000.42
98,500.40
101,0 0.40
99,500.42
101,000.38
99,000.41
98,500.40
99,000.39

2,483,509.54

112,000.38 (2 written over the last 2)
112,0 0.37
116,000.36
112,000.36
112,000.37
111,0 0.35
115,000.36

790,002.55

H 2427-8 i
·096 pat.

146,000.36
147,000.36
149,000.37
148,000.35
153,000.32
152,000.34
153,000.36
139,000.34
139,000.34
142,000.36
138,000.34
148,000.36
135,000.37
135,000.36
135,000.34
136,000.36
134,000.37
133,000.34
140,000.35
140,000.36
146,000.36
142,000.32
145,000.34
141,000.35
141,000.34

3,563,008.76

H 2427-8 184 iii
·096 pat.

142,000.34
132,000.40
136,000.36
135,000.37
136,000.35
131,000.36
134,000.38
136,000.36
138,000.36
140,000.36
143,000.38
141,000.36
142,000.34
139,000.35
138,000.38
136,000.38
138,000.35
138,000.36
141,000.34
140,000.36
138,000.35
140,000.32
141,000.36
134,000.35

3,315,008.62

H2298 i

2/...

000.46
000.42
500.44
000.42
000.44
000.46
000.44
000.46
000.44
000.42
000.48
000.46
500.46
000.44
000.48
000.46
000.44
000.46
000.44
000.48
000.44
500.46
000.42
000.44
000.46
500.48
000.44
000.44

012.58

=919.52

H2298 ii
·072 pat. 90/100

94000.46
94000.44
92,000.44
90,000.44
92,500.44
91,000.46
92,000.46
92,000.42
920,000.46
92.500.44
91,000.44
95,000.46
93,500.46
92,000.44
93,000.40
93,500.44
93,000.46
95,500.46
95,000.42
92,000.41
95,500.48
94000.45
93,5 0.46
92,000.48

2,060,510.72
−92
214
+92
22325
= 549

H501
·058 pat 90/95·

55,500.54
54000.54
54000.54
55,500.54
56,000.56
56,000.54
56,000.56
55,000.58
55,500.55
54000.54
53,500.54
56,000.56
55,000.56
55,500.54
53,000.60
56,000.54
56,000.56
55,500.58
54000.54
55,500.56
54000.56
54000.58
53,000.58

1,262,51279

M2160 185
·076 galv rem?

108,500.00
107,800.00
107,500.00
110,500.00
110,000.00
108,500.00
107,500.00
107,000.00
107,000.00
107,000.00
106,000.00
106,000.00

1,29~~3~~300.00
25

= 1077·08

S1203 i

·123

7400.27
8000.28
8100.26
8800.23
8200.25
8400.25
8700.23
8900.28
7900.26
7900.25
8000.25
8200.25
8200.25
8000.24
8100.25
7900.26
8000.24
8400.27
8000.26
8100.23
8100.25
7900.26
8000.24
8100.28
8000.26

430635

S1203 ii

·123

2790025
2820023
2850027
28500.27
27900.27
28000.24
28400.26
28800.27
29000.25
27200.26
27400.25
28000.24
28100.25
28600.23
28000.24
28400.24
27200.25
28100.24
28200.25
27900.24
28200.25
28800.26
29000.24
29000.23
28200.28
27400.25

704406.24

S1203 ·123 iii

2810027
2720025
2800023
27500.26
28000.27
28400.27
27900.24
29000.25
27600.25
28900.25

S1203 IV

·123

28400.28
27900.29
27600.26
27800.27
28000.23
27900.25
28000.26
28300.25
27200.27
28000.26
28400.24
28800.25
27900.26
28000.25
27600.25
27900.26
28400.24
28200.26
27900.27
28000.25
27900.26
28200.24
28000.27
27600.26
28400.26
28100.27
28000.23

756406.94

$\frac{286490}{102} = 2808 \cdot 72$

$\bar{t_w} = 25 \cdot 314.$

6/6/1·123

$\bar{w} = 2808 \cdot 72$ lbs

BL = 49·45 ·122 plo.

$\Sigma w = 52 \cdot 7$

$Ef = \frac{49 \cdot 45}{52 \cdot 7}$

$= 93 \cdot 7\%$

dep = 6·3%

703.30
704.40
700.80
756.40

2,86490

·122 plo. 105/110.

27.40
28.00
28.10
28.80
28.20
28.40
28.70
28.90
27.90
27.90
28.00
28.20
28.20
28.00
28.10
27.90
28.00
28.40
28.00
28.10
28.10
27.90
28.00
28.10
28.00

703.30

·122 plo	·122 plo	·122 plo
27.90	28.10	28.40
28.20	27.20	27.90
28.50	28.00	27.60
27.90	27.30	27.80
28.00	28.00	28.00
28.40	28.40	27.90
28.80	27.90	28.00
29.00	29.00	28.30
27.00 2	27.60	27.20
27.40	28.90	28.00
28.00	28.10	28.40
28.10	28.20	28.80
28.60	24.00	27.90
28.00	4.40	28.00
28.40	27.40	27.60
27.20	28.00	27.90
28.10	28.30	28.40
28.20	28.40	28.20
27.90	28.00	27.90
28.20	28.40	28.00
28.80	27.60	27.90
29.00	27.50	28.20
29.00	28.60	28.00
28.20	28.20	27.60
27.40	27.40	28.40
	27.90	28.10
		28.00
704.20 4	700.80	756.40

$\frac{286490}{102} = 2808.72$ lbs

$\frac{2582}{102} = 25.314$ twists

Some Tests for the Efficiency of Ropes.

With accompanying wire tests.

The wires were unstrained

$6 \,|\, \begin{matrix}18\\12\\6\\1\end{matrix} \,|\, \cdot 076$ wire 85/90   5217 Kirk.   79.2 tons $\delta l = 2.66''$

$\Sigma w = 103.5$ 4.88"   24.45 lbs per 6'

Av. tens. 895.5 lbs.   Av twists. 40.76   n = 259.

$Ef = \frac{79.2}{103.5} = 76.7\%$ dep = 23.3 %

q = 67.5 tons □"

$6 \,|\, \begin{matrix}6\\1\end{matrix} \,|\, \cdot 094 \; 6$ 42 HMC. $\overline{w} = 1413.9$ lbs $\overline{tw} = 35.17$

$\Sigma w = 1413.9 \times 42 \div 2240 = 26.5$ tons : BL = 25.72

$Ef = \frac{25.72}{26.5} = 97\%$ dep = 3%

$\frac{12 \,|\, \begin{matrix}6\\1\end{matrix} \,|\, \cdot 105}{6 \,|\, \begin{matrix}6\\1\end{matrix} \,|\, \cdot 105}$ K1010.   126. M.   BL = 94.75 t. $\Sigma w = 133$.

$Ef = 71.5\%$ dep = 28.5 %

$6 \,|\, \begin{matrix}18\\12\\6\\1\end{matrix} \,|\, \cdot 049.$ T. 1159
n = 222   43.6 t. $\Sigma w = 504.17 \times 222 \div 2240 = 50$ t.

$Ef = \frac{43.6}{50} = 87.4\%$ dep = 12.6

6 | 18, 12, 6, 1 | ·036 . $\bar{w}$ = 258.647 lbs. Σw = 25.7 t. BL = 21.46

$Ef = \frac{21.46}{25.7} = 83.3\%$ dep = 16.7 %

6 | 18, 12, 6, 1 | ·030 $\bar{w}$ = 170.8 Σw = 17.0 t. BL = 14.02

$Ef = \frac{14.02}{17} = 82.5\%$ dep = 17.5 %

6 | 12 | ·032 g 85/90. $\bar{w}$ = 169.25 Σw = 5.45 t BL = 5.08

$Ef = \frac{5.08}{5.45} = 93.5\%$ dep = 6.5 %

6 | 12, 6, 1 | ·032 g $\bar{w}$ = 176.47 Σw = 9 t. BL = 8.08 t

$Ef = \frac{8.08}{9} = 89.7\%$ dep = 10.3 %

6 | 15, 9 | ·026 g $\bar{w}$ = 126.7 lbs Σw = 8.15 t. BL = 6.52 t

$Ef = \frac{6.52}{8.15} = 80.4\%$ dep = 19.6

6 | 18, 12, 6, 1 | ·045 $\bar{w}$ = 406.88 Σw = 40.4 t. BL = 34.4 t

$Ef = \frac{34.4}{40.4} = 85.3\%$ dep = 14.7 %

6 | 12, 6, 1 | ·058 $\bar{w}$ = 610.55 Σw = 31.1 t BL = 27.4 t

$Ef = \frac{27.4}{31.1} = 88.2\%$ dep = 11.8 %

6 | 12, 6, 1 | ·066 $\bar{w}$ = 834.36 Σw = 42.6 t BL = 38.4 t.

$Ef = \frac{38.4}{42.6} = 90\%$ dep = 10%.

6 | 18, 12, 6, 1 | ·022

4 1160.

$c = 1.52''$ BL = 9.52 t. $w = 961.8$ lbs

Ef = 8.42 / 9.52 = 88.4 % dep = 11.6 %

10 | 6 | ·112

6 | 6 | ·090

$\bar{w}_1 = 2670.96$ & $\bar{w}_2 = 1757.8$ 87.55 tons

$\Sigma w = 99.8$ tons Ef = $\frac{87.55}{99.8}$ = 88 %

dep. 12 %

10 | 6, 1 | ·111

6 | 6, 1 | ·090

$\bar{w}_1 = 2179.37$ $\bar{w}_2 = 1757.8$ 101 tons

$\Sigma w = 101.3$ Ef = $\frac{101}{101.3}$ = 99.5 dep = ·5 %

6 | 37 | ·105

162 tons. $\bar{w} = 209.4$. $n = 222$

$\Sigma w = 208$ tons Ef = $\frac{162}{208}$ = 78 % dep = 22 %

12 | 7 |

6 | 7 | ·034

$n = 126$ $\Sigma w = 11.2$ t. $\bar{w} = 199$ BL = 8.63 t

Ef. = $\frac{8.63}{11.2}$ = 77.2 % dep 22.8 %

6 | 18, 12, 6, 1 | ·062

$n = 222$ $\bar{w} = 747.3$ $\Sigma w = 74$ t BL = 62.7 t

Ef = $\frac{62.7}{74}$ = 85 % dep = 15 %

6 | 18, 12, 6, 1 | ·054

$n = 222$ $\bar{w} = 570$ $\Sigma w = 56.6$ t BL = 46.8

Ef = $\frac{46.8}{56.6}$ = 83 % dep = 17 %

$6\left|\begin{matrix}6\\1\end{matrix}\right|\cdot 112$ $\quad \bar{w} = 2157$ lbs. $\quad \Sigma w = 40.7\,t. \quad BL = 37.48$

$$Ef = \frac{37.48}{40.7} = 92\,\% \qquad dep = 8\,\%$$

$6\left|\begin{matrix}12\\6\\1\end{matrix}\right|\cdot 1$ $\quad \bar{w} = 1599.8 \quad \Sigma w = 81.4\,t. \quad BL = 76.6$

$$Ef = \frac{76.6}{81.4} = 94\,\% \qquad dep = 6\,\%$$

$6\left|\begin{matrix}15\\9\\3\end{matrix}\right|\cdot 036\,g$ $\quad \bar{w} = 248.275 \quad \Sigma w = 18.1\,t \quad BL = 16.42\,t.$

$$Ef = \frac{16.42}{18.1} = 91.1\,\% \qquad dep = 8.9\,\%$$

$6\left|\begin{matrix}18\\12\\6\\1\end{matrix}\right|\cdot 105$ $\quad 7'' = c. \quad \bar{w} = 2071.1 \quad \Sigma w = 206\,t.$

$BL = 165\,t. \quad Ef = 165/206 = 80.2\,\%$

$dep = 19.8\,\%$

$6\left|\begin{matrix}6\\1\end{matrix}\right|\cdot 124$ $\quad \bar{w} = 3021. \quad \Sigma w = 56.6\,t. \quad BL = 51.7\,t.$

$$Ef = \frac{51.7}{56.6} = 91.8\,\% \qquad dep = 8.8\,\%$$

$6\left|\begin{matrix}6\\1\end{matrix}\right|\cdot 124$ $\quad Ef = \frac{51.1}{56.6} = 90.4. \quad dep = 9.6\,\%$

$6\,|\,{}^{12}_{6}_{1}\,|\,.1$ $\bar{\omega} = 1535.43$ $\Sigma w = 78.2\,t$ $BL = 73.55\,t$

$Ef = \frac{73.55}{78.2} = 94\%$ $dep = 6\%$

$6/6/082$ $\bar{\omega} = 1220$ $\Sigma w = 19.6\,t$ $BL = 18.5\,t$

$Ef = \frac{18.5}{19.6} = 94.4\%$ $dep = 5.6\%$

$6\,|\,{}^{6}_{1}\,|\,096$ $\bar{\omega} = 1350.2$ $\Sigma w = 25.4\,t$ $BL = 23.5$

$Ef = \frac{23.5}{25.4} = 92.5\%$ $dep = 7.5\%$

$6/6/072$ $\bar{\omega} = 989.4$ $\Sigma w = 15.9$ $BL = 15.3$

$Ef = \frac{15.3}{15.9} = 96\%$ $dep = 4\%$

$6\,|\,{}^{6}_{1}\,|\,.082$ $\bar{\omega} = 1077.95$ $\Sigma w = 20.2\,t$ $BL = 19.25$

$Ef = \frac{19.25}{20.2} = 95.7$ $dep = 4.3\%$

$6\,|\,{}^{6}_{1}\,|\,.082$ $\bar{\omega} = 1196.5$ $\Sigma w = 22.45\,t$ $BL = 21.15$

$Ef = \frac{21.15}{22.45} = 94.3\%$ $dep = 5.7\%$

With second group of tests

$\bar{\omega} = 1199$

6/6/1/ .072 $\bar{w} = 923.08$ lbs. $\Sigma w = 17.3$ $BL = 17.05$

$Ef = \frac{17.05}{17.3} = 98.5\%$ dep = 1.5 %

6/9/6/1/ .116 .076 .081 $\bar{w} = 2626.0$ $\Sigma w \simeq 85\ t$ $BL = 80\ t$

$Ef = \frac{80}{85} = 93.8\%$ dep = 6.2%

6/6/1/ .082 $\bar{w} = 1.002$ $\Sigma w = 18.787\ t.$ $BL = 17.60$

$Ef = \frac{17.60}{18.787} = 93.5\%$ dep = 6.5 %

6/6/1/ .094. $\bar{w} = 1413.9$ $\Sigma w = 26.8\ t.$ $BL = 25.72$

$Ef = \frac{25.72}{26.8} \simeq 95\%$ dep = 5 %

6/6/1/ .072 $\bar{w} = 919.52$ $\Sigma w = 17.25\ t.$ $BL = 16.40$

$Ef = \frac{16.40}{17.25} = 95.5\%$ dep = 4.5 %

6/6/1/ .082 $\bar{w} = (1203)$ $\Sigma w = (22.7)$ $BL = 21.13\ t$

$Ef = \frac{21.13}{(22.7)} = 93\%$ dep = 7%

6/12/6/1/ .058 $\bar{w} = 549$ $\Sigma w = 28\ t$ $BL = 25.60\ t$

$Ef = \frac{25.60}{28} = 91.5\%$ dep = 8.5 %

$6/\frac{.6}{1}/.082$ $\quad \overset{Br}{w} = (1075')$ $\quad \Sigma w = (20.2\ t)$ $\quad BL = 19.4\ t$

$Ef = \frac{19.4}{20.2} = 96\%$ $\quad dep = (4\%)$

$6\Bigg/\begin{matrix}18\\12\\6\\1\end{matrix}\Bigg/.038$ $\quad$ Br. av. $w = (233)$ $\quad \Sigma w = 23.2\ t.$ $\quad BL = 20.3$

$Ef = \frac{20.3}{23.2} = 87\%$ $\quad dep = 13\%$

$6/\frac{6}{1}/.124$ $\quad$ Br av $w = 2702$ $\quad \Sigma w = 50.7$ $\quad BL = 47.03$

$Ef = \frac{47.03}{50.7} = 93\%$ $\quad dep = 7\%$

$6\Bigg/\begin{matrix}18\\12\\6\\1\end{matrix}\Bigg/.076$ $\quad \bar{w} = 1077.08$ $\quad \Sigma w = 106.5$ $\quad BL = 91.35$

$Ef = \frac{91.35}{106.5} = 86\%$ $\quad dep = 14\%$

$6/\frac{6}{1}/.123$ $\quad$ 18/5/14 $\quad \bar{w} = 286490/102 = 2808.72$

$t\bar{w} = \frac{2582}{102} = 25.314$ $\quad BL = 49.45\ t$

$Ef = \frac{49.45}{52.7} = 93.7\%$

$\Sigma w = 52.7$ $\quad dep = 6.3\%$

In the following group of tests the wire tables were formed by disintegrating the broken rope and testing the individual wires. These are more irregular and are apt to give too low a value of the depreciation.

329. 14/X/16 $6\left|\begin{matrix}18\\12\\6\\1\end{matrix}\right|$ ·060 HW $p = 8$ $c = 4\frac{4}{8}$" 53·5 tons g

strand $p_1 =$ [illegible] $c_1 = 1\frac{3}{8}$

average of wires 684 lbs $\Sigma w = 67·8$ tons

$Ef = \frac{53·5}{67·8} = 79\%$ dep 21 %.

Here the 53·5 tons is too low, as failure occurred at the grip

$6\left|\begin{matrix}12\\6\\1\end{matrix}\right|$ 036 4/X/16 $p = 4$" $c = 1\frac{3}{4}$" $p_1 = 2·7$" $c_1 = ·57$" $\alpha^\circ = 73°33'$

$\omega = 16°27'$ $BL = 10t$ $n = 114$

$Ef = \frac{10}{11·1} = 90\%$ dep 10%.

$6\left|\begin{matrix}12\\6\\1\end{matrix}\right|$ ·036 15/VII/16 $p = 4\frac{1}{2}$" $c = 1\frac{3}{4}$" $p_1 = 2·7$ $c_1 = \frac{9}{16}$"

$BL = 10·07$ tons.

average of wires 205 lbs. BL of $\Sigma w = \frac{114 \times 205}{2240} = 10·4$ tons

$Ef. = \frac{10·07}{10·4} = 97\%$ dep $= 3\%$.

This is typically too low, as Σw is too low as these values are not from the unstrained wires but from those in the disintegrated rope.

On testing the strands I got 3529 lbs as average.

ie $\frac{6 \times 3529}{2240} = 9·46$ tons as Σ strands. This is also too low as is to be expected.

$6\left|\begin{matrix}12\\6\\1\end{matrix}\right|$ ·042 HW 14/X/16

Average of wires 291 lbs. $\therefore \Sigma w = \frac{291 \times 114}{2240} = 14·8$

$Ef = \frac{14·2}{14·8} = 96\%$ dep 4%.

$6\left|\begin{matrix}12\\6\\1\end{matrix}\right|$ ·0425 12/X/16

Average of wires 306 $\Sigma w = 15·6$ $Ef = \frac{14·5}{15·6}$ 93·2 %

dep = 6·8 %

6/1/128 Aerial B. West. $\alpha = 81° 48'$ $w = 8° 12'$

Six tests gave for BL in tons 6.5, 6.7, 6.4, 6.75, 6.5, 6.79

average value 6.62 tons or 73.66 □"

This was approximately equal to the sum of the strengths of the wires. NB w is small.

6/12/H/098g No. 267 G.F.S.W.R. 43.7 (8p 43.5)
$p = 10\frac{3}{4}''$ $C = 4\frac{1}{2}''$ $p_1 = 5\frac{1}{8}$ $c_1 = 1\frac{1}{2}''$

Average of wires (7) 14.33 lbs. $\Sigma w = 46.1$ tons

$Ef = \frac{43.7}{46.1} = 95\%$ dep 5%

Contrast this with the following:—

The wire tables (33 tests) gave an average for the unstrained wire of 15.94 lbs.

Hence $\frac{72 \times 15.94}{2240} = 51.3$ tons $Ef = \frac{43.7}{51.3} = 85\%$ dep = 15%.

This shows perhaps to an exceptionally marked extent the difference between the original wire tests and those of the wires (as undamaged as possible) out of the disintegrated specimen.

In testing the wires of a disintegrated rope I used to select the undamaged parts by the touch, ie by running them through my fingers and rejecting those parts that had any roughness on them

My tests of the strands gave 6.50 tons on the average.

I found the elastic limit of these wires at about 60% of the breaking load.

$6 / \frac{15}{9} / .086$ Ex Sp plo. No 285 $p = 11\frac{1}{2}$ $c = 5''$ 66.2
$p_1 = 5\frac{1}{4}$ $c_1 = 1\frac{3}{4}$

Average of wires 26   1131 lbs ∴ $\Sigma w = \frac{1131 \times 144}{2240} = 72.9$ tons
$Ef = \frac{66.2}{72.9} = 91\%$. dep = 9%.
Tests of strands in large machine average 10.35 tons
These were all damaged at grips & difficult to hold.

18/7/.021. W.W.   3.2. g   wires too fine for satisfactory test.
strands average 500.4 lbs: core = 6/6/1 fibre av = 2035 lbs.
∴ Σ strands = 3.59 tons $Ef \frac{3.2}{3.59} = 89\%$ dep 11% on strands.

$6 / \frac{18}{12} / .032$ No 294   13.3 h h. $p = 5''$ $c = 2\frac{4}{8}''$ $p_1 = 2.1''$ $d_1 = .225''$
[15]   Av of wires 181 lbs. $\alpha = 74°6'$ $\alpha_1 = 73°54'$
$\Sigma w = \frac{180(181)}{2240} = 14.55$. $Ef \frac{13.3}{14.55} = 91.4\%$ dep 8.6%

7/7/.169   M'. (guar. 80 tons) galv plo   96.5 t
Av of wires. 4879.   ∴ $\Sigma w = \frac{49 \times 4879}{2240} = 107$ tons
$Ef = \frac{96.5}{107} = 90.2$ dep 9.8%.

7/7/.018   301 A   Two tests gave as BL 3830 lbs & 3480 lbs. Two tests were made with the ends ~~laid~~ spliced back in thimbles. [and filled solid with white metal] The breaking loads were 3190 & 3760, both lower than the above. Failure occurred at splice.

1 14.5

$6\left|\begin{smallmatrix}12\\6\\1\end{smallmatrix}\right|$ ·05506 H.W 18.2 t.g. 25/IX/16. $p = 5\frac{1}{4}''$ $c = 2\frac{3}{8}''$
$p_1 = 3\frac{3}{8}$ $c_1 = \frac{3}{4}''$

Average of wires 375·6

$\Sigma w = \frac{375\cdot6 \times 114}{2240} = 19.2\,t.$ $Ef = \frac{18\cdot2}{19\cdot2} = 94\cdot8$ dep = 5·2 %.

I got an average value on breaking ~~the~~ strands of 5650 lbs or Σ strands = 15·1 tons. This as with most of this group of results (re strands) is too low and is due to the cutting of ~~the~~ skins of some outer wires when the rope was being tested. I usually found it difficult to get undamaged strands in sufficient lengths.

$6\left|\begin{smallmatrix}12\\6\\1\end{smallmatrix}\right|$ ·065 5/X/16 $p = 7\frac{1}{4}''$ $c = 3\frac{1}{4}''$ $c_1 = 1''$ $p_1 = 4''$ 34·9

On testing strands to compare flat & D grips I got as averages of 3 (i) flat grip 4·81 tons
(ii) D grips 5·27 tons.

Showing that ~~the flat~~ grips are not suitable for ropes. The D grip is one flat and one round.

Average of 7 wires 771 lbs. $\therefore \Sigma w = \frac{114 \times 771}{2240} = 39.3$ tons

$Ef = \frac{34\cdot9}{39\cdot3} = 89\%$ dep 11 %.

$6\left|\begin{smallmatrix}12\\6\\1\end{smallmatrix}\right|$ ·066 G.S.W.R. L.L. 35·3

Average of 8 wires 742 lbs. $\Sigma w = 37\cdot7$ tons.

Ef = 93·8 % dep 6·2 %.

Average of strands gave 5·786 tons.

$\therefore \Sigma$ strands = 34·72 tons ie slightly below BL as wd be expected if ~~the~~ strands are slightly damaged.

Ex. Flex. Galv. S Wire Rope. 28/4/16 Ordinary lays

6 | 18, 12, 6, 1 | ·0185 Broke at 5·45 tons: then unwound specimen mean of 6 wires 162 lbs. Σ wires 6·16 tons

$$Ef. = \frac{5·45}{6·16} = 88·3\% \quad dep\ 11·7\%$$

Too few wires tested:
The 6 strands were broken, and gave an average of 1702 lbs equivalent to 4·56 tons: this shows damage to certain wires in the strands due to the destruction test
Specimen collapsed after about ½ of the wires had been broken.

6|37/047. pitch 6·3" Circ = 3·25" G. F. S. W.R. 31·8 tons
outer wires 3° r. Tests of diameters of wires ·025" + ·023 ·020 ·025 ·021 ·022 ; ·0215 ·021 ·022 ·0225 ·022
mean diameter ·025" + ·022" = ·047"
tests of 6 wires = 417 lbs. per wire 41·2 tons

$$Ef = \frac{31·8}{41·2} = 77·5\% \quad dep\ 22·5\%$$

6|37/050.H. Two identical specimens tested, one with the ends coned solid with spelter. This was to be a special comparison test. The ordinary specimen broke at 37·2 tons pitch 6·5" circ = 3·42": plough steel
The cone-ended specimen was taken by coned C.I. grips carefully fitted to the steel grip boxes.
Minimum section C.I. = 2(15) = 30 □"
At 35 tons the heavy C.I. blocks fractured

This was most unexpected and spoilt this comparison.
I tested a large number of wires from these specimens noting those which failed at the grips. These actually gave a slightly higher average than those which broke free.

6 | 12/6/1 | 09.6 H.W. Bk 90/100 (Specified 59) $p = 11\frac{1}{2}''$ $c = 4\frac{5}{8}''$ 58.2g

p_1 $5\frac{1}{2}''$ $c_1 = 1\frac{1}{2}''$

Average of wires 1225. $\Sigma w = \frac{114 \times 1225}{2240} = 62.5$

$Ef = \frac{58.2}{62.5} = 92.6$ dep 7.4

The rope failed at the grips. The strands broke on the average at 9.11 tons. ∴ Σ strands = 54.66 tons. There were the usual difficulties of holding the strands and of course a certain amount of deterioration in them

The Orthogonal Surface on which fracture of a straight strand would occur.

If a wire fractures, this produces a weak spot in the strand. Failure would then tend to occur throughout a surface passing through this spot and orthogonal to the other wires. This would be given by the orthogonal trajectory of a family of helices on a right circular cylinder, the helices having the constant angle α. If a be the radius the family of helices is given by

$$x = a\cos(\theta+\beta)$$
$$y = a\sin(\theta+\beta)$$
$$z = a\tan\alpha.\theta$$
$$\therefore dx = -a\sin(\theta+\beta)\,d\theta$$
$$dy = a\cos(\theta+\beta)\,d\theta$$
$$dz = a\tan\alpha\,d\theta$$

$\therefore$ for the orthogonal trajectory

$$-a\sin(\theta+\beta)\,dx + a\cos(\theta+\beta)\,dy + a\tan\alpha.dz = 0$$
$$\therefore -y\,dx + x\,dy + a\tan\alpha.dz = 0$$

Also as the helices lie on $x^2+y^2=a^2$ the Pfaffian condition for $P\,dx + Q\,dy + R\,dz = 0$

viz $P\left(\frac{\partial Q}{\partial z} - \frac{\partial R}{\partial y}\right) + Q.\left(\frac{\partial R}{\partial x} - \frac{\partial P}{\partial z}\right) + R\left(\frac{\partial P}{\partial y} - \frac{\partial Q}{\partial x}\right) = 0$

Since $P = -\frac{y}{x^2+y^2}$, $Q = \frac{x}{x^2+y^2}$, $R = \frac{1}{a}\tan\alpha$

becomes $-\left\{\frac{x^2+y^2-2y^2}{(x^2+y^2)^2}\right\} - \left\{\frac{x^2+y^2-2x^2}{(x^2+y^2)^2}\right\} = 0$

which is true. Integrating we get

$\tan^{-1}\frac{y}{x} + \frac{1}{a}\tan\alpha . z + C = 0$ or taking the surface through $(a,0,0)$ we have

$z = -a\cot\alpha \tan^{-1}\frac{y}{x}$ a helicoid of revolution cutting $x^2+y^2 = a^2$ in the curve required i.e. in

$x = a\cos\theta$
$y = a\sin\theta$
$z = -a\cot\alpha . \theta$

So the orthogonal family is

$x = a\cos(\theta+\gamma)$
$y = a\sin(\theta+\gamma)$
$z = -a\cot\alpha . \theta.$

and the required pitch is $-2\pi a \cot\alpha$.

A large number of ropes to the same specification.

When a large number of ropes are made according to the same specification, and at the same time, the question arises as to how the values of their breaking loads should compare with each other.

As an example of this consider group 332A on 19/X/16 in which 20 ropes were made according to the specification $6 \left| \frac{1R}{H} \right| .022$ F.S.W.R. The pitch was $2\frac{1}{2}$" and the circumference $1\frac{1}{8}$".

The residuals have been formed and tabulated in the accompanying table.

It will be seen that the average error is under 3% of the BL. The max. error is 13.4% and the R.M.S. error 4.13% of the B.L.

In this case the R.M.S. value (which is considered usually the most representative in the Theory of Errors) is rather high, owing to the single large residual .352. We note that there is a specially strong rope, giving a max error (on the right side) of about 13%. The specially weak rope is unlikely in such a group, as wires toward the lower limit of strength would be rejected, while those near the upper limit would all be passed, out of store, for the rope construction

If there has been no opportunity of testing the wires when unstrained and before they have been formed into ropes the tester is only able to examine them after the rope specimen has been broken. The wires are then weakened by the overstraining under the combined stresses and are more irregular and uncertain in the results they give. A further weakening effect is due to local damage on the surface which in some cases - as in certain forms of cables - is strongly marked. A test room depreciation deduced from these values would be distinctly too low. Many experimenters have only such values to depend on, as the others can only be obtained at the works, where the ropes are made.

332 A. $\frac{5}{16}$ F.S.W.R. 19/x/16

6/$\frac{12}{H}$/.022 **Twenty Ropes tested.**

All to the same specification.

Tons.	Resid.l	(Residual)^2
2.65	-.002	4
3.00	-.352	12 39 04
2.70	-.052	27 04
2.63	+.018	3 24
2.59	+.058	33 64
2.63	+.018	3 24
2.53	+.118	1 39 24
2.72	-.072	51 84
2.65	-.002	4
2.45	+.198	3 92 04
2.55	+.098	96 04
2.68	-.032	10 24
2.76	-.112	1 25 44
2.67	-.022	4 84
2.72	-.072	51 84
2.70	-.052	27 04
2.57	+.078	60 84
2.60	+.048	23 04
2.60	+.048	23 04
2.56	+.088	77 44
52.96	0.000	$\frac{1}{20}$ .238880 = .0119440

Average 2.648 Average Error = .077

R.M.S. Error = .1093 Max Error = .352

Efficiency.

One may define the test-room efficiency of a rope as the ratio of the breaking load to the sum of the strengths of the wires. This is quite a different thing from what may be called the commercial efficiency of a winding rope, which may be defined as the ratio of the useful work done (in foot tons) to the cost of the rope (in pounds).

The test-room efficiencies of a number of ropes have been calculated from the wire tests of the unstrained wires. These have been grouped according to constructions, and the results plotted. Defining the depreciation as (1 - efficiency), diagrams of the depreciation are shown for the windings 6/18/12/6/1/d and 6/6/1/d
See Diagrams of Depreciations
(Two Sheets)

It will be observed that the test-room depreciation of the former is roughly three times that of the latter. This result hoeever I consider somewhat delusive, as it does not take into account the bending deteriorations, which for equal strengths would be greater in the latter, nor of course does it indicate in any way the relative lives of the ropes.

The irregularities in the depreciations are striking, and are most marked with finer wires for a given strength. Plough is more uncertain than ordinary crucible steel. The writers who recommend it so highly, and who say that the problem of deep mining is only solubde by its use are evidently overstating their case. Plough seems to be in a more unstable condition than ordinary crucible steel, and though it may give good results in a test-room it may also be uncertain/

uncertain and its duration may be short.

The writer actually heard from the experience of a well known engineer of a recent high grade steel which when cold and under no applied forces not only fractured, but actually shot out of itself a piece about the size of a hazle nut! This shows that some high grade steels may be in an actually unstable condition and hence may fail unexpectedly. In the present state of steel rope construction it seems as if the problem of deep mining would be met best by using two stages in the lift, instead of aiming at the use of extra special plough steel, and using a single lift.

Fracture.

In the fracture of a rope specimen in the testing machine a curious phenomenon tends to occur upon which the writer has seen no comment. When a stretched strand fails, the energy stored on it is dissipated rapidly in vibrations. If however all the strands fail together, then owing to the tension in them before fracture, and their sudden release, a torsional wave is set up in the specimen. This runs along the rope and is reflected. At a certain point the meeting of these two torsional waves will cause a sudden conversion of kinetic into strain energy, the result of which will be a tightening and loosening of the strands at the same instant in contiguous portions. As a considerable amount of energy may be stored at breaking point, the strain energy due to the torsional wave may strain the strands momentarily far beyond the range of recovery, leaving a bulbous appearance at one place on the rope. I have called this an 'aneurism.' Very rudimentary specimens occur pretty frequently, but perfect ones are of rare occurrence, say once in about ~~sixty~~ 100 tests. Photographs of some aneurisms are shown. These are bulbous in the case of the stranded ropes, but the case of the 6/1.128 aerial suggests the 'die-away' waves given by the family of curves $y = A e^{-bx} \sin(Cx + D)$

After fracture the strands and wires are found to be untwisted slightly. The fracture of a strand would tend to be an orthogonal surface, but this is masked since the metal is drawn down at the points of failure in most cases. The ordinary cup and cone formation is noticed in the individual mild steel wires.

Special Forms of Ropes.

The writer's remarks and tests have dealt chiefly with ordinary stranded ropes. The Lang Lay and multi-strand ropes may be included under these. The Lang Lay as already mentioned has a somewhat better efficiency than that of a corresponding standard rope.

Among the multiple-stranded ropes there is a group of special interest, the non-rotating ropes. These have the code-name 'Kilindo' at Bruntons. A typical Kilindo is formed as follows. Eighteen strands are wound, the wires being laid left-handedly. Six strands of these are laid left-handedly about a core, and outside these 12 strands are laid right-handedly. This rope does not rotate and may be used for free winding. The tendency to ~~left~~ right-handed rotation of the outer 12 strands is balanced by the ~~right~~ left-handed tendency of the inner six, plus the sum of the ~~right~~ left-handed tendencies of the eighteen strands. This rope though highly useful does not give the highest efficiency of the steel for raising loads, due probably to the great bending effects in the constituent wires, since out of 126 wires there are 108 wires all of which are bent round core wires of equal diameter with themselves. Thus the bending strains in this rope even when straight are particularly heavy.

These ropes are recommended highly by Hrabak, who also speaks enthusiastically of what we may call one-strand ropes, but he does not take into account their disadvantages.

Some tests of Kilindo ropes are shown.

Kilindo Ropes. Non-rotating

12 | 6 | ·105 BL = 94·75 tons
6 | 1 |

12 | 9 | ·070
6 | 5 | ·053
  | 1 | ·038
  | | ·069
  | | ·052
  | | ·038

BL = 64·4 tons

12 | 6 | ·058
   | 1 | ·056
6 | 6 | ·057
   | 1 | ·060

BL = 28·10 tons

12 | 6 | ·059
   | 1 |
6 | 6 | ·058
   | 1 |

BL = 26·57 tons 77·5 t □"

12 | 6 | ·034
   | 1 |
6 | 6 |
   | 1 |

BL = 8·63 tons. 75·5 t □"

12 | 6 | ·019
   | 1 |
15 6 | 6 |
   | 1 |

BL = 3·12 tons

~~~~~~~~~~~~~~~~

10 | 6 | ·066
   | 1 | 7
13 5 | 6 | ·059
   | 1 | 9

31·5 tons

10 | 6 | ·114
/11 6 | 6 | ·090

101·3 tons

10 | 6 | ·112
   | 1 | 3
/11 6 | 6 | ·090
   | 1 | ·090

87·55 tons
~~~~~~~~~~~~~~~~

One-strand ropes.

Were these judged by their tensile strength alone they would be highly satisfactory. Unfortunately this is not sufficient. When one merely observes that they cannot be spliced, their limitations are painfully evident. They have certain restricted uses as aerials, guide ropes, and as stationary ropes in general.

Locked coil ropes are particular cases of one-strand ropes. The locked coil has a beautifully cylindrical surface, and makes an excellent guide rope, but it is easily injured by kinking, and it is specially stiff. A further disadvantage is that internal broken wires can give no indication at the surface. This is a serious objection to their use. Even these slightly exceptional types are rarely made, and probably over 100 ordinary stranded ropes are made for a single locked coil.

Some attention has been directed recently to tapered ropes. It is well known that a very long rod supporting a load has, for uniform strength, a profile given by an exponential curve. As a rope cannot be constructed of this form, the taper is formed by constructing the rope in 2 or 3 cylindrical portions, circum-cylinders to the theoretical shape. These are determined after the manner in which the plates are arranged for the flanges of a plate girder.

These different parts may be formed in various ways none of which are very satisfaftory. Thus wires may be cut out to form the thinner part, or else the thicker portion may be formed by brazing thicker wires to the original wires, or else by merely inserting new wires. The counterbalancing disadvantages are evident.

Chapter VI

The Rope in Use.

BENDING and [illegible]

Investigations into the [illegible] effect of coiling a steel rope round a drum have followed [illegible] the simple Reuleaux formula for bending. The [illegible] curvature is then taken to be $\frac{1}{R}$ where R is the radius [illegible] and the ordinary bending equation [illegible].

Hrabak [illegible] a table, [illegible] Young's Modulus [illegible] on whether the wire is [illegible] cable. He tabulates the [illegible] E_s is the Young's Modulus of the [illegible] E' that of the wire in the rope. [illegible] m/m.

	Wire	Strand	Rope	Cable
E	E_0	$.6E_0$	[illegible]	$.2148E_0$
E'	E_0	$.4336E_0$	[illegible]	$.2918E_0$

From these values he deduces "σ" the bending stress in kgs. □ m/m. from the equation $\sigma = E$ [illegible]. Thus we have $\sigma = 10,000 \frac{\delta}{R}$, $\sigma =$ [illegible] $\frac{\delta}{R}$, $\sigma = 4000 \frac{\delta}{R}$, $\sigma =$ [illegible] $\frac{\delta}{R}$ for the wire, strand, rope, and cable respectively.

Him [illegible]

BENDING and FLEXIBILITY.

Investigations into the straining effect of coiling a steel rope round a drum have followed chiefly the simple Reuleaux formula for bending. The change in curvature is then taken to be $\frac{1}{R}$ where R is the radius of coiling, and the ordinary bending equation is used.

Hrabak, finding that the values so obtained are unsuitable, endeavoured to alter this equation by supposing that Young's Modulus E "for a wire" has different values depending on whether the wire is by itself, or is in a strand, rope or cable. He tabulates the following values:-

E_o is the Young's Modulus of the material: E that of the rope: E' that of the wire in the rope. He takes E_0 as 20,000 kgs □ m/m.

	Wire	Strand	Rope	Cable.
E	E_0	$.6E_0$	$.36E_0$	$.216E_0$
E'	E_0	$.6636E_0$	$.4400E_0$	$.2918E_0$

From these values he deduces "σ" the bending stress in kgs. □ m/m. from the equation $\sigma = E\,\frac{1}{2}.\,\frac{\delta}{R}$. Thus we have $\sigma = 10{,}000\,\frac{\delta}{R}$, $\sigma = 6635\,\frac{\delta}{R}$, $\sigma = 4400\,\frac{\delta}{R}$, $\sigma = 2918\,\frac{\delta}{R}$ for the wire, strand, rope, and cable respectively.

His /

His methods and treatment seem to me completely incorrect. E, too, is a property of the material, and should not be affected by whether the wire is by itself, or is in a strand, or a rope, or a cable. The use of the formula, too, which applies to the elastic behaviour of solid rods, is also unjustfiable, and this shows the necessity for further consideration of this subject. Since in a rope the wires are not parallel to the axis, and as they may move relatively to each other, it is manifestly incorrect to treat the rope as if it were an elastic rod. The bending stress formula, however, might be modified empirically and rendered more applicable, so as to allow for the relative shifting of the wires.

The radius of curvature of a wire in a one-strand rope of radius a, and helical angle α, is $\rho = a \sec^2 \alpha$, where we consider the wire as a helix on the cylinder of radius a. If the one-strand rope be coiled round a drum of radius R, we may find the change of curvature by considering that the cylindrical rope has become a tore with principal radii of curvature a and R + 2a, for the outer fibres. Hence by a theorem in the curvature of surfaces we have $\frac{1}{\rho} = \frac{\cos^2 \theta}{a} + \frac{\sin^2 \theta}{R + 2a}$. If we put $\theta = a$ we get the change of curvature for the wire at its outermost point (where the stress is greatest), in the form $\frac{1}{\rho_1} - \frac{1}{\rho_2} = \frac{\sin^2 \alpha}{R + 2a}$ instead of the assumed value $\frac{1}{R}$.

To examine the case of an ordinary rope. Let d be the diameter, a, the radius of a strand, the wires being supposed fine; R, the coiling radius, and α the angle of the helix. Then considering the wire in the neighbourhood of a crown, we may suppose that we have a portion of a tore whose principal radii are approximately a and $(R + d)\ \mathrm{Sec}^2(90^\circ - \alpha)$

$$\therefore\ \frac{1}{\rho} = \frac{\mathrm{Cos}^2\,\theta}{a} + \frac{\mathrm{Sin}^2\,\theta}{(R + d)\,\mathrm{cosec}^2\alpha}$$

$$\therefore\ \text{when } \theta = \alpha \quad \frac{1}{\rho} = \frac{\mathrm{Cos}^2\alpha}{a} + \frac{\mathrm{Sin}^4\alpha}{R + d.}$$

hence the change of curvature of the wire is approximately $\frac{\mathrm{Sin}^4\alpha}{R + d}$ which is still less than the previous value.

To apply this we should require to introduce into the bending equation a factor λ determined by experiment so as to allow empirically for the relative movements of the wires

$$\therefore\ \frac{\lambda\,\mathrm{Sin}^4\alpha}{R + d} = \frac{2p}{Ed} \quad \text{or} \quad p = \frac{\lambda\,\mathrm{Sin}^4\alpha\,Ed}{R + d}$$

where p is the bending stress in the outer fibres.

If $e = \frac{1}{2000}$ be a permissible strain in a solid bar then if we put $\frac{r}{R} = \frac{1}{2,000}$ the radius of the drum would require to be $R \nless 2000r$. If $r = \frac{3}{4}"$ $\therefore$ $R \nless 125'$ which of course is absurd in the case of a rope, but which is the value that follows from applying the bending equation for a solid. Actually owing /

owing to the movement of the wires a very much smaller value is permissible, particularly in the case of a fibre core. Thus with a yield point at 50 tons □" and a value of E of 33×10^6 if we take $e \doteq \frac{1}{300}$ and put $\frac{1}{300} = \mu \frac{r}{R}$ then assuming $\mu = \frac{1}{3}$ we have $R \doteq 100r$.

Various empirical rules are given for the sizes of pulleys or winding drums. Thus Diescher (1905) says that the diameter of the drum should be greater than 50 times the diameter of the rope ($R > 50r$). This limiting value seems much too small for winding ropes, and twice this value would be more satisfactory. Thus for winding ropes $R \doteq 100r$ has also been suggested. If δ = diameter of wire Hrabak gives $R \doteq 700\delta$ (say crane ropes 500δ to 800δ) and $R = 1200\delta$ for winding ropes.

It is evident that experimental results are of vital importance in this subject. An interesting set of observations on the effect of the bending of crane ropes is given by Biggart (Proc. Inst. E.C. Ci.) In this case the sheaves and drums were of small diameters and the ropes failed finally by repeated bending.

A steel rope of circumference $1\frac{3}{4}$" was loaded to one-tenth of its breaking load and run round a $10\frac{1}{2}$" pulley. Then $R = 19r$ or $r = .053R$. The unlubricated rope went 16,000 times round before fracture. On being lubricated the number of turns /

turns rose to 38,700. With a 24" pulley the figures were R = 43 r, or r = .023R, 74,000 turns when unlubricated, and 386,000 when lubricated.

The figures for a Langs Lay rope on the first pulley are given as 53,000 and 107,600, but if other factors were the same, this must have been exceptionally favourable to the Langs Lay.

Some experiments of this nature are also recorded in Glückauf 1913. Wire of 177 kgs. □ m/m. and diameter 1 m/m. was loaded to 8 kgs. □ m/m. and run round a pulley 175.4 m/m. in diameter. It underwent 148,710 bends before breaking. Seven-wire strands were then formed of this wire and run on the pulley as before, with in all cases the same tensile stress. The number of bends fell to an average of about 47,000. With a pulley 180.4 m/m. in diameter the single wire made 210,790 bends, and the strand began to fracture after 40,860 bends. A three strand rope began to break at 22,860 bends and was completely destroyed after 36,460. A five-strand rope with hemp core began to break after 35,000 bends and was completely destroyed after 40,160 bends. The fibre core would doubtless account for this rise.

Thus both theory and experiment show the necessity for large pulleys or drums. According to Hrabak this is so important /

important that he attributes to a great extent the failure of winding ropes to the effect of bending stress, as calculated by his method. If that were so, however, the failures would occur at those parts of the ropes that were most frequently bent. This, however, is not the case, as has been shown already by statistics of failures. Accordingly we see that the large drums and pulleys used at the present day in deep mining are probably sufficiently great, and are not, as a rule, the direct cause of these failures.

Incidentally Biggart's tests show the great importance of the lubrication of a rope, a matter which is now well recognised. Its effect is partly preservative, and partly the reducing of the friction between the layers and ~~lorries.~~ wires. Where two layers of a strand cross, the relative movements produce a nicking or sawing effect. The writer has seen these cuts very deep in a bran new cable of construction 3/3/3/.1" which had merely undergone a tensile test. (Specimens on view). By bending constantly round a pulley this effect is enormously increased. A tail-rope of a well known South African mine failed recently, and a specimen of it sent to this country was seen by me. Though it ran light it had evidently failed in this manner due to bending stress.

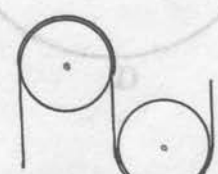
Kroen /

Kroen (Oesterr, Zeit. f. B und H 1904) chronicles the sudden failure of an unlubricated mining rope. In this case though the outer wires looked perfect, the unseen inner ones had corroded badly, due to lack of lubrication.

Empirical formulae have been given for the life of a rope under bending stresses. Thus let D be the diameter of the drum, d that of the rope, L the life of the rope with a very large drum L_1, its life with a small drum. Then $D \not< 100d$; a satisfactory value is D = 125d.

$$\text{Then } L_1 = \tfrac{3}{4}L \quad \text{when } D = 68d.$$
$$L_1 = \tfrac{1}{2}L \quad \text{when } D = 48d.$$
$$L_1 = \tfrac{1}{4}L \quad \text{when } D = 36d.$$

Reverse bending should always be avoided. The life of a crane rope with a single bend may be even halved on the introduction of reverse bending.



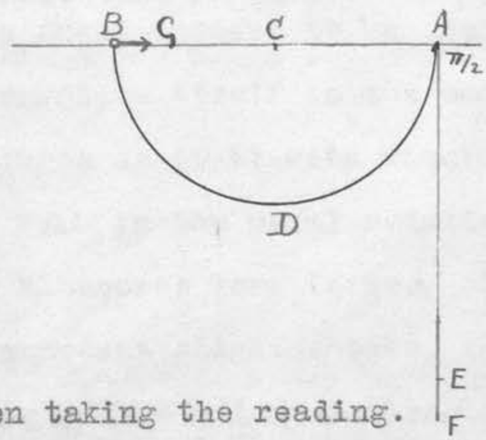
Flexibility may be obtained by reducing the angle of the helix; by the use of, or increase of, the fibre core; and by reducing the diameter of the wires. Since T = w cosec α where T is the tension, and w the vertical load on the wire, we see that the increase of flexibility by decreasing α would be at the expense of increased tension in the wire. Use of, or increase of, a fibre core, means a thicker rope, which for certain purposes might be inadmissible.

Increase /

Increase in the number of wires means naturally an increase in cost. Hence a compromise among these is arranged.

Flexibility Tests in the Laboratory.

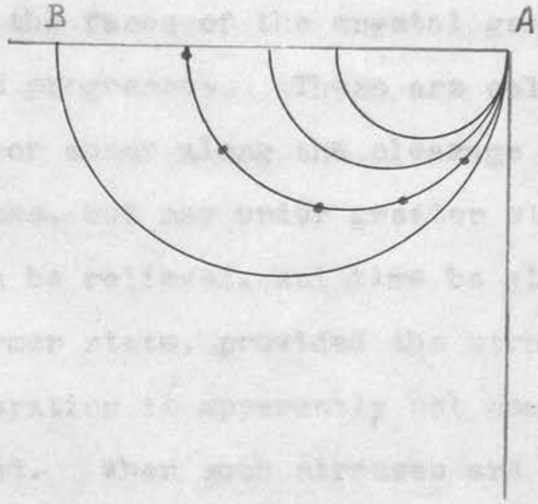
The writer thinks that flexibility tests of winding-ropes would be of value, especially for listing in makers' catalogues. A very simple method would be somewhat as follows. Clamp the specimen in a vice as at A with a short length AEF projecting. Mark off a length say AE = ℓ = 50d (i.e. 50 diameters). Put a loop of cord round the rope at E and pull it into a semi-circle of radius R = $\frac{50d}{2\pi}$ by means of the hook of a spring-balance G. The spring balance reading will enable us to compare the flexibilities of different ropes. The writer tried this without any apparatus, merely taking BC = CA = CD and then taking the reading.



The curve is in this case not a semi-circle but an elastic curve which approximates to an arch of a ~~semi-circle~~, sine curve.

If the circle should be thought better than the elastic curve, for purposes of comparison with pulley wheels, an arrangement such as the following would be simple.

A is the vice, and semicircles are drawn on a board as shown. Holes are made at intervals along the arcs, and pegs placed in them so as to form quickly a cylinder of



the required radius. The rope is then bent round this and the spring balance reading taken, the axis of the instrument being in the line AB. Comparative values are all that are required as in the case of the Brinell test numbers.

Fatigue and Shock.

The microscope shows that when a metal is strained beyond the elastic limit, fine lines appear on the faces of the crystal grains, and increase in number as the strain progresses. These are called slip bands, and are due to slipping or shear along the cleavage planes of the crystals. They are not cracks, but may under greater strain develop into cracks. If the strain be relieved, and time be given, the metal tends to return to its former state, provided the strain has not been excessive. But the recuperation is apparently not complete after the yield point has been passed. When such stresses are long continued, the material fails under fatigue. This may be looked on as a time-integral of the strains, rather than the setting up of a coarse crystalline structure in the material, although the latter condition may be brought about by incessant shocks.

The cause of breakage under sudden shock appears to be that as time is not given for the metal to accommodate itself to the sudden stress by slipping or flouring, it ruptures as if it were abnormally brittle. Thus for a given impulse $I = F\Delta t$, in the usual notation, if Δt become very small then the force F becomes very large. If breakage does not occur, but there be constant slight shocks, these cause slip with the consequent hardening of the material along the slip lines. This may be analogous to the hardening effect of drawing, or overdrawing, a wire, in which though the tensile strength is apparently increased, yet owing to high internal strains failure may occur at a load much lower then what would be expected: particularly after the lapse of time.

In/

In the case of a winding rope at work stresses far above those due to the static load may be introduced. The following tables are quoted from Bruntons catalogue, showing the observed load on a winding rope, due to shock, caused by short lengths of slack chain at the commencement of winding, as registered by a dynamometer.

First Test.

No. 1 Empty cage lifted gently.	4030 lbs.
2 " " " "	4030 "
" 1 with $2\frac{1}{2}$" slack chain	5600 "
2 " " " "	5600 "
1 " 6 " "	8950 "
2 " " " "	8950 "
1 " 12 " "	12300 "
2 " " " "	12300 "

Second Test.

Cage and four empty tubs weighed by machine = 6375 lbs.

No. 1 Cage lifted gently	6375 lbs.
No. 2 " " "	6725 " (?)
No. 1 with 3" slack chain	11200 "
No. 2 " " " "	11200 "
No. 1 " 6" " "	12250 "
No. 2 " " " "	12250 "
No. 1 " 12 " "	15675 "
No. 2 " " " "	15675 "

Third Test.

Cage and full tubs weighed by machine		11300 lbs.
No. 1 lifted gently		11300 lbs.
No. 2 " "		11525 "
" 1 with 3" slack chain		19025 "
" 2 " " " "		19025 "
" 1 " 6" " "		23500 "
" 2 " " " "		25700 "
" 1 " 12 " " "		27950 "
" 2 " " " "		25750 "

In the usual treatment of the shock due to a load applied suddenly to a tensile rod we have R the maximun resistance of the rod, ξ the corresponding extension, and W the load which produced the elongation e. Then $\frac{R}{\xi} = \frac{W}{e}$. Also if the load fall through a height s we have $W(s+\xi) = \frac{1}{2}R\xi$

hence $R = W\{1 + \sqrt{1 + \frac{2s}{e}}$ if s = o $\therefore R = 2W$

i.e. if a load be applied suddenly, the stress is double what it would be if applied slowly. Naturally this differs considerably from the results given in the tables, but the two are not quite comparable. One cannot compute the shock given by the engine in winding, as accurately as one can compute the gravitational one, the dynamometer too would probably not register the peak of the curve, and the theory assumes a homogeneous elastic bar instead of a rope. Still there is a fair resemblance. If the tables be plotted it is seen/

seen that a parabolic law of nearly the same kind as that given by the theory seems to be followed viz:- $R = W(1 + k\sqrt{S})$ where k is a constant which for the second table is roughly .38 It will be seen that the greatest value in the first table is three times that produced by the steady load, careless winding might easily produce worse results. In fact one of the essentials that deep mining may be a commercial success is that there should be a skilled engine-man in charge. Even steady winding with too high an acceleration greatly increases the stresses above those due to static load.

The effect of the high strains due to starting with a jerk would be felt most severely at the point where the rope was attached to the cage, as the shock would be reduced in intensity as it travelled away from this point owing to the springiness of the rope. The constant repetition of these shocks would weaken the rope unduly at this point.

Vibrations in a winding rope seem to have a weakening effect. Rapid vibrations in a steel rod may set up a coarser and weaker crystalline structure in the material. When a loaded cage is suspended at the end of a long rope, and waves are travelling along it, they are reflected at the point of attachment. At that point the kinetic energy will be partly converted into strain energy - as is shown in the analogous case of 'aneurisms' - and further the rapid transverse vibrations relatively to the fixed position of the rope at the point of attachment produce rapidly alternating bending stresses, particularly if the harmonics present produce any resonance effect.

It is interesting to observe that this is the neighbourhood where a long winding rope is most apt to fail. The weakest point is not where the bending stresses due to the pulley and drum are greatest, as it should be according to Hrabak, nor even where in addition the greatest stresses due to tension occur. It is actually at the place where there is not bending round the drum, and where the direct tension is least. In confirmation of this the following facts are selected from a group of mining statistics. In the Dortmund and Breslau districts, between the years 1899 and 1903, 3052 winding ropes were discarded. Of these 41 broke suddenly when in use. Of the breakages more than half were near the cage and only 2 near the drum. The breaks occurred usually at the commencement of the lift - which fortunately minimises loss of life - and naturally the age of the rope was one of the important factors.

Hence arises the necessity for the constant recapping of winding ropes. It removes the material which has deteriorated most from overstrain, and ensures that new portions of the rope undergo from time to time the positions of heavy strain due to combined tension and bending round the pulley. It is found too that the portion of the rope which remains coiled on the winding drum is undamaged.

Thus the effect of fatigue seems to be not so much the formation of a coarser structure as that the sums of all the elementary strains reach in the aggregate a condition of strain in the grains in which there is less and less recuperability, till finally rupture occurs. The rope when near failure may still exhibit high tensional strength, just as there may be a high tensile strength across the section where a/

a bar is drawing down just before fracture. In that condition however the material would be dangerous to use. So in a rope the time integral of the work done could not exceed some definite value, in other words a winding rope would only have a definite life before it became dangerous to use. This duration is surprisingly short, in many cases it does not exceed a year.

Other Working Conditions.

Under working conditions there are a number of considerations, in addition to those that have been mentioned, which add complexity to the problem of the steel rope. Also in the bibliography which has been given, it will be found that statements made by some writers are directly contradicted by others.

Rope attachements give great trouble. It is almost impossible to get fastenings which will not damage the rope, and yet be equally efficient. If, as seems to be the case, the effects of vibrations cause deterioration while working, there might be a better attachment than the short socket which is run in solid with white metal, though this is effective in the test room.

An arrangement which would damp these vibrations out would be desirable, and should not be impossible to obtain. Thus a gradual change from the flexibility of the rope to the stiffness of the socket, instead of as at present an abrupt one, seems desirable. The very fact of the constant recappings calls attention to this source of weakness.

Splices are further causes of trouble in ordinary multi-strand ropes, and are not so efficient as is the un-spliced rope. A 40' splice on a 1¾" circumference rope may, however, have a strength of 80 tons per sq inch. One-strand ropes cannot be spliced, though they may be joined by brazing. Mining engineers now ask for continuous wires in ropes a mile long.

There has been considerable controversy as to whether the frictional support of the surrounding wires supports effectively a broken one. A well known authority states, as the result of his/

his own experiments, that wires in a rope may be cut some 18" in advance of each other successively, and that the rope is little the worse. This seems incredible, and the writer has had no opportunity yet of testing its accuracy. It is controverted too by a paragraph in the Report of the Commission appointed by the Transvaal Government (q.v.) dealing with winding ropes.

For deep mining the highest class of plough steel is much advised at the present day, but, considering some of the foregoing paragraphs, it is not surprising to find that these ropes are relatively less efficient than some of much lower tensile strength. The writer could quote results from present Admiralty work in support of this view.

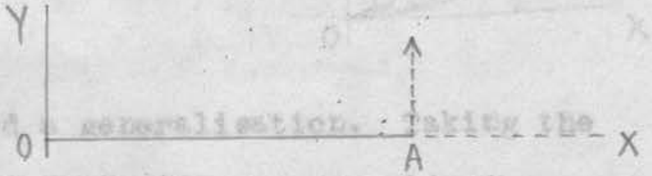
Deterioration occurs frequently as the result of chemical changes. Lubricants and preservatives are essential for guarding a rope from decay, as moisture is apt to get into the interior, and cause rust. Lubricants which harden with age should be avoided. Those ropes whose fibre cores are sometimes dry and sometimes wet are particularly liable to corrosion, as are those also which are immersed in sea water.

Galvanising the wires is to some extent a preservative. Mining ropes are apt to be affected by the acidulated water which often occurs in shafts. Caldecott (Proc. Iron and Steel Soc. Journal 1911 i) describes some tests which he made to verify this. A wire of the best plough steel, which broke at 31.5 twists when untreated, was immersed in acidulated water. The hydrogen set free is said to be partly occluded. After 14 and 15 hours of this treatment/

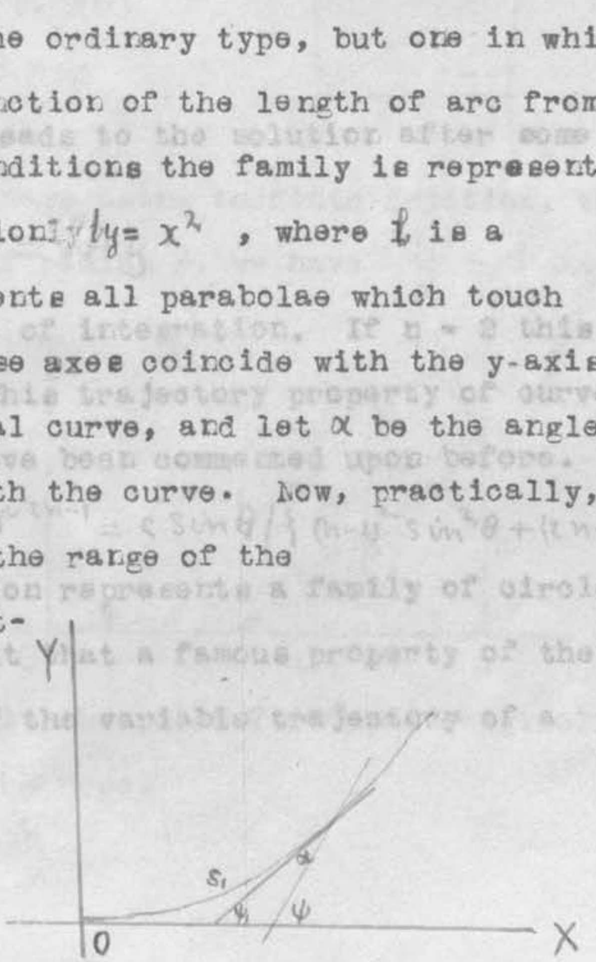
treatment, though there was apparently no corrosion, the wire only withstood 12 and 5 twists respectively. The tensile strength was little affected. Boiling such wires in water for 3 hours apparently restored their resistance to torsion and bending. The conditions most favourable for the occlusion of hydrogen occur when the preservatives are used irregularly, and the acid water saturates the fibre core and acts on the central wires which are excluded from the air.

There is much that might be said on the subjects mentioned in the last few pages but the field is so wide that it lies rather beyond the scope of a paper such as this.

An interesting problem arose in connection with some engineering work on which the writer was engaged recently. He was at the time assisting an Admiralty engineer, who was engaged in constructing flexible defences. Without indicating the engineering work, one of the mathematical problems may be stated as follows. A flexible steel rope is floated, let us say, and may be drawn out through the fixed origin O. The initial position of part of the rope is coincident with the X-axis OAX.



A is a fixed point on the X axis. The point on the rope coinciding initially with A is pulled in the direction perpendicular to OX. The rope takes successively the positions of the members of a singly infinite family of curves. Of this family we require a trajectory, not of the ordinary type, but one in which the angle of intersection is a function of the length of arc from the origin. Under the engineering conditions the family is represented sufficiently closely by the equation $ly = x^2$, where l is a variable parameter. This represents all parabolae which touch the X-axis at the origin, and whose axes coincide with the y-axis. Let the suffix $_1$ denote the original curve, and let α be the angle of intersection of the trajectory with the curve. Now, practically, $\alpha = \psi_1$, so that $\psi = 2\psi_1$ within the range of the investigation. Denoting differentiation by a dash, we have



$$\frac{2y_1'}{1 - y_1'^2} = y'$$

Forming/

Forming the differential equation of the family we have $y_1' = 2y_1/x_1$,

$\therefore 1+y'^2 = \left(1 + 2\frac{yy'}{x}\right)^2 \quad \therefore y_1' = \frac{4xy}{x^2-4y^2}$

as $y' = 0$ is trivial.

This is homogeneous, so putting $y = vx$ we have $\frac{dx}{x} = \frac{1-4v^2}{3v+4v^2}\,dv$.

of which the integral is

$\log x = \frac{1}{3}\log v - \frac{2}{3}\log(3+4v^2) + \log c$

This simplifies to $(3x^2+4y^2)^2 - Cy = 0$

The network is

roughly as indicated.

The form of the solution suggested a generalisation. Taking the more general equation $ly = x^n$ as the family of generalised parabolae, its differential equation is $y' = \frac{ny}{x}$. Hence for the trajectory, since $y_1'^2 y' + 2y_1' - y' = 0$ we have the differential equation.

$y'(x^2 - n^3 y^2) = 2nxy$

This is again homogeneous, and leads to the solution after some reduction.

$\{(2n-1)x^2 + n^2y^2\}^n = Ay$

where A is an arbitrary constant of integration. If n = 2 this reduces to the former result. This trajectory property of curves of this type does not seem to have been commented upon before.

In polars, the curve is $r^{2n-1} = c\sin\theta / \{(n-1)^2\sin^2\theta + (2n-1)\}^n$

Incidentally if n = 1 the equation represents a family of circles. Thus we get the unexpected result that a famous property of the circle occurs under the guise of the variable trajectory of a pencil of radiating lines.

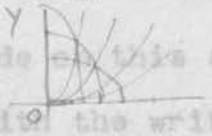
If/

If the angle α be constant along the curve, we have $y_1' = 2y_1/x_1$, and $y_1' = \frac{y'-m}{1+my'}$, where m = $\tan\alpha$. Hence the differential equation of this trajectory is $y'(x - 2my) = 2y + mx$

Integrating, we get as its equation

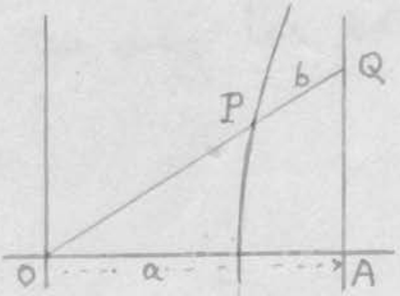
$$\log k \sqrt{mx^2 + xy + 2my^2} = \frac{3}{\sqrt{8m^2-1}} \tan^{-1} \frac{x + 4my}{x\sqrt{8m^2-1}}$$

If $km^{\frac{1}{2}}$ approach a definite limit as $\alpha \to \frac{\pi}{2}$ we have the equation $x^2 + 2y^2 = \lambda$ which is the orthogonal trajectory of the family $ly = x^2$



To determine the path of a point upon the rope, suppose first that the rope is pulled out in a straight line through O. Then since P. is fixed relatively ~~rotating~~ to Q, and PQ = b the ~~loine~~ locus of the point P. denoted by (x,y) or (r,θ) is the conchoid $r = a\sec\theta - b$

or $(x^2+y^2)(x-a)^2 - b^2x^2 = 0$

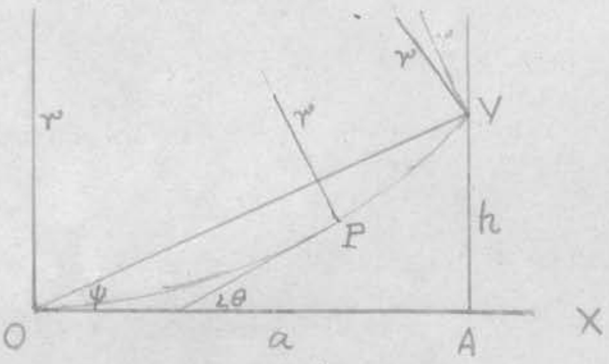


If, as is approximately the case owing to fluid friction, the rope lies in an arc of a circle of radius r, we have $\frac{h}{a} = \tan\psi$

Let P be the point (x,y)

Then a is a constant while h and r are both variables! $\therefore r = \frac{a^2+h^2}{2h}$

$$\begin{cases} x = r\sin 2\theta \\ y = r(1-\cos 2\theta) \end{cases}$$



Now let l be the distance from P to the point V (which was originally at A) measured along the arc of the rope.

$$\therefore 2r\psi = 2\frac{a^2+h^2}{2h}\tan^{-1}\frac{h}{a}$$

Hence/

Hence for the locus of P

$$x = \frac{h^2+a^2}{2h}\left\{\sin\left(2\tan^{-1}\frac{h}{a} - \frac{2hl}{h^2+a^2}\right)\right\}$$

$$y = \frac{h^2+a^2}{2h}\left\{1 - \cos\left(2\tan^{-1}\frac{h}{a} - \frac{2hl}{h^2+a^2}\right)\right\}$$

Where h is a variable parameter, and a and l are constants. This pair of equations gives the locus required, and from them it may be plotted. For different values of l we get the paths of all points on the rope.

Some practical experiments were made on this subject by the engineer already referred to, together with the writer.

Six Plates of Photographs

of Specimens

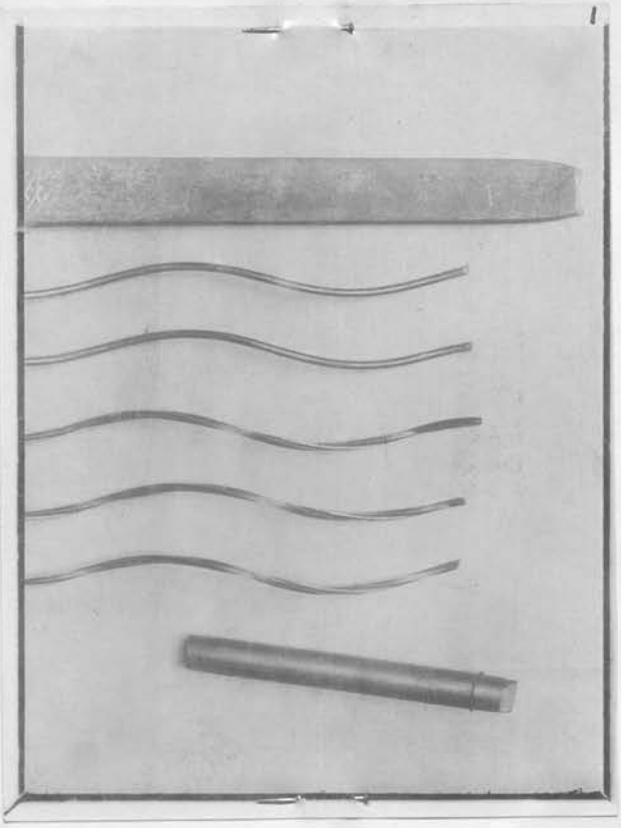
which have been referred to

during this paper.

Photographs by Mr. Horsburgh

The specimens may be seen

if desired.



1 2 3 4 5 6 7

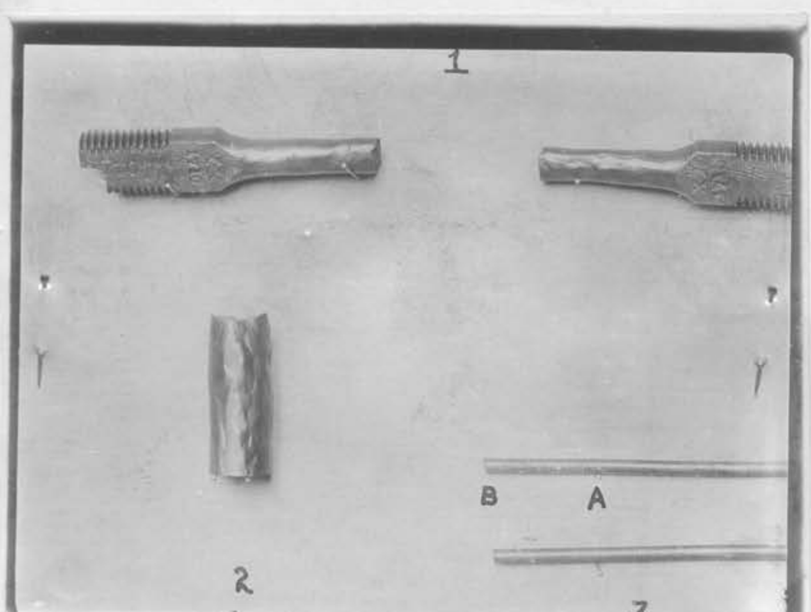
Photograph No. 1.

(1) Modified cup and cone on fracture of flat bar of mild steel.

(2) & (3) Wires untwisted from a 6/1 core. There is no appearance of torsion on these (cylindrical) wires

(4), (5), & (6) Wires untwisted from a locked coil rope. The effect of the torsion is very distinct.

7.) A piece of wire about 9" × 3/4". It is supposed to be perfectly homogeneous but on being broken in tension in 2 places we see at the one end a 'cup & cone' fracture, at the other a straight orthogonal fracture with no drawing down.



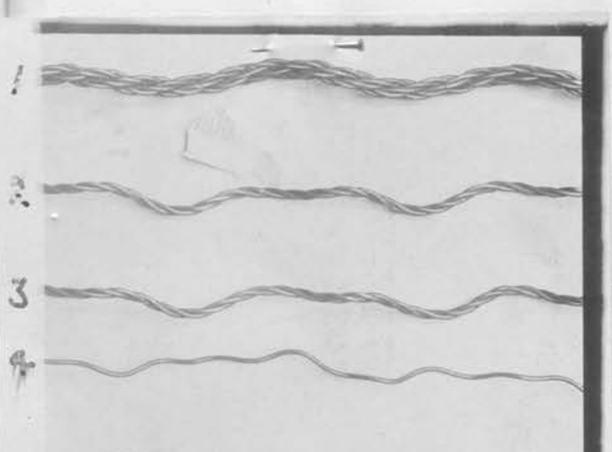
Photograph No. 2

(1) A perfectly cylindrical gunmetal specimen broken in torsion. Note how the specimen is crumpled and how it shows that shear has occurred in the grains of the metal

(2.) A perfectly cylindrical

gunmetal specimen broken in simple tension. Note the crumpling of the cylindrical surface, and the clear evidence of shearing having occurred in the crystalline grains of the metal: also the different orientations of the different grains

(3) Specimen showing lack of homogeneity, unexpectedly, in a wire. Some of twists were given to a 8" length of wire. These have all taken place in a length of about 1". (in the part AB). as may be seen in the photographs.



Photograph No 3.

Photograph to illustrate the behaviour of strands and wires in a rope and to show the large amount of permanent deformation in certain cases

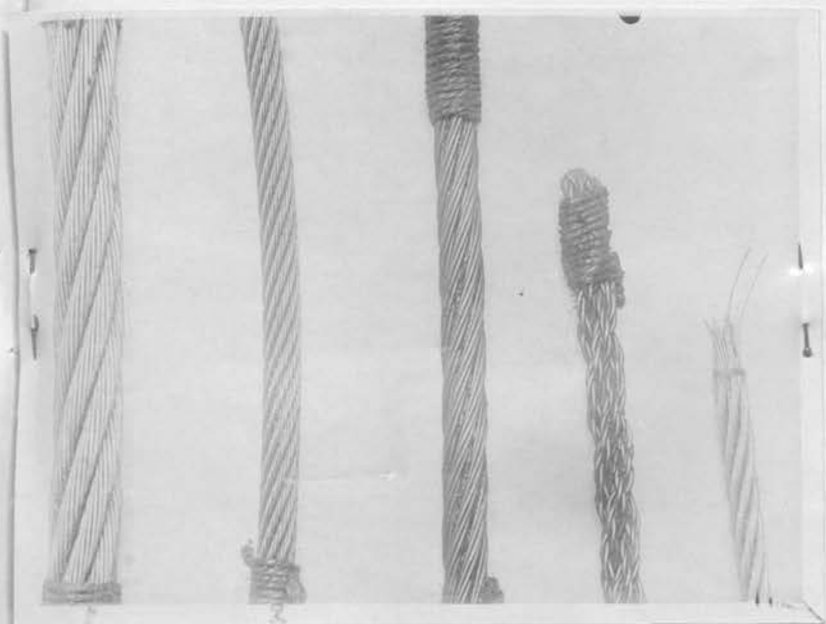
(1.) is a rope untwisted from a cable.

(2) & (3) are strands of the above rope

Note simple sine curve in 1 and higher harmonics in 2 & 3. also the weakening effect due to larger values of α in 2 & 3 than in 1.

(4)(5) & (6) are wires from the cable: note higher harmonics: great weakening due to large value of α. also a very bad nicking (surface damage) is

present, though it does not show up in the photo.
(7) is a strand from a rope (simple sine curve)
(8) & (9) are wires from ~~the~~ strand: higher harmonics present. greater tensile stress in the wire. The actual bending of the wires is even more unfavourable than is shown in the photograph.



1 2 3 4 5

Photograph No 4

Some Typical Constructions

(1) Ordinary Lay. Heavy rope. $6/\frac{12}{H}/d$. H.

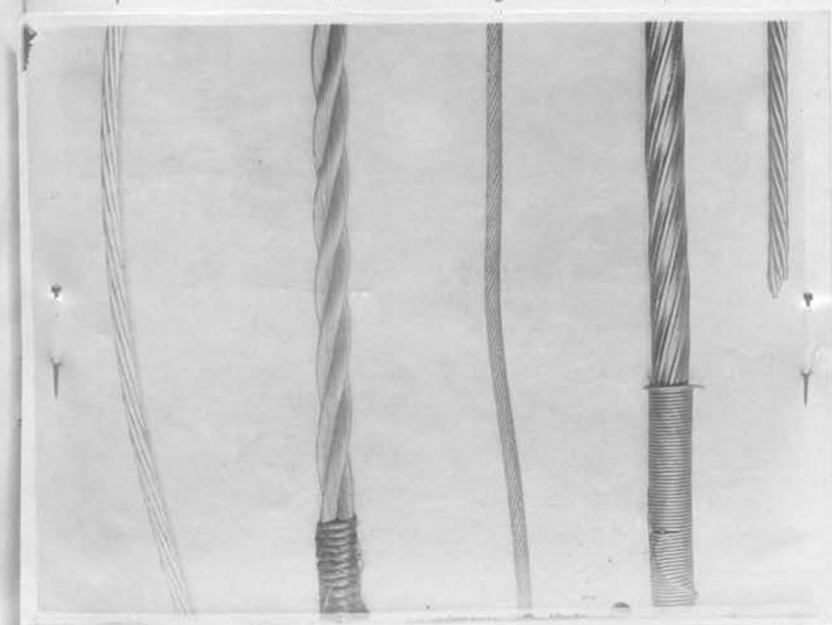
(2) Ordinary Lay
larger value of ω.

(3) Langs Lay

(4.) Cable (peculiar type)

(5) Ordinary Lay: a fracture

1 2 3 4 5



Photograph No 5

Some Typical Constructions

(1) An Aerial $\frac{6}{1}/d$

(2) A rare winding 3/n/d

(3) An extra flexible rope: fine wires: many strands: fibre core: large value of ω.

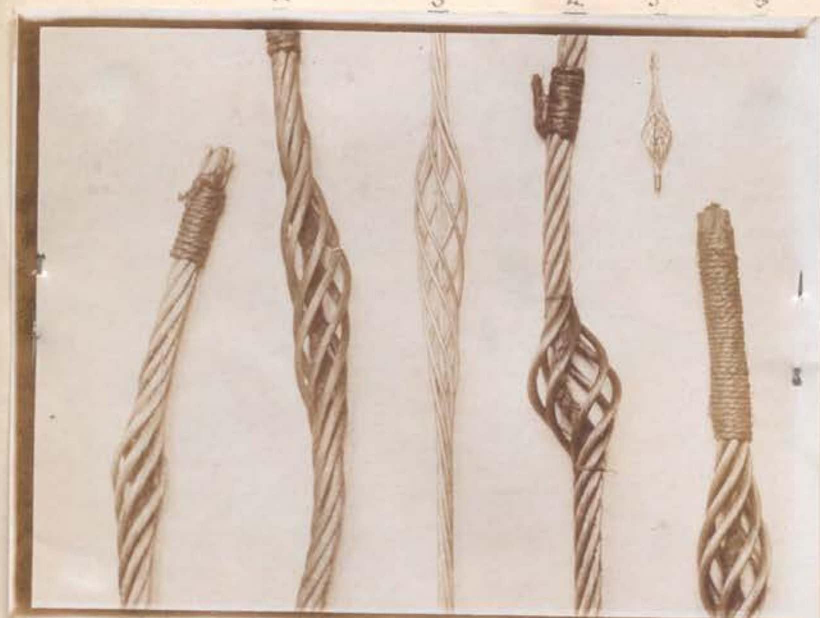
(4) A locked coil rope

(5) Fracture of a $\frac{6}{1}/d$ strand of heavy wire

Photograph No. 6.

Fracture of a heavy rope
Note drawing down at fracture: also the abnormally symmetrical breakage: and the expansion of and markings on the fibre core.

1 2 3 4 5 6



Photograph No. 7

'Aneurisms' at Fracture.
Note the large bulbs on 4 & 6.
(3) is an 'Orial': note ~~the~~ sine curves with decreasing amplitudes (die-away waves)

5) is a 12/6/1/d 1-strand rope. The two bulbs are shown one within the other.