VAN NOSTRAND'S SCIENCE SERIES

[illegible] [illegible]

SUSPENSION BRIDGES AND CANTILEVERS

[illegible] PROPORTIONS [illegible] SPANS

[illegible]

[illegible]

NEW YORK
D. VAN NOSTRAND COMPANY,
23 MURRAY AND 27 WARREN STREETS.
1911.

SUSPENSION BRIDGES AND CANTILEVERS

THEIR ECONOMIC PROPORTIONS AND LIMITING SPANS

Submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy, in the Faculty of Pure Science, Columbia University.

BY

D. B. STEINMAN, C. E., PH. D.

Assistant Professor of Civil Engineering at the University of Idaho.

NEW YORK

D. VAN NOSTRAND COMPANY,

23 MURRAY AND 27 WARREN STREETS.

1911.

PREFACE.

In recent engineering literature there is frequent reference to the question of the relative adaptability of the cantilever and suspension bridges to long span construction and to the dearth of adequate data from which the limiting and economic spans for the two bridge-types might be deduced. In order to supply this deficiency and to determine as definitely as practicable the length of span at which the suspension bridge becomes economically superior to the cantilever, the author has undertaken the investigations which are summarized in the following pages.

In connection with these investigations there have arisen several subsidiary problems of design. It was found necessary to determine the economic rise-ratio for suspension bridges, the minimum depth of stiffening trusses for adequate rigidity, the economic depth of stiffening truss, the best span-ratios and the minimum width for cantilevers and allied questions of design or construction. The solutions of these problems, together with outlines of the methods of designing the different parts of the bridge structures are included in this book.

The author desires to express his indebtedness to Professor W. H. Burr of Columbia University for his valuable suggestions and helpful guidance, to Professor C. N. Little of the University of Idaho for help in correcting the manuscript and other kind assistance, and to the Department of Bridges of New York City for considerable information and data freely placed at the author's disposal.

COLD SPRING ON THE HUDSON,
August 1, 1911.

CONTENTS

SUSPENSION BRIDGES AND CANTILEVERS

CHAPTER I

INTRODUCTION

Art. 1

Statement of Problem and Proposed Method of Investigation

Each type of bridge construction has some limiting span-length which it cannot, physically, exceed. This *maximum span* may be defined as the length at which the ratio of the intrinsic weight to the applied weight becomes infinite. In other words, it is the length at which the structure cannot carry any load in excess of its own weight; any attempt to increase the load resulting in members of infinite cross-section. Under the stress of necessity, the span of any type of bridge may be pushed as close as may be desired to the maximum span-length; but this can be done only at a very great sacrifice of economy, as the cost of the structure increases very rapidly when the span approaches the limiting value. The length of the maximum span for any form of bridge may be determined with sufficient definiteness from theoretical considerations applied to the data of actual designs; but it must be borne in mind that the results of such determination are subject to expansive revision when the methods of design or the materials of construction undergo improvement.

In addition to a maximum span-length, each bridge type has an *economic range of spans*, within which it will be less costly than any other form of construction. If, for any two comparable types of structure, a *span of* *equal cost* be determined, that span will be the inferior economic limit for one of the bridge-types and the superior economic limit for the other.

The term *economic span* will be used to designate the span at which the cost of a bridge would exceed the capitalized value of its usefulness to the builders. Although this is a problem of great practical significance, it does not lend itself to accurate treatment in any general manner owing to the large possible variations in local conditions, such as the magnitude and financial importance of the traffic expected, the cost of real estate for land spans and approaches, and the difficulty encountered in locating suitable foundations. The results of a general determination of the economic span, as here defined, will therefore be of doubtful practical value except for purposes of illustration or comparison.

The maximum and economic span-lengths for bridges of ordinary span have been fixed pretty definitely by the results of numerous designs and comparative estimates. We may take our values of these limiting lengths from the consensus of opinion among engineers as evidenced by their uniformity of practice. Thus the ordinary truss bridge finds its range of usefulness between the limiting spans of about 120 and 550 ft., there being but three truss spans exceeding the latter value. Below this range, the steel girder or concrete arch is more economical; above these limits the steel arch enters into competition. The latter construction, in turn, ceases to be economical at about 800 ft., although the proposed Hell Gate Arch is to have a span of 978 ft.

For longer spans, the selection of a bridge structure narrows down to a choice between the *suspension bridge* and the *cantilever*. The relative economy of these two forms of construction has long been a mooted question. It is true that the longest span in existence, viz., the Forth Bridge, is of the cantilever type, but it is a question whether the selection of this type was not a mistake. "It is not a design which would ever be imitated. Its proportions are very injudiciously taken, and there is a failure to reach the degree of economy which ought to exist even in the cantilever."[1]

In the preliminary investigations for the Quebec Bridge, the Phoenix Bridge Company made comparative estimates of a cantilever and a suspension bridge for the 1800-ft. span. "Although the cantilever type exhibited the more economic results of the two as the members were then computed, at the present time the economy of the adopted type is not so clear as it was originally thought to be."[2] The collapse of that ill-fated structure, and the investigations following the completion of the Queensboro Bridge have shaken

[1] W. H. Burr, Proceedings of the Engineers' Club of Philadelphia, December, 1899.

[2] Editorial in *Engineering Record*, Sept. 5, 1908.

the general confidence in the cantilever type of construction and have directed the attention of engineers to the more adequate design of compression members in such structures. When these members are designed in accordance with the recent disclosures, it is a question whether the previously accepted economic limit for cantilevers, viz., about 2000 ft., will not have to be considerably reduced.

The limiting *economic span* for cantilevers is placed by Prof. Burr [1] at 2000 ft. for railway bridges and at 1400–1600 ft. for highway bridges; by Prof. Merriman [2] at 1500 ft.; and by Prof. Melan [3] at 500 meters. Gustav Lindenthal [4] (M. Am. Soc. C.E.) would

[1] Proceedings of Engineers' Club of Philadelphia, December, 1899. *Ancient and Modern Engineering* (New York, 1903), p. 177.

[2] *Roofs and Bridges* (New York, 1905), Part IV, pp. 110, 155.

[3] *Handbuch der Ingenieur-Wissenschaften* (Leipzig, 1906). II. Band, V. Abteilung, s. 206.

[4] *Engineering* (London), December 19, 1890 also Proceedings Am. Soc. C. E., Sept. 21, 1904.

use the cantilever for spans between 500 and 2000 ft., the steel arch between 2000 and 4000 ft., and the suspension bridge for all greater spans. Jos. Mayer[1] (M. Am. Soc. C.E.) considers the minimum economic span for the suspension type to be 800 ft. for highway bridges and 1300 ft. for railway bridges. No mention is made of data upon which these estimates are based.

The question of *maximum span* has also been under discussion. In 1894, a prominent bridge engineer declared before a congressional committee that "a bridge of 2800 ft, would be just capable of holding its own weight without carrying any live or moving load."[2] A few months later, a board of engineers approved a design for a suspension bridge of 3100-ft. span and showed its "feasibility of manufacture and cost." This Board, appointed by act of Congress to determine the practicability of a long-span bridge across

[1] Proceedings Am. Soc. C. E., October, 1904.
[2] *Engineering Record*, Nov. 18, 1899.

the Hudson River at New York City, and consisting of Major C. W. Raymond, W. H. Burr, G. Bouscaren, Theodore Cooper and Geo. S. Morison, conducted a series of investigations and reported that, at the proposed site, a 2000-ft. clear-span cantilever could be built for $27,000,000, a 3100-ft. clear-span cantilever for $51,000,000, and a 3100-ft. clear-span suspension bridge for $31,000,000.[1] These results indicate that the maximum practicable limit for suspension bridges is above 3000 ft., and that the economic limit for cantilever bridges is far below that value.

In the same year the Secretary of War directed the formation of "a Board of Officers of the Engineer Corps who shall investigate and report their conclusions as to the maximum length of span practicable for suspension bridges and consistent with an amount

[1] Senate Executive Documents, 53d Congress, 3d Session, No. 12, Report of Board of Engineers on the N. Y. and N. J. Bridge, Aug. 23d 1894.

of traffic probably sufficient to warrant the expense of construction." Assuming that the bridge of maximum span is supported by sixteen $21\frac{1}{2}$-inch cables, and has to carry a uniform live-load of 27,540,000 lbs. $\div L$. the Board obtained a value of $L = 4335$ ft. for the practical maximum span.[1] The above assumptions, however, were rather arbitrary; any other combination of assumed values for cable-section and loading would have resulted in a different value for the maximum span-length.

Although comparative designs of the two types of long-span bridges have been prepared in individual instances for the particular local conditions obtaining, the writer has been unable to find any general comparison of the two bridge-types for the purpose of establishing their relative economic or

[1] Senate Executive Documents, 53d Congress, 3d Session, No. 12, Report of Board of Engineer Officers to Make Investigations of Certain Bridges, Sept. 29, 1894.

limiting spans. He has therefore undertaken the determination of these values, namely:

1. The maximum practicable span for the suspension-bridge form of construction.

2. The maximum practicable span for cantilevers.

3. The maximum economic span for suspension bridges.

4. The maximum economic span for cantilevers.

5. The span of equal cost for the two types; in other words, the span at which the cantilever ceases to be economically superior to the suspension bridge.

The method proposed for the solution of these problems is to prepare designs and estimates of a wide range of cantilevers and suspension bridges and to deduce therefrom the laws of variation of weight and cost with length of span. The relations between span and weight, thus established, will fix the maximum feasible span for each form of construction. The cost-curves of the two types will indicate their comparative economy at different spans as well as the critical span of equal cost. Finally, an estimate of the maximum probable traffic returns, compared with the costs of different spans, will determine the economic limiting length for each type.

The cost of a structure for a given span will, of course, be affected by local conditions such as prices of material, specified unit stresses, depth of foundations, etc. In order that the comparison between the cantilever and the suspension bridge may be an absolutely fair one, it is essential that all such arbitrary or varying factors be chosen with extreme care and be kept exactly the same for both types of construction. Furthermore, in order that the results for the limiting spans may be the true maximum values, it is necessary to carefully determine and use the most favorable proportions, material and form of construction for each design.

TABLE I.—NOTABLE

Date.	Name.	Location.	Engineer.
1903	Williamsburg..	East R., N. Y....	L. L. Buck..
1883	Brooklyn.....	East R., N. Y....	Roebling....
1909	Manhattan....	East R., N. Y....	Dept. of Br..
1869	[1] Niagara	Niagara Falls....	Keefer......
1867	Ohio R.......	Cincinnati, O....	Roebling....
1851	[2] Niagara	Lewiston, N. Y ..	Serrell......
1900	Miampimi.....	Mexico..........	....
1848	[3] Wheeling.....	Ohio R.. W. Va..	Ellet........
1903	Elizabeth.....	Budapest........	Dept. of Br..
1834	[4] Freiburg......	Switzerland......	Chaley......
1855	Niagara Ry...	Niagara Falls....	Roebling....
1899	Niagara	Lewiston, N. Y..	R. S. Buck..
1900	Rochester.....	Ohio R., Pa	....
1877	[5] Point.........	Pittsburg........	Hemberle...
1902	Vernaison.....	France..........	....
1896	E. Liverpool ..	Ohio............	....
1864	Clifton	Bristol, Eng.....	....
1845	Lancz........	Budapest........	Clark.......
1855	Morgantown ..	W. Virginia......	....
1825	Menai	Wales...........	Telford .....
1905	Villefranche...	France..........	(Gisclard)...
1904	Caperton	W. Virginia......	Cooney .....
1868	[6] Moldau.......	Prague..........	....
1852	[7] Charleston....	W. Virginia......	Ellet........
1818	Tweed........	Berwick, Eng....	Brown......
.....	Grand Ave....	St. Louis........	....
1862	Lambeth	London.........	....
1826	[8] Conway	Chester, Eng.....	....

[1] Strengthened 1888. Wrecked and rebuilt 1889. Replaced by arch 1896.
[2] Removed 1864.
[3] Rebuilt 1854 and 1862.
[4] Two cables added 1881.
[5] Reconstructed 1905.
[6] Rebuilt with cables 1900.
[7] Failed 1904.
[8] Rebuilt 1904.

Suspension Bridges.

Span.		Rise $=f$	Cables.		Truss.		Loading.		
l	l_1		No.	Size.	D'p'h	W't'	L.L.	D.L.	$\frac{\text{D.L.}}{\text{L.L.}}$
1600	596	177	4	18¾"	40	118	6300	16620	2.6
1595	*930	†128	4	15⅝	9, 17	85	2600	8200	3.2
1470	*725	160	4	21¼	24	122	8000	18000	2.2
1268									
1057	*281	†90	4	12½	28	52	3600		
1042	....	87	8	....	.....	21			
1030	....	†	2	....	5	....	100	300	3.0
1010	....	....	4	8					
951	145	95	4	20"E.B.	23	66	5500	14500	2.6
870	174	63	6	2, 8	5	21			
821	....	†54	4	10¼	16	25	1800	1800	1.0§
800	34	53	4	10	14	28	2400	2850	1.3
800	*416	72	2	7	18				
800	145	88	2	8"E.B.‡	8	34	1700		
764	*172	†	2	....	4	17	680	600	0.9
705	....	....	2	7⅝					
702	....	....	...	Chains					
663	*285	48	4	Chains					
608	150	42	6	3¼	5	20	2000		
578	*260	43	16	Chains	.....	....	....	2500	
512	128	†	2	‡Wire	0	20	2000	2000	1 0
510	*	37	2	1½	0	6	120	100	
482	....	....	8	Chains	.....				
478	....	25	4	3¼	0	17			
450	....	30	12	Chains					
400	*150	40	4	‡Chains	.....	60			
363	....	....	.4.	‡Chains					
327	....	22	...	Chains					

* Provided with suspenders in side spans.
† Stiffened with diagonal stays.
‡ Braced cable construction.
§ Railway bridge. Replaced by arch in 1897.

CHAPTER II

STUDY OF SUSPENSION BRIDGES

Art. 2

Suspension Bridges

The economic utilization of the materials of construction demands that, as far as possible, the predominating stresses in any structure should be those for which the material is best adapted. The superior economy of steel in tension and the uncertainties involved in the design of large-sized compression members point emphatically to the conclusion that the material of long-span bridges, for economic designs, must be found to the greatest possible extent in tensile stress. This requirement is best fulfilled by the suspension-bridge type.

The superior economy of the suspension type for long-span bridges is due fundamentally to the following causes:

1. The very direct stress-paths from the points of loading to the points of support.

2. The predominance of tensile stress.

3. The highly increased ultimate resistance of steel in the form of cable-wire.

With the exception of the Forth Bridge, the Queensboro Bridge and the Quebec Bridge (under construction), all structures exceeding 1000 ft. in span have been suspension bridges. Table I gives a list of the most notable structures of this type, with their principal dimensions. It is seen from this table that all suspension bridges erected after what might be called the experimental period (1796–1876) have a minimum span of about 800 ft. and a maximum span of 1600 ft.

In order to secure information needed in determining the maximum and economic spans for suspension bridges, in addition to the data supplied by existing structures, the writer has undertaken the design of three suspension bridges, having span-lengths of 1500, 2250 and 3000 ft., respectively. To justify the large expenditure involved in structures of this magnitude, they will be assumed to be railroad bridges, with additional provision for electric cars, driveway and footwalks.

Before we can proceed with the designing of the structures, it is necessary to find the most favorable solutions of the following problems:

1. The choice between wire-cable and eye-bar construction.

2. The economic ratio of cable-rise to length of span.

3. The best ratio of depth of stiffening truss to length of span.

Art. 3

Wire Cable *vs.* Eye-bars

One of the first questions to be decided in the design of a suspension bridge is the choice between a steel-wire cable and a chain of eye-bars for the principal carrying member. The latter enables the bracing for the prevention of deformation under moving load to be incorporated in the cable system; the other requires a separate stiffening truss for the reduction of these deflections. A third method of bracing the suspension bridge against deformation is the introduction of diagonal stays between the towers and the roadway, as was done in the Ohio River, Brooklyn and Vernaison Bridges. This method, however, has been abandoned in recent designs as the stays have been shown to be of doubtful utility and, furthermore, fail to act in unison with the cable and suspenders under changes of temperature.

The earliest suspension bridges were built with chains. James Finley, the pioneer builder of suspension bridges in America, used common wrought-iron chains for all of his bridges from the 70-ft. span at Uniontown, Pa.

(1796), up to his greatest achievement, the 309-ft. span of the Schuylkill Bridge (1808). In 1818, Brown substituted a chain of eye-bars, bolted together, in building the Tweed Bridge of 450-ft. span. This construction was followed in the Menai Bridge, built by Telford in 1825, and the Hammersmith Bridge (London) built by Clark in 1827. The following year an advance was marked by the use of open-hearth steel for the chains of the Karl Bridge at Vienna (312 ft. span). Steel eye-bar chains remained in use for bridges of constantly increasing span, including Brunel's Hungerford Bridge (London, 1845), Clark's Bridge at Budapest of 663 ft. span (1845), and the Clifton Bridge of 702 ft. span (Bristol, 1864).

In the meantime, John A. Roebling was at work at Saxonburg, Pa., inventing and developing the manufacture of wire rope. He soon conceived the possibility of its application in the construction of suspension bridges, in place of the eye-bar chains, on account of its superior strength and ease of erection. Beginning with the use of wire cable for the suspension of canal aqueducts, he proceeded to apply it to more ambitious structures. In 1848, Chas. Ellet built the wire-cable bridge over the Ohio River at Wheeling with a span of 1010 ft. which was blown down in 1854. In 1851, Roebling commenced his 821-ft. suspension bridge over Niagara Falls, the first and only suspension structure to be built for heavy railroad traffic. In 1867, he completed the Covington and Cincinnati Bridge over the Ohio River, with a span of 1057 ft. These achievements of Roebling, however, were but a preliminary training for "the monumental work that was to cost him his life while crowning it with glory." When he presented his plans for spinning his steel wires over the vast span of the Brooklyn Bridge, he had to defend his ideas against the scoffing of the whole world and had to fight his opponents inch by inch before the right to try was given him. The bridge was finished by his son in 1883, and held the record for length of span (1595.5 ft.) until the Williamsburg Bridge (1600 ft.) was completed by L. L. Buck in 1903. With the third span across the East River, the Manhattan Bridge of 1470 ft. span, opened in 1909, we are brought to the present day in the history of suspension bridges.

Since the time of Roebling, wire cables have been used in all suspension bridges with but one exception: the Elizabeth Bridge over the Danube River at Budapest (1903). Its span of 951 ft. is the largest of any suspension bridge outside of America.

In nearly all of the above bridges, a stiffening truss is the means employed to prevent the deformations due to live-load, wind and changes of temperature. Another practicable method is to build the cable as a trussed structure like an inverted two-hinged or three-hinged arch. This method was used in the Point St. Bridge at Pittsburg (span = 800 ft.) which was built by Hemberle in 1877. In this bridge the cable is composed of 8-inch eyebars and is trussed on its upper side by bracing connecting it to two straight chord-members running from the ends to the middle of the cable.

In 1894, Gustav Lindenthal offered a design for a suspension bridge over the Hudson River, with a clear-span of 3100 ft., in which he used two pairs of parallel cables connected by a system of bracing in a vertical plane.[1] He proposed building the cables of pin-connected wire links, claiming for such construction the advantages of accurate work and close inspection in the shop, rapid erection, and possibility of varying the cable-section as required.

In preparing the design of the Manhattan Bridge over the East River, the New York Department of Bridges followed Lindenthal's scheme, using

[1] Report of Board of Engineer Officers on the N. Y. and N. J. Bridge, 1894. Appendix D.

braced cables built up of eye-bars. The following year, with a change of city administration, that plan was abandoned and the structure redesigned with wire cables. In September, 1904, Lindenthal explained and defended his design in a paper read before the American Society of Civil Engineers,[1] which gave rise to a long series of very fruitful discussions.[2] The principal advantages claimed for the two types may be summarized as follows:

Advantages of the Braced-cable Type of Suspension Bridge

1. By having the greatest depth of the bracing at the one-quarter points, where the maximum moments occur, the stiffness of the bridge with a given expenditure of material is greatly increased.

2. The small depth along the middle third of the span reduces the temperature stresses.

[1] Transactions Am. Soc. C. E., Sept. 21, 1904.
[2] Ibid., Oct., 1904 to Mar., 1905.

3. The stiffened-cable construction saves one chord of the truss as the cable itself forms the upper chord.

4. The section of an eye-bar chain may be varied with the stress, whereas the entire wire cable must have the maximum section.

5. Greater weight, if it does not increase the cost, is an advantage in a bridge, as it serves to increase the rigidity of the structure.

6. The pin-connections facilitate the speedy erection of the cable.

Disadvantages of the Braced-cable Type

1. An unpleasant appearance is produced by the lattice-work up in the air.

2. Since the bottom chords of the bracing run to the top of the towers, special wind-chords at the floor-level become necessary for lateral stiffness, and these may be as heavy as the bottom chords themselves.

3. It is impossible to calculate the

stresses accurately on account of the difficulty in adjusting the members. The safe working stresses should therefore be reduced by at least 5 per cent.

4. The braced-cable type exposes a large area to the wind at the highest elevation, thereby greatly increasing the wind-stresses in the bracing and in the towers.

5. If the floor is not stiffened vertically, every suspender receives a heavier concentrated load and every shock from moving loads is transmitted directly to the cables instead of being absorbed by the floor system.

6. The braced system introduces many elements of uncertainty and complexity in the structure, and the history of bridge design shows that "the lines of progress have been in the direction of eliminating uncertain elements and holding fast to those features which secure certainty in the determination of stresses."

7. The practical difficulty, hazard and expense of making satisfactory

connections between a cable and the web-members of an overhead bracing system preclude the use of wire cables, and to abandon the wire cables is to abandon all the essential advantages of the suspension bridge. The superior economy of the wire cable over eye-bar construction rests on the following considerations:

(*a*) Steel wire with an elastic limit of 180,000 lbs. per sq.in., is obtainable at a cost of but twice as much per pound as nickel-steel eye-bars with one-fourth the elastic limit.[1]

(*b*) The eye-bar heads and pins add about 25 per cent to the weight of the cable.

(*c*) An eye-bar chain will therefore weigh about four times as much, and cost about twice as much as a wire cable to carry an equal load, if the same factor of safety is to be maintained.

(*d*) The increased dead-weight of

[1] Cf. R. S. Buck and Jos. Mayer, Trans. Am. Soc. C. E., Oct., 1904.

the cable, when eye-bars are used, results in increased stresses in cable, towers and anchorages.

(*e*) The wire cable is self-supporting during erection and all the problems involved have been worked out and successfully demonstrated. The eye-bars, on the other hand, would require a temporary supporting cable; and the manufacture and erection of eye-bars of suitable size for very long spans present many unsolved difficulties.

Many of the advantages enumerated above, particularly those bearing on the economy of the respective types, practically balance each other, so that, in consequence, there is really no material difference between the costs of the two forms of construction. In a comparative design of the two types for a proposed bridge at Cologne, of 722 ft. span, O. Erlinghagen found that the eye-bar chain would require about twice as much material as the wire cable but, on account of the difference in unit prices, the total cost of the two structures was almost exactly the same.[1] Jos. Mayer (M. Am. Soc. C.E.) compared the two types for a span of 3000 ft., and found the braced-cable type to weigh 5000 lbs. more per linear foot than the other.[2] Prof. J. Melan found the difference of cost between chain and cable for the Elizabeth Bridge at Budapest to be negligible, the eye-bar chain being adopted for other considerations.[3] The two designs for the Manhattan Bridge showed a difference in cost of 7 per cent in favor of the eye-bar type, although the chain in the latter weighed $2\frac{1}{2}$ times as much as the wire cable.[4]

Omitting from consideration the possibility of using the overhead system of bracing in conjunction with a wire cable, a construction which would combine the essential advantages of

[1] *R. R. Gazette*, Nov. 20, 1903.

[2] Transactions Am. Soc. C. E., Vol. 48, p. 371.

[3] Transactions Am. Soc. C. E., Feb., 1905.

[4] *Engineer* (London), Aug. 28, 1903.

both systems but of which the feasibility has not yet been demonstrated, and without presuming to decide between the relative advantages of the two types of cable construction, the writer will adopt the *wire-cable type* in the present investigations for the following reasons:

1. As both types are practically equal in cost, this choice will not affect the results for the economic lengths of span.

2. As the wire cable affords a great saving in weight, it will yield a larger value for the maximum practicable span.

3. As this choice conforms with the accepted past and present practice in suspension bridge design, and as no radical changes need be expected in the proximate future, the results obtained will be better adapted for comparison with the data of existing structures and of greater value in estimating future designs.

Art. 4

The Economic Ratio of Rise to Span

(*a*) *Cost of Cable.* Let n = the ratio of the rise (f) to the span (l) of the cable. The total load per linear foot carried by the cable consists of two parts: g_0 = the weight of the cable itself, and g_1 = the weight of the total suspended (dead and live) load. As is well known, if α is the inclination of the cable at the towers, the maximum tension in the cable will be

$$T = H \cdot \sec \alpha = (g_0 + g_1)\frac{l^2}{8f}\sqrt{1+16n^2}. \quad (1)$$

The weight of the cable per *horizontal* linear foot is given by

$$g_0 = (1 + \tfrac{8}{3}n^2)\frac{T}{s_0} \cdot \gamma_0, \quad . \quad . \quad (2)$$

where s_0 is the unit working stress and γ_0 is the weight per linear foot per square inch of cross-section. Substituting the value of T from Eq. (1), Eq. (2) may be written,

$$g_0 = k(g_0 + g_1) \cdot l \cdot \frac{1}{n} \sqrt{1+16n^2} \quad . \quad (3)$$

where

$$k = (1 + \tfrac{8}{3}n^2)\frac{r_0}{8s_0} \quad . \quad . \quad . \quad (4)$$

The factor $(1+\frac{8}{3}n^2)$, for all practical values of n, varies only from the value 1.02 to 1.05; hence the quantity k may be considered as practically independent of the rise-ratio n. The solution of Eq. (3) gives

$$g_0 = g_1 \frac{kl\frac{1}{n} \cdot \sqrt{1+16n^2}}{1 - kl\frac{1}{n} \cdot \sqrt{1+16n^2}} \quad . \quad . \quad (5)$$

If L_0 = the total horizontal length of cable and c_0 = the cost per pound of the cable material, the total cost of the cable will be,

$$C_0 = L_0 \cdot c_0 \cdot g_0.$$

Substituting the value of g_0 from Eq. (5), we obtain

$$C_0 = a \cdot (g_1 l^2) \cdot \frac{k\frac{1}{n}\sqrt{1+n^2}}{1 - kl\frac{1}{n} \cdot \sqrt{1+n^2}}. \quad (6)$$

where

$$a = \frac{L_0}{l} \cdot c_0. \quad . \quad . \quad . \quad (7)$$

Numerical Values. Allowing for the weight of cable wrapping, a mean value for γ_0 is 3.5. Hence, by Eq. (4), for a range of

$$\frac{f}{l} = \frac{1}{7} \text{ to } \frac{1}{10},$$

we may take,

$$k = \frac{0.455}{s_0}. \quad . \quad . \quad . \quad (4')$$

If $c_0 = 15$ cents per lb. and $\frac{L_0}{l}$ has its minimum value of 1.5 (for no suspenders in side spans),

$$a = 22.5. \quad . \quad . \quad . \quad . \quad (7')$$

If the side-spans are suspended, $\frac{L_0}{l}=2$, hence

$$a=30.0 \quad . \quad . \quad . \quad . \quad (7'')$$

(*b*) *Cost of Suspension Rods.* If L_2 is the total length of bridge provided with suspension rods, the total load carried by them will be g_1L_2. Since the cable is a parabola, the average length of the rods is $f/3$. If s_2 is the unit stress, γ_2 the unit weight, and c_2 the unit cost, the total cost of the rods will be

$$C_2=c_2\cdot\frac{g_1\cdot L_2}{s_2}\cdot\gamma_2\cdot\frac{f}{3}$$

This may be written

$$C_2=b\cdot(g_1l^2)\cdot n \quad . \quad . \quad . \quad (8)$$

where

$$b=\frac{c_2\gamma_2}{3s_2}\cdot\frac{L_2}{l}. \quad . \quad . \quad . \quad (9)$$

Numerical Values. If $s_2=30{,}000$ lbs. per sq.in., $\gamma_2=3.4$, $c_2=12$ cents per lb., and $L_2/l=1$ (i.e. no suspenders in the side-spans), then

$$b=.00045. \quad . \quad . \quad . \quad (9')$$

If $\frac{L_2}{l}=2$ (side-spans suspended), then

$$b=.00090. \quad . \quad . \quad . \quad (9'')$$

(*c*) *Cost of Towers.* With the entire bridge fully loaded, the total compression in each tower will be twice the end-shear in the cable or

$$P_3=(g_0+g_1)\cdot l. \quad . \quad . \quad (10)$$

If s_3 is the working intensity of stress, the required section for each tower is

$$A_3=\frac{P_3}{s_3}\cdot=\frac{(g_0+g_1)l}{s_3}, \quad . \quad (11)$$

or, substituting the value of g_0 from Eq. (5),

$$A_3=\frac{g_1 l}{s_3}\cdot\frac{1}{1-kl\cdot\frac{1}{n}\sqrt{1+16n^2}}. \quad (12)$$

Let γ_3 = the weight per linear foot of tower per square inch of cross-section, c_3 = the unit cost of the material, $\tau\cdot f=$

total height of tower; then the total cost of the two towers will be

$$C_3 = 2 \cdot A_3 \cdot \gamma_3 \cdot \tau \cdot f \cdot c_3,$$

or, substituting the value of A_3 from Eq. (12),

$$C_3 = c(g_1 l^2) \cdot \frac{n}{1 - kl\frac{1}{n} \cdot \sqrt{1+16n^2}}, \quad (13)$$

where

$$c = 2\tau \cdot \frac{\gamma_3 \cdot c_3}{s_3}. \quad . \quad . \quad . \quad (14)$$

Numerical Values. A comparative study of existing structures yields the following mean values for the constants: $\gamma_3 = 6.5$ (including diagonal members, details, etc.), $c_3 = 5.6$ cents per lb. (price of structural steel and erection), $s_3 = 8000$ lbs. per sq.in. (for the direct stress exclusive of bending stresses), $\tau = 1.6$ (a mean value for the longer spans). With these values, Eq. (14) gives

$$c = .0145. \quad . \quad . \quad . \quad (14')$$

Thus far, in the analysis, there is nothing essentially new. We now proceed to apply the above results to our immediate purpose.

Total Cost. The total cost of the structure, exclusive of truss, anchorages, substructure, etc. (which are independent of n), may be obtained by adding together the right-hand members of Eqs. (6), (8), (13), giving the result,

$$C=g_1l^2\left[a\cdot\frac{k\cdot\frac{1}{n}\cdot\sqrt{1+16n^2}}{1-kl\cdot\frac{1}{n}\cdot\sqrt{1+16n^2}}\right.$$

$$\left.\cdot+bn+c\cdot\frac{n}{1-kl\cdot\frac{1}{n}\cdot\sqrt{1+16n^2}}\right],$$

or, expanding the radical,

$$C=g_1l^2\cdot\left[\frac{ak(1+8n^2-32n^4+\ldots)+cn^2}{n-kl(1+8n^2-32n^4+\ldots)}+bn\right]. \quad (15)$$

The condition for a minimum total cost then becomes

$$\frac{\delta C}{\delta n}=g_1l^2.$$

$$\cdot\left[\frac{\begin{array}{l}(n-kl-8kln^2+32kln^4-\ldots)\\ .(2cn+16akn-128akn^3+\ldots)\\ -(cn^2+ak+8akn^2-32akn^4+\ldots)\\ .(1-16kln+128kln^3-\ldots)\end{array}}{n^2-2kl(n+8n^3-32n^5+\ldots)+k^2l^2(1+16n^2)}+b\right]=0.$$

Clearing of fractions, and arranging the terms according to the ascending powers of n, we obtain,

$$(bk^2l^2-ak)-(2ckl+2bkl)n+(8ak+b+c+16bk^2l^2)n^2 -(16bkl)n^3-(96ak)n^4+\ldots=0. \quad (16)$$

It may be readily shown that the terms containing n^3 or higher powers of n are absolutely negligible in comparison with the remaining terms, and they will therefore be dropped from the equation. Solving the resulting quadratic equation for n, we obtain

$$n=\frac{(b+c)2kl\pm\sqrt{4(b+c)ak+32a^2k^2+k^2\cdot(32abk+4bc+4c^2)l^2-64b^2k^4l^4}}{2(b+c)+16ak+32bk^2l^2} \quad (17)$$

On account of the relatively small values of b and k, the terms containing bk^2 and b^2k^4 may be neglected without any appreciable error for any feasible length of span. The equation is thus simplified to

$$n=\frac{2k(b+c)\cdot l\pm\sqrt{4(b+c)ak+32a^2k^2+4ck^2(b+c)l^2}}{2(b+c)+16ak} \quad (18)$$

This equation shows:

1. That the economic rise-ratio (n) increases with the length of span.

2. That the economic rise-ratio increases with any increase in the cable-factors (a, k) and decreases with any increase in the tower-factor (c) or the suspension-rod factor (b). See Eqs. (4), (7), (9), (14).

Substitution of Numeral Values. Case I. No suspenders in the side-spans. By Eqs. (4′) (7′), (9′) and (14′)

$$k=\frac{.455}{s_0} \qquad b=.00045.$$

$$a=22.5 \qquad c=.0145.$$

Substituting these values in Eq. (18), we obtain

$$n=\frac{.0299l\pm\sqrt{2.961s_0+16210+.000867l^2}}{.0658s_0+360} \tag{18a}$$

If $s_0=60{,}000$ lbs. per sq.in., this becomes

$$n=.0070l+\sqrt{.0105+.000047l^2}, \tag{18$'a$}$$

where l is the span-length in thousands of feet. Hence, if

$$\left.\begin{array}{ll} l=0, & n=.103=\dfrac{1}{9.7} \\[2ex] l=1000', & n=.110=\dfrac{1}{9.1} \\[2ex] 2000', & n=.118=\dfrac{1}{8.5} \\[2ex] 3000', & n=.126=\dfrac{1}{7.9} \\[2ex] 4000', & n=.135=\dfrac{1}{7.4} \end{array}\right\} \text{Economic ratios of rise to span.}$$

Case II. Suspended side-spans.

By Eqs. (4′), (7″), (9″) and (14′),

$$k=\frac{0.455}{s_0} \qquad b=.0009,$$

$$a=30 \qquad c=.0145.$$

Substituting these values in Eq. (18), we obtain

$$n=\frac{.0308l\pm\sqrt{4.06s_0+28{,}800+.000894l^2}}{480+.0677s_0} \tag{18b}$$

If $s_0 = 60{,}000$ lbs. per sq.in., this becomes

$$n = .0068l \pm \sqrt{.0133 + .000044l^2}, \qquad (18'b)$$

where l is the span-length in thousands of feet. Hence, if

$$\left.\begin{array}{ll} l=0, & n=.116=\dfrac{1}{8.7} \\[2ex] l=1000', & n=.123=\dfrac{1}{8.2} \\[2ex] \quad 2000', & n=.130=\dfrac{1}{7.7} \\[2ex] \quad 3000', & n=.138=\dfrac{1}{7.3} \\[2ex] \quad 4000', & n=.146=\dfrac{1}{6.9} \end{array}\right\} \text{Economic ratios of rise to span.}$$

The above results justify the value of $n = \frac{1}{8}$ generally recommended for spans of the usual length.

Working Stress in the Cable

In the preceding treatment, a value of 60,000 lbs. per sq.in., was assumed for the unit stress in the cable. This conforms to generally approved practice, and affords a safety factor of three (on the elastic limit).

The following considerations indicate that the safety factor may be judiciously reduced as the span is increased:

1. On a longer span it takes more time for a maximum load to come upon the bridge, so that the application of stress is more gradual.

2. On a longer span with the same traffic, the combination of loads producing maximum stress will be much rarer in occurrence.

3. As the span increases, the dead-load becomes a greater percentage of the total load, so that the range of stress variation in the cable is diminished.

4. The resistance of tension members to suddenly applied stress increases with their length, on account of the increase in the resilience of the members.

5. It is reasonable to expect some improvement in the cable material before the larger spans are built. Furthermore, the best material can be afforded in the largest spans.

For the above reasons, the unit cable stress should be specified as an increasing function of the span. For this purpose, the following formula will be convenient:

$$s_0 = 180{,}000 \cdot \left(\frac{l+2000}{l+9000}\right); \quad . \quad (19)$$

this gives

$$\left.\begin{aligned} s_0 &= 60{,}000 \text{ at } l = 1500 \\ s_0 &= 75{,}000 \text{ at } l = 3000 \\ s_0 &= 86{,}500 \text{ at } l = 4500 \end{aligned}\right\} \quad . \quad (19')$$

and causes s_0 to approach the limiting value of $s_0 = 180.000 (= \text{E.L.})$ as l approaches ∞.

For substitution in the general formulæ of the preceding investigation, it will be more convenient to replace (19) by a linear equation which will give essentially the same values for s_0 for all practical values of l. Such an equation is

$$s_0 = 45{,}000 + 10l \quad . \quad . \quad . \quad (20)$$

This gives, as before,

$$\left.\begin{aligned} s_0 &= 60{,}000 \text{ at } l = 1500 \\ s_0 &= 75{,}000 \text{ at } l = 3000 \end{aligned}\right\} \quad . \quad (20')$$

Economic Rise-ratio, Corrected for Variable s_0. Instead of assuming the constant value of $s_0=60{,}000$, let the value of s_0 be specified by the linear formula

$$s_0=45{,}000+10l. \quad . \quad . \quad (20)$$

Substituting this value in Eqs. (18*a*) and (18*b*) we obtain the two formulæ

$$n=\frac{.0093l+\sqrt{.01359+.0027l+.0000787l^2}}{1+0.198l} \qquad (21a)$$

and

$$n=\frac{.00874l+\sqrt{.01701+.0033l+.000072l^2}}{1+0.192l} \qquad (21b)$$

Case I. If there are no suspenders in the side-spans, Eq. (21*a*) gives for

$l=0$, $(s_0=45{,}000)$, $n=.116$
$l=1000$, $(s_0=55{,}000)$, $n=.115$
$l=2000$, $(s_0=65{,}000)$, $n=.113$
$l=3000$, $(s_0=75{,}000)$, $n=.111$
$l=4000$, $(s_0=85{,}000)$, $n=.110$

Hence, for suspension bridges of this type, the economic cable-rise is about *one-ninth* of the span.

Case II. If the side-spans are also suspended from the cable, Eq. (21*b*) gives for

$l=0,\quad (s_0=45{,}000),\ n=.130$
$l=1000',\ (s_0=55{,}000),\ n=.127$
$l=2000',\ (s_0=65{,}000),\ n=.124$
$l=3000',\ (s_0=75{,}000),\ n=.122$
$l=4000',\ (s_0=85{,}000),\ n=.120$

Hence, for suspension bridges of this type, the economic cable-rise is about *one-eighth* of the span.

The above rise-ratios will be used in the following designs. The versed-sine (f_1) in the side-span is fixed by the relation

$$\frac{f_1}{f}=\left(\frac{l_1}{l}\right)^2 \quad . \quad . \quad . \quad (22)$$

necessary for equal cable inclinations at the towers. In the absence of any governing conditions, the side-spans will be assumed one-half the length of the main span, so that we must have

$$f_1 = \frac{f}{4} \quad . \quad . \quad . \quad . \quad (22')$$

ART. 5

MINIMUM DEPTH FOR THE STIFFENING TRUSS

If a simple truss of span l is covered with a uniform load q, the deflection at the mid-point will be

$$N_0 = \frac{5}{384} \frac{ql^4}{EI}; \quad . \quad . \quad . \quad (1)$$

the inclination (or slope) at the ends of the span will be

$$\frac{dN}{dx} = \int_0^{\frac{l}{2}} \frac{M}{EI} \cdot dx = \frac{16}{384} \frac{ql^3}{EI}; \quad . \quad (2)$$

the bending moment at the mid-point is

$$M = \frac{ql^2}{8}; \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and the corresponding chord-stress is

$$s_1 = \frac{Md}{2I}, \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where d is the depth of truss and I is its moment of inertia (assumed constant).

Eliminating M and q from Eqs. (1), (3) and (4), we obtain

$$s_1 = 4.8 \frac{Ed}{l^2} \cdot N_0. \quad . \quad . \quad (5)$$

Eliminating q from Eqs. (1) and (2) we obtain

$$\frac{dN}{dx} = 3.2 \frac{N_0}{l}. \quad . \quad . \quad . \quad . \quad (6)$$

Eliminating N_0 from Eqs. (5) and (6), we find

$$\frac{dN}{dx} = \frac{2}{3} \cdot \frac{s_1}{E} \cdot \frac{l}{d}. \quad . \quad . \quad . \quad (7)$$

In the stiffening truss hinged at the towers, the maximum stresses occur with a load extending over one-half of the span. Each half of the truss then acts very nearly as a simple beam carrying a uniform load (=actual load − suspender forces). We may therefore apply the preceding formulæ, (1) to (7), upon replacing l by the half-span of the suspension bridge $\left(=\frac{l}{2}\right)$. Eq. (7) then becomes

$$\frac{dN}{dx}=\frac{1}{3}\frac{s_1}{E}\cdot\frac{l}{d}. \quad . \quad . \quad . \qquad (7')$$

Hence, if the maximum allowable grade $\left(\frac{dN}{dx}\right)$ is specified, the minimum depth of truss will be defined by

$$\frac{d}{l}=\frac{1}{3}\frac{s_1}{E}\div\frac{dN}{dx}. \quad . \quad . \qquad (8)$$

If $s_1=20{,}000$ (i.e., 30,000 minus wind-stresses, secondary stresses, column-flexure stresses, etc.), $E=30{,}000{,}000$, and $\frac{dN}{dx}=1$ per cent (a limiting value for railroad bridges), we find

$$\textbf{Min. }\frac{\mathrm{d}}{\mathrm{l}}=\frac{1}{45}. \quad . \quad . \quad . \qquad (9)$$

Art. 6

Economic Depth of Stiffening Truss

It can readily be shown that the cost of the cable is unaffected by any change in the depth of the stiffening truss, within the limits of practice. The effect upon the weight of the web-members is also negligible. We may therefore define the economic depth of stiffening truss as the depth which will render the chord-areas of the truss a minimum.

By Eq. (5) of the preceding article the intensity of stress in the chords of the truss produced by a cable deflection $= \Delta f$ is

$$s = 4.8 \frac{Ed}{l^2} \cdot \Delta f. \quad . \quad . \quad . \quad (1)$$

If ΔL is the total elongation of the cable, then [1]

$$\Delta f = \frac{15}{16(5n - 24n^3)} \cdot \Delta L \quad . \quad . \quad (2)$$

[1] Cf. Melan, *Theorie der eisernen Bogen- und Hängebrücken* (Leipzig, 1906), p. 14, Eq. (39.)

For $n=\frac{f}{l}=\frac{1}{8}$, this equation reduces to

$$\Delta f=1.62\cdot\Delta L \quad . \quad . \quad . \quad (2')$$

The cable-stretch, ΔL, is composed of the elongation due to live-load plus the temperature expansion, or

$$\Delta L=\frac{s_0}{E}\cdot\frac{p}{g+p}\cdot L\pm wt\cdot L, \quad . \quad (3)$$

where s_0 is the total cable stress producible by the combined effect of the live-load (p) and the dead-load (g).

The total length of the cable is given by [1]

$$L=l\cdot\left(1+\frac{8}{3}n^2-\frac{32}{5}n^4\right)$$
$$+2l_1\left(1+\frac{8}{3}n_1{}^2\right)\sec\alpha_1 \quad (4)$$

For $n=\frac{1}{8}$ and $n_1=\frac{1}{16}$, this yields

$$L=2.11l. \quad . \quad . \quad . \quad (4')$$

[1] Cf. Melan, *Theorie der eisernen Bogen- und Hängebrücken* (Leipzig, 1906), p. 14, Eq. (43).

Substituting the values of (2′), (3) and (4′) successively in (1), we obtain

$$s = 16.44\left(s_0\frac{p}{g+p} + Ewt\right)\frac{d}{l} \quad . \quad (5)$$

If M is the bending moment produced by the live-load, and k is the corresponding unit stress, the chord-section will be

$$A_1 = \frac{M}{k.a}. \quad . \quad . \quad . \quad . \quad (6)$$

The value of the moment may be written

$$M = m \cdot p \cdot l^2, \quad . \quad . \quad . \quad (7)$$

where m is a factor nearly constant for all spans

($=\frac{1}{60}$ approximately [1]).

If s_1 is the total allowable chord-stress, deducting the stress (s) caused by the deflections, there remains,

$$k = s_1 - s \quad . \quad . \quad . \quad . \quad (8)$$

[1] Cf. Burr, *Ancient and Modern Engineering* (1903), p. 175.

Substituting the values of (7), (8) and (5) successively in (6), there results

$$A_1 = \frac{mpl^2}{d\left\{s_1 - 16.44\left(s_0\frac{p}{g+p} + Ewt\right)\frac{d}{l}\right\}} \qquad (9)$$

For a minimum chord-area, the denominator of the above expression must be made a maximum. The necessary condition is

$$s_1 - 32.88\left(s_0 \cdot \frac{p}{g+p} + Ewt\right)\frac{d}{l} = 0,$$

or

$$\text{Economic } \frac{d}{l} = \frac{s_1}{32.88\left(s_0\frac{p}{g+p} + Ewt\right)} \qquad (10)$$

Substituting

$$s_1\left(= \frac{30000}{1 + \frac{l^2}{8000r^2}}\right) = 26000,$$

and $Ewt \doteq 12000$, Eq. (10) becomes

$$\text{Economic } \frac{d}{l} = \frac{791}{s_0\frac{p}{g+p} + 12000}. \qquad (10')$$

Assuming a cable-stress increasing with the span-length (cf. Art. 4) and taking $\frac{g}{p}$ from the results of the writer's designs, we find, with the aid of Eq. (10′), for

$$
\begin{array}{llll}
l=1500, & \frac{g}{p}=1.8, & s_0=60{,}000, & \text{Econ. } \frac{d}{l}=\frac{1}{42}; \\
\quad =2250, & \quad =2.3, & \quad =67{,}500, & \qquad\quad =\frac{1}{41}; \\
\quad =3000, & \quad =3.1 & \quad =75{,}000 & \qquad\quad =\frac{1}{38}. \\
 & & & \text{Mean}=\frac{1}{40}.
\end{array}
$$

This value is somewhat higher than the average of past practice, probably because most designs have been a compromise between the demands of economy and those of æsthetics. The Williamsburg Bridge is the only long-span structure conforming to the above economic ratio, but its appearance is undoubtedly marred by the excessive depth of the stiffening truss.

Eq. (9) yields

$$A_1 \doteq \infty \text{ for } \begin{cases} \dfrac{d}{l} \doteq 0, \text{ or,} \\ \dfrac{d}{l} \doteq \dfrac{s_1}{16.44\left(s_0 \dfrac{p}{g+p} + Ewt\right)} \\ \qquad = 2 \cdot \left(\text{Econ. } \dfrac{d}{l}\right). \end{cases}$$

That is, the cost of the stiffening truss approaches infinity as the depth departs from the economic value either toward a value twice as great or toward a zero value. This shows that the truss depth is a very important factor in the economic design of a suspension bridge.

For the purpose of this investigation, economy of weight and cost is of greater significance than any æsthetic considerations. We shall therefore adhere to the depth-ratio derived above, even at a sacrifice of appearance.

It will be noted that the above value of $d\left(=\frac{1}{40}l\right)$ is but little in excess of the minimum permissible depth $\left(=\frac{1}{45}l\right)$ as found in the preceding section.

BIBLIOGRAPHY ON SUSPENSION BRIDGES

Williamsburg, (N. Y.).

Engineering Record, 1895 (II, pp. 127, 142); 1898 (II, p. 228); 1902 (I, p. 148); 1903 (I, pp. 80, 482; II, pp. 277, 756, 809); 1908 (I, p. 658).

Engineering News, 1896 (II, p. 126); 1897 (II, p. 173); 1898 (I, p. 114); 1899 (I, p. 330); 1901 (I, p. 289; II, p. 2); 1902 (I, p. 182; II, pp. 124, 198); 1903 (I, p. 81; II, p. 535).

Railroad Gazette, 1896 (July 31); 1898 (Feb. 11).

Iron Age, 1896 (Sept. 24).

Zentralblatt d. Bauverwaltung, 1896 (p. 442).

Zeitschrift d. Ver. deutscher Ing., 1904 (p. 1213).

Engineering, 1905 (Oct. 27).

Brooklyn, (N. Y.).

Deutsche Bauzeitung, 1870, 1873, 1876, 1878, 1880.

Journal of the Franklin Institute, 1873.

Scientific American, 1873, 1876, 1877, 1878, 1882.

Engineering, 1873, 1876, 1877, 1878, 1879, 1890.

Schweiz. Bauzeitung, 1883.

Engineer, 1874, 1877, 1881.

Annales des ponts et chaussées, 1874.

Trans. of the Amer. Soc. of Civ. Engrs., 1877.

Nouv. ann. de la constr., 1879, 1880

Harper's Magazine, May, 1883.

Johnson's Cyclopædia (1896); "Bridges."

Railroad Gazette, Nov. 23, 1894; Dec. 9, 1898; Jan. 10, 1902.

Van Nostrand's Science Series, No. 32.

Engineering News, 1901 (Oct. 10); 1902.

Manhattan, (N. Y.).

Engineering Record, 1900 (May 12); 1898 (Jan. 22); 1904 (July 2, Dec. 17); 1905 (July 29, Nov. 25, Dec. 2); 1906 (Aug. 25); 1908 (Nov. 21, Oct. 31); 1908 (Apr. 4, Aug. 8, Dec. 5); 1909 (Apr. 3, Oct. 2); 1909 (July 31).

Engineering News, 1905 (Aug. 3); 1909 (Oct. 14).

Scientific American, 1908.

Niagara.

Ann. des ponts et chaussées, 1877.

Engineering (London), 1881.

Nouv. ann. de la constr., 1880.

Zeitschr. f. Bauk., 1883.
Railway Age, 1898 (Dec. 30).
Engineering Record, 1897 (Apr. 24), 1899 (Aug. 26).
Engineering News, 1899 (Jan. 12).

Ohio R. (Cincinnati).
Engineering Record, 1898 (Sept. 10, Nov. 26)

Miampimi (Mexico).
Engineering Record, 1900 (Oct. 20).
Zeitschr. f. Transportw. u. Strassenb., 1902 (p. 348).

Elizabeth (Budapest).
"Die Eisenkonstruktion der Elisabeth-Kettenbrücke im Budapest" (Published by the Government), 1904.
Deutsche Bauzeitung, 1895.
Schweiz. Bauzeitung, 1895 (I, p. 48); 1897 (I, p. 148; II, p. 168).
Engineer, 1895 (II, p. 106); 1904 (I, pp. 379, 429, 438, 503, 514, 579, 628).
Engineering Record, 1895 (Oct. 5); 1895 (Aug. 24); 1900 (Nov. 10).
Oesterr. Monatschrift f. d. Oeffent. Bandienst, Apr., 1899.
Zeitschr. d. österr. Arch. u. Ing. Ver., 1904 (pp. 261, 277).
Zeitschr. f. Transportw. u. Strassenb., 1904 (p. 366).
Engineering News, 1905 (Aug. 24).
Engineering Mag., 1906 (March).

Freiburg, (Saane R., Switzerland).

Chaley, "Pont suspendu sur la Saane à Freiburg," Paris, 1835.
Allgemeine Bauzeitung, 1836.
Zeitschr. f. Bauw., 1863.
Nouvelles annales de la construction, 1881.
Riese, "Die Ingenieurbawerke der Schweiz."

Rochester, (Ohio R.).

Engineering News, 1897 (I, p. 194).

Point (Pittsburg).

Engineering News, 1877.
Railroad Gazette, 1878.
Ann. des ponts et chaussées, 1879, II.
Deutsche Bauzeitung, 1879.
Engineering Record, 1903 (I, pp. 2–10); 1901 (I, pp. 424, 455); 1905 (I, p. 517).

Vernaison (France).

Génie civil, 1903 (I, p. 145).
Engineer (London), 1903 (p. 62).
Nouv. ann. de la constr., 1903 (p. 162).
Sci. Am. Supp., 1903 (Oct. 10).
Engineering Record, 1904 (Sept. 10).

E. Liverpool (Ohio).

Engineering News, 1897 (I, p. 198).

Clifton (Bristol, Eng.).

Zeitschr. d. österr Ing. u. Arch. Ver., 1863.
Zeitschr. d. Arch. u. Ing. Ver. zu Hannover, 1865.

Lancz (Budapest).

Clark, "An Account of the Suspension Bridge across the River Danube," London, 1853.

Morgantown (Monongahela R., W. Va.).

Engineering News, 1905 (Mar. 9); 1907 (Apr. 18).

Menai (Wales).

Smiles, "Lives of the Engineers" (Telford).

Villefranche de Conflent (France).

Engineering Record, 1905 (I, p. 171).

Caperton (W. Va.).

Engineering Record, 1904 (Aug. 6).

Moldau (Prague).

Köstlin, "Ueber die neue Moldau-Brücke in Prag," in Zeitschr. d. österr Arch. u. Ing. Ver., 1868.

Schmitt, "Der neue Kettensteg über die Moldau in Prag," Prague, 1870.

Charleston, (W. Va.).

Engineering News, 1905 (Feb. 2).

Engineering Record, 1904 (Dec. 24), (Dec. 31).

Tweed (Berwick, Eng.).

American Encyclopedia, "Suspension Bridges."

Lambeth (London).

Heidmann, "Die Lambeth-Brücke in London," in Zeitschr. d. österr. Ing. u. Arch. Ver., 1863.

Conway (Chester, Eng.).

"The Conway Suspension Bridge," Engineer, 1881 (p. 27).

Engineer, (London), 1904 (May 20).

Hudson R. (Projects).

Report of Board of Engineers, Washington, 1894.

Ann. des travaux publ., 1890 (p. 175).

Engineering News, 1894 (Sept. 13); 1901 (May 16).

Engineering Record, 1894 (II, pp. 375, 390); 1895 (I, p. 275, II, p. 20).

Railroad Gazette, 1894 (Sept. 14).

Génie civil, 1894 (I, p. 193), 1895 (I, p. 57).

Stahl u. Eisen, 1896 (p. 174).

Scientific American, 1896 (May 2).

Proc. of the Am. Soc. of Civ. Eng., 1896 (p. 469).

Trans. Assn. of Civ. Engs. of Cornell Univ., (G. Lindenthal) 1896.

Engineering Magazine, 1898 (Dec.).

Proc. N. Y. R. R. Club, 1901 (Apr. 18).

CHAPTER III

DESIGN OF SUSPENSION BRIDGES

ART. 7

PRINCIPAL DATA FOR DESIGN OF SUSPENSION BRIDGES

		No. 1.	No. 2.	No.3.
l = Span	=	1500,	2250,	3000 ft.
l_1 = Side-span = $l/2$	=	750,	1125,	1500 ft.
f = versed-sine = $0.12l$	=	180,	270,	360 ft.
f_1 = versed-sine in side-span = $f/4$	=	45,	67.5,	90 ft.
d = depth of truss = $.024l$	=	36,	54,	72 ft.
a = panel length (between suspenders)	=	18.5,	22.3,	24.8 ft.

Type: Stiffening truss hinged at the towers. Suspension rods in side-spans.

Loading:

4 railroad tracks at	3000 lbs.	=	12000 lbs. p.l.f.
2 lines of cars at	1000	=	2000
40 ft. of roadway at	75	=	3000
20 ft. of roadway at	50	=	1000
Total congested load		=	18000 lbs. p.l.f.

Total width of structure = 115 ft. + 2 cantilevers at 10 ft.

4 Cables, spaced 37′.5 + 40′ + 37′.5 c. to c.

4 Trusses, spaced 37′.5 + 40′ + 37′.5 c. to c.

Art. 8

Design of the Stiffening Truss

By proper adjustment of the suspension rods after the erection is completed, all strain may be taken out of the stiffening truss before live-load is applied. The dead-load is thus carried wholly by the cable and may be entirely omitted from consideration in designing the stiffening truss. The latter will therefore be designed merely for the uniform live-load of 4500 lbs. per linear foot, a temperature variation of $\pm 60°$ F., and a lateral wind pressure of 30 lbs. per square foot.

The formulæ used will be those based on the Theorem of Least Work, as developed by J. Melan in his "Theorie der eisernen Bogenbrücken und Hängebrücken."[1] This theory has been found

[1] *Handbuch der Ingenieur - Wissenschaften* (Leipzig, 1906), II. Band. V. Abteilung. XII. Kapitel, pp. 17–50. Cf. Müller-Breslau, "Theorie der durch einen Balken versteiften Kette." *Zeitschr. d. Arch. und Ing. Ver. zu Hannover*, 1881, p. 57. Am Ende, "Suspension Bridges with Stiffening Girders," Proc. of the Inst. of

by the writer to give results essentially the same as those yielded by formulæ established in a different manner by M. Maurice Lévy in his "Calcul des ponts suspendus rigides,"[1] and by those of C. Schwend in his treatise on suspension bridges.[2]

The above theories involve the following common assumptions:[3]

1. The cable is supposed perfectly flexible, freely assuming the form of the equilibrium polygon of the suspender forces.

2. The truss is considered a beam, initially straight and horizontal, of constant moment of inertia and tied to the cable throughout its length.

C.E., 1899, p. 306; and A. J. Dubois, "The Stresses in Framed Structures," New York, 1896.

[1] *Annales des Ponts et Chausseés*, 1886, II., p. 179, et seq.

[2] Schwend, *Ueber Berechnung und Konstruktion von Hängebrücken unter Anwendung von Stahldraht-Kabeln und Versteifungsbalken* (Leipzig, 1887).

[3] Cf. M. T. Godard, *Annales des Ponts et Chausseés*, 1894, II., and Melan, p. 17.

3. The dead-load of truss and cable is assumed uniform per linear unit, so that the initial curve of the cable is a parabola.

4. The form and ordinates of the cable curve are assumed to remain unaltered upon application of loading.

All of these assumptions, with the exception of the last, are very near the actual conditions even in the case of flexible trusses. The last assumption is admissible only with trusses of sufficient rigidity, and its exclusion results in the "Genauere Theorie," developed by Melan.[1] For the purposes of this investigation, the Least Work Theory will be deemed sufficiently accurate, its variations from the Exact Theory being negligible and on the side of safety.

Live-load Stresses. The bending moment at any section (x) of the main span (l), produced by a load (p) covering the entire length of the bridge, is

$$M_{\text{tot}}=\tfrac{1}{2}px(l-x)\left[1-\frac{8}{5N}\left(1+2\frac{f_1}{f}\cdot\frac{I}{I_1}\cdot\frac{l_1{}^3}{l^3}\right)\right] \quad (1)$$

[1] Melan, p. 50, et seq.

where

$$N=\tfrac{8}{5}\left(1+2\frac{I}{I_1}\cdot\frac{l_1}{l}\cdot\frac{f_1^2}{f^2}\right)+3\frac{I}{A_0f^2}$$
$$\cdot\left[1+\frac{16}{3}\cdot\frac{f^2}{l^2}\cdot+2\frac{l_2}{l}\left(1+\frac{16}{3}\frac{f_1^2}{l_1^2}+\tan^2\alpha_1\right)\right]\quad(2)$$

The results of preliminary estimates of truss and cable gave

for $\quad l = 1500 \quad 2250 \quad 3000$

$$\frac{I}{A_0f^2}=\quad\frac{1}{62}\quad\frac{1}{75}\quad\frac{1}{94}.$$

With these values, assuming $I=I_1$, we obtain

$$N = 1.82,\ 1.80,\ 1.78.$$

and

$$M=0.0322,\ 0.0278,\ 0.0230px(l-x).$$

The same relation obtains for the side spans, upon substituting l_1 for l. The above figures may be interpreted as indicating that the truss in each case serves to carry

6.44% 5.56% 4.60%

of the total load, the remainder being carried by the cable.

The position ($\xi = n \cdot l$) of a concentration producing zero bending moment at any section (x) of the truss is called the *critical point* for that section and is given by

$$-n^3+n^2+n=N\cdot\frac{f}{l}\cdot\frac{x}{y}$$

$$=.218, \quad .216, \quad .214\frac{x}{y}. \qquad (3)$$

The roots of this equation for different values of x are most easily obtained from a graph of the function

$$f(n) = -n^3+n^2+n,$$

which, once plotted, can be used for all suspension bridge designs.

For the greatest negative moment at any section (x) of the main span, the load should cover both side spans and the portion ($l-\xi$) of the main span between the farther end and the critical point. The resulting bending moment is

$$M_{\min} = -\frac{2px(l-x)}{5N}$$

$$\left\{[2-n-4n^2+3n^3](1-n)^2+4\frac{I}{I_1}\cdot\frac{l_1{}^3}{l^3}\cdot\frac{f_1}{f}\right\} \qquad (4)$$

A graph of the function $f(n) = (2-n-4n^2+3n^3)$ was used by the writer to simplify the labor involved in the repeated application of the above formula.

For the greatest positive moment at any section of the main span, that span is loaded from $x=0$ to $x=\xi$, giving

$$M_{\max} = M_{\text{tot}} - M_{\min}. \qquad . \quad (5)$$

There are no critical points in the side spans. For the greatest negative moment at any section (x) in one of the side spans, load the other two spans, giving

$$M_{\min} = -\frac{2px(l_1-x)}{5N} \left\{ 2\frac{f_1}{f} \cdot \frac{l^2}{l_1{}^2}\left(1+\frac{I}{I_1}\frac{l_1{}^3}{l^3}\cdot\frac{f_1}{f}\right)\right\} \quad (6)$$

which reduces to

$$M_{\min} = -.455, \quad -.459, \quad -.462px(l_1-x).$$

Loading the span itself produces the greatest positive moments:

$$M_{\max} = M_{\text{tot}} - M_{\min} = .487, \ .487, \ .486px(l_1-x).$$

With all spans completely loaded, the shear at any section (x) of the main span will be

$$S_{tot}=\tfrac{1}{2}p(l-2x)\left[1-\frac{8}{5N}\left(1+2\frac{I}{I_1}\cdot\frac{l_1{}^3}{l^3}\cdot\frac{f_1}{f}\right)\right. \qquad (7)$$

In the designs at hand, this reduces to

$$S_{tot}=.0644, \quad .0556, \quad .0460p\left(\frac{l}{2}-x\right),$$

the coefficient in each case representing the fraction of the total load carried by the truss. The same relations apply to the side spans upon replacing l by l_1.

The critical point ($\xi=n\cdot l$) for zero shear at any section (x) of the truss is given by

$$n+n^2-n^3=\frac{N}{4}\cdot\frac{l}{l-2x}. \qquad . \quad (8)$$

This formula is solved by the same graph as that used for Eq. (3). For maximum shear at any section of the truss, the load should extend from $x=0$ to the given section, and from the critical point to the farther end of the span. The shear will then be

$$S_{\max}=\tfrac{1}{2}pl\left(1-\frac{x}{l}\right)^2$$

$$\cdot\left\{1-\frac{8}{N}\left(1-\frac{2x}{l}\left(\left[\frac{1}{5}\left(1-\frac{x}{l}\right)^3-\frac{1}{2}\left(1-\frac{x}{l}\right)^2+\frac{1}{2}\right]\right\}\right.\right.$$

$$+\tfrac{1}{2}pl(1-n)^2$$

$$\cdot\left\{\frac{8}{N}\left(1-\frac{2x}{l}\right)\left[\tfrac{1}{5}(1-n)^3-\tfrac{1}{2}(1-n)^2+\tfrac{1}{2}\right]-1\right\} \quad (9)$$

There will be no critical point for any section where

$$x>\frac{l}{2}\left(1-\frac{N}{4}\right)=.272l, \quad .275l, \quad .278l.$$

For all such sections, $n=1$, and the last term in the equation for $S_{\max}$ vanishes.

There are no critical points in the side spans, the maximum shear at any section being simply

$$S_{\max}=\tfrac{1}{2}pl_1\left(1-\frac{x}{l_1}\right)^2$$

$$\cdot\left\{1-\frac{8}{N}\cdot\frac{I}{I_1}\cdot\frac{l_1}{l}\cdot\frac{f_1^2}{f^2}\left(1-\frac{2x}{l_1}\right)\left[\frac{1}{5}\left(1-\frac{x}{l_1}\right)^3\right.\right.$$

$$\left.\left.-\frac{1}{2}\left(1-\frac{x}{l_1}\right)^2+\frac{1}{2}\right]\right\} \quad (10)$$

A graph of the function

$$f(n)=\tfrac{1}{5}(1-n)^3-\tfrac{1}{2}(1-n)^2+\tfrac{1}{2}$$

serves to simplify the application of Eqs. (9) and (10).

The stresses in the diagonal web members are obtained by dividing the shear at any section by the number of web members cut by that section, and multiplying the quotient by the secant of their inclination to the vertical.

Temperature Stresses. The cable-tension produced by a rise in temperature (t) is given by

$$H_t=-\frac{3EIwtL}{f^2N\cdot l} \quad . \quad . \quad . \quad (1)$$

For an extreme variation of $t=\pm 60°$ F., $Ewt=11{,}720$. Taking the value of I from preliminary estimates, Eq. (1) yielded

$$H_t=260, \quad 420, \quad 560 \text{ kilo-pounds.}$$

The resulting bending moment at any section of the truss is given by

$$M_t=H_tY \quad . \quad . \quad . \quad . \quad (2)$$

and the transverse shear by

$$S_t = H_t \cdot \tan \tau, \quad . \quad . \quad (3)$$

where τ is the inclination of the cable at the given section.

Wind Stresses. Let $p =$ the total horizontal wind-load per linear foot. The resulting lateral deflection (h) causes a displacement of the plane of the cable and suspenders from the vertical, thereby giving rise to a force of restitution (r) equal to the horizontal component of the suspender tensions. If v is the mean vertical distance of the truss and live load below the cable chord, then the reaction component of the displaced weight (W) will be

$$r = \frac{h}{v} \cdot W. \quad . \quad . \quad . \quad . \quad (1)$$

Considering the truss as a beam acted on by a uniform horizontal load $(p-r)$, we have

$$h = \frac{5}{384}(p-r)\frac{l_4}{EI}. \quad . \quad . \quad (2)$$

From (1) and (2), there results

$$r = \frac{\frac{W}{v} \cdot \frac{5}{384} \cdot \frac{l_4}{EI}}{1 + \frac{W}{v} \cdot \frac{5}{384} \cdot \frac{l_4}{EI}} \cdot p. \quad . \quad (3)$$

In the designs at hand, Eq. (3) yields

$$r/p = 19\%; \quad 45\%; \quad 57\%$$

in the main spans, and

$$r/p = 3.5\%; \quad 9.3\%; \quad 20.3\%$$

in the side-spans.

The specified wind-load (p) consists of a pressure of 30 lbs. per square foot acting on the exposed surface of one truss and on half that of the remaining trusses, also on a train of cars 14 ft. high. On the round surface of the cables, only one-half of the above pressure is considered effective. The total wind pressure in our designs is thus found to be

$$p = 1220; \quad 1400; \quad 1545 \text{ lbs. p.l.f.}$$

and the *effective* horizontal pressure will be

$$p - r = 988; \quad 772; \quad 671 \text{ lbs. p.l.f.}$$

in the main spans, and

$$p-r=1177; \quad 1270; \quad 1231 \text{ lbs. p.l.f.}$$

in the side-spans.

The resulting lateral deflections, by Eq. (2), will then be

$$h=18\tfrac{1}{2}''; \quad 48\tfrac{1}{4}''; \quad 61''$$

at the center of the main span, and

$$h=1\tfrac{3}{8}''; \quad 3\tfrac{1}{4}''; \quad 7''$$

at the center of the side-span.

Each of the above pressures $(p-r)$ must be resolved into two parts acting in the planes of the upper and lower lateral systems respectively. On account of the wind pressure on the floor and train, the lower chords get the major share of the wind-load, amounting, in the present designs, to about 63% of the total pressure.

The system of bracing adopted is similar to that used on the Manhattan Bridge. The upper lateral bracing consists of diagonals and struts connecting the inside to the outside trusses. There is no bracing over the roadway or sidewalks. The upper lateral system is therefore composed of two independent horizontal trussses, 37.5 ft. deep, so that the chord-stresses due to the wind moments will equal $M_w \div 75$.

The lower lateral system consists of the four lower chords tied together by the floor beams and special diagonal braces extending across the entire floor. Assuming the wind-stresses in the chords to vary as their respective distances (20 ft. and 57.5 ft.) from the neutral axis, the stress in the outside lower chords will equal $M_w \div 129$.

It is thus found that the wind-stresses in the upper and lower chords are almost equal, so that the same sections may be used for both.

In designing the members of the lateral systems, the wind pressure is considered as a moving load. The maximum shear at any section (x) is given by

$$S = \frac{p}{2l}(l-x)^2,$$

and the resulting stresses are obtained

by dividing this shear by the number of laterals cut by the section and multiplying the quotient by the secant of their inclination.

Working Stresses. The chords of the stiffening truss are made of nickel steel and are designed for working stresses of 30,000 lbs. per square inch in tension and for $30{,}000 \div \left(1+\frac{l^2}{8000r^2}\right)$ in compression.

The web members, bracing and connection details are of structural steel and are designed for working stresses of 20,000 lbs. per square inch in tension and for $20{,}000 \div \left(1+\frac{l^2}{8000r^2}\right)$ in compression.

Computations. The limitation of space renders it impracticable to reproduce here the detailed computations of the stresses and weights of members. For the same reason, the design of the floor system will not be given here. The final weights, however, are tabulated in the following article:

Art. 9

Design of Suspenders

The load carried by the suspenders consists of the following items:

	S. B. No. 1.	S. B. No. 2.	S. B. No. 3.
Truss and bracing	2,624	4,015	5,786 lbs.
Floor	3,712	3,800	3,812
Suspenders	126	207	320
Total Dead-load	6,462	8,022	9,918
Live-load	4,500	4,500	4,500
Total load p.l.f. $(=g_1)$	10,962	12,522	14,418 lbs.
Total load per suspender	202,800	279,800	358,000 lbs.

With a specified working stress of 30,000 lbs. per square inch, the required sections for the suspenders will be:

	6.8	9.3	11.9 sq. in.
Their average length $(=\frac{1}{3}f+d)=$	96	144	192 ft.
Hence, their mean weight=	126	207	320

$\underbrace{\hspace{6em}}_{\text{lbs. p.l.f. of truss.}}$

as assumed above.

ART. 10

DESIGN OF CABLES

Preliminary Estimate. For an accurate design of the cable its weight must be known in advance. For this purpose, use is made of Eq. (5) of Art. 4, viz.:

$$g_0 = g_1 \cdot \frac{k \cdot l \cdot \dfrac{1}{n}\sqrt{1+16n^2}}{1 - kl \cdot \dfrac{1}{n}\sqrt{1+16n^2}}.$$

With $k = \dfrac{1}{136000}$, and $n = \dfrac{f}{l} = 0.12$, the above reduces to

$$g_0 = g_1 \frac{.000068l}{1 - .000068l},$$

or, for

$$l = 1500, \quad 2250, \quad 3000,$$
$$g_0 = .114g_1, \quad .181g_1, \quad .257g_1.$$

Taking the values of the total suspended load (g_1) from the preceding article, we find the weight of the cable to be

$$g_0 = 1250, \; 2270, \; 3710 \text{ lbs. p.l.f.}$$

After a first design these values were slightly altered to those given below for the final computation.

Final Computation. The total load carried by the cables consists of the following items:

	S. B. No. 1.	S. B. No. 2.	S. B. No. 3.
Dead-load on suspenders (as above)	6,462	8,022	9,918
Weight of cable	1,286	2,160	3,720
Total dead-load $(=g)$	7,748	10,182	13,638
Live-load $(=p)$	4,500	4,500	4,500
Total load p.l.f. $(=g+p)$	12,248	14,682	18,138

For a live-load (p) covering the main span, the horizontal component of the cable tension will be

$$H=\frac{1}{5N}\frac{pl^2}{f}. \quad . \quad . \quad . \quad (1)$$

In the designs at hand, this gives

$$H=.9170; \quad .9250; \quad .9365\ pl.$$

For a live-load (p) covering one of the side-spans, the cable tension is given by

$$H=\frac{1}{5N}\frac{f_1}{f}\cdot\frac{I}{I_1}\cdot\frac{l_1^2}{l^2}\cdot\frac{l}{f}\cdot pl_1. \quad . \quad (2)$$

In the present designs this gives

$$H = .0572; \quad .0578; \quad .0585\ pl_1.$$

Combining the above values, we find the cable tension for a uniform live-load (p) covering all the spans to be

$$H_p = .9742; \quad .9840; \quad .9950\ pl.$$

As the cable sustains the entire dead-load (g) without any relief from the stiffening truss, the corresponding horizontal tension will be

$$H_g = \frac{gl^2}{8f} = \frac{gl_1^2}{8f_1}, \quad . \quad . \quad . \quad (3)$$

or, in the designs at hand,

$$H_g = 1.0417\ gl.$$

Substituting the values of (g) and (p) in the above expressions for H, we obtain

$H_g =$	12,100,000,	23,880,000,	42,600,000 lbs.
$H_p =$	6,135,000,	9,960,000,	13,440,000 lbs.

As previously given (Art. 8), the cable tension producible by a fall of temperature is

$H_t =$	260,000,	420,000,	560,000 lbs.

Hence,

Total H=18,495,000, 34,260,000, 56,600,000 lbs.

Multiplying this value by the secant of the inclination of the cable at the towers, (sec. = 1.109), we find the maximum cable tension to be

T_{max} = 20,510,000 lbs., 38.000,000 lbs., 62,770,000 lbs.

With the specified unit stress of 60,000 lbs. per square inch, the required cable section (per truss) will be

$$A_0 = 342, \quad 633, \quad 1046 \text{ sq.in.}$$

This section will be provided as follows:

S. B. No. 1. One cable of 37 strands, each containing 319 wires of 0.192 in. diam. Diam. = $23\frac{3}{4}$ in. Total area = 342 sq.in.

S. B. No. 2. Two cables of 37 strands, each containing 296 wires of 0.192 in. diam. Diam. = $22\frac{7}{8}$ in. Total area = 634 sq.in.

S. B. No. 3. Three cables of 37 strands, each containing 326 wires of 0.192 in. diam. Diam. = 24 in. Total area = 1047 sq.in.

Each cable will be wrapped with a single layer of No. 10 (B. W. G.) iron wire.

Allowing for catenary, cable wrapping, etc., the mean weight of the cables will be

$$g_0 = 1286, \quad 2160, \quad 3720 \text{ lbs. p.l.f.}$$

as assumed above.

Art. 11

Design of Towers

Each tower will consist of four box-columns, one for each cable system, rigidly tied together by transverse bracing in a vertical plane. Comparative designs by the writer indicated a small economy of material in favor of pin-bearing columns, but this saving is more than outweighed by the more expensive construction, greater difficulty of erection, uncertainty of action and æsthetic inferiority due to the impression of instability. The more usual design, namely with the columns rigidly fixed at the base, will therefore be followed.

Assuming the required clearance of the truss above M. H. W. to be 135, 160 and 185 ft. for the respective bridges, and assuming the top of the masonry piers to be 30 ft. above M. H. W., the total height of the steel towers will be: for

S. B. No. 1, $180+36+135-30=321$ ft.
S. B. No. 2, $270+54+160-30=454$ ft.
S. B. No. 3, $360+72+185-30=587$ ft.

Deducting the height of the pedestal castings, the effective height of the towers will be

$$h=316;\ 448;\ 580 \text{ ft.};$$

and the height up to the stiffening truss will be

$$h_1=100;\ 124;\ 148 \text{ ft.}$$

The maximum fiber stress in the tower columns will occur when the live-load covers the main span and the farther side-span at maximum temperature. Under this condition of loading, the top of the tower will be deflected toward the main span as a result of the following deformations:

1. The upward deflection (Δf_1) at the center of the unloaded side-span.

2. The elongation of the cable between the anchorage and the tower due to the elastic strain produced by the applied loads.

3. The elongation of the cable due to thermal expansion.

These deformations are computed as follows:

(1) The upward deflection (Δf_1) is found by considering the side-span as a simple beam subjected to a downward loading equal to the suspended dead-load (p) and an upward loading equal to the suspender tensions $\left(t = H \div \frac{l^2}{8f}\right)$. If $p_1 (= t - p)$ is the resultant of these loadings, the central deflection will be

$$\Delta f_1 = \frac{5}{384} \frac{p_1 l_1^4}{EI} \quad . \quad . \quad . \quad (1)$$

For the spans under investigation, this gives

$$\Delta f_1 = 2.630;\ 3.760;\ 4.885 \text{ ft.}$$

(2) The elastic elongation of the cable in the side-span is given by

$$\Delta L_1 = \frac{H}{EA_0} \cdot \int \frac{ds^3}{dx^2}$$
$$= \frac{H}{EA_0} \cdot l_1 \left(1 + 8\frac{f_1^2}{l_1^2} + \frac{3}{2} \tan^2 \alpha_1 \right), \quad (2)$$

which reduces to

$$\Delta L_1 = 1.915;\ 2.875;\ 3.860 \text{ ft.}$$

(3) The temperature expansion of the cable in the side-span is given by

$$\Delta L_1 = wt \int \frac{ds^2}{dx}$$
$$= wt \cdot l_1 \left(1 + \frac{16}{3} \frac{f_1^2}{l_1^2} + \tan^2 \alpha_1 \right), \quad (3)$$

which reduces to

$$\Delta L_1 = 0.390;\ 0.585;\ 0.780 \text{ ft.}$$

The length of the cable in the side-span is given very closely by

$$L_1 = l_1 \left(1 + \frac{8}{3} \frac{f_1^2}{l_1^2} + \frac{1}{2} \tan^2 \alpha_1 \right), \quad (4)$$

from which we find

$$\frac{dL_1}{dl_1}=\left(1+\frac{8}{3}\frac{f_1^2}{l_1^2}+\tfrac{1}{2}\tan^2\alpha_1\right)=1.125, \qquad (5)$$

and

$$\frac{dL_1}{df_1}=\frac{16}{3}\frac{f_1}{l_1}=0.32. \quad . \quad . \quad (6)$$

The deflection of the top of the tower is then given by

$$y_0=\varDelta l_1=\frac{dl_1}{dL_1}\Sigma(\varDelta L_1)+\frac{dl_1}{dL_1}\frac{dL_1}{df_1}\cdot\varDelta f_1. \qquad (7)$$

Substituting the values from (1), (2), (3), (5) and (6) in (7), we obtain the maximum tower deflection,

$$y_0=2.798; \quad 4.150; \quad 5.515 \text{ ft.}$$

Considering this deflection as produced by an unbalanced horizontal force P applied at the top of the tower, this force may be calculated if the sectional dimensions of the tower are known. As these are not known in advance, the following procedure is adopted:

Assume the moment of inertia of the section of the tower to have a maximum value (I_0) at the base and to diminish regularly toward the top according to some appropriate law. A study of actual designs indicates the applicability of the law of variation represented by the empirical formula

$$I = I_0(1 - \sqrt{x/h}), \quad . \quad . \quad (8)$$

where x is the distance of any section above the base. Substituting this relation in the differential equation of the elastic curve of the cantilever

$$EI\frac{d^2y}{dx^2} = P(h - x),$$

and integrating, there results

$$P = \frac{30}{23}\frac{EI_0}{h^3}y_0. \quad . \quad . \quad . \quad (9)$$

In the designs at hand, this reduces to

$$P = 3.470I_0; \quad 1.736I_0; \quad 1.094I_0.$$

The other loads acting on the tower are the vertical reaction ($V = 2H \cdot \tan\,\alpha$)

at the saddles, and the end-shears (V_1) at the point of suspension of the stiffening truss. In the designs at hand, for the condition of loading under consideration, we find

$V=$ 17,150,000; 30,700,000; 52,100,000 lbs.
$V_1=-$1,037,000; $-$1,852,000; $-$2,640,000 lbs.

At any section (x) of the tower, the horizontal deflection (y) from the initial vertical position of the axis is given with sufficient accuracy by the equation for the elastic curve of the cantilever:

$$y=y_0\left[\frac{3}{2}\left(\frac{x}{h}\right)^2-\frac{1}{2}\left(\frac{x}{h}\right)^3\right]. \quad . \qquad (10)$$

This gives, for $x=h_1$,

$$y_1=0.376,\quad 0.436,\quad 0.492 \text{ ft.}$$

The maximum fiber stress at any section of the tower will be

$$s=\frac{V}{A}+\frac{M\cdot d}{I}+\left[\frac{V_1}{A}\right]_0^{h_1}, \quad . \qquad (11)$$

where

$$M=P(h-x)+V(y_0-y)$$
$$+\left[V_1(y_1-y)\right]_0^{h_1}. \qquad (12)$$

The moment of inertia for the form of section used here is given approximately by

$$I = 0.50A \cdot d^2. \quad . \quad . \quad . \quad (13)$$

Substituting (12) and (13) in (11), and applying the resulting equation to the base of the tower, we find

$$s = \left(\frac{P}{I_0}\right) \cdot hd_0 + \frac{2Vy_0}{A_0 d_0} + \frac{2V_1 y_1}{A_0 d_0} + \frac{V+V_1}{A_0}. \quad (14)$$

Using an allowable fiber stress of $s = 24{,}000$ lbs. per square inch, and substituting the numerical values of P/I_0, V, V_1, h, y_0, and y_1, as given above, there results the following relation:

S. B. No. 1:

$$24{,}000 = 1096d_0 + \frac{96000000}{A_0 d_0} + \frac{16113000}{A_0},$$

S. B. No. 2:

$$24{,}000 = 788d_0 + \frac{255000000}{A_0 d_0} + \frac{28848000}{A_0},$$

S. B. No. 3:

$$24{,}000 = 647d_0 + \frac{800000000}{A_0 d_0} + \frac{49460000}{A_0}.$$

This relation is satisfied by the following values:

S. B. No. 1: $A_0 = 3240$ sq.in.,
$d_0 = 15$ ft.; $\therefore\ I_0 = 365{,}000$ in.^{2} ft.^{2}

S. B. No. 2: $A_0 = 4260$ sq.in.,
$d_0 = 17$ ft.; $\therefore\ I_0 = 625{,}000$ in.^{2} ft.^{2}

S. B. No. 3: $A_0 = 7200$ sq.in.,
$d_0 = 20$ ft.; $\therefore\ I_0 = 1{,}440{,}000$ in.^{2} ft.^{2}

The horizontal force P is now determined from Eq. (9) as

$$P = 694{,}000;\ 1{,}085{,}000;\ 1{,}575{,}000 \text{ lbs.}$$

All the remaining sections of the tower may now be proportioned, using Eq. (8) as a guide and checking the maximum fiber stress by Eqs. (11) and (12). The mean section of the tower is thus found to be

$$\text{Mean } A = 2210;\ 3240;\ 5550 \text{ sq.in.},$$

and the total weight, including connection details and bracing (about 100 per cent), is found to be

Weight = 4,465,000; 9,720,000; 22,406,000 lbs. per column. (Structural steel.)

Pedestals. The pressure at the foot of each tower column is a maximum when the live-load extends over all the spans, and is then made up of the following items:

	S. B. No. 1.	S. B. No. 2.	S. B. No. 3.
Max. Cable Reaction (V)	17,500,000	32,500,000	53,830,000
Max. Truss Reaction (V_1)	326,000	422,000	466,000
Wt. of Tower	4,465,000	9,720,000	22,406,000
Wt. of Pedestal	420,000	810,000	1,200,000
Total load (lbs.)	22,711,000	42,452,000	77,902,000
Bearing area required at 15 tons per sq. ft.	757	1448	2597

In order to evenly distribute the above loads over the requisite area of masonry, the tower legs will rest on pedestals of cast steel (annealed) having the following dimensions:

	S. B. No. 1.	S. B. No. 2.	S. B. No. 3.
Top of casting....	10×30	18×34	24×40
Bottom of casting	20×40	30×48	36×72
Height...........	5 ft.	6 ft.	7 ft.
Weight of casting (lbs.)..........	420,000	810,000	1,200,000

Art. 12

Design of Masonry Piers

The steel castings at the bases of the tower columns are anchored on pedestal blocks of selected granite. The top of the pier is made just large enough to hold these pedestals, except where a larger section is required to reduce the pressure in the masonry to 12 tons per square foot. The pier is built of $1:2\frac{1}{2}:5$ concrete with limestone (ashlar) facing. The upper pier, above the starling, is given the section of a rectangle with semicircular ends and has a batter of 1:20 on sides and ends. In the lower pier, the sides (batter 1:20) are continued at each end in two circular arcs to form a cutwater (batter 3:20).

Below the masonry is a rectangular cribwork, used as a coffer-dam during construction. It is built of 12×12 in. timber, and is filled with concrete as the sinking progresses. It rests directly on the pneumatic caisson which has a steel working chamber 7 ft. high, and a reinforced-concrete roof 3 ft. thick. After reaching rock, the caisson and shafts are carefully filled with 1:2:4 Portland cement concrete.

Since the economic depth of foundations increases with the length of span, it will be assumed that the pier-depths for the bridges under design are somewhat greater for the longer spans. The following are the principal elevations assumed:

	S. B. No. 1.	S. B. No. 2.	S. B. No. 3.
Top of pier	30	30	30
Starling	5	5	5
Mean high water (=datum)	0	0	0
Base of pier=top of cribwork	−15	−15	−15
River bottom	−20	−25	−30
Base of cribwork=top of caisson	−80	−90	−100
Cutting-edge of caisson = surface of rock	−90	−100	−110

The principal sectional dimensions of the piers, determined as outlined above, are as follows:

	S. B. No. 1.	S. B. No. 2.	S. B. No. 3.
Top of pier.......	177×42	195×50	225×74
Base of upper pier.	179×44	197×52	227×76
Top of lower pier.	200×44	222×52	259×76
Base of pier......	206×46	228×54	265×78
Cribwork.........	212×52	234×60	271×82
Caisson..........	212×52	234×60	271×82

A complete design and estimate of the piers yielded the following quantities of material required:

	S. B. No. 1.	S. B. No. 2.	S. B. No. 3.	
Pier masonry.....	12,890	15,490	26,300	cu.yds.
Concrete filling in cribwork.......	25,300	37,400	67,800	"
Concrete filling in caisson.........	4,080	5,200	8,230	"
Timber in cribwork	620	790	1,080	M.ft. B.M.
Steel in caisson and shafts..........	1,150,000	2,320,000	2,650,000	lbs.
Earth excavation..	28,600	39,000	65,000	cu.yds

Art. 13

Design of Anchorages

The anchorage, as a mass, is required to offer sufficient frictional resistance to sliding to resist the tension of the cable. Dividing the maximum horizontal tension (H) by the coefficient of friction ($\mu=0.6$), the quotient will be the necessary weight of anchorage masonry. Introducing a factor of safety of 2, the masonry required for the anchorage is thus found to be

63,500; 109,000; 183,200 cu.yds.

This will be built of concrete with limestone facing as in the case of the piers.

Enclosed in the base of the anchorage are heavy box girders to which the cables are anchored by means of chains of eye-bars. The total amount of steel work in each anchorage is found to be

1,037,500; 2,472,500; 4,090,000 lbs.

The anchorage will be supported on a concrete foundation resting on bearing piles if necessary. The volume of material in this foundation is found to be

5,290; 10,400; 16,650 cu.yds.

Art. 14

Estimate of Cost

In order to establish an equitable schedule of unit prices for the two types of bridges, a critical study was made of the different bids received by New York City for the Williamsburg, Manhattan and Queensboro Bridges. These structures were selected as combining the qualifications of recentness of date with similarity of construction and magnitude to the designs under investigation. The prices of the successful bidders were adopted except where they differed so widely from the following bids as to indicate their having been unbalanced for some special reason. The unit prices determined by this comparison are incorporated in the following estimates of cost.

SUSPENSION BRIDGE. SPAN = 1500 FT.

Estimate of Cost.

Material.	Quantity.	Price.	Amount.	Total.
Cables, etc.:	lbs.	c.	$	$
4 cables at 342 sq. in.	15,940,000	12.5	1,992,500	
Suspenders	1,452,000	10.0	145,200	
Steel castings (cable bands, etc.)	1,645,000	9.0	148,050	
				2,285,750
Suspended superstructure:				
Truss chords (nickel steel)	23,632,000	8.0	1,890,560	
Webs and bracing (struct. steel)	7,269,000	5.6	407,060	
Floor system (structural steel)	16,026,000	5.6	897,460	
				3,195,080
Towers (321 ft. high):				
Structural steel	35,720,000	5.6	2,000,320	
Steel castings	3,360,000	9.0	302,400	
				2,302,720

Anchorage steel:				
Eye-bars and riveted work........	2,075,000	5.0	103.750	
				103,750
Total steel work				$7,887,300
Tower foundations:				
Masonry in pier (cu. yds.)........	12,890	$18	232,020	
Concrete in cribwork (cu. yds.)....	25,300	$7.50	189,750	
Concrete in caisson (cu. yds.).....	4 080	$12	48,960	
Timber in cribwork (M. ft. B.M)..	620	$45	27,900	
Steel in caisson (lbs.)............	1,150,000	4½c.	51,750	
Earth excavation (cu. yds.).......	28,600	$4	114,400	
				1,329,560
Anchorages:				
Masonry (cu. yds.)..............	63,500	$18	1,143,000	
Concrete in foundation (cu. yds.)..	5,920	$12	71,040	
				2,428,080
Total substructure........				$3,757,640
Grand total........				$11,644,940

SUSPENSION BRIDGE. SPAN = 2250 FT.

Estimate of Cost.

Material.	Quantity.	Price.	Amount.	Total.
Cables, etc.:	lbs.	c.	$	$
8 cables at 317 sq. in.	40,220,000	12.5	5,027,500	
Suspenders	3,656,000	10.0	365,600	
Steel castings (cable bands, etc.)	5,600,000	9.0	494,000	
				5,887,100
Suspended superstructure:				
Truss chords (nickel steel)	53,960,000	8.0	4,316,800	
Webs and bracing (struct. steel)	17,934,000	5.6	1,004,300	
Floor system (structural steel)	24,039,000	5.6	1,346,180	
				6,667,280
Towers (454 ft. high):				
Structural steel	77,960,000	5.6	4,365,760	
Steel castings	6,480,000	9.0	583,200	
				4,948,960

Anchorage Steel:				
Eye-bars and riveted work........	4,945,000	5.0	247,250	
				247,250
Total steel work				$17,750,590
Tower foundations:			278,820	
Masonry in pier (cu. yds.).........	15,490	$18	280,500	
Concrete in cribwork (cu. yds.)....	37,400	$7.50	62,400	
Concrete in caisson (cu. yds.).....	5,200	$12	35,550	
Timber in cribwork (M. ft. B.M.)..	790	$45	104,400	
Steel in caisson (lbs.).............	2,320,000	$4\frac{1}{2}$c.	156,000	
Earth excavation (cu. yds.).......	39,000	$4		1,835,340
Anchorages:				
Masonry (cu. yds.)................	109,000	$18	1,962,000	
Concrete in foundation (cu. yds.)..	10,400	$12	124,800	
				4,173,600
Total substructure..........................				$6,008,940
Grand total				$23,759,530

SUSPENSION BRIDGE—SPAN = 3000 FT.

Estimate of Cost.

Material.	Quantity.	Price.	Amount.	Total.
Cables, etc.:	lbs.	c.	$	$
12 cables at 349 sq. in..........	92,280,000	12.5	11,535,000	
Suspenders	9,040,000	10.0	904,000	
Steel castings (cable bands, etc.)	13,650,000	9.0	1,228,500	
				13,667,500
Suspended superstructure:				
Truss chords (nickel steel)......	104,400,000	8.0	8,352,000	
Webs and bracing (struct. steel)	29,418,000	5.6	1,647,410	
Floor system (structural steel) ..	32,052,000	5.6	1,794,910	
				11,794,320
Towers (587 ft. high):				
Structural steel................	179,248,000	5.6	10,037,890	
Steel castings	9,600,000	9.0	864,000	
				10,901,890

Anchorage Steel:				
Eye-bars and riveted work......	8,180,000	5.0	409,000	
				409,000
Total steel work............	....	....	....	$36,772,710
Tower foundations:				
Masonry in pier (cu. yds).......	26,300	$18	473,400	
Concrete in cribwork (cu. yds.)..	67,800	$ 7.50	508,500	
Concrete in caisson (cu. yds.)...	8,230	$12	98,760	
Timber in cribwork (M. ft. B.M.)	1,080	$45	48,600	
Steel in caisson (lbs.)..........	2,650,000	4½c.	119,250	
Earth excavation (cu. yds.).....	65,000	$ 4	260,000	
				3,017,020
Anchorages:				
Masonry (cu. yds.).............	183,200	$18	3,297,600	
Concrete in foundation (cu. yds.)	16,650	$12	199,800	
				6,994,800
Total substructure..........	....	....	....	$10,011,820
Grand total................	....	....	....	$46,784,530

CHAPTER IV

CONCLUSIONS FOR SUSPENSION BRIDGES

Art. 15

Empiric Formulæ for Weights of Suspension Bridges

From the results of the preceding designs, we may construct semi-empirical formulæ for the weights of the different parts of a suspension bridge. Such formulæ will be useful in preparing estimates for other spans and loadings; also in drawing general conclusions as to maximum and limiting spans.

Let the weights (per linear foot) of live-load, cable, suspenders, truss (including bracing) and floor be represented by L, C, S, T and F, respectively. The weight of the cable is evidently proportional to the total load it sustains and to the length of span, provided the rise-ratio remains unchanged. The weight of the suspenders is likewise proportional to the load they carry and to the span, as a longer span requires a proportionally greater average length of suspenders. The weight of the truss may be considered in two parts: the larger portion provides for the live-load and is proportional to that load and to the span length, if the depth ratio remains constant; the other part of the truss-weight represents the contribution of the wind-stresses and will vary with the square of the span if the width of bridge remains constant. The weight of the floor system is evidently proportional to the assumed live-load, and is practically independent of the length of span. Introducing the necessary coefficients of proportionality, the above relations may be formulated as follows:

$$\left.\begin{aligned} C &= a(C+L+S+T+F)\cdot l \\ S &= b(L+S+T+F)\cdot l \\ T &= c(L)\cdot l + d\cdot l^2 \\ F &= e\cdot L \end{aligned}\right\} \quad . \quad (1)$$

Substituting the values of weights and spans from the preceding designs, the spans being measured in units of 1000 ft., the above relations yield the following values for the undetermined coefficients.

	S. B. No. 1.	S. B. No. 2.	S. B. No. 3.	Mean.
$a=$	.070	.066	.068	.068
$b=$	.0077	.0073	.0074	.0075
$c=$	.35	.34	.36	.35
$d=$	105	105	105	105
$e=$	.83	.84	.85	.84

The uniformity in the above coefficients for the different spans confirms the rationality of the relations assumed above. Introducing the empirical constants in those relations, we obtain the following formulæ for suspension bridges:

$$\left.\begin{aligned} C &= .068(C+L+S+T+F)\cdot l \\ S &= .0075(L+S+T+F)\cdot l \\ T &= .35\cdot L\cdot l+105\ l^2 \\ F &= .84\ L \end{aligned}\right\} . \qquad (2)$$

Art. 16

Maximum Span for Cable

The theoretical limiting span for a suspension bridge is the span at which the cable-section becomes infinitely large in proportion to the load it can carry. The defining equation for this condition is, therefore,

$$\frac{A_0}{g_1} = \infty \quad . \quad . \quad . \quad . \quad (1)$$

where g_1 is the intensity of the total load suspended from the cable.

If g_0 = the weight of the cable per linear horizontal unit, and n = the rise-ratio $= \frac{f}{l}$, the maximum tension in the cable will be

$$T = H \cdot \sec \alpha = \left(g_0 + g_1\right)\frac{l^2}{8f}\sqrt{1+16n^2}. \quad (2)$$

The weight g_0 is given by the equation

$$g_0 = \left(1 + \frac{8}{3}n^2\right)\frac{T}{s_0} \cdot \gamma_0 \quad . \quad . \quad (3)$$

where s_0 is the unit working stress and γ_0 is the weight per linear foot per sq.in. of cross-section of the cable. From Eqs. (2) and (3) we obtain

$$A_0=\frac{T}{s_0}=\frac{l\cdot\sqrt{16+\frac{1}{n^2}}}{8s_0-\left(1+\frac{8}{3}n^2\right)\cdot\gamma_0\cdot l\cdot\sqrt{16+\frac{1}{n^2}}}\cdot g_1 \tag{4}$$

Introducing the condition for maximum span, as defined by Eq. (1), we obtain the relation

$$8s_0-\left(1+\frac{8}{3}n^2\right)\cdot\gamma_0\cdot\sqrt{16+\frac{1}{n^2}}\cdot l=0.$$

Hence,

$$l_{\max}=\frac{8s_0}{\left(1+\frac{8}{3}n^2\right)\sqrt{16+\frac{1}{n^2}}\cdot\gamma_0}. \tag{5}$$

This equation shows that the maximum limiting span is independent of the live-load or weight of the stiffening truss. Equating the first derivative of the second member of (5) to zero, we find the rise-ratio giving the absolute maximum span to be

$$n = \frac{f}{l} = .306. \quad . \quad . \quad . \quad (6)$$

With this value, Eq. (5) becomes

$$l_{max} = 1.085 \frac{s_0}{\gamma_0}. \quad . \quad . \quad (5')$$

Numerical Values. For very heavy cables, the weight of the cable-wrapping may be neglected; hence γ_0 is simply the density-factor of steel $= 3.4$.

The extreme limit which no cable-span can ever exceed is that for which s_0 equals the elastic limit of the best cable material or $s_0 = 180{,}000$. Eq. (5′) then gives

$$\text{Extreme } l_{max} = 65{,}520 \text{ ft.} \quad . \quad (7)$$

For practical purposes it is necessary to introduce a safety factor in the working stress; reducing the latter to $s_0 = 60{,}000$, we obtain, by Eq. (5′),

$$l_{max} = 21{,}840 \text{ ft} \quad . \quad . \quad . \quad (7')$$

This span with a rise-ratio of $n = .306$, would require towers about 7000 ft.

high; the above result, therefore, is of no practical significance.

Replacing the above value of n by the economic ratio

$$n=\frac{f}{l}=\frac{1}{8}, \quad . \quad . \quad . \quad . \quad (6')$$

and retaining $s_0=60{,}000$, Eq. (5) yields

$$\text{Practical } l_{\max}=15{,}160 \text{ ft.} \quad . \quad (7'')$$

This value gives the limit of span which may be approached, but not exceeded, by successively reducing the amount of extraneous load for any given cable-section or by increasing the cable-section for any given load so that $\frac{A_0}{g_1} \doteq \infty$. At the maximum span given by Eqs. (7), (7′) or (7″), the cable-section may have any finite value so long as there is no load suspended from it. The addition of the smallest load will necessitate reducing the span or else increasing the section A_0 to infinity.

It may be noted that the limiting span increases directly with the working stress s_0 and inversely with the cable-weight factor γ_0.

In comparison with the above limiting values, it is of interest to consider the largest existing cable-span. This is a cableway at Caperton, W. Va., built in 1898, and having a span of $l=2100$ ft., or only about one-seventh of the span-length which may yet be attained.

Art. 17

Maximum Span for Suspension Bridges

From Eq. (2) of Art. 15, we obtain the following empirical expression for the weight of the cable (C) in terms of the suspended loading and the length of span (l):

$$C=\frac{.068l}{1-.068l}(L+S+T+F). \quad . \quad (1)$$

Substituting the empirical expressions for S, T and F in terms of the live-load L, Eq. (1) becomes, practically,

$$C=\frac{.068l(1.84L+.35Ll+105l^2)}{(1-.068l)(1-.0075l)}. \quad (2)$$

The theoretical maximum span for the suspension bridge is the span at which the cable-section becomes infinite. This condition is realized when the denominator of Eq. (2) reduces to zero, or

$$l_{max}=\frac{1}{.068}=14{,}700 \text{ ft.}$$

This is the upper limit of feasible spans for suspension bridges and represents the span at which the suspension bridge ceases to be self-supporting. It is somewhat smaller than the maximum span-limit (15,160 ft.) for a simple cable, as determined in the preceding article, simply because the weight of cable wrapping and fastenings was not considered in that investigation.

Another method of deducing the limiting span, possessing the advantage of greater generality inasmuch as it is applicable to other forms of bridge-structures, is as follows: Let $C_1=$ the weight of the cable and $W_1=$the total suspended load, per linear foot, for any span (l_1). For any other span

(l), the weight of the cable is given by the proportion

$$\frac{C}{C_1}=\frac{(C+W)l}{(C_1+W_1)l_1}. \quad . \quad . \quad (3)$$

Solving this equation, we obtain

$$C=\frac{WC_1l}{(C_1+W_1)l_1-C_1l}. \quad . \quad (4)$$

For $C=\infty$, the denominator of the above expression must reduce to zero, or

$$l_{max}=\frac{(C_1+W_1)\cdot l_1}{C_1}. \quad . \quad . \quad (5)$$

This formula enables the limiting span to be calculated from the results of any single design.[1] In the designs at hand,

$l=$	1,500	2,250	3,000
$C=$	1,286	2,160	3,720
$W=$	11,162	12,522	14,418
$\therefore l_{max}=$	14,300	15,300	14,600 ft.

[1] The same formula, with C denoting the weight of the arch-rib, was used by the writer in determining the maximum spans for steel and concrete arches. See Thesis submitted for the Degree of C.E. at Columbia University.

The practical agreement between these values indicates the reliability of the above method of determining the maximum span from a single design. Taking the mean of the above values, there results

$$l_{\max} = 14{,}700 \text{ ft.}$$

a value identical with that yielded by the first method of this article.

Although the above is the limiting feasible span, defined by $C = \infty$, it is evident that the sections will become too large for practical construction long before that length of span is reached. In order to determine the *practical* maximum span, a value for the maximum cable-section must first be fixed.

The cables of the three largest suspension spans, viz., the Brooklyn, Williamsburg and Manhattan Bridges, are $15\frac{5}{8}$, $18\frac{3}{4}$ and $21\frac{1}{2}$ inches in diameter, respectively. Cables with a diameter of 24 inches were used in one of the designs in this investigation, but it is doubtful whether any larger diameter can be put together without excessive difficulty of manipulation and uncertainty of proper distribution of stress among the different strands.

With the exception of some old chain bridges, there is no bridge on record with more than six cables. Twice that number, or four groups of three, were used in one of the writer's designs, but it is extremely improbable that a greater number than 16 could be practically combined in one structure.

Assuming, then, a section of 16 cables of 24 inches diameter for the bridge of maximum span, we have

$$C_{max} = 20,000 \text{ lbs.}$$

Solving Eq. (2), Art. 15, for the length of span in terms of the cable-weight and live-load, there results

$$l = \frac{C}{.0734C + .1253L + .0238Ll + 7.14l^2}. \quad (6)$$

Substituting in this equation the maximum value of C, as just established, and assuming different values of the live-

load, we obtain the following values for the maximum span:
For

$L=0$,	$l_{max}=9{,}500$ ft.
$L=10{,}000$,	$l_{max}=4{,}900$ ft.
$L=15{,}000$,	$l_{max}=4{,}000$ ft.
$L=20{,}000$,	$l_{max}=3{,}500$ ft.

The first of the above results simply signifies that 9500 ft. is the span at which the cable will just be able to support the wind-bracing. As this condition is one of zero loading, it may be omitted from practical consideration. Furthermore, it is hardly probable that a structure of the magnitude under investigation would ever be planned for a lighter loading than about 10,000 lbs. per linear foot, particularly when it is remembered that this would require about 10 lbs. of steel for every pound of useful load.

It will therefore suffice to restrict the conditions of the problem to the practical limits of $L=10{,}000$ to $L=20{,}000$ lbs. of live-load per linear foot. We thus find that *the maximum practical* *span for suspension bridges ranges from* 3500 *to* 4900 *ft., depending upon the assumed live-load.*

Art. 18

Empiric Formula for Cost of Suspension Bridges

The expression for the cost of any span (l) will be assumed of the general form

$$C = al + bl^2 + cl^3. \quad . \quad . \quad . \quad (1)$$

Since we have but three values determined for C by actual design, the formula is limited to an equal number of terms.

From the results of the preceding estimates, we have

$C = \$11,645,000$ for $l = 1500$ ft.
$C = \$23,760,000$ for $l = 2250$ ft.
$C = \$46,785,000$ for $l = 3000$ ft.

Substituting these values in (1), and solving the resulting three equations for the unknown coefficients, we obtain

$$C = 8900l - 3.77l^2 + .0020l^3. \quad . \quad (2)$$

as the general cost-formula for suspension bridges. This gives the combined cost of steel work and substructure for any span for an assumed live-load of 18,000 lbs. per linear foot. For any other loading, the above coefficients should be changed in proportion.

Art. 19

Economic Span for Suspension Bridges

As established in the preceding article, the cost of a suspension bridge is given by the expression

$$C = 8900l - 3.77l^2 + .0020l^3. \quad . \quad (1)$$

Of this cost, about 65 per cent represents the steel work and the remainder provides for the masonry and anchorages.

A study of the contracts for recent long-span bridges shows an additional cost of about 20 per cent for pavements, tracks, railings, ornamental work, electric lighting, etc. To this must be added the cost of terminal structures and real estate for the approaches. In a city structure the last item, as in the case of the Manhattan Bridge, may amount to more than the cost of the bridge itself. A fair average value for this item is about 100 per cent. Adding the above items, we find

$$\text{Total first cost of bridge} = 220\%\ C. \quad (2)$$

The rate of interest will be assumed at 5 per cent. The cost of maintenance, including repairs, painting, lighting, etc., averages about $4\frac{1}{2}$ per cent of the cost of the superstructure. In addition, a certain annuity must be set aside for the periodic renewal of the superstructure. The foundations may be permanent, but the steel work has a limited life. The life-periods of various suspension bridges, or the periods before reconstruction or removal, whether terminated by failure or increased traffic demands, have been as follows:

1827	[1] Hammersmith (London)	.55	years.
1829	[2] Regnitz (Bamberg) . . .	.59	"
1834	[2] Freiburg (Switzerland)	18 29	" "
1839	[1] Weser (Hamlin)	51	"
1845	[1] Neckar (Mannheim)	46	"
1850	Fairmount (W. Va.) . . .	40	"
1851	[3] Niagara (Old S. B. at Lewiston)	13	"
1852	[4] Charleston (W. Va.)	52	"
1855	[3] Niagara Falls (Railway Bridge)	42	"
1867	[5] Cincinnati (Ohio R.) . .	.31	"
1868	[1] Moldau (Prague)	32	"
1869	[3] Niagara Falls (Hwy. Bridge).	19 1 17	" " "
1877	[6] Point Bridge (Pittsburg)	.28	"
	Mean Life Period	31	years.

[1] Melan, "Konstruktion der Hängebrücken" (Leipzig, 1906), p. 204.

[2] Nouv. ann. de la constr., 1881. Also Riese, "Die Ingenieurbauwerke der Schweiz."

[3] *Eng. Record*, 1897 (Apr. 24); 1899 (Aug. 26).

[4] *Eng. News*, 1905 (Feb. 2). *Eng. Record*, 1904 (Dec. 24).

[5] *Eng. Record*, 1898 (Sept. 10, Nov. 26).

[6] *Eng. Record*, 1905 (May 6–13).

This value, or 30 years in round numbers, will be adopted as the probable life of the steel work of a suspension bridge. It is true that the newer bridges possess the advantages of improved material and construction, but the more severe traffic to which they are subjected and the smaller margin of safety provided in their design prevent them from attaining as long a life as some of the old structures. For a railroad bridge strained to its full capacity, the above value of the life-period is certainly not too small. At 5 per cent compound interest, a sinking fund to meet the cost of renewal in 30 years will require an annuity of 1.505 per cent. (See Annuity Tables.) The annual charge against the bridge will therefore consist of the following items:

Interest charge $= 5\% \times 220\% \, C$	$= 11\% \, C$
Repairs and maintenance .... $= 4.5\% \times 65\% \, C$	$= 3\% \, C$
Depreciation = Annuity for renewal in 30 years $= 1.505\% \times 65\% \, C$	$= 1\% \, C$
Total annual charge	$= 15\% \, C$

The limiting economic span is that at which the revenue from traffic (T) just balances the annual cost of the structure. We may therefore write

$$15\%C = T. \quad . \quad . \quad . \quad (3)$$

as the defining condition for the economic span.

In determining the maximum traffic returns (T) to be expected from a long-span bridge, we are guided by the following considerations: The Brooklyn Bridge now carries about 118,000,000 paid passengers per annum.[1] The maximum daily is 30 per cent greater than this rate and the maximum hourly is 500 per cent greater still.[2] The Williamsburg Bridge, opened 20 years later, is a close competitor, with a passenger traffic of 75,000,000 per annum[3]; at the present rate of increase, it will

[1] Report of Public Service Comm., 1st District, N. Y., 1909.

[2] *Engineering Record*, 1910 (June 11).

[3] *Engineering News*, 1910 (Jan. 27).

soon equal the older structure in volume of traffic. The usefulness of both these structures is steadily growing, despite the opening of several competing routes of communication across the same river. Each bridge helps to build up the districts which it connects, thereby creating increased traffic for itself. Thus there were 9,000,000 passengers crossing the Brooklyn Bridge in 1884,[1] 42,000,000 passengers in 1893,[1] and 118,000,000 passengers in 1909.[2] The total number of passengers annually crossing the East River increased 500 per cent in the 17 years after the opening of the Brooklyn Bridge,[3] and 240 per cent more since the Williamsburg Bridge was opened.[4] These facts indicate that

[1] Statement of Chas. Macdonald to Bd. of Eng. Officers, 1894; also *Engineering News*, 1893 (Feb. 23).

[2] Report of Public Service Comm., 1st Distaict, N. Y., 1909.

[3] Lindenthal in Discussions at the N. Y. R. R. Club, Apr. 18, 1901.

[4] *Engineering News*, 1910 (Jan. 27).

any large bridge, if judiciously located, will ultimately get all the traffic it can accommodate.

In the absence of any better guide, let us take the amount of travel on the Brooklyn Bridge as the maximum traffic to be expected on any other long-span structure. This value may justly be augmented by 50 per cent for the greater capacity of a six-track bridge, but this additional profit will be disregarded to compensate for the early years of undeveloped traffic. We will therefore assume 118,000,000 passengers using the bridge in a year. For a span of the length under consideration, a toll of 5 cents per passenger would be an equitable rate. The same charge is now made for ferry or tunnel transportation across the Hudson River, and bridge travel would surely be preferred for its greater speed and comfort.

At night, when the passenger traffic is a minimum, the tracks can be used for the transportation of freight. There are about 6000 cars of freight, inbound and outbound, at Jersey City daily, and about half of this belongs to New York. We may therefore safely count on at least 1500 cars of freight daily crossing a six-track bridge over the Hudson River or any similar location.

The total annual traffic over a long-span bridge may therefore attain the following value:

118,000,000 passengers at 5 cents	=$5,900,000
547,500 cars of freight at $4	= 2,190,000
$\therefore$ T = total annual revenue	=$8,090,000

Substituting this value in eq. (3), we obtain

$$C = \$54,000,000$$

as the maximum economic cost for a long-span bridge. With this value of C, the solution of eq. (1) yields

$$\text{Economic } l = 3170 \text{ ft.}$$

In the case of the proposed Hudson River Bridge, of somewhat shorter span, calculations indicated a profit of less than 1 per cent on the investment,[1] thus confirming the above result.

Conclusion. The limiting economic span for suspension bridges is about 3170 *ft., and will be less wherever the probable traffic returns are smaller than assumed in this investigation.*

[1] H. G. Prout in Discussions at the N. Y. Railroad Club, Apr. 18, 1901.

CHAPTER V

STUDY OF CANTILEVERS

Art. 20

Cantilever Bridges—Historical Sketch

In adaptability to long spans and possibility of erection without false-work, the cantilever is the sole competitor of the suspension bridge. Both of these types have attained prominence by remarkable examples of design and construction. With but one exception, however, the suspension type has never been employed for fast railway traffic. Its use has been confined to highway bridges or wherever æsthetic requirements prevailed. The banner bridges of the suspension type, those over the East River, have been attributed to "an ingrained fad of the New York

Department of Bridges." For long railway spans, the cantilever has almost invariably been given the preference on account of its superior rigidity at a given cost. The longest span in the world (Forth Bridge 1710 ft.) is of the cantilever form, and the Quebec Bridge, now under construction, will raise the record for length of span to 1800 ft.

Although cantilever design is a comparatively recent development in engineering, the idea is by no means a new one. Bridges of logs, put together on the cantilever principle, have been used in tropical countries since prehistoric times.[1] In 1783, a wooden cantilever bridge of 112-ft. span was reported by travelers in Thibet.[2] An 1800-ft. "flying pendant lever bridge" to cross the East River and a 3000-ft. span across the North River were proposed by Pope in 1810.[3] Fairbairn's proposal

[1] *Van Nostrand's Magazine*, Jan., 1886.

[2] Pope, Treatise on Bridge Architecture, New York, 1811.

[3] Ibid.

for the Britannia Bridge, in 1845, was a cantilever design.[1] Stephenson, in 1846, and Edwin Clark, in 1850, suggested the cantilever idea.[2] In the latter year Sir John Fowler built a wooden model to illustrate the form of construction.[3] In 1859 Prof. Ritter of Hanover proposed cutting the chord of a continuous truss at the points of contraflexure and worked out the stresses in the resulting cantilever structure for a span of 526 ft. The first cantilever design actually constructed, however, was a bridge of 124 ft. span over the Main River near Hassfurt, designed and built by Gerber in 1867.[4] On this account, cantilevers are known as "Gerber Bridges" on the continent. In 1871, Fowler and Baker built two cantilever spans of 800 ft. over the Severn, and in 1873 Baker designed a

[1] *Engineering* (London), Mar. 5, 1886.

[2] *Engineering* (London), Feb. 28, 1890.

[3] Proc. of the Inst. of C. E., IX, p. 256.

[4] Mehrtens, "Der deutsche Brückenbau im 19. Jahrundert," Berlin, 1900.

cantilever ferry bridge of 650 ft. span over the Tees.[1] The first cantilever bridge for railway traffic, a span of 148 ft., was built in 1876 over the Warthe at Posen.[2] In the same year, the first American cantilever, the Kentucky Viaduct, was built by C. Shaler Smith.[3] In this structure and in the Niagara Cantilever built in 1883 by C. C. Schneider for the Michigan Central Railroad, the possibility of erection without falsework was first demonstrated.[4] In 1881, four years after the completion of the Kentucky Viaduct, the final designs for the Forth Bridge were approved. The successful completion of that remarkable structure in 1889[5] marked the end of the experimental period for the cantilever and served to fix that type in its present dominant position in long-span construction.

[1] *Engineering News*, Nov. 24, 1904.
[2] *Engineering* (London), Feb. 28, 1890.
[3] Trans. Am. Soc. of C. E., Nov., 1878.
[4] Trans. Am. Soc. of C. E., Nov. 1885.
[5] *Engineering* (London), Dec. 6, 1889.

A table of the most noted cantilever bridges with their principal dimensions is appended. It will be observed that only three cantilevers exceed 1000 ft. in span, whereas eight suspension bridges have exceeded this value. It is mainly between the limits of 500 and 1000 ft. that cantilevers predominate. The high values of the ratio of dead-load to live-load are significant, indicating a greater expenditure of metal than is required in suspension bridges.

It will also be noticed that there are comparatively few cantilevers below 500 ft. span, that being the domain of the ordinary truss. With increasing span-length, however, the cantilever bridge becomes superior to the simple truss because of the increasing significance of the following advantages.

1. No obstruction of the channel during erection and the saving of the cost of falsework.

2. Lower economic depth of truss.

3. Smaller required width resulting in a saving in the piers and in the floor system.

TABLE II—NOTABLE

Date.	Name.	Location.	Engineer.
1908	[1] Quebec......	St. Lawrence R.	Cooper.........
1889	Forth.......	Scotland.......	Fowler & Baker
1908	Queensboro..	East R., N. Y...	Dept. of Br.
....	Lansdowne. .	India..........	....
1903	Monongahela.	Pittsburg.......	Boller & Hodge
1892	Memphis	Mississippi R. ..	Morison.......
1910	Beaver......	Ohio R., Pa....	....
1903	Mingo.......	Ohio R.........	Boller & Hodge
1905	Thebes......	Miss. R., Ill. ...	Modjeski & Noble.......
1904	Ruhrort.....	Rhine R., Germany........	....
1891	Red Rock....	Colorado R.....	....
1902	Marietta.....	Ohio R., Ohio. .	....
1902	Czernavod...	Danube R......	....
1887	[2] Poughkeepsie	Hudson R......	....
1906	Long Lake ..	New York	....
1903	Connel Ferry.	Scotland.......	Barry.........
1897	Francis Joseph	Budapest.......	....
1883	Niagara.	Niagara Falls...	Schneider.....
1876	[3] Kentucky R.	Ohio...........	C. S. Smith. ...
1883	Fort Snelling	Mississippi R., Minn........	Schneider.....

[1] Collapsed 1908, before completion.
[2] Reconstructed 1906.

4. More favorable distribution of the dead-load, the material being massed toward the piers.

CANTILEVER BRIDGES

Sp'n $=L$	S.S. $=l$	C.A. $=m$	A.A. $=n$	Width	Depth.	Loading. L.L.	D.L.	$\frac{\text{D.L.}}{\text{L.L.}}$
1800	675	562½	500	67	98–315	13000	26000	2.0
1710	350	680	680	32–120	50–350	4480	21000	4.7
1182	0	591	630	60	45–185	8440	27000	3.2
820	200	310	248					
812	360	226	346	32	60–126	9000	9000	1.0
790	452	169	621	30	78	4000	7000	1.75
769	285	242	320	......	....	.....	11000	
700	310	195	298	......	....	9000	8000	0.9
671	366	152½	521	32	50–75	8000	10000	1.25
667	443	112	390	36	46–82			
660	....	.....	.....	25				
650	270	300	600	27				
623								
548	208	170	525	30	38–75	6000		
525	175	175	0	24	20–60	920	840	0.9
524	232	146	106	21	30–118	4000	7620	1.9
514	102	206	257			6000		
495	120	187½	207½	28	....	3000		
375	300	75	375	18	38			
							2530	0.85
315	105	105	105					

[3] Replaced by truss bridge, 1910.

5. More favorable distribution of the wind-load, for the same reason.

6. Decreased wind-load stresses.

In order to establish data for determining the economic and maximum spans, complete designs and estimates will be made for cantilevers of three different spans: 1000, 1500 and 2000 ft., respectively. The condition of loading and specifications for allowable working stresses will be assumed the same as for the suspension bridges previously designed.

Before we can proceed with the design of the cantilevers, it is necessary to find the most favorable solutions of the following problems.

1. Economic span-ratios for cantilevers.

2. Economic width for cantilevers.

Art. 21

Economic Span-ratios for Cantilevers

Let l = length of suspended span;

m = length of cantilever arm;

n = length of anchor arm.

Then the total channel span will be

$$L=l+2m \quad . \quad . \quad . \quad . \quad (1)$$

and the total length of structure will be

$$S=l+2m+2n \quad . \quad . \quad . \quad (2)$$

Assuming that the weight per linear foot of truss in any span or arm is equal to some constant factor times the length of that span or arm, let

a = suspended span factor;
b = cantilever arm factor;
c = anchor arm factor.

Then the weight of the whole structure will be

$$W=al^2+2bm^2+2cn^2 \quad . \quad . \quad (3)$$

This will be a minimum for

$$al=bm=cn \quad . \quad . \quad . \quad (4)$$

Hence the economic lengths of the suspended span, cantilever arm and anchor arm are inversely proportional to the respective dead-load factors; in other words, *the economic lengths are such as to make the weight per linear foot uniform over all parts of the bridge.*

From (1), (2) and (4) we obtain [1]

$$l=\frac{b}{b+2a}\cdot L, \quad m=\frac{a}{b+2a}\cdot L,$$

$$n=\frac{ab}{c(b+2a)}\cdot L. \qquad (5)$$

Numerical Values. The weight factors a, b and c should be obtained by actual computation of weights of structures similar to those under consideration. The resulting values will, of course, be found to vary more or less with different loadings and span-ratios. By omitting from consideration all spans of unusual proportions, and reducing the results to a common assumed loading (=18,000 lbs. per linear foot as in the following designs), the writer obtained

[1] Cf. Burr's solution of the problem in his "Stresses in Bridges and Roof Trusses, etc." (Wiley, 1908), App. V., p. 472.

the following average values of the truss-weight factors:

$$a=14,\ b=42,\ c=21.$$[1]

Substituting these values in Eqs. (5), we obtain

$$l=0.60\ L,\ m=0.20\ L,\ n=0.40\ L,$$

for the economic span-ratios of a cantilever bridge. Prof. Burr[2] recommends values of

$$l=0.5 \text{ to } 0.55\ L;\quad m=0.20\ L;$$
$$n=0.42 \text{ to } 0.5\ L.$$

An exact theoretical solution of the problem,[3] eliminating the use of empirical constants, shows that the total moment areas will be a minimum for

$$l=0.68\ L;\quad m=0.16\ L,\quad n=0.37\ L.$$

[1] Compare these values with those yielded by the writer's designs, viz.: $a=13.6$, $b=42.3$, $c=21.7$.

[2] Burr's "Stresses in Bridges and Roof Trusses, etc." (Wiley, 1908), App. V, p. 472.

[3] Marburg in Proc. of Eng. Club of Phila., July, 1896.

This solution is practically defective, however, in disregarding the web-members and lateral bracing and in assuming uniform dead-load over the whole structure.

A study of the spans of the cantilevers tabulated in a preceding article, omitting those of extraordinary form, yields the following results:

Extreme values:

l/L	m/L	n/L
.20 – .66	.17 – .40	.28 – .78

Mean values:

.38	.31	.45

These values compared with those established above indicate that, in past practice, the suspended span as a rule has been made too long and the cantilever arms too short for the best economy.

For the designs in this investigation, the writer has adopted a compromise between the dictates of theory and those of conformity with past practice. The lengths of the suspended spans will be made for

$$
\begin{array}{rccc}
L = & 1000 & 1500 & 2000, \\
l = & 500 & 650 & 800, \\
\hline
\end{array}
$$

so that

$$
l/L = \quad 0.5 \qquad 0.43 \qquad 0.4.
$$

The suspended span is thus made a diminishing fractional part of the total span as the latter increases in length; otherwise the length of the suspended truss would become prohibitive before the limiting cantilever span is reached. (See Art. 26.)

The lengths of the anchor arms will be made

$$
n = 0.4L
$$

thereby conforming with the ratio indicated by both theory and practice. This determination of the best length for the anchor arm, however, is purely academic as, in any actual design of a cantilever, the location of the piers is determined by natural conditions and the requirements of navigation rather than from any theoretical investigations.

Art. 22

Minimum Width for Cantilevers [1]

On account of the saving in piers and floor members, it is desirable that the width of any bridge structure should be a minimum consistent with the demands of lateral rigidity. In simple truss bridges it is generally considered that adequate stiffness is provided by a distance c. to c. of trusses of $\frac{1}{18}$ of the span. The minimum width for cantilevers may then be defined as that width which will insure the same degree of rigidity as the above.

Using the same notation as in the preceding article, the total length of span for a cantilever bridge is denoted by

$$L=l+2m \quad . \quad . \quad . \quad .(1)$$

[1] Adapted from an analysis given to his classes by Prof. Burr.

If a lateral load, p per linear foot, acts on the structures, the central deflection will be

$$h=\frac{p}{EI}\left[\frac{5}{384}l^4+\frac{l}{2}\frac{m^3}{3}+\frac{m^4}{8}\right] \quad . \quad . \qquad (2)$$

This reduces to

$$\left.\begin{array}{l} h=.00260\dfrac{p}{EI}L^4 \text{ for } l=0.5L \\ \text{and} \\ h=.00315\dfrac{p}{EI}L^4 \text{ for } l=0.4L \end{array}\right\} \quad . \qquad (3)$$

In a simple truss of span l' the central deflection is given by

$$h=\frac{5}{384}\cdot\frac{p}{EI}l'^4. \quad . \quad . \quad . \quad . \qquad (4)$$

With equal rigidity, the simple truss and the cantilever must suffer the same deflections. Equating the right-hand members of Eqs. (3) and (4), there result

$$\left.\begin{array}{l} l'=.668L \quad \text{for} \quad l=0.5L \\ \text{and} \\ l'=.701L \quad \text{for} \quad l=0.4L \end{array}\right\} \quad . \qquad (5)$$

The distance c. to c. of trusses should not be less than

$$w=\frac{l'}{18},$$

or, substituting the relations of Eq. (5)

$$\text{Minimum } w=\frac{1}{27} \text{ to } \frac{1}{25}L. \quad . \quad (6)$$

It is interesting to note here that the mean width-ratios for the structures listed in the Table of Cantilevers is

$$w=\frac{1}{23}L,$$

a value on the safe side of the required ratio.

In the designs at hand a ratio of $w=\frac{1}{25}L$ will be adopted except in the shortest span where the required space for the roadway will necessitate a slightly greater width-ratio, namely,

$$w=\frac{1}{20}L.$$

BIBLIOGRAPHY ON CANTILEVERS

Quebec.

Engineering (London), 1900 (II, 189, 241); 1902 (II, 419); 1903 (I, 92); 1905 (II, Sept. 22).

Canadian Engineer, 1902 (May).

Engineering News, 1897 (Oct. 14); 1902 (Nov. 20); 1905 (Sept. 14); 1906 (July 6); 1907 (Oct. 31).

Engineering Record, 1905 (Mar. 4, Apr. 1, Apr. 8, Sept. 16); 1906 (June 23, Dec. 29); 1908 (Mar. 14, Apr. 25); 1910 (Sept. 24, Oct. 1, Oct. 15).

Railroad Gazette, Vol. XXXIX, No. 11.

Forth.

Engineering (London), 1882 (Sept. 1, 8); 1883, 1884, 1885 (Feb. 6); 1886, 1887, 1888, 1889 (Dec. 6); 1890 (Feb. 28, pp. 213–283).

Queensboro.

Engineering Record, 1901 (Mar. 16); 1902 (Dec. 13); 1903 (Feb. 28, Aug. 22); 1904 (Mar. 3); 1905 (Mar. 4, 18, May 20, 27, June 10); 1906 (Jan. 6, 27, Feb. 10, 17, 24, Mar. 3, 17, Sept. 15); 1907 (Dec. 21); 1908 (Apr. 11, May 28, Aug. 8, Nov. 14).

Engineering News, 1907 (Nov. 23); 1908 (Nov. 12, 19).

Iron Age, 1907 (Mar. 7).

Railroad Gazette, 1901 (Aug. 16); 1903 (Oct. 2).
Scientific American, 1903 (Sept. 19).

Marietta (Ohio).
Engineering News, 1902 (Nov. 20).
Engineering (London), 1902 (II, p. 418).
Engineering Record, 1903 (Sept. 26).
Railroad Gazette, 1902 (July 11).

Monongahela (Pittsburg).
Engineering News, 1902 (Nov. 20).
Engineering (London), 1902 (II, p. 417).
Railroad Gazette, 1902 (Mar. 14); 1903 (Aug. 14).
Engineering Record, 1902, 1903 (Jan. 3); 1904 (Mar. 5, Apr. 2, Apr. 9).

Memphis (Tenn.).
Engineering News, 1892 (Feb. 27, Mar. 12, May 12, June 16, Aug. 11, Sept. 15).

Mingo Junction.
Engineering News, 1902 (Nov. 20).
Engineering (London), 1902 (II, p. 417).
Engineering Record, 1904 (June 25, July 2); 1903 (Oct. 3).

Thebes (Ill.).
Railway Age, 1902 (June 20).
Engineering News, 1902 (Nov. 20); 1905 (May 11).
Engineering (London), 1902 (II, p. 416); 1903 (I, p. 326).

Engineering Record, 1904 (Nov. 12, Dec. 24); 1905 (Mar. 4); 1905 (July 22, Sept. 16).
Trans. Assn. of Civ. Eng. of Cornell Univ., 1905.
Engineer (London), 1905 (July 21).
Railroad Gazette, 1903 (Jan. 9); Vol. XXXVIII, No. 21.

Ruhrort (Germany).
Schweizerische Bauzeitung, 1904 (June 18).
Engineering (London), 1904 (II, 7, 35).
Engineering News, 1904 (July 14).
Engineer (London), 1907 (Nov. 1).
Zeitschrift d. Ver. Deutscher Ing., 1904 (July 2).

Connel Ferry (Scotland).
Engineer (London), 1903 (Sept. 11).
Engineering (London), 1903 (July 31).
Engineering Record, 1904 (July 2).

Poughkeepsie (N. Y.).
Engineering (London), 1887 (May 13).
Engineering Record, 1905 (Oct. 28); 1906 (Aug. 18).

Long Lake (N. Y.).
Engineering Record, 1906 (Sept. 29).

Francis Joseph (Budapest).
Zeitscrhrift d. Oesterr. Ing. u. Arch. Ver., 1897 (Feb. 26).
Génie Civil, 1897 (May 8).

Engineer (London), 1897 (May 14).
Stahl und Eisen, 1898 (Feb. 1).
La Revue Technique, 1898 (Sept. 25).

Niagara.

Trans. Am. Soc. C. E., Nov., 1885.
Engineering (London), 1886 (Mar. 5).
Engineering Record, 1900 (Oct. 13).
Scientific American, 1900 (Oct. 20).

Kentucky R.

Trans. Am. Soc. C. E. Nov., 1878.
Engineering Record, 1898 (July 9); 1910 (Nov. 26).

CHAPTER VI

DESIGN OF CANTILEVERS

ART. 23

PRINCIPAL DATA FOR DESIGN OF CANTILEVER BRIDGES

	No. 1.	No. 2.	No. 3.
L = total span = $m + l + m$ =	ft. 1000	ft. 1500	ft. 2000
l = suspended span =	500	650	800
m = cantilever arm =	250	425	600
n = anchor arm =	400	600	800
w = width c. to c. of trusses =	50	60	80
d = depth of suspended truss =	50–85	75–110	100–135
h = depth at towers =	150	225	300

Load: $L.L = 18{,}000$ lbs. p.l.f.
Wind = 30 lbs. per sq.ft.

Working Stresses.	*Tension.*	*Compression.*
Structural steel	20,000	$\dfrac{20{,}000}{1+\dfrac{l^2}{8000r^2}}$
Nickel steel	30,000	$\dfrac{30{,}000}{1+\dfrac{l^2}{8000r^2}}$

For erection stresses, the above may be increased by 20 per cent.

ART. 24

ESTIMATE OF COST

As there are no points of special interest involved in the design of the cantilever bridges, the details of the computations and the tables of stresses are here omitted. The total quantities of material in the different parts of the structures are presented in the following estimates of cost. In these estimates, the same unit prices are used as in the case of the suspension bridges. (See Art. 14.)

CANTILEVER BRIDGE No. 1.

($L = 1000.$)

ESTIMATE OF COST.

Material.	Quantity. lbs.	Price. cts.	Amount. $
Suspended Span.			
Truss, structural steel .	1,446,400	5.6	80,998
nickel steel.....	3,074,800	8.0	245,984
Floor, structural steel .	2,837,500	5.6	158,900
Bracing, struct. steel ..	1,132,800	5.6	63,437
Pins, nickel steel......	246,000	10.0	24,600
Total...............	....	......	573,919
Cantilever Arm.			
Truss, structural steel .	2,051,000	5.6	114,856
nickel steel	2,390,600	8.0	191,248
Floor, structural steel .	1,426,000	5.6	79,856
Bracing, struct. steel. .	593,800	5.6	33,253
Pins, nickel steel	179,200	10.0	17,920
Total..............	....	......	874,266
Anchor Arm.			
Truss, structural steel .	2,559,400	5.6	143,326
nickel steel	3,647 600	8.0	291,808
Floor, structural steel .	2,280,000	5.6	127,680
Bracing, struct. steel. .	926,000	5.6	51,856
Pins, nickel steel......	223,500	10.0	22,350
Total..............	....	......	1,274,040
Tower.			
Structural steel.......	5,472,000	5.6	306,432
Steel castings	514,500	9.0	46,296
Total..............	....	......	705,456

CANTILEVER BRIDGE No. 1.

($L = 1000.$)

ESTIMATE OF COST—(*Continued*).

Material.	Quantity. lbs.	Price. cts.	Amount. $
Anchorage.			
Eye-bars and riveted work	785,000	5.0	39,250
Total.	. . . .	. . . . . .	78,500
Total steel work	. . . .	. . . . . .	$3,506,181
Main Piers.			
Pier masonry (cu.yds.)	7,590	$18	136,620
Concrete filling in crib-work.	15,700	7½	117,750
Concrete filling in caisson.	2,850	12	34 200
Timber in cribwork (B.M.).	404 M	45	18,180
Steel in caisson and shafts.	1,270,500	4.5	57,172
Earth excavation, (cu.yds.).	18,540	$4	74,160
Total.	. . . .	. . . . . .	876,164
Anchorages.			
Masonry (cu.yds.).	12,370	$18	222,660
Concrete in foundation	3,285	12	39,420
Total.	. . . .	. . . . . .	524,160
Total substructure. .	. . . .	. . . . . .	$1,400,324
Total cost of bridge . . .	. . . .	. . . . . .	$4,906,505

CANTILEVER BRIDGE NO. 2.

($L=1500$.)

ESTIMATE OF COST.

Material.	Quantity. lbs.	Price. cts.	Amount. $
Suspended Span.			
Truss, structural steel	2,675,200	5.6	149,811
nickel steel....	5,731,800	8.0	458,544
Floor, structural steel.	4,387,500	5.6	245,700
Bracing, struct. steel..	2,264,000	5.6	126,784
Pins, nickel steel.....	492,000	10.0	49,200
Total............	....	......	1,030,039
Cantilever Arm.			
Truss structural steel.	5,365,400	5.6	300,462
nickel steel....	6,765,000	8.0	541,200
Floor, structural steel.	2,960,000	5.6	165,760
Bracing, struct. steel..	1,428,600	5.6	80,002
Pins, nickel steel.....	432,300	10.0	43,230
Total............	....	......	2,261,308
Anchor Arm.			
Truss, structural steel.	5,455,400	5.6	305,502
nickel steel....	8,631,600	8.0	690,528
Floor, structural steel.	4,180,000	5.6	234,080
Bracing, struct. steel..	1,852,200	5.6	103,723
Pins, nickel steel.....	447,000	10.0	44,700
Total............	....	......	2,757,066
Tower.			
Structural steel.......	16,155,000	5.6	904,680
Steel castings........	1,324,000	9.0	119,160
Total............	....	......	2,047,680

CANTILEVER BRIDGE NO. 2.

($L=1500.$)

ESTIMATE OF COST—(*Continued*).

Material.	Quantity. lbs.	Price. cts.	Amount. $
Anchorage.			
Eye-bars and riveted Work	1,794,100	5.0	89,705
Total			179,410
Total steel work			$8,275,503
Main Piers.			
Pier masonry (cu. yds.)	10,810	$18	194,580
Concrete filling in crib-work	24,560	7½	184,200
Concrete filling in caisson	3,780	12	45,360
Timber in cribwork (B.M.)	558M	45	45,110
Steel in caisson and shafts	1,682,000	4.5	75,690
Earth excavation (cu. yds.)	26,480	4	105,920
Total			1,261,720
Anchorages.			
Masonry (cu. yds.)	24,380	18	438,840
Concrete in foundations	6,450	12	77,400
Total			1,032,480
Total substructure			$2,294,200
Total cost of bridge			$10,569,703

CANTILEVER BRIDGE NO. 3.

($L=2000$.)

Estimate of Cost.

Material.	Quantity. lbs.	Price. cts.	Amount. $
Suspended Span.			
Truss, structural steel.	5,142,800	5.6	287,987
nickel steel	11,070,800	8.0	885,664
Floor, structural steel.	7,456,000	5.6	417,536
Bracing, struct. steel. .	4,350,000	5.6	243,600
Pins, nickel steel	944,800	10.0	94,480
Total			1,929,267
Cantilever Arm.			
Truss, structural steel.	13,116,200	5.6	734,507
nickel steel	15,931,499	8.9	1,274,512
Floor, structural steel.	6,204,000	5.6	347,424
Bracing, struct. steel. .	3,456,400	5.6	193,558
Pins, nickel steel	1,042,000	10.0	104,200
Total	. . . .	. . . . . .	5,308,402
Anchor Arm.			
Truss, structural steel.	11,136,200	5.6	623,627
nickel steel	18,845,000	8.0	1,507,600
Floor, structural steel.	8,272,000	5.6	463,232
Bracing, struct. steel. .	3,704,400	5.6	207,446
Pins, nickel steel	894,000	10.0	89,400
Total	. . . .	. . . . . .	5,782,610
Tower.			
Structural steel.	37,638,000	5.6	2,107,728
Steel castings	2,520,000	9.0	226,800
Total	. . . .	. . . . . .	4,669,056

CANTILEVER BRIDGE NO. 3.

($L = 2000$.)

ESTIMATE OF COST—(*Continued*).

Material.	Quantity. lbs.	Price. cts.	Amount. $
Anchorage.			
Eye-bars and riveted work	3,374,300	5.0	168,715
Total	....	......	337,430
Total steel work.			$18,026,765
Main Piers.			
Pier masonry (cu. yds.)	17,860	18	321,480
Concrete filling in cribwork.............	45,530	7½	341,475
Concrete filling in caisson	6,070	12	72,840
Timber in cribwork (B.M.)	820M	45	36,900
Steel in caisson and shafts.............	2,701,000	4.5	121,545
Earth excavation (cu. yds.)..........	45,570	$4	182,280
Total	....	......	2,153,040
Anchorages.			
Masonry (cu. yds.) . . .	45,950	$18	827,100
Concrete in foundation	12,075	12	144,900
Total	....	......	1,944,000
Total substructure..	....	......	$4,097,040
Total cost of bridge ...	....	......	$22,123,805

CHAPTER VII

CONCLUSIONS FOR CANTILEVERS

Art. 25

Empiric Formulæ for Weights of Cantilever Spans

Let T_1, T_2, T_3 = truss-weights per linear foot, in suspended span, cantilever arm and anchor arm, respectively; F = weight of floor, per linear foot; LL = live load per linear foot.

We may then construct semi-empiric formulæ for the truss-weights from the results of the preceding designs as follows:

Suspended Span. The weight per linear foot of a simple truss, if the relative dimensions are kept fairly constant, is proportional to the span and to the total load carried. Introducing a factor of proportionality, a, we have

$$T_1 = a(T_1 + F + LL) \cdot l. \quad . \quad . \quad (1)$$

Applying this equation to the preceding designs, we find

$$a = .00056, \quad .00053, \quad .00053;$$

or, as a mean value,

$$a = .00054.$$

Cantilever Arm. The weight of the cantilever arm may be considered as composed of two parts: one due to the reaction of the suspended span applied as an end-concentration, and the other due to the weight and loading of the arm itself. This relation may be expressed symbolically as

$$T_2 = b_1(T_1 + F + LL) \cdot l \\ + b_2 \cdot (T_2 + F + LL)m. \quad . \quad (2)$$

The results of the preceding designs, substituted in the formula, yield

$$b_1 = .00087 \quad .00085 \quad .00087$$
$$b_2 = .00023 \quad .00023 \quad .00023$$

or as mean values,

$$b_1 = .00086$$

and

$$b_2 = .00023$$

A simpler formula, involving but one undetermined coefficient, may be constructed from the observed fact that the weight per linear foot of the cantilever arm varies with the total loading and with the square root of the channel span, or

$$T_2 = b(T_2 + F + LL) \cdot \sqrt{L}. \quad . \quad . \qquad (3)$$

The constant of proportionality, b, is determined from the preceding designs as

$$b = .0133, \quad .0134, \quad .0134.$$

The close agreement between these values of b indicates the reliability of the above formula even under varying values of the suspended span ratio. Taking the mean value, we have

$$b = .0134.$$

Anchor Arm. A rational formula for the anchor arm would involve too many factors for practical usefulness. A simple empirical formula, however, is suggested by the observation that the weight per linear foot of the anchor arm varies with its total load and with the square root of its length. We may therefore write

$$T_3 = c(T_3 + F + LL) \cdot \sqrt{n}. \quad . \quad .(4)$$

Substituting the results of the preceding designs, eq. (4) yields

$$c = .0190, \quad .0189, \quad .0191,$$

or, as a mean value,

$$c = .0190.$$

As the total amount of steel is not materially affected by limited changes in the form or proportions of the trusses, and as variations in the spans and in the loading are fully provided for in the above formulæ, they may properly be applied to any other cantilever bridges designed for any live-load, provided the same working stresses are used. Whenever improved material or construction justifies higher unit stresses, the empirical constants in the above formulæ should be reduced in the inverse proportion.

Art. 26

Theoretical Limiting Spans for Cantilevers

Maximum Channel Span. A solution of the empiric formula for the weight of the cantilever arm, as established in the preceding article, yields

$$T_2 = \frac{b(F+LL)\cdot\sqrt{L}}{1-b\cdot\sqrt{L}}. \quad . \quad (1)$$

This expression will become infinite when the denominator reduces to zero, i.e., when

$$\sqrt{L} = \frac{1}{b} = \frac{1}{.0134},$$

or

$$L = 5600.$$

Hence *the maximum possible span for a cantilever bridge is* 5600 *ft.* This value may be approached, but never exceeded by increasing the ratio of dead-load to live-load indefinitely.

Note that the corresponding maximum span for the suspension bridge is 14,700 ft., or about 2.6 times as great as the above.

Maximum Suspended Span. A solution of the empiric formula for the weight of the suspended span, as established in the preceding article, yields

$$T_1 = \frac{a(F+LL)}{1-al} \cdot l. \quad . \quad . \quad (2)$$

This expression will become infinite when the denominator reduces to zero, i.e., when

$$l = \frac{1}{a} = \frac{1}{.00054},$$

or

$$l_{\max} = 1850.$$

Hence the maximum possible length for the suspended span is 1850 *ft.* This value has a theoretical significance similar to that of L in the preceding paragraph.

Maximum Length of Anchor Arm. A solution of the empiric formula of the preceding article for the weight of the anchor arm yields

$$T_3 = \frac{c(F+LL)\sqrt{n}}{1-c\sqrt{n}}. \quad . \quad . \quad (3)$$

This expression becomes infinite for

$$\sqrt{n} = \frac{1}{c} = \frac{1}{.0190}.$$

Hence

$$n_{\max} = 2760.$$

The limiting length of anchor arm is therefore 2760 ft.

Combining the above values of limiting spans, we find that the cantilever bridge of maximum length will have the following proportions:

$$l = 1850, \quad m = 1875, \quad n = 2760$$

$$L = l + 2m = 5600, \; S = l + 2m + 2n = 11,120.$$

It will be observed that $l_{\max} = 0.35 L_{\max}$. This is less than the economic ratio for ordinary spans and is a justification of the writer's plan of reducing the relative length of the suspended truss as the total length of span (L) is increased. It is also seen that $n_{max}=0.49L_{max}$, a value approximating the economic ratio.

Art. 27

Theoretical Limiting Span for a Simple Truss

From the weights obtained for the three suspended spans in the foregoing designs ($l=500$, 650, 800 ft.), the limiting spans for ordinary truss bridges may be deduced. A correction must first be applied, however, for the increased stresses produced in some of the members by the cantilever method of erection. A study of the above designs indicates an extra truss-weight, attributable to these erection stresses, of

$$6.3\%, \quad 6.1\%, \quad 6.0\%,$$

respectively, or, as an average, 6.1 per cent of the total weight. Consequently, for a given span, a simple truss would weigh about 6.1% less than the suspended truss of a cantilever bridge. The empiric formula for the latter may then be adapted to the ordinary truss by simply reducing the weight-factor by the above percentage, giving

$$T = .00051(T + F + LL)l.$$

This yields $T = \infty$ for

$$l_{max} = \frac{1}{.00051} = 1960 \text{ ft.}$$

It thus appears that the limiting length for a simple truss is about three times the longest span yet attempted.

Art. 28

Maximum Practicable Span for Cantilevers

The theoretical maximum span established in the preceding article is the limiting span which may be approached by increasing the sections of the truss-members indefinitely. It is evident, however, that long before that span is reached, the required cross-sections will become too great for actual construction.

The longest span at which the cross-sections of the members will not exceed an assigned maximum value, determined by the limitations of design, fabrication, transportation or erection, will be termed the *maximum practicable span.*

In the three cantilever designs executed above, viz.

$$L=1000, \quad 1500, \quad 2000 \text{ ft.},$$

the maximum required section is found in the lower chord of the anchor arm and amounts to

$$A_{\max}=574, \quad 1302, \quad 2338 \text{ sq.in.}$$

It will be observed that these cross-sections are almost exactly proportional to the *squares* of the respective channel spans. Considering also that the section must vary with the live-load for which the structure is designed, we may write the proportion

$$A_{\max}=k(LL)L^2.$$

Substituting the values of $A_{\max}$, LL and L from the above designs, and solving for the unknown coefficient, we find

$$k = .031, \quad .032, \quad .032,$$

so that the above formula becomes

$$A_{\max} = .032(LL)L^2, \quad . \quad . \quad . \quad (1)$$

where L is supposed given in 1000 ft. units.

Hence the maximum practicable span for a cantilever is given by

$$L_{\max} = \sqrt{31.2\frac{A_{\max}}{LL}}, \quad . \quad . \quad (2)$$

where $A_{\max}$ is the greatest practicable cross-section (in sq. in.) and LL is the assumed live-load (in lbs. p.l.f.).

Value of $A_{\max}$. The largest cross-sections ever fabricated are the following:

Queensboro	1120	sq.in.
Quebec	843	"
Beaver	639	"
Kansas City (Truss) ...	485	"
St. Louis (Truss)	441	"
Monongahela	348	"
Thebes	317	"
Memphis	228	"

All of the above chord-sections are of the multiple rib type. The number of ribs composing the section never exceeds four, that being the number used in the Quebec, Queensboro, Thebes and Memphis Bridges. Any larger number of ribs would make the action of the whole number as a unit extremely problematic; and, in the light of recent experience, no conservative engineer would propose such a section.

The greatest depth of rib is 5′6½″ occurring in the Beaver Bridge, followed by a depth of 4′6½″ in the Quebec and St. Louis Bridges. In Lindenthal's design for the Hell Gate Arch (977′6″ span), a 10 ft. depth of rib is proposed. This is so far in advance of any previous design, and involves so difficult a problem of adequate stiffening and bracing, besides the difficulties of fabrication, that it may well be taken as the extreme limit for practicable depth of rib.

The greatest thickness of rib is 5¾″ in the Queensboro Bridge, followed by

$4\frac{7}{16}''$, $4\frac{1}{4}''$, and $3\frac{1}{2}''$ in the Monongahela, Hell Gate and Quebec Bridges, respectively. On account of the extreme difficulty of riveting through so great a thickness, it is hardly probable that any greater thickness than the above, or say 6″ at the most, will ever be used.

Combining the above limitations, we find that the greatest practicable chord-section would consist of 4 ribs, 10 ft. deep and 6 in. thick. Adding the largest angles obtainable for the flanges, the total area will be, in round numbers,

$$A_{\max} = 3000 \text{ sq.in.}$$

With the necessary diaphragms and lacing, such a member would weigh over 7 tons per linear foot.

This value of $A_{\max}$ is nearly three times the cross-section of the largest member ever fabricated (1120 sq.in. in the Queensboro Bridge) and over twice the largest section to be used in the Hell Gate Arch (1437 sq. in.). A member of 2300 sq.in. occurs in the plans for the Hudson River Bridge of 2160 ft.

span designed by the Union Bridge Company in 1893, and a slightly larger cross-section (2338 sq.in.) is found necessary in the writer's design of a 2000 ft. cantilever bridge. But the above sectional area of 3000 sq.in. is far in excess of any chord section ever proposed.

Value of L_{max}. Substituting $A_{max}=3000$ in eq. (2) above, we find the following values of the maximum span for different assumed live loads:

For

$LL=10{,}000$ lbs. p.l.f.	$L_{max}=3060$ ft.
$LL=15{,}000$ lbs. p.l.f.	$L_{max}=2500$ ft.
$LL=20{,}000$ lbs. p.l.f.	$L_{max}=2160$ ft.

As it could hardly be considered practical to design a cantilever bridge of the magnitude under consideration for a smaller live load than about 10,000 lbs. per linear foot, we conclude that *the maximum practical span for the cantilever type ranges from about* 2000 *to* 3000 *ft., depending upon the assumed live load.*

Compare these with the corresponding

values established above for the suspension bridge, viz.,

$$l_{max} = 3500 \text{ to } 4900 \text{ ft.},$$

indicating the greater suitability of the suspension type to extreme long-span construction.

Art. 29

Empiric Formula for Cost of Cantilever Bridges

As in the case of suspension bridges, the expression for the cost of any span (L) will be assumed of the general form:

$$C = aL + bL^2 + cL^3. \quad . \quad . \quad . \quad (1)$$

Since we have but three values for C determined by actual design, the formula is limited to an equal number of terms.

From the results of the preceding estimates, we have

$$\begin{aligned} C &= \$4{,}905{,}000 && \text{for } L = 1000 \text{ ft.} \\ C &= 10{,}570{,}000 && \phantom{\text{for }} L = 1500 \text{ ft.} \\ C &= 22{,}125{,}000 && \phantom{\text{for }} L = 2000 \text{ ft.} \end{aligned}$$

Substituting these values in eq. (1), the unknown coefficients are determined, giving

$$C = 6350L - 5.25\,L^2 + .0038L^3, \qquad (2)$$

as the general cost-formula for cantilever bridges. This gives the cost of steelwork and substructure for an assumed live load of 18000 lbs. per linear foot. For any other loading, the cost may be taken as varying in proportion.

Art. 30

Economic Span for Cantilevers

As established in the preceding article, the cost of a cantilever bridge, including steelwork and substructure, is given by the expression

$$C = 6350\,L - 5.25L^2 + .0038L^3 \qquad (1)$$

Assuming the same cost of approaches, volume of traffic, life of steelwork, expense of maintenance and rate of interest as for the suspension type, the limiting economic span for the cantilever will be defined by the same total cost as in the case of the suspension bridge, viz.,

$$C = \$54,000,000.$$

As shown in Art. 19, this is the greatest expenditure for a long-span bridge, exclusive of approaches and accessories, that is warranted by the maximum traffic returns to be reasonably expected. Substituting this value in eq. (1) and solving we find

$$L = 2700 \text{ ft.}$$

as the maximum economic span for cantilevers.

Hence, the greatest span for which the cantilever type may be profitably employed is 2700 ft. or less, depending upon the probable maximum traffic returns.

CHAPTER VIII

FINAL COMPARISONS AND CONCLUSIONS

ART. 31

COSTS OF SUSPENSION BRIDGES AND CANTILEVERS

In the accompanying table are given the costs for various spans of suspension bridges and cantilevers as determined by the respective empiric formulæ. The following relations may be gleaned from the table:

1. The cantilever is cheaper than the suspension type at a span of 1500 ft. or less. The suspension is cheaper than the cantilever type at a span of 1750 ft. or more.

2. The cost per foot of length for suspension bridges is a minimum for a span of about 1000 ft., indicating a rapid decrease of economy in the use of the type for shorter spans.

COSTS OF SUSPENSION BRIDGES AND CANTILEVERS.

for $LL = 18{,}000$ lbs. p.l.f.

Span $= l$	Suspension Bridges. Total Cost $= C$	Cost per Foot. $= C \div 2l$	$K = C \div l^2$	Cantilever Bridges. Total Cost $= C$	Cost per Foot. $= C \div 1.8l$	$K = C \div l^2$
	$	$		$	$	
250	2,023,000	4,040	32.3	1,343,000	2,980	21.6
500	3,758,000	3,760	15.0	2,288,000	2,540	9.2
750	5,395,000	3,595	9.6	3,410,000	2,525	6.1
1000	7,130,000	3,565	7.1	4,905,000*	2,725	4.9
1250	9,140,000	3,655	5.8	7,035,000	3,130	4.5
1500	11,645,000*	3,880	5.2	10,570,000*	3,910	4.7
1750	14,130,000	4,040	4.5	15,370,000	4,880	5.0
2000	18,720,000	4,680	4.7	22,125,000*	6,150	5.5
2250	23,760,000*	5,280	4.7	30,990,000	7,640	6.1
2500	29,950,000	5,990	4.8	42,570,000	9,450	6.8
2750	37,390,000	6,790	4.9	56,910,000	11,500	7.5
3000	46,785,000*	7,780	5.2	74,650,000	13,850	8.3
3250	57,710,000	8,870	5.5	95,740,000	16,360	9.1
3500	71,050,000	10,160	5.8	121,120,000	19,240	10.0
3750	85,780,000	11,450	6.1	150,710,000	22,300	10.7
4000	103,200,000	12,900	6.4	184,900,000	25,680	11.5

Suspension: $C = 8900l - 3.77l^2 + 0.002l^3$ or $C = K.l^2$

Cantilever: $C = 6350l - 5.25l^2 + .0038l^3$ or $C = K.l^2$

* Values obtained by actual design. Other values interpolated or extrapolated by aid of empiric formulæ given below.

3. The cost per foot of length for cantilevers is a minimum for a span of about 600 ft., indicating a rapid decrease of economy in the use of the type for shorter spans.

4. Between the limits of 1500 and 3000 ft. for suspension bridges, and of 1000 and 1750 ft. for cantilevers, the value of $K(=C \div l^2)$ remains fairly constant. Hence, for all normal spans, the cost of either type may be estimated as varying approximately with the square of the span. Within the above ranges, as an average value,

$$C = 4.7 l^2 \text{ for suspension bridges}$$

and

$$C = 4.8\ L^2 \text{ for cantilevers.}$$

5. The value of K for the suspension bridges is a minimum for a span of about 1800 ft., indicating that that is the span for which the suspension type is economically best adapted.

6. The value of K for the cantilevers is a minimum for a span of about 1250 ft., indicating that that is the span for which the cantilever type is economically best adapted.

7. The limiting economic span, i.e. the greatest span for profitable erection, defined by $C = \$54,000,000$, is shown

by the table to be about 3200 ft. for the suspension type and about 2700 ft. for the cantilever type.

The tabulated costs, where they lie outside of the spans actually designed, are subject to the inherent errors of any method of extrapolation; but the above results are sufficiently accurate for the purposes of this investigation.

Art. 32

Span of Equal Cost

Plotting the costs for the three suspension spans designed above, a smooth curve passing through the three points and the origin constitutes a cost-graph for suspension bridges. In the same manner, the graph representing the costs for different cantilever spans is constructed. The point where the two curves intersect marks the span of equal cost for the two types of construction, and is found at

$$l = 1670 \text{ ft.}$$

Below this span, the cantilever bridge is cheaper; above this span, the suspension bridge exhibits the greater economy. As this value lies within the range of spans actually designed for each bridge, i.e., between the known points on each graph, the error of the above method, involved in extending the results of individual designs to other spans, is negligible.

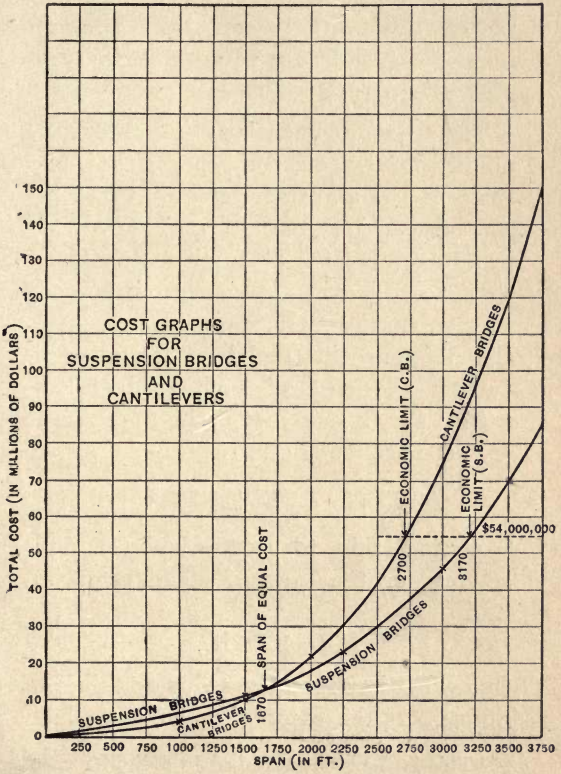
The analytical equivalent of the above process consists in comparing the cost-formulæ for the two types of bridges. The cost of a suspension bridge, designed for a live-load of 18,000 lbs. per linear foot, as established in Art. 19, is given by

$$C = 8900l - 3.77l^2 + .0020l^3, \qquad (1)$$

and that of a cantilever bridge for the same loading, as established in Art. 39, by

$$C = 6350l - 5.25l^2 + .0038l^3, \quad . \quad (2)$$

where l denotes the total channel span. Equating expressions (1) and (2), and


COST GRAPHS
FOR
SUSPENSION BRIDGES
AND
CANTILEVERS
TOTAL COST (IN MILLIONS OF DOLLARS)
SPAN (IN FT.)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
3250
3500
3750
SUSPENSION BRIDGES
CANTILEVER BRIDGES
SPAN OF EQUAL COST
1670
ECONOMIC LIMIT (C.B.)
2700
ECONOMIC LIMIT (S.B.)
3170
$54,000,000

solving, we find, for the span of equal cost,

$$l = 1670 \text{ ft.}$$

exactly as before.

The above comparison is somewhat unfair to the suspension type, as the side-spans in the above designs were $0.5l$ in the suspension bridges and only $0.4l$ in the cantilevers. Assuming, therefore, that steel viaduct approaches are added to the cantilever bridges to make up the difference in total length, and estimating the cost of such viaducts at $1000 per linear foot,[1] the expression (2) becomes modified to

$$C = 6550l - 5.25l^2 + .0038l^3. \quad . \quad (3)$$

Equating this to expression (1) and solving for the span of equal cost, we find

$$l = 1626 \text{ ft.},$$

somewhat less than the value established above. If the comparison of costs had

[1] This is the price assumed in a similar case by the U. S. Board of Engineers in 1894.

been made between bridges of equal total length instead of between bridges of equal channel span, the result would have been still more favorable to the suspension bridge, reducing the critical span to about

$$l = 1500 \text{ ft.}$$

Neglecting these differences in favor of the suspension type, we conclude that $l = 1670$ ft. is the extreme upper limit of spans at which the cantilever can compete with the suspension bridge, when economy is the sole criterion.

Art. 33

Summary

The results of the preceding investigations may be summarized as follows:

1. *Maximum Span for a Cable.* The greatest span theoretically possible for a steel cable of any cross-section is 65,520 ft. based on the ultimate resistance; 21,840 ft. based on a safe working-stress of 60,000 lbs. per sq.in.; 15,160 ft.

if the rise is restricted to the economic ratio of one-eighth the span; and 14,700 ft. if the weight of cable-wrapping and fastenings is taken into consideration.

2. *Maximum Span for Suspension Bridges.* The last value, 14,700 ft., is also the maximum span theoretically possible for a stiffened suspension bridge. The greatest practicable span, defined by a maximum section of 16 cables of 24 inches diameter with a minimum live-load of 10,000 lbs. per linear foot, is 4300 ft.

3. *Economic Span for Suspension Bridges.* The greatest suspension span for which the necessary outlay would be warranted by the probable traffic returns is 3170 ft.

4. *Maximum Span for Cantilever Bridges.* The greatest span theoretically possible for a cantilever bridge is 5600 ft. In this maximum span, the suspended span will be 1850 ft., the cantilever arms 1875 ft., and the anchor arms 2760 ft. The practical limit for cantilevers, defined by a maximum chord-

section of 3000 sq.in., with a minimum live-load of 10,000 lbs. per linear foot, is 3060 ft.

5. *Maximum Span for Truss.* The greatest span theoretically possible for a simple truss is 1960 ft.

6. *Economic Span for Cantilever Bridges.* The maximum economic span for cantilevers, defined by the condition of zero net profit on the investment, is 2700 ft.

7. *Span of Equal Cost.* The critical span at which the suspension bridge becomes economically superior to the cantilever bridge is 1670 ft.

Summary:

	S. B.	C. B.
Theoretical max. span..	14,700	5,600
Practical max. span....	4,900	3,060
Max. economic span....	3,170	2,700
Span of equal cost	1,670	

Art. 34

Conclusions

In the foregoing designs, special care was taken to proportion the depths of truss in both types for equal and ample rigidity, so that the single inherent advantage claimed for cantilevers, viz. greater stiffness for railway traffic, is eliminated from consideration. Consequently no advantage remains to the cantilever type above the limiting span of 1670 ft. The suspension bridge, on the other hand, is universally admitted to possess greater aesthetic qualifications; and, for a long-span city structure, this is a factor of decisive importance. For this reason alone the above value for the span of equal cost should be considerably reduced in favor of the suspension type, to obtain the "span of equal merit."

The preceding investigations have been restricted to designs for heavy railway traffic. For highway bridges, a relatively lighter stiffening truss may be used in the suspension type, thereby causing a considerable reduction in the span of equal cost.

Confining our attention to economic considerations, our final conclusions may be stated as follows:

1. *The range of economic usefulness for cantilevers extends from the upper limit for the truss or arch to a span of* 1670 *ft. Beyond this value, the cantilever would be more costly than the suspension type, although yielding a probable profit on the investment up to a span of* 2700 *ft.*

2. *The range of economic usefulness for suspension bridges begins at* 1670 *ft. (or less in the case of highway bridges) and extends to the upper economic limit of* 3170 *ft. Above this limit, the construction of suspension bridges would be practically feasible, but not as a profitable investment, up to an extreme limit of* 4900 *ft.*

Vita

Born June 11, 1886.

B. S. (Summa cum laude), College of the City of New York, 1906.

A. M., C. E., Columbia University, 1909. ***Ph. D.,*** 1911.

Fellow in Applied Mathematics, College of the City of New York, 1906-1909. ***Tutor in Surveying*** 1909-1910. ***James Scholar in Applied Science,*** Columbia University, 1907-1909. ***University Scholar in Engineering,*** 1909-1910. ***Instructor in Applied Physics,*** Stuyvesant Evening High School, 1909-1910.

Instructor in Civil Engineering, University of Idaho, 1910-1911. ***Assistant Professor,*** 1911.

CATALOGUE

OF

SCIENTIFIC PUBLICATIONS

OF THE

D. VAN NOSTRAND COMPANY,

23 Murray and 27 Warren Streets, New York.

A B C CODE. (See Clausen-Thue.)

ABBOT, H. L., Gen'l. The Defence of the Sea-coast of the United States. Lectures delivered before the U. S. Naval War College. 8vo, red cloth **$2.00**

ABBOTT, A. V. The Electrical Transmission of Energy. A Manual for the Design of Electrical Circuits. New edition, revised, and entirely rewritten. 8vo, cloth, 368 illus., 675 pp. ....net, **$5.00**

ADAM, P. Practical Bookbinding. With illus-trations and figures. Translated from the German by Thomas E. Maw. 8vo, cloth, illustrated ....net, **$2.50**

ADAMS, J. W. Sewers and Drains for Populous Districts. Embracing Rules and Formulas for the dimensions and construction of works of Sanitary Engineers. 8vo, cloth **$2.50**

ADDYMAN, F. T. Practical X-Ray Work. Part I, Historical. Part II, Apparatus and its Management. Part III, Practical X-Ray Work. Illustrated with twelve plates from photographs. 8vo, cloth, illustrated ......net, **$4.00**

A 1 CODE. (See Clausen-Thue.)

AIKMAN, C. M., Prof. Manures and the Prin-ciples of Manuring. 8vo, cloth **$2.50**

ALEXANDER, J. H. Elementary Electrical En-gineering in Theory and Practice. A classbook for Junior and Senior Students and Working Electricians. 12mo, cloth, illus. **$1.50**

——J. H. Universal Dictionary of Weights and Measures, Ancient and Modern, reduced to the Standards of the United States of America. New Edition, enlarged. 8vo, cloth **$3.50**

ANDERSON, G. L., A.M. **(Captain of U. S. Artillery).** Handbook for the use of Electricians in the operation and care of Electrical Machinery and Apparatus of the United States Seacoast Defenses. Prepared under the direction of the Lieutenant-General Commanding the Army. With tables, diagrams and illustrations. 8vo, cloth, illustrated **$3.00**

——**J. W. Prospector's Handbook. A Guide for** the Prospector and Traveller in search of Metal-bearing or other Valuable Minerals. Eighth Edition, revised. 8vo, cloth **$1.50**

ANDÉS, L. Vegetable Fats and Oils: Their Practical Preparation, Purification and Employment for Various Purposes. Their Properties, Adulteration and Examination. A Handbook for Oil Manufacturers and Refiners, Candle, Soap and Lubricating-oil Manufacturers, and the Oil and Fat Industry in general. Translated from the German. With 94 illus. 8vo, cloth ....net, **$4.00**

——**Animal Fats and Oils. Their Practical Pro**duction, Purification and Uses for a great variety of purposes; their Properties, Falsification and Examination. A Handbook for Manufacturers of Oil and Fat Products, Soap and Candle Makers, Agriculturists, Tanners, etc. Translated by Charles Salter. With 62 illustrations. 8vo, cloth ....net, **$4.00**

——**Drying Oils, Boiled Oil, and Solid and Liquid** Driers. A practical work for manufacturers of Oils, Varnishes, Printing Inks, Oilcloth and Linoleum, Oil-cakes, Paints, etc. 8vo, cloth, illustrated ....net, **$5.00**

——**Iron Corrosion, Anti-fouling and Anti-cor**rosive Paints. Translated from the German by Charles Salter. Illustrated with engravings and half-tone cuts. 8vo, cloth ....net, **$4.00**

——**Oil Colors, and Printers' Ink. A Practical** Handbook treating of Linseed-oil, Boiled Oil, Paints, Artists' Colors, Lampblack, and Printers' Inks (black and colored). Translated from the German by Arthur Morris and Herbert Robson. With 56 figures and diagrams. 8vo, cloth, 212 pages ....net, **$2.50**

ANNUAL REPORTS on the Progress of Chemistry for 1904. Vol. I. Issued by the Chemical Society. 8vo, cloth ....net, **$2.00**
Vol. II (1905). 8vo, cloth ....net, **$2.00**
Vol. III (1906) 8vo, cloth ....net, $2.00

ARNOLD, E. Armature Windings of Direct-Current Dynamos. Extension and Application of a General Winding Rule. Translated from the original German by Francis B. DeGress, M.E. With numerous illus. 8vo, cloth **$2.00**

——R., Dr. Ammonia and Ammonium Compounds. A Practical Manual for Manufacturers, Chemists, Gas Engineers, and Drysalters. Second Edition. 12mo, cloth **$2.00**

Art of Dyeing Wool, Silk and Cotton. Translated from the French of M. Hellott, M. Macquer and M. Le Pileur D'Apligny. First published in English in 1789. 8vo, cloth, illus. ....net, **$2.00**

ASHE, S. W., and KEILEY, J. D. Electric Railways, Theoretically and Practically Treated; **Rolling Stock.** With numerous figures, diagrams, and folding plates. Second Edition. 12mo, cloth, illustrated ....net, **$2.50**

——Vol. II. **Engineering Preliminaries and Di**rect Current. Sub-Stations. 8vo, cloth. Illustrated ....net, **$2.50**

ATKINSON, A. A., Prof. (Ohio University). Electrical and Magnetic Calculations, for the use of Electrical Engineers and Artisans, Teachers, Students and all others interested in the Theory and Application of Electricity and Magnetism. Second Edition, revised. 8vo, cloth, illustrated ....net, **$1.50**

——P. The Elements of Electric Lighting, including Electric Generation, Measurement, Storage and Distribution. Tenth Edition, fully revised and new matter added. Illustrated, 12mo, cloth **$1.50**

——The Elements of Dynamic Electricity and Magnetism. Fourth Edition. 120 illustrations. 12mo, cloth **$2.00**

——Power Transmitted by Electricity and its Application by the Electric Motor, including Electric Railway Construction. Fourth Edition, fully revised, new matter added. 12mo, cloth, illustrated **$2.00**

AUCHINCLOSS, W. S. Link and Valve Motions Simplified. Illustrated with 29 woodcuts and 20 lithographic plates, together with a Travel Scale, and numerous useful tables. Fourteenth Edition, revised. 8vo, cloth **$2.00**

AYRTON, H. The Electrical Arc. With numerous figures, diagrams and plates. 8vo, cloth, illustrated **$5.00**

——**W. E., M.I.C.E. Practical Electricity.** A Laboratory and Lecture Course for the first-year students of Electrical Engineering, based on the International Definitions of the Electrical Units. Vol. I, Current, Pressure, Resistance, Energy, Power, and Cells. Completely rewritten and containing many figures and diagrams. 12mo, cloth **$2.00**

BACON, F. W. A Treatise on the Richards Steam-engine Indicator, with directions for its use. By Charles T. Porter. Revised, with notes and large additions as developed by American practice; with an appendix containing useful formulae and rules for engineers. Illustrated. Fourth Edition. 12mo, cloth, **$1.00**

BAKER, Arthur L., Prof. (Univ. of Roch.). Quaternions ....In Press.

——**M. N. Potable Water and Methods of De**tecting Impurities. New Edition, revised and largely rewritten. 16mo, cloth. (Van Nostrand's Science Series) **$0.50**

BALCH, G. T., Col. Methods of Teaching Patriotism in the Public Schools. 8vo, cloth, **$1.00**

BALE, M. P. Pumps and Pumping. A Handbook for Pump Users. 12mo, cloth **$1.50**

BALL, S. R. Popular Guide to the Heavens. A series of eighty-three plates, many of which are colored and lithographed, with explanatory text and index. Small 4to, cloth, illus. ....net, **$4.50**

BARBA, J. The Use of Steel for Constructive Purposes. Method of Working, Applying and Testing Plates and Bars. With a Preface by A. L. Holley, C.E. 12mo, cloth **$1.50**

BARKER, A. H. Graphic Methods of Engine Design. Including a Graphical Treatment of the Balancing of Engines. 12mo, cloth, **$1.50**

BARNARD, F. A. P. Report on Machinery and Processes of the Industrial Arts and Apparatus of the Exact Sciences at the Paris Universal Exposition, 1867. 152 illustrations and 8 folding plates. 8vo, cloth **$5.00**

——**J. H. The Naval Militiaman's Guide. Full** leather, pocket size **$1.25**

BARRUS, G. H. Boiler Tests: Embracing the Results of one hundred and thirty-seven evaporative tests, made on seventy-one boilers, conducted by the author. 8vo, cloth **$3.00**

——Engine Tests: Embracing the Results of of over one hundred feed-water tests and other investigations of various kinds of steam-engines, conducted by the author. With numerous figures, tables, and diagrams. 8vo, cloth, illustrated **$4.00**
The above two purchased together **$6.00**

BARWISE, S., M.D. (London). The Purification of Sewage. Being a brief account of the Scientific Principles of Sewage Purification and their Practical Application. 12mo, cloth, illustrated. New Edition ....net, **$3.50**

BAXTER, WM. J. Commutator Construction. Pamphlet **$0.25**

——Switchboards. For Power, Light and Railway Service **$1.50**

BEAUMONT, R. Color in Woven Design. With 32 colored plates and numerous original illustrations. Large, 12mo **$7.50**

——W. W. Practical Treatise on the Steam-engine Indicator, and Indicator Diagrams. With notes on Engine Performances, Expansion of Steam, Behavior of Steam in Steam-engine Cylinders, and on Gas- and Oil-engine Diagrams. Second Edition, revised and enlarged. 8vo, cloth, illustrated ....net, **$2.50**

BEECH, F. Dyeing of Cotton Fabrics. A Practical Handbook for the Dyer and Student. Containing numerous recipes for the production of Cotton Fabrics of all kinds, of a great range of colors, thus making it of great service in the dye-house, while to the student it is of value in that the scientific principles which underlie the operations of dyeing are clearly laid down. With 44 illustrations of Bleaching and Dyeing Machinery. 8vo, cloth, illustrated. ....net, **$3.00**

——Dyeing of Woolen Fabrics. With diagrams and figures. 8vo, cloth, illustrated ..net, **$3.50**

BECKWITH, A. Pottery. Observations on the Materials and Manufacture of Terra-cotta, Stoneware, Firebrick, Porcelain, Earthenware, Brick, Majolica, and Encaustic Tiles. Second Edition. 8vo, paper **$0.60**

BEGTRUP, J., M.E. The Slide Valve and its Functions. With Special Reference to Modern Practice in the United States. With numerous diagrams and figures. 8vo, cloth **$2.00**

BERNTHSEN, A. A Text-book of Organic Chemistry. Translated by George M'Gowan, Ph.D. Fifth English Edition, revised and extended by author and translator. Illustrated. 12mo, cloth ....net, $2.50

BERRY, W. J., Prof. (Polytechnic Inst. Brooklyn). Differential Equations of the First Species. 12mo, cloth, illus. ....In Press.

BERSCH, J., Dr. Manufacture of Mineral and Lake Pigments. Containing directions for the manufacture of all artificial artists' and painters' colors, enamel colors, soot and metallic pigments. A text-book for Manufacturers, Merchants, Artists and Painters. Translated from the second revised edition by Arthur C. Wright, M.A. 8vo, cloth, illustrated, net, $5.00

BERTIN, L. E. Marine Boilers: Their Construction and Working, dealing more especially with Tubulous Boilers. Translated by Leslie S. Robertson, Assoc. M. Inst. C. E., M. I. Mech. E., M.I.N.A., containing upward of 250 illustrations. Preface by Sir William White, K.C.B., F.R.S., Director of Naval Construction to the Admiralty, and Assistant Controller of the Navy. Second Edition, revised and enlarged. 8vo, cloth, illustrated ......net, $5.00

BIGGS, C. H. W. First Principles of Electricity and Magnetism. A book for beginners in practical work, containing a good deal of useful information not usually to be found in similar books. With numerous tables and 343 diagrams and figures. 12mo, cloth, illustrated $2.00

BINNS, C. F. Ceramic Technology. Being Some Aspects of Technical Science as applied to Pottery Manufacture. 8vo, cloth ....net, $5.00

——Manual of Practical Potting. Compiled by Experts. Third Edition, revised and enlarged. 8vo, cloth ....net, $7.50

BIRCHMORE, W. H., Dr. How to Use a Gas Analysis. 12mo, cloth, illus., 75 pp. ..net, $1.25

BLAKE, W. H. Brewer's Vade Mecum. With Tables and marginal reference notes. 8vo, cloth ....net, $4.00

——W. P. Report upon the Precious Metals. Being Statistical Notices of the Principal Gold and Silver producing regions of the world, represented at the Paris Universal Exposition. 8vo, cloth $2.00

BLYTH, A. W., M.R.C.S., F.C.S. Foods: Their Composition and Analysis. A Manual for the use of Analytical Chemists, with an Introductory Essay on the History of Adulterations. With numerous tables and illustrations. Fifth Edition, thoroughly revised, enlarged and rewritten. 8vo, cloth $7.50

——M.R.C.S., F.C.S., Poisons: Their Effects and Detection. A Manual for the use of Analytical Chemists and Experts, with an Introductory Essay on the Growth of Modern Toxicology. New Edition ....net, $7.50

BODMER, G. R. Hydraulic Motors and Turbines. For the use of Engineers, Manufacturers and Students. Third Edition, revised and enlarged. With 192 illustrations. 12mo, cloth $5.00

BOILEAU, J. T. A New and Complete Set of Traverse Tables, showing the Difference of Latitude and Departure of every minute of the Quadrant and to five places of decimals. 8vo, cloth $5.00

BONNEY, G. E. The Electro-platers' Handbook. A Manual for Amateurs and Young Students of Electro-metallurgy. 60 illustrations. 12mo, cloth $1.20

BOOTH, W. H. Water Softening and Treatment, Condensing Plant, Feed Pumps, and Heaters for Steam Users and Manufacturers. 8vo, cloth, illustrated ....net, $2.50

——Superheaters and Superheating. 8vo, cloth. ....In Press.

BOURRY, E. Treatise on Ceramic Industries. A Complete Manual for Pottery, Tile and Brick Works. Translated from the French by Wilton P. Rix. With 323 figures and illustrations. 8vo, cloth, illustrated ....net, $8.50

BOW, R. H. A Treatise on Bracing. With its application to Bridges and other Structures of Wood or Iron. 156 illus. 8vo, cloth $1.50

BOWIE, AUG. J., Jr., M.E. A Practical Treatise on Hydraulic Mining in California. With Description of the Use and Construction of Ditches, Flumes, Wrought-iron Pipes and Dams; Flow of Water on Heavy Grades, and its Applicability, under High Pressure, to Mining. Ninth Edition. Small quarto, cloth. Illustrated $5.00

BOWKER, Wm. R. Dynamo, Motor and Switchboard Circuits. For Electrical Engineers. A

practical book, dealing with the subject of Direct, Alternating, and Polyphase Currents. With over 100 diagrams and engravings. 8vo, cloth ....net, **$2.25**

BOWSER, E. A., Prof. An Elementary Treatise on Analytic Geometry. Embracing Plane Geometry, and an Introduction to Geometry of three Dimensions. Twenty-first Edition. 12mo, cloth **$1.75**

——An Elementary Treatise on the Differential and Integral Calculus. With numerous examples. Twenty-first Edition. Enlarged by 640 additional examples. 12mo, cloth ...**$2.25**

——An Elementary Treatise on Analytic Mechan-ics. With numerous examples. Sixteenth Edition. 12mo, cloth **$3.00**

——An Elementary Treatise on Hydro-mechan-ics. With numerous examples. Fifth Edition. 12mo, cloth **$2.50**

——A Treatise on Roofs and Bridges. With Numerous Exercises, especially adapted for school use. 12mo, cloth. Illustrated, **net, $2.25**

BRASSEY'S Naval Annual for 1907. Edited by T. A. Brassey: With numerous full-page diagrams, half-tone illustrations and tables. Twenty-first year of publication. 8vo, cloth, illustrated ....net, **$5.00**

BRAUN, E. The Baker's Book: A Practical Handbook of the Baking Industry in all Countries. Profusely illustrated with diagrams, engravings, and full-page colored plates. Translated into English and edited by Emil Braun. Vol. I., 8vo, cloth, illustrated, 308 pages **$2.50**
Vol. II., 363 pages, illustrated **$2.50**

British Standard Sections.. Issued by the En-gineering Standards Committee, Supported by The Institution of Civil Engineers, The Institution of Mechanical Engineers, The Institution of Naval Architects, The Iron and Steel Institute, and The Institution of Electrical Engineers. Comprising 9 plates of diagrams, with letter-press and tables. Oblong pamphlet, 8¾x15 ....**$1.00**

BROWN, SIR HANBURY, K.C.M.G. Irrigation: Its Principles and Practice as a Branch of Engineering. 8vo, cloth, 301 pp. Illus., net, **$5.00**

——WM. N. The Art of Enamelling on Metal. With figures and illustrations. 12mo, cloth, illustrated ....net, $1.00

——Handbook on Japanning and Enamelling, for Cycles, Bedsteads, Tinware, etc. 12mo, cloth, illustrated ....net, **$1.50**

——House Decorating and Painting. With Numerous illustrations. 12mo, cloth, net,**$1.50**

——History of Decorative Art. With Designs and Illustrations. 12mo, cloth .....net, **$1.25**

——Principle and Practice of Dipping, Burnishing, Lacquering and Bronzing Brass Ware. 12mo, cloth ....net, **$1.00**

——Workshop Wrinkles for Decorators, Painters, Paper-Hangers and Others. 8vo, cloth. ....net, **$1.00**

BRUCE, E. M., Prof. Pure Food Tests: the Detection of the Common Adulterants of Foods by Simple Qualitative Tests. A ready manual for Physicians, Health Officers, Food Inspectors, Chemistry Teachers, and all especially interested in the Inspection of Food. 12mo, cloth, illustrated ....In Press.

BRUHNS, Dr. New Manual of Logarithms to Seven Places of Decimals. Seventh Edition. 8vo, half morocco **$2.50**

BRUNNER, R. Manufacture of Lubricants, Shoe Polishes and Leather Dressings. Containing instructions for the preparation of all kinds of lubricants, such as axle and machinery greases, oils for lubricating sewing machines, and other working machinery, mineral lubricating oils, clockmakers' oils, as well as shoe polishes, leather varnishes, dressings for all kinds of leather and dégras. Translated from the Sixth (enlarged) German edition by Chas. Salter. 8vo, cloth, illustrated ....net, **$3.00**

BULMAN, H. F., and REDMAYNE, R. S. A. Colliery Working and Management; comprising the duties of a colliery manager, the superintendence and arrangement of labor and wages, and the different systems of working coal-seams. With engravings, diagrams, and tables. Second Edition, revised and enlarged. 8vo, cloth, illustrated ....net, **$6.00**

BURGH, N. P. Modern Marine Engineering, Applied to Paddle and Screw Propulsion. Consisting of 36 colored plates, 259 practical woodcut illustrations and 403 pages of descriptive matter. The whole being an exposition of the present practice of James Watt & Co., J. & G. Rennie, R. Napier & Sons, and other celebrated firms. Thick quarto, half morocco. **$10.00**

BURT, W. A. Key to the Solar Compass, and Surveyor's Companion. Comprising all the rules necessary for use in the field; also description of the Linear Surveys and Public Land System of the United States, Notes on the Barometer, Suggestions for an Outfit for a Survey of Four Months, etc. Seventh Edition. Pocket size, full leather **$2.50**

BUSKETT, E. W. Fire Assaying: a Practical Treatise on the Fire Assaying of Gold, Silver, and Lead, including descriptions of the appliances used. 12mo, cloth, illus., 105 pp., net, **$1.25**

CAIN, W., Prof. Brief Course in the Calculus. With figures and diagrams. 8vo, cloth, illustrated ....net, **$1.75**

——Theory of Steel-concrete Arches and of Vaulted Structures. New Edition, revised and enlarged. 16mo, cloth, illustrated. (Van Nostrand Science Series) **$0.50**

CAMPIN, F. On the Construction of Iron Roofs. A Theoretical and Practical Treatise, with woodcuts and plates of roofs recently executed. 8vo, cloth **$2.00**

CARPENTER, Prof. R. C., and DIEDERICHS, Prof. H. Internal Combustion Engines. With figures and diagrams. 8vo, cloth, illustrated. ....net, **$4.00**

CARTER, E. T. Motive Power and Gearing for Electrical Machinery. A treatise on the Theory and Practice of the Mechanical Equipment of Power Stations for Electrical Supply and for Electric Traction. Second Edition, revised in part by G. Thomas-Davies. 8vo, cloth, illustrated **$5.00**

CATHCART, Wm. L., Prof. Machine Design. Part I. Fastenings. 8vo, cloth, illustrated. ....net, **$3.00**

——and CHAFFEE, J. S. Course of Graphic Statics Applied to Mechanical Engineers. 8vo, cloth. Illus. ....In Press.

CHAMBERS' MATHEMATICAL TABLES, con-sisting of Logarithms of Numbers 1 to 108,000, Trigonometrical, Nautical and other Tables. New Edition. 8vo, cloth **$1.75**

CHARPENTIER, P. Timber. A Comprehensive Study of Wood in all its Aspects, Commercial and Botanical. Showing the Different Applications and Uses of Timber in Various Trades, etc. Translated into English. 8vo, cloth, illus. ....net, **$6.00**

CHILD, C. T. The How and Why of Electricity. A Book of Information for non-technical readers, treating of the Properties of Electricity, and how it is generated, handled, controlled, measured and set to work. Also explaining the operation of Electrical Apparatus. 8vo, cloth, illustrated **$1.00**

CHRISTIE, W. W. Boiler-waters, Scale, Corrosion, Foaming. 8vo, cloth, illustrated, net, **$3.00**

——Chimney Design and Theory. A Book for Engineers and Architects, with numerous halftone illustrations and plates of famous chimneys. Second Edition, revised. 8vo, cloth, **$3.00**

——Furnace Draft: its Production by Mechanical Methods. A Handy Reference Book, with figures and tables. 16mo, cloth, illustrated. (Van Nostrand's Science Series) **$0 50**

CHURCH'S LABORATORY GUIDE: a Manual of Practical Chemistry for Colleges and Schools, specially arranged for Agricultural Students. Eighth Edition, revised and party rewritten by Edward Kinch, F.I.C. 8vo, cloth, illustrated. 349 pp. ....net, **$2.50**

CLAPPERTON, G. Practical Paper-making. A Manual for Paper-makers and Owners and Managers of Paper Mills, to which is appended useful tables, calculations, data, etc., with illustrations reproduced from micro-photographs. Second Edition, revised and enlarged. 8vo, cloth, illustrated, 226 pp. .....net, **$2.50**

CLARK, D. K., C.E. A Manual of Rules, Tables and Data for Mechanical Engineers. Based on the most recent investigations. Illustrated with numerous diagrams. 1012 pages. 8vo, cloth. Sixth Edition **$5.00**

——Fuel: its Combustion and Economy; consisting of abridgments of Treatise on the Combustion of Coal. By C. W. Williams, and the Economy of Fuel, by T. S. Prideaux. With extensive additions in recent practice in the Combustion and Economy of Fuel, Coal, Coke, Wood, Peat, Petroleum, etc. Fourth Edition. 12mo, cloth **$1.50**

——The Mechanical Engineer's Pocket-book of Tables, Formulae, Rules and Data. A Handy Book of Reference for Daily Use in Engineering Practice. 12mo, cloth. Sixtl Edition, carefully resised throughout **$2.00**

——Tramways: Their Construction and Working. Embracing a comprehensive history of the system, with accounts of the various modes of traction, a description of the varieties of rolling stock, and ample details of Cost and Working Expenses. Second Edition, rewritten and greatly enlarged, with upwards of 400 illustrations. Thick 8vo, cloth $9.00

——J, M. New System of Laying Out Railway Turnouts instantly, by inspection from tables. 12mo, cloth $1.00

CLAUSEN-THUE, W. The A B C Universal Commercial Electric Telegraphic Code; specially adapted for the use of Financiers, Merchants, Ship-owners, Brokers, Agents, etc. Fourth Edition. 8vo, cloth $5.00
Fifth Edition of same $7.00

——The A 1 Universal Commercial Electric Tele-graphic Code. Over 1240 pages and nearly 90,000 variations. 8vo, cloth $7.50

CLEEMANN, T. M. The Railroad Engineer's Practice. Being a Short but Complete Description of the Duties of the Young Engineer in Preliminary and Location Surveys and in Construction. Fourth Edition, revised and enlarged. Illustrated. 12mo, cloth $1.50

CLEVENGER, S. R. A Treatise on the Method of Government Surveying as prescribed by the U. S. Congress and Commissioner of the General Land Office, with complete Mathematical, Astronomical, and Practical Instructions for the use of the United States Surveyors in the field. 16mo, morocco $2.50

CLOUTH, F. Rubber, Gutta-Percha, and Balata. First English Translation with Additions and Emendations by the Author. With numerous figures, tables, diagrams, and folding plates. 8vo, cloth, illustrated ....net, $5.00

COFFIN, J. H. C., Prof. Navigation and Nautical Astronomy. Prepared for the use of the U. S. Naval Academy. New Edition. Revised by Commander Charles Belknap. 52 woodcut illustrations. 12mo, cloth ....net, $3.50

COLE, R. S., M.A. A Treatise on Photographic Optics. Being an account of the Principles of Optics, so far as they apply to photography. 12mo, cloth, 103 illus. and folding plates, $2.50

COLLINS, J. E. The Private Book of Useful Alloys and Memoranda for Goldsmiths, Jewelers, etc. 18mo, cloth $0.50

——T. B. The Steam Turbine; or the New Engine. 8vo, cloth, illustrated ....In Press.

COLVIN, FRED H. American Compound Locomotives. 8vo, cloth **$1.50**

——Motions, Links. Valves and Valve Setting. Pocket size **$0.50**

——Pocketbook, The Railroad. A quick reference Cyclopedia of Railroad information. **$1.00**

——Tapers, Turning and Boring. Pamphlet. **$0.25**

——and CHENEY, W. L. Arithmetic, Machine Shop. 4th ed. Pocket size **$0.50**

——Arithmetic, Engineers. Pocket Book containing the foundation principles involved in making such calculations as come into the practical work of the Stationary Engineer. **$0.50**

——and STABEL. Threads and Thread Cutting. Pamphlet **$0.25**

COOPER, W. R., M.A. Primary Batteries: Their Construction and Use. With numerous figures and diagrams. 8vo, cloth, illustrated, net, **$4.00**

——"The Electrician" Primers; being a series of helpful Primers on Electrical Subjects for the use of Students, Pupils, Artisans, and General Readers. Three volumes complete in one. Thick 8vo, cloth, illustrated **$5.00**

COPPERTHWAITE, Wm. C. Tunnel Shields, and the Use of Compressed Air in Subaqueous Works. With numerous diagrams and figures. 4to, cloth, illustrated ....net, **$9.00**

CORNWALL, H. B., Prof. Manual of Blow-pipe Analysis, Qualitative and Quantitative. With a Complete System of Determinative Mineralogy. 8vo, cloth, with many illustrations, **$2.50**

COWELL, W. B. Pure Air, Ozone and Water. A Practical Treatise of their Utilization and Value in Oil, Grease, Soap, Paint, Glue and other Industries. With tables and figures. 12mo, cloth, illustrated ....net, **$2.00**

CRAIG, B. F. Weights and Measures. An Account of the Decimal System, with Tables of Conversion for Commercial and Scientific Uses. Square 32mo, limp cloth **$0.50**

CRANE, W. E. Engineering, American Stationary. 8vo, cloth **$2.00**

CROCKER, F. B., Prof. Electric Lighting. A Practical Exposition of the Art. For use of Engineers, Students, and others interested in the Installation or Operation of Electrical Plants. Vol. I. The Generating Plant. New Edition, thoroughly revised and rewritten. 8vo, cloth, illustrated **$3.00**
Vol. II. Distributing Systems and Lamps. Fifth Edition. 8vo, cloth, illustrated ..**$3.00**

——and WHEELER, S. S. The Management of Electrical Machinery. Being a thoroughly revised and rewritten edition of the authors' "Practical Management of Dynamos and Motors." 12mo, cloth, illustrated ......net, **$1.00**

CROSSKEY, L. R. Elementary Perspective: Arranged to meet the requirements of Architects and Draughtsmen, and of Art Students preparing for the elementary examination of the Science and Art Department, South Kensington. With numerous full-page plates and diagrams. 8vo, cloth, illustrated **$1.00**

——and THAW, J. Advanced Perspective, involving the Drawing of Objects when placed in Oblique Positions, Shadows and Reflections. Arranged to meet the requirements of Architects, Draughtsmen, and Students preparing for the Perspective Examination of the Education Department. With numerous full-page plates and diagrams. 8vo, cloth, illus. **$1.50**

DALBY, H. A. Rules and Dispatching, Train. Leather. Pocket size **$1.50**

DAVIES, E. H. Machinery for Metalliferous Mines. A Practical Treatise for Mining Engineers, Metallurgists and Managers of Mines. With upwards of 400 illustrations. Second Edition, rewritten and enlarged. 8vo, cloth. ....net, **$8.00**

——D. C. A Treatise on Metalliferous Minerals and Mining. Sixth Edition, thoroughly revised and much enlarged by his son. 8vo, cloth. ....net, **$5.00**

DAY, C. The Indicator and Its Diagrams. With Chapters on Engine and Boiler Testing; including a Table of Piston Constants compiled by W. H. Fowler. 12mo, cloth. 125 illustrations **$2.00**

DEITE, Dr. C. Manual of Soapmaking, including medicated soaps, stain-removing soaps, metal polishing soaps, soap powders and detergents. With a treatise on perfumes for scented soaps, and their production and tests for purity and strength. Edited from the text of numerous experts. Translated from the original by S. I. King, F.C.S. 4to, cloth, illustrated ....net, **$5.00**

DE LA COUX, H. The Industrial Uses of Water. With numerous tables, figures, and diagrams. Translated from the French and revised by Arthur Morris. 8vo, cloth ....net, **$4.50**

DENNY, G. A. Deep-level Mines of the Rand, and their future development, considered from the commercial point of view. With folding plates, diagrams, and tables. 4to, cloth, illustrated ....net, **$10.00**

DERR, W. L. Block Signal Operation. A Practical Manual. Pocket Size. Oblong, cloth. New Edition, rewritten and greatly enlarged. **$1.50**

DIBDIN, W. J. Public Lighting by Gas and Electricity. With tables, diagrams, engravings and full-page plates. 8vo, cloth, illustrated. ....net, **$8.00**

——Purification of Sewage and Water. With tables, engravings, and folding plates. Third Edition, revised and enlarged. 8vo, cloth, illus. and numerous folding plates **$6.50**

DIETERICH, K. Analysis of Resins, Balsams, and Gum Resins: their Chemistry and Pharmacognosis. For the use of the Scientific and Technical Research Chemist. With a Bibliography. Translated from the German, by Chas. Salter. 8vo, cloth ....net, **$3.00**

DINGER, H. C., Lieut., U.S.N. Handbook for the Care and Operation of Naval Machinery. 12mo, cloth, illustrated ....In Press.

DIXON, D. B. The Machinist's and Steam Engineer's Practical Calculator. A Compilation of Useful Rules and Problems arithmetically solved, together with General Information applicable to Shop-tools, Mill-gearing, Pulleys and Shafts, Steam-boilers and Engines. Embracing valuable Tables and Instructions in Screw-cutting, Valve and Link Motion, etc. Fourth Edition. 16mo, full morocco, pocket form **$1.25**

DOBLE, W. A. Power Plant Construction on the Pacific Coast ....In Press.

DODD. Geo. Dictionary of Manufactures, Mining, Machinery, and the Industrial Arts. 12mo, cloth **$1.50**

DORR, B. F. The Surveyor's Guide and Pocket Table-book. Fifth Edition, thoroughly revised and greatly extended. With a second appendix up to date. 16mo, morocco flaps $2.00

DRAPER, C. H. An Elementary Text-book of Light, Heat and Sound, with Numerous Examples. Fourth Edition. 12mo, cloth, illustrated $1.00

——Heat and the Principles of Thermo-dynamics. With many illustrations and numerical examples. 12mo, cloth $1.50

DUCKWALL, E. W. Canning and Preserving of Food Products with Bacteriological Technique. A practical and scientific handbook for Manufacturers of Food Products, Bacteriologists, Chemists, and Students of Food Problems. Also for Processors and Managers of Food Product Manufactories. With figures, tables, and half-tones. 8vo, cloth, illustrated. ....net, $5.00

DYSON, S. S. Practical Testing of Raw Materials. A Concise Handbook for Manufacturers, Merchants, and Users of Chemicals, Oils, Fuels, Gas Residuals and By-Products, and Paper-making Materials, with Chapters on Water Analysis and the Testing of Trade Effluents. 8vo, cloth, illustrations, 177 pages, net, $5.00

ECCLES, R. G. (Dr.), and DUCKWALL, E. W. Food Preservatives: their Advantages and Proper Use; The Practical versus the Theoretical Side of the Pure Food Problem. 8vo, paper $0.50
Cloth $1.00

EDDY, H. T., Prof. Researches in Graphical Statics. Embracing New Constructions in Graphical Statics, a New General Method in Graphical Statics, and the Theory of Internal Stress in Graphical Statics. 8vo, cloth, $1.50

——Maximum Stresses under Concentrated Loads. Treated graphically. Illustrated. 8vo, cloth $1.50

EISSLER, M. The Metallurgy of Gold. A Practical Treatise on the Metallurgical Treatment of Gold-bearing Ores, including the Processes of Concentration and Chlorination, and the Assaying, Melting and Refining of Gold. Fifth Edition, revised and greatly enlarged. Over 300 illustrations and numerous folding plates. 8vo, cloth $7.50

——The Hydro-Metallurgy of Copper. Being an Account of processes adopted in the Hydro-metallurgical Treatment of Cupriferous Ores, including the Manufacture of Copper Vitriol. With chapters on the sources of supply of Copper and the Roasting of Copper Ores. With numerous diagrams and figures. 8vo, cloth, illustrated ....net, **$4.50**

——The Metallurgy of Silver. A Practical Treatise on the Amalgamation, Roasting and Lixiviation of Silver Ores, including the Assaying, Melting and Refining of Silver Bullion. Illustrated. Second Edition, enlarged. 8vo, cloth **$4.00**

——The Metallurgy of Argentiferous Lead. A Practical Treatise on the Smelting of Silver-Lead Ores and the Refining of Lead Bullion. Including Reports on Various Smelting Establishments and Descriptions of Modern Smelting Furnaces and Plants in Europe and America. Illustrated. 8vo, cloth **$5.00**

——Cyanide Process for the Extraction of Gold and its Practical Application on the Witwatersrand Gold Fields in South Africa. Third Edition, revised and enlarged. Illustrations and folding plates. 8vo, cloth **$3.00**

——A Handbook on Modern Explosives. Being a Practical Treatise on the Manufacture and Use of Dynamite, Gun-cotton, Nitroglycerine, and other Explosive Compounds, including the manufacture of Collodion-cotton, with chapters on Explosives in Practical Application. Second Edition, enlarged with 150 illustrations. 12mo, cloth **$5.00**

ELIOT, C. W., and STORER, F. H. A Compendious Manual of Qualitative Chemical Analysis. Revised with the co-operation of the authors, by Prof. William R. Nichols. Illustrated. Twentieth Edition, newly revised by Prof. W. B. Lindsay. 12mo, cloth ....net, **$1.25**

ELLIOT, G. H., Maj. European Light-house Systems. Being a Report of a Tour of Inspection made in 1873. 51 engravings and 21 woodcuts. 8vo, cloth **$5.00**

ENGSTROM, D. A. Tables, Bevel Gear. A collection of Tables to enable anyone to figure bevel gears without the use of Trigonometry. Cloth **$1.00**

ENNIS, WM. D. Mechanical Equipment of Industrial Works. 8vo, cloth. Illus. ...**In Press.**

——Linseed Oil. 8vo, cloth. Illus. ...In Press.

ERFURT, J. Dyeing of Paper Pulp. A Practical Treatise for the use of paper-makers, paper-stainers, students and others. With illustrations and 157 patterns of paper dyed in the pulp, with formulas for each. Translated into English and edited, with additions, by Julius Hubner, F.C.S. 8vo, cloth, illustrated, net, **$7.50**

ERSKINE-MURRAY, JAMES, D.Sc.; fellow of the Royal Society of Edinburgh; Member of the Institution of Electrical Engineers. A Handbook of Wireless Telegraphy: Its Theory and Practice. For the use of Elec. Engineers, Students, and Operators. 8vo, cloth. Illustrated ....net, **$3.50**

EVERETT, J. D. Elementary Text-book of Physics. Illustrated. Seventh Edition. 12mo, cloth **$1.50**

EWING, A. J., Prof. The Magnetic Induction in Iron and other metals. Third Edition, revised. 159 illustrations. 8vo, cloth **$4.00**

FAIRÍE, J., F.G.S. Notes on Lead Ores: Their Distribution and Properties. 12mo, cloth, **$1.00**

——Notes on Pottery Clays: The Distribution, Properties, Uses and Analysis of Ball Clays, China Clays and China Stone. With tables and formulae. 12mo, cloth **$1.50**

FANNING, J. T. A Practical Treatise on Hy-draulic and Water-supply Engineering. Relating to the Hydrology, Hydro-dynamics and Practical Construction of Water-works in North America. 180 illus. 8vo, cloth. Sixteenth Edition, revised, enlarged, and new tables and illustrations added. 650 pp, **$5.00**

FAY, I. W., Prof. (Polytechnic Inst. Brooklyn). The Coal-tar Colors; Their Origin and Chemistry. 8vo, cloth, illustrated ......In Press.

FERNBACH, R. L. Glue and Gelatine; a Prac-tical Treatise on the Methods of Testing and Use. 8vo, cloth ....net, **$3.00**

——and GOSLAU, JUSTUS. Laboratory Guide to Commercial Analysis, Organic and Inorganic ....In Press.

FISH, J. C. L. Lettering of Working Drawings. Thirteen plates, with descriptive text. Oblong, 9x12½, boards **$1.00**

FISHER, H. K. C., and DARBY, W. C. Students' Guide to Submarine Cable Testing. Third (new and enlarged) Edition. 8vo, cloth, illustrated $3.50

——**W. C. The Potentiometer and its adjuncts.** 8vo, cloth $2.25

FISKE, B. A., Lieut., U.S.N. Electricity in Theory and Practice; or, The Elements of Electrical Engineering. Eighth Edition. 8vo, cloth. $2.50

FLEISCHMANN, W. The Book of the Dairy. A Manual of the Science and Practice of Dairy Work. Translated from the German, by C. M. Aikman and R. Patrick Wright. 8vo, cloth $4.00

FLEMING, J. A., Prof. The Alternate-current Transformer in Theory and Practice. Vol. I., The Induction of Electric Currents; 611 pages. New Edition, illustrated. 8vo, cloth, $5.00 Vol. II., The Utilization of Induced Currents. Illustrated. 8vo, cloth $5.00

——**Centenary of the Electrical Current, 1799-**1899. 8vo, paper, illustrated $0.50

——**Electric Lamps and Electric Lighting. Be**ing a course of four lectures delivered at the Royal Institution, April-May, 1894. 8vo, cloth, fully illustrated $3.00

——**Electrical Laboratory Notes and Forms, Ele**mentary and Advanced. 4to, cloth, illustrated. $5.00

——**A Handbook for the Electrical Laboratory** and Testing Room. 2 volumes. 8vo, cloth. ....net, $5.00

FLEURY, H. The Calculus Without Limits or Infiinitesimals. Translated by C. O. Mailloux. ....In Press.

FOLEY, N., and PRAY, Thos., Jr. The Mechanical Engineers' Reference Book for Machine and Boiler Construction, in two parts. Part 1 —General Engineering Data. Part 2—Boiler Construction. With 51 plates and numerous illustrations, specially drawn for this work. Folio, half morocco. New Edition ...In Press.

FORNEY, M. N. Catechism of the Locomotive. Second Edition, revised and enlarged. 46th thousand. 8vo, cloth $3.50

FOSTER, H. A. Electrical Engineers' Pocketbook. With the Collaboration of Eminent Specialists. A handbook of useful data for Electricians and Electrical Engineers. With innumerable tables, diagrams, and figures. New, Revised and Enlarged Edition. Pocket size, full leather, 1000 pp. ....In Press.

——**J. G., Gen., U.S.A. Submarine Blasting in** Boston Harbor, Massachusetts. Removal of Tower and Corwin Rocks. Illustrated with 7 plates. 4to, cloth **$3.50**

FOX, Wm., and THOMAS, C. W., M.E. A Practical Course in Mechanical Drawing. Third Edition, revised. 12mo, cloth, with plates, **$1.25**

FRANCIS, J. B., C.E. Lowell Hydraulic Experiments. Being a selection from experiments on Hydraulic Motors on the Flow of Water over Weirs, in Open Canals of uniform rectangular section, and through submerged Orifices and diverging Tubes. Made at Lowell, Mass. Fourth Edition, revised and enlarged, with many new experiments, and illustrated with 23 copper-plate engravings. 4to, cloth, **$15.00**

FRASER, R. H., and CLARK, C. H. Marine Engineering ....In Press.

FULLER, G. W. Report on the Investigations into the Purification of the Ohio River at Louisville, Kentucky, made to the President and Directors of the Louisville Water Company. Published under agreement with the Directors. 3 full-page plates. 4to, cloth. ....net, **$10.00**

FURNELL, J. Students' Manual of Paints, Colors, Oils and Varnishes. 8vo, cloth, illustrated ....net, **$1.00**

GANT, L. W. Elements of Electric Traction, for Motormen and Others. 8vo, cloth. Illustrated. 217 pp., London, 1907 ....net, **$2.50**

GARCKE, E., and FELLS, J. M. Factory Accounts: their principles and practice. A handbook for accountants and manufacturers, with appendices on the nomenclature of machine details, the rating of factories, fire and boiler insurance, the factory and workshop acts, etc., including also a large number of specimen rulings. Fifth Edition, revised and extended. 8vo, cloth, illustrated **$3.00**

GEIKIE, J. Structural and Field Geology, for Students of Pure and Applied Science. With figures, diagrams, and half-tone plates. 8vo, cloth, illustrated ....net, **$4.00**

GERBER, N. Chemical and Physical Analysis of Milk, Condensed Milk, and Infants' Milk-Food. 8vo, cloth **$1.25**

GERHARD, Wm. P. Sanitation, Water-supply and Sewage Disposal of Country Houses. 12mo, cloth **$1.25**

GERHARDI, C. W. H. Electricity Meters; Their Construction and Management. A Practical Manual for Central Station Engineers, Distribution Engineers, and Students. With tables and 215 figures and diagrams. 8vo, cloth, illus. ....net, **$4.00**

GESCHWIND, L. Manufacture of Alum and Sulphates, and other Salts of Alumina and Iron; their uses and applications as mordants in dyeing and calico printing, and their other applications in the Arts, Manufactures, Sanitary Engineering, Agriculture and Horticulture. Translated from the French by Charles Salter. With tables, figures and diagrams. 8vo, cloth, illustrated ....net, **$5.00**

GIBBS, W. E. Lighting by Acetylene, Generators, Burners and Electric Furnaces. With 66 illustrations. Second Edition, revised. 12mo, cloth **$1.50**

GILLMORE, Q. A.| Gen. Treatise on Limes, Hydraulic Cements and Mortars. Papers on Practical Engineering, United States Engineer Department, No. 9, containing Reports of numerous Experiments conducted in New York City during the years 1858 to 1861, inclusive. With numerous illustrations. 8vo, cloth **$4.00**

——Practical Treatise on the Construction of Roads, Streets and Pavements. Tenth Edition. With 70 illustrations. 12mo, cloth, **$2.00**

——Report on Strength of the Building Stones in the United States, etc. 8vo, illustrated, cloth **$1.00**

GOLDING, H. A. The Theta-Phi Diagram. Practically Applied to Steam, Gas, Oil and Air Engines. Second Edition, revised and enlarged. 12mo, cloth, illustrated ....net, **$1.25**

GOODEVE, T. M. A Text-book on the Steam-engine. With a Supplement on Gas-engines. Twelfth Edition, enlarged. 143 illustrations. 12mo, cloth **$2.00**

GORE, G., F.R.S. The Art of Electrolytic Separation of Metals, etc. (Theoretical and Practical.) Illustrated. 8vo, cloth **$3.50**

GOULD, E. S. The Arithmetic of the Steam-engine. 8vo, cloth **$1.00**

——Practical Hydrostatics and Hydrostatic Formulas. With numerous figures and diagrams. (Van Nostrand's Science Series.) 16mo, cloth, illustrated, 114 pp. **$0.50**

GRAY, J., B.Sc. Electrical Influence Machines: Their Historical Development, and Modern Forms, with instructions for making them. With numerous figures and diagrams. Second Edition, revised and enlarged. 12mo, cloth, illus., 296 pp. **$2.00**

GREENWOOD, E. Classified Guide to Technical and Commercial Books. Subject List of Principal British and American Works in print. 8vo, cloth ....net, **$3.00**

GRIFFITHS, A. B., Ph.D. A Treatise on Manures, or the Philosophy of Manuring. A Practical Handbook for the Agriculturist, Manufacturer, and Student. 12mo, cloth **$3.00**

——Dental Metallurgy. A Manual for Students and Dentists. 8vo, cloth, illustrated, 208 pp. ....net, **$3.50**

GROSS, E. Hops, in their Botanical, Agricultural and Technical Aspect, and as an article of Commerce. Translated from the German by Charles Salter. With tables, diagrams, and illustrations. 8vo, cloth, illustrated, net, **$4.50**

GROSSMAN, J. Ammonia, and Its Compounds. With tables and figures. 12mo, cloth, illustrated ....net, **$1.25**

GROVER, F. Practical Treatise on Modern Gas and Oil Engines. 8vo, cloth, illustrated. ....net, **$2.00**

GRUNER, A. Power-loom Weaving and Yarn Numbering, according to various systems, with conversion tables. An auxiliary and text-book for pupils of weaving schools, as well as for self-instruction, and for general use by those engaged in the weaving industry. Illustrated with colored diagrams. 8vo, cloth, net, **$3.00**

GUELDNER, VON HUGO. The Design and Construction of Internal Combustion Engines. 8vo, cloth ....In Press.

GUNTHER, C. O., Prof. Integration by Trigono- metric and Imaginary Substitution. With an Introduction by J. Burkitt Webb. 12mo, cloth, illustrated ....In Press.

GURDEN, R. L. Traverse Tables: Computed to Four places, Decimals for every single minute of angle up to 100 of Distance. For the use of Surveyors and Engineers. New Edition. Folio, half morocco $7.50

GUY, A. E. Experiments on the Flexure of Beams, resulting in the Discovery of New Laws of Failure by Buckling. Reprinted from the "American Machinist." With diagrams and folding plates. 8vo, cloth, illustrated, 122 pages ....net, $1.25

——A. F. Electric Light and Power: Giving the Result of Practical Experience in Central-station Work. 8vo, cloth, illustrated $2.50

HAEDER, H., C.E. A Handbook on the Steam- engine. With especial reference to small and medium-sized engines. For the use of Engine-makers, Mechanical Draughtsmen, Engineering Students and Users of Steam Power. Translated from the German, with considerable additions and alterations, by H. H. P. Powles. Third English Edition, revised. 8vo, cloth, illustrated, 458 pages $3.00

HALL, C. H. Chemistry of Paints and Paint Vehicles. 8vo, cloth ....net, $2.00

——W. S., Prof. Elements of the Differential and Integral Calculus. Sixth Edition, revised. 8vo, cloth, illustrated ....net, $2.25

——W. S. Descriptive Geometry, with Numerous Problems and Practical Applications. Comprising an 8vo volume of 76 pages of text and a 4to atlas of 31 plates. 2 vols., cloth, net, $3.50

HALSEY, F. A. Slide-valve Gears. An Expla- nation of the Action and Construction of Plain and Cut-off Slide Valves. Illustrated. Seventh Edition. 12mo, cloth $1.50

——The Use of the Slide Rule. With illustrations and folding plates. Fourth Edition, revised and enlarged. 16mo, boards. (Van Nostrand's Science Series. No. 114) $0.50

——The Locomotive Link Motion, with Diagrams and Tables. 8vo, cloth, illustrated $1.00

——Worm and Spiral Gearing. Revised and Englarged Edition. 16mo, cloth (Van Nostrand's Science Series, No. 116.) Illustrated. $0.50

——The Metric Fallacy, and "The Metric Failure in the Textile Industry," by Samuel S. Dale. 8vo, cloth, illustrated **$1.00**

HAMILTON, W. G. Useful Information for Railway Men. Tenth Edition, revised and enlarged. 562 pages, pocket form. Cloth ...**$1.00**

HAMMER, W. J. Radium, and Other Radio-active Substances; Polonium, Actinium and Thorium. With a consideration of Phosphorescent and Fluorescent Substances, the Properties and Applications of Selenium, and the treatment of disease by the Ultra-Violet Light. Second Edition. With engravings and photographic plates. 8vo, cloth, illustrated, 72 pp. **$1.00**

HANCOCK, H. Text-book of Mechanics and Hy-drostatics, with over 500 diagrams. 8vo, cloth. ....net, **$1.50**

HARDY, E. Elementary Principles of Graphic Statics. Containing 192 diagrams. 8vo, cloth, illustrated ....net, **$1.50**

HARRISON, W. B. The Mechanics' Tool-book. With Practical Rules and Suggestions for use of Machinists, Iron-workers and others. With 44 engravings. 12mo, cloth **$1.50**

HART, J. W. External Plumbing Work. A Treatise on Lead Work for Roofs. With numerous figures and diagrams. 8vo, cloth, illustrated ....net, **$3.00**

——Hints to Plumbers on Joint Wiping, Pipe Bending, and Lead Burning. Containing 184 figures and diagrams. 8vo, cloth, illustrated. ....net, **$3.00**

——Principles of Hot-water Supply. With num-erous illustrations. 8vo, cloth .....net, **$3.00**

——Sanitary Plumbing and Drainage. With numerous diagrams and figures. 8vo, cloth, illustrated ....net, **$3.00**

HASKINS, C. H. The Galvanometer and its Uses. A Manual for Electricians and Students. Fourth Edition. 12mo, cloth **$1.50**

HAUFF, W. A. American Multiplier: Multipli-cations and Divisions of the largest numbers rapidly performed. With index giving the results instantly of all numbers to 1000 x 1000 equals 1,000,000; also tables of circumferences and areas of circles. Cloth, 6½x15½ **$5.00**

HAUSBRAND, E. Drying by Means of Air and Steam. With explanations, formulas, and tables, for use in practice. Translated from the German by A. C. Wright, M.A. 12mo, cloth, illustrated ....net, **$2.00**

——Evaporating, Condensing and Cooling Apparatus: Explanations, Formulae, and Tables for Use in Practice. Translated from the Second Revised German Edition by A. C. Wright, M.A. With numerous figures, tables and diagrams. 8vo, cloth, illustrated, 400 pages ....net, **$5.00**

HAUSNER, A. Manufacture of Preserved Foods and Sweetmeats. A Handbook of all the Processes for the Preservation of Flesh, Fruit, and Vegetables, and for the Preparation of Dried Fruit, Dried Vegetables, Marmalades, Fruit-syrups, and Fermented Beverages, and of all kinds of Candies, Candied Fruit, Sweetmeats, Rocks, Drops, Dragees, Pralines, etc. Translated from the Third Enlarged German. Edition, by Arthur Morris and Herbert Robson, B.Sc. 8vo, cloth, illustrated.....net, **$3.00**

HAWKE, W. H. The Premier Cipher Telegraphic Code, containing 100,000 Words and Phrases. The most complete and most useful general code yet published. 4to, cloth **$5.00**

——100,000 Words Supplement to the Premier Code. All the words are selected from the official vocabulary. Oblong quarto, cloth, **$5.00**

HAWKESWORTH, J. Graphical Handbook for Reinforced Concrete Design. A series of plates, showing graphically, by means of plotted curves, the required design for slabs, beams, and columns under various conditions of external loading, together with practical examples showing the method of using each plate. 4to, cloth ....net, **$2.50**

HAWKINS, C. C., and WALLIS, F. The Dynamo: Its Theory, Design, and Manufacture. 190 illustrations. 12mo, cloth ....net, **$3.00**

HAY, A. Alternating Currents; Their Theory, Generation, and Transformation. 8vo, cloth, illustrated ....net, **$2.50**

——Principles of Alternate-current Working. 12mo, cloth, illustrated **$2.00**

HEAP, D. P., Major, U.S.A. Electrical Appliances of the Present Day. Report of the Paris Electrical Exposition of 1881. 250 illustrations. 8vo, cloth **$2.00**

HEAVISIDE, O. Electromagnetic Theory. 8vo, cloth, two volumes ....each, **$5.00**

HECK, R. C. H. Steam-Engine and Other Steam Motors. A text-book for engineering colleges and a treatise for engineers. Vol I. The Thermodynamics and the Mechanics of the Engine. With numerous figures, diagrams, and tables. 8vo, cloth, illustrated, net, **$3.50**
Vol. II. Form, Construction, and Working of the Engine: The Steam Turbine. 8vo, cloth, illustrated ....net, **$5.00**

——Abridged edition of above volumes (Elementary). 8vo, cloth ....In Press.

HEDGES, K. Modern Lighting Conductors. An Illustrated Supplement to the Report of the Lightning Research Committee of 1905, with Notes as to Methods of Protection and Specifications. With figures, half-tones, and folding tables. 8vo, cloth, illustrated, net, **$3.00**

HEERMANN, P. Dyers' Materials. An Introduction to the Examination, Valuation, and Application of the most important substances used in Dyeing, Printing, Bleaching and Finishing. Translated by Arthur C. Wright, M.A. 12mo, cloth, illustrated ....net, **$2.50**

HENRICI, O. Skeleton Structures, Applied to the Building of Steel and Iron Bridges. 8vo, cloth, illustrated **$1.50**

HERMANN, F. Painting on Glass and Porcelain and Enamel Painting. On the basis of Personal Practical Experience of the Condition of the Art up to date. Translated by Charles Salter. Second greatly enlarged edition. 8vo, cloth, illustrated ....net, **$3.50**

HERRMANN, G. The Graphical Statics of Mechanism. A Guide for the Use of Machinists, Architects and Engineers; and also a Text-book for Technical Schools. Translated and annotated by A. P. Smith, M.E. Fourth Edition. 12mo, cloth, 7 folding plates, **$2.00**

HERZFELD, J., Dr. The Technical Testing of Yarns and Textile Fabrics, with reference to official specifications. Translated by Chas. Salter. With 69 illustrations. 8vo, cloth. ....net, **$3.50**

HILL. J. W. The Purification of Public Water Supplies. Illustrated with valuable tables, diagrams, and cuts. 8vo, cloth **$3.00**

——Interpretation of Water Analysis. In Press.

HIROI, I. Statically-Indeterminate Stresses in Frames Commonly Used for Bridges. With figures, diagrams, and examples. 12mo, cloth, illustrated ....net, **$2.00**

HIRSCHFIELD, PROF. C. F. (Cornell Univ.) Engineering Thermodynamics. 8vo, cloth. Illus. ....In Press.

HOBART, J. F. Brazing and Soldering. Pamphlet **$0.25**

HOBBS, W. R. P. The Arithmetic of Electrical Measurements, with numerous examples, fully worked. Revised by Richard Wormell, M.A. Ninth Edition. 12mo, cloth **$0.50**

HOFF, J. N. Paint and Varnish Facts and Formulas. A hand-book for the maker, dealer, and user of paints and varnishes. Containing over 600 recipes. 8vo, cloth ....net, **$3.00**

——Wm. B., Com., U.S.N. The Avoidance of Collisions at Sea. 18mo, morocco **$0.75**

HOLLEY, A. L. Railway Practice. American and European Railway Practice in the Economical Generation of Steam, including the Materials and Construction of Coal-burning Boilers, Combustion, the Variable Blast, Vaporization, Circulation, Superheating, Supplying and Heating Feed Water, etc., and the Adaptation of Wood and Coke-burning Engines to Coal-burning; and in Permanent Way, including Road-bed, Sleepers, Rails, Joint Fastenings, Street Railways, etc. With 77 lithographed plates. Folio, cloth **$12.00**

HOLMES, A. B. The Electric Light Popularly Explained. Fifth Edition. Illustrated. 12mo, paper **$0.40**

HOPKINS, N. M. Experimental Electrochemistry: Theoretically and Practically Treated. With 132 figures and diagrams. 8vo, cloth, illustrated ....net, **$3.00**

——Model Engines and Small Boats. New Methods of Engine and Boiler Making, with a chapter on Elementary Ship Design and Construction. 12mo, cloth **$1.25**

HORNER, J. Engineers' Turning, in Principle and Practice. A Handbook for Working Engineers, Technical Students, and Amateurs. With 488 figures and diagrams. 8vo, cloth, illustrated ....net, **$3.50**

HOUSTON, E. J., and KENNELLY, A. E. Algebra Made Easy. Being a clear explanation of the Mathematical Formulae found in Prof. Thompson's "Dynamo-electric Machinery and Polyphase Electric Currents." With figures and examples. 8vo, cloth, illustrated ...**$0.75**

——The Interpretation of Mathematical Formulae. With figures and examples. 8vo, cloth, illustrated **$1.25**

HOWARD, C. R. Earthwork Mensuration on the Basis of the Prismoidal Formulae. Containing Simple and Labor-saving Methods of obtaining Prismoidal Contents directly from End Areas. Illustrated by Examples and accompanied by Plain Rules for Practical Use. Illustrated. 8vo, cloth **$1.50**

HOWORTH, J. Art of Repairing and Riveting Glass, China and Earthenware. Second Edition. 8vo, pamphlet, illustrated ...net, **$0.50**

HUBBARD, E. The Utilization of Wood-waste. A Complete Account of the Most Advantageous Methods of Working Up Wood Refuse, especially Sawdust, Exhausted Dye Woods and Tan as Fuel, as a Source of Chemical Products for Artificial Wood Compositions, Explosives, Manures, and many other Technical Purposes. Translated from the German of the second revised and enlarged edition. 8vo, cloth, illustrated, 192 pages ....net, **$2.50**

HUMBER, W., C.E. A Handy Book for the Calculation of Strains in Girders, and Similar Structures, and their Strength; consisting of Formulae and Corresponding Diagrams, with numerous details for practical application, etc. Fourth Edition. 12mo, cloth **$2.50**

HUMPHREYS, A. C. (Stevens Institute). Lecture Notes on some of the Business Features of Engineering Practice. 8vo, cloth, with supplement ....net, **$1.25**

HURST, G. H., F.C.S. Color. A Handbook of the Theory of Color. A practical work for the Artist, Art Student, Painter, Dyer and Calico Printer, and Others. Illustrated with 10 colored plates and 72 illustrations. 8vo, cloth. ....net, **$2.50**

——Dictionary of Chemicals and Raw Products Used in the Manufacture of Paints, Colors, Varnishes and Allied Preparations. 8vo, cloth. ....net, **$3.00**

——Lubricating Oils, Fats and Greases: Their Origin, Preparation, Properties, Uses and Analysis. 313 pages, with 65 illustrations. 8vo, cloth ....net, **$3.00**

——Soaps. A Practical Manual of the Manufac-ture of Domestic, Toilet and other Soaps. Illustrated with 66 engravings. 8vo, cloth. ....net, **$5.00**

——Textile Soaps and Oils: A Handbook on the Preparation, Properties, and Analysis of the Soaps and Oils Used in Textile Manufacturing, Dyeing and Printing. With tables and illustrations. 8vo, cloth ....net, **$2.50**

HUTCHINSON, R. W., Jr. Long Distance Elec-tric Power Transmission: being a Treatise on the Hydro-electric Generation of Energy; its Transformation, Transmission, and Distribution. 12mo, cloth, illus., 345 pp. ....net, **$3.00**

——and IHLSENG, M. C. Electricity in Mining; being a Theoretical and Practical Treatise on the Construction, Operation, and Maintenance of Electrical Mining Machinery. 12mo, cloth, illustrated ....In Press.

——W. B. Patents and How to Make Money out of Them. 12mo, cloth **$1.25**

HUTTON, W. S. Steam-boiler Construction. A Practical Handbook for Engineers, Boiler-makers and Steam-users. Containing a large collection of rules and data relating to recent practice in the design, construction and working of all kinds of stationary, locomotive and marine steam-boilers. With upwards of 540 illustrations. Fourth Edition, carefully revised and much enlarged. 8vo, cloth **$6.00**

——Practical Engineer's Handbook, comprising a Treatise on Modern Engines and Boilers, Marine, Locomotive and Stationary. Fourth Edition, carefully revised, with additions. With upwards of 570 illustrations. 8vo, cloth, **$7.00**

——The Works' Manager's Handbook of Modern Rules, Tables and Data for Civil and Mechanical Engineers, Mill-wrights and Boiler-makers, etc., etc. With upwards of 150 illustrations. Fifth Edition, carefully revised, with additions. 8vo, cloth **$6.00**

INGLE, H. Manual of Agricultural Chemistry. 8vo, cloth, illustrated, 388 pages ....net, **$3.00**

INNES, C. H. Problems in Machine Design. For the use of Students, Draughtsmen and others. Second Edition, 12mo, cloth ......net, **$2.00**

——Air Compressors and Blowing Engines. Specially adapted for engineers. With 285 figures, diagrams, etc. 12mo, cloth, illustrated. ....net, **$2.00**

——Centrifugal Pumps, Turbines and Water Motors. Including the Theory and Practice of Hydraulics. Fourth and enlarged edition. 12mo, cloth ....net, **$2.00**

ISHERWOOD, B. F. Engineering Precedents for Steam Machinery. Arranged in the most practical and useful manner for Engineers. With illustrations. Two volumes in one. 8vo, cloth **$2.50**

JAMIESON, A., C.E. A Text-book on Steam and Steam-engines, including Turbines and Boilers. Specially arranged for the use of Engineers qualifying for the Institution of Civil Engineers, the Diplomas and Degrees of Technical Colleges and Universities, Advanced Science Certificates of British and Colonial Boards of Education, and Honors Certificates of the City and Guilds of London Institute, in Mechanical Engineering, and Engineers generally. Fifteenth Edition, revised. Illustrated. 8vo, cloth **$3.00**

——Elementary Manual on Steam and the Steam-engine. Specially arranged for the use of First-year Science and Art, City and Guilds of London Institute, and other Elementary Engineering Students. Tenth Edition, revised. 12mo, cloth **$1.50**

JANNETTAZ, E. A Guide to the Determination of Rocks: being an Introduction to Lithology. Translated from the French by G. W. Plympton, Professor of Physical Science at Brooklyn Polytechnic Institute. 12mo, cloth, **$1.50**

JEHL, F., Mem. A.I.E.E. The Manufacture of Carbons for Electric Lighting and Other Purposes. A Practical Handbook, giving a complete description of the art of making carbons, electros, etc. The various gas generators and furnaces used in carbonizing, with a plan for a model factory. Illustrated with numerous diagrams, tables, and folding plates. 8vo, cloth, illustrated ....net, **$4.00**

JENNISON, F. H. The Manufacture of Lake Pigments from Artificial Colors. A useful handbook for color manufacturers, dyers, color chemists, paint manufacturers, drysalters, wallpaper-makers, enamel and surface-paper makers. With 15 plates illustrating the various methods and errors that arise in the different processes of production. 8vo, cloth. ....net, **$3.00**

JEPSON, G. Cams, and the Principles of their Construction. With figures, half-tones, full-page and folding plates. 8vo, cloth, illustrated ....net, **$1.50**

JOCKIN, Wm. Arithmetic of the Gold and Sil-versmith. Prepared for the use of Jewelers, Founders, Merchants, etc., especially for those engaged in the conversion and alloying of gold or other metals, the mixing of various substances, etc. With numerous examples. 12mo, cloth, 56 pp. **$1.00**

JOHNSON, W. McA. "The Metallurgy of Nick-el." ....In Press.

JOHNSTON, J. F. W., Prof. and CAMERON, Sir Chas. Elements of Agricultural Chemistry and Geology. Seventeenth Edition. 12mo, cloth **$2.60**

JONES, H. C. Outlines of Electrochemistry. With tables and diagrams. 4to, cloth, illustrated **$1.50**

——Electrical Nature of Matter and Radioac-tivity. 12mo, cloth **$2.00**

——M. W. The Testing and Valuation of Raw Materials used in Paint and Color Manufacture. 12mo, cloth ....net, **$2.00**

JORGENSEN, CHAS. JULIUS. The Mastery of Color. A simple and perfect color system, based upon the spectral colors, for educational purposes and practical use in the Arts and Crafts. Text and Plates in two volumes, with slide mat for finding neutral gray in combinations. (Plates of permanent, delicate texture, heavily mounted and protected.) Small 4to. Half morocco.

JOYNSON, F. H. The Metals Used in Construc-tion. Iron, Steel, Bessemer Metal, etc. Illustrated. 12mo, cloth **$0.75**

——Designing and Construction of Machine Gearing. Illustrated. 8vo, cloth **$2.00**

JUPTNER, H. F. V. Siderology: The Science of Iron. (The Constitution of Iron Alloys and Iron.) Translated from the German. 8vo, cloth, 345 pages, illustrated ....net, **$5.00**

KANSAS CITY BRIDGE, THE. With an Ac-count of the Regimen of the Missouri River and a Description of the Methods used for Founding in that River, by O. Chanute, Chief Engineer, and George Morison, Assistant Engineer. Illustrated with 5 lithographic views and 12 plates of plans. 4to, cloth **$6.00**

KAPP, G., C.E. Electric Transmission of En-ergy and its Transformation, Subdivision and Distribution. A practical handbook. Fourth Edition, revised. 12mo, cloth **$3.50**

——Dynamos, Motors, Alternators and Rotary Converters. Translated from the third German edition, by Harold H. Simmons, A.M.I.E.E. With numerous diagrams and figures. 8vo, cloth, 507 pages **$4.00**

KEIM, A. W. Prevention of Dampness in Build-ings. With Remarks on the Causes, Nature and Effects of Saline Efflorescences and Dry Rot. For Architects, Builders, Overseers, Plasterers, Painters and House Owners. Translated from the second revised German edition. With colored plates and diagrams. 8vo, cloth, illustrated, 115 pages ....net, **$2.00**

KELLER, S. S., Prof. Mathematics for Engin-eering Students. Part I., Algebra and Trigonometry. (Carnegie Schools Textbook Series.) 12mo, half leather, illus., 250 pp. ...net, **$1.50**

KELSEY, W. R. Continuous-current Dynamos and Motors, and their Control: being a series of articles reprinted from The Practical Engineer, and completed by W. R. Kelsey. With many figures and diagrams. 8vo, cloth, illustrated **$2.50**

KEMP, J. F., A.B., E.M. (Columbia Univ.). A Handbook of Rocks. For the use without the microscope. With a glossary of the names of rocks and of other lithological terms. Third Edition, revised. 8vo, cloth, illustrated, **$1.50**

KEMPE, H. R. The Electrical Engineer's Pock-et-book of Modern Rules, Formulae, Tables and Data. Illustrated. 32mo, morocco, gilt. **$1.75**

KENNEDY, R. Modern Engines and Power Gen-erators. A Practical Work on Prime Movers and the Transmission of Power: Steam, Elec-

tric, Water, and Hot-air. With tables, figures, and full-page engravings. 6 vols. 8vo, cloth, illustrated **$15.00**
Single volumes, each **$3.00**

——**Electrical Installations of Electric Light,** Power, Traction, and Industrial Electrical Machinery. With numerous diagrams and engravings

Vol. I. The Electrical Circuit, Measurement, Elements of Motors, Dynamos, Electrolysis. 8vo, cloth, illus. **$3.50**

Vol. II. Instruments, Transformers, In-stallation Wiring, Switches and Switchboards. 8vo, cloth, illustrated **$3.50**

Vol. III. Production of Electrical Energy Prime Movers, Generators and Motors. 8vo, cloth, illustrated **$3.50**

Vol. IV. Mechanical Gearing; Complete Electric Installations; Electrolytic, Mining and Heating Apparatus; Electric Traction; Special Applications of Electric Motors. 8vo, cloth, illustrated **$3.50**

Vol. V. Apparatus and Machinery used in Telegraphs, Telephones, Signals, Wireless Telegraph, X-Rays, and Medical Science. 8vo, cloth, illustrated **$3.50**
Complete sets of the five volumes **$15.00**

KENNELLY, A. E. Theoretical Elements of Electro-dynamic Machinery. 8vo, cloth, **$1.50**

KERSHAW, J. B. C. Fuel, Water, and Gas An-alysis, for Steam Users. 8vo, cloth, net, **$2.50**

KINGDON, J. A. Applied Magnetism. An Intro-duction to the Design of Electromagnetic Apparatus. 8vo, cloth **$3.00**

KINZBRUNNER, C. Alternate Current Wind-ings; Their Theory and Construction. A Handbook for Students, Designs, and all Practical Men. 8vo, cloth, illustrated ....net, **$1.50**

——**Continuous Current Armatures; Their Wind-**ing and Construction. A Handbook for Students, Designers, and all Practical Men. 8vo, cloth, illustrated ....net, **$1.50**

KIRKALDY, W. G. Illustrations of David Kirk-aldy's System of Mechanical Testing, as Originated and Carried on by him during a Quarter of a Century. Comprising a Large Selection of Tabulated Results, showing the Strength and other Properties of Materials used in Construction, with Explanatory Text and Historical Sketch. Numerous engravings and 25 lithographed plates. 4to, cloth **$10,00**

KIRKBRIDE, J. Engraving for Illustration: Historical and Practical Notes, with illustrations and 2 plates by ink photo process. 8vo, cloth, illustrated ....net, **$1.50**

KIRKWOOD, J. P. Report on the Filtration of River Waters for the Supply of Cities, as practiced in Europe, made to the Board of Water Commissioners of the City of St. Louis. Illustrated by 30 double-page engravings. 4to, cloth **$7.50**

KLEIN, J. F. Design of a High-speed Steam-engine. With notes, diagrams, formulas and tables. Second Edition, revised and enlarged. 8vo, cloth, illustrated ....net, **$5.00**

KLEINHANS, F. B. Boiler Construction. A Practical explanation of the best modern methods of Boiler Construction, from the laying out of sheets to the completed Boiler. With diagrams and full-page engravings. 8vo, cloth, illustrated **$3.00**

KNIGHT, A. M., Lieut.-Com., U.S.N. Modern Seamanship. Illustrated with 136 full-page plates and diagrams. 8vo, cloth, illustrated. Second Edition, revised ....net, **$6.00**
Half morocco **$7.50**

KNOTT, C. G., and MACKAY, J. S. Practical Mathematics. With numerous examples, figures and diagrams. New Edition. 8vo, cloth, illustrated **$2.00**

KOESTER, F. Steam-Electric Power Plants and their Construction ....In Press.

KOLLER, T. The Utilization of Waste Products. A Treatise on the Rational Utilization, Recovery and Treatment of Waste Products of all kinds. Translated from the German, second revised edition. With numerous diagrams. 8vo, cloth, illustrated ....net, **$3.50**

——Cosmetics. A Handbook of the Manufacture, Employment and Testing of all Cosmetic Materials and Cosmetic Specialties. Translated from the German by Chas. Salter. 8vo, cloth. ....net, **$2.50**

KRAUCH, C., Dr. Testing of Chemical Reagents for Purity. Authorized translation of the Third Edition, by J. A. Williamson and L. W.

Dupre. With additions and emendations by the author. 8vo, cloth ....net, **$4.50**

LAMBERT, T. Lead, and its Compounds. With tables, diagrams and folding-plates. 8vo, cloth .... net, **$3.50**

——Bone Products and Manures. An Account of the most recent improvements in the manufacture of Fat, Glue, Animal, Charcoal, Size, Gelatine and Manures. With plans and diagrams. 8vo, cloth, illustrated ....net, **$3.00**

LAMBORN, L. L. Cottonseed Products. A Manual of the Treatment of Cottonseed for its Products and Their Utilization in the Arts. With Tables, figures, full-page plates, and a large folding map. 8vo, cloth, illustrated. .... net,**$3.00**

——Modern Soaps, Candles, and Glycerin. A practical manual of modern methods of utilization of Fats and Oils in the manufacture of Soaps and Candles, and the recovery of Glycerin. 8vo, cloth, illustrated ....net, **$7.50**

LAMPRECHT, R. Recovery Work After Pit Fires. A description of the principal methods pursued, especially in fiery mines, and of the various appliances employed, such as respiratory and rescue apparatus, dams, etc. With folding plates and diagrams. Translated from the German by Charles Salter. 8vo, cloth, illustrated ....net, **$4.00**

LARRABEE, C. S. Cipher and Secret Letter and Telegraphic Code, with Hog's Improvements. The most perfect Secret Code ever invented or discovered. Impossible to read without the key. 18mo, cloth **$0.60**

LASSAR-COHN, Dr. An Introduction to Modern Scientific Chemistry, in the form of popular lectures suited to University Extension Students and general readers. Translated from the author's corrected proofs for the second German edition, by M. M. Pattison Muir, M. A. 12mo, cloth, illustrated **$2.00**

LATTA, M. N. Handbook of American Gas-Engineering Practice. With diagrams and tables. 8vo, cloth, illus., 460 pp....net, **$4.50**

LEASK, A. R. Breakdows at Sea and How to Repair Them. With 89 illustrations. Second Edition. 8vo, cloth **$2.00**

——**Triple and Quadruple Expansion Engines** and Boilers and their Management. With 59 illustrations. Third Edition, revised. 12mo, cloth **$2.00**

——**Refrigerating Machinery: Its Principles and** Management. With 64 illustrations. 12mo, cloth **$2.00**

LECKY, S. T. S. "Wrinkles" in Practical Navigation. With 130 illustrations. 8vo, cloth. Fourteenth Edition, revised and enlarged. ....net, **$9.00**

LEFÈVRE, L. Architectural Pottery: Bricks, Tiles, Pipes, Enameled Terra-Cottas, Ordinary and Incrusted Quarries, Stoneware Mosaics, Faiences and Architectural Stoneware. With tables, plates and 950 cuts and illustrations. With a preface by M. J.-C. Formigé. Translated from the French, by H. K. Bird, M.A., and W. Moore Binns. 4to, cloth, illustrated. ....net, **$7.50**

LEHNER, S. Ink Manufacture: including Writing, Copying, Lithographic, Marking, Stamping and Laundry Inks. Translated from the fifth German edition, by Arthur Morris and Herbert Robson, B.Sc. 8vo, cloth, illustrated. ....net, **$2.50**

LEMSTROM, Dr. Electricity in Agriculture and Horticulture. Illustrated ....net, **$1.50**

LEVY, C. L. Electric-light Primer. A simple and comprehensive digest of all the most important facts connected with the running of the dynamo, and electric lights, with precautions for safety. For the use of persons whose duty it is to look after the plant. 8vo, paper. **$0.50**

LIVERMORE, V. P., and WILLIAMS, J. How to Become a Competent Motorman. Being a Practical Treatise on the Proper Method of Operating a Street Railway Motor Car; also giving details how to overcome certain defects. Revised Edition entirely rewritten and enlarged. 16mo, cloth, illustrated **$1.00**

LOBBEN, P., M.E. Machinists' and Draftsmen's Handbook, containing Tables, Rules, and Formulas, with numerous examples, explaining the principles of mathematics and mechanics, as applied to the mechanical trades. Intended as a reference book for all interested in Mechanical work. Illustrated with many cuts and diagrams. 8vo, cloth **$2.50**

LOCKE, A. G. and C. G. A Practical Treatise on the Manufacture of Sulphuric Acid. With 77 constructive plates, drawn to scale measurements, and other illustrations. Royal 8vo, cloth **$10.00**

LOCKWOOD, T. D. Electricity, Magnetism, and Electro-telegraphy. A Practical Guide for Students, Operators, and Inspectors. 8vo, cloth. Third Edition **$2.50**

——Electrical Measurement and the Galvano-meter: its Construction and Uses. Second Edition. 32 illustrations. 12mo, cloth **$1.50**

LODGE, O. J. Elementary Mechanics, including Hydrostatics and Pneumatics. Revised Edition. 12mo, cloth **$1.50**

——Signalling Across Space, Without Wires: being a description of the work of Hertz and his successors. With numerous diagrams and half-tone cuts, and additional remarks concerning the application to Telegraphy and later developments. Third Edition. 8vo, cloth, illustrated ....net, **$2.00**

LORD, R. T. Decorative and Fancy Fabrics.. A Valuable Book with designs and illustrations for manufacturers and designers of Carpets, Damask, Dress and all Textile Fabrics. 8vo, cloth, illustrated ....net, **$3.50**

LORING, A. E. A. Handbook of the Electro-magnetic Telegraph. 16mo, cloth, boards. New and enlarged edition **$0.50**

LUCE, S. B. (Com., U.S.N.) Text-book of Sea-manship. The Equipping and Handling of Vessels under Sail or Steam. For the use of the U. S. Naval Academy. Revised and enlarged edition, by Lieut. Wm. S. Benson. 8vo, cloth, illustrated **$10.00**

LUCKE, C. E. Gas Engine Design. With fig-ures and diagrams. Second Edition, revised. 8vo, cloth, illustrated ....net, **$3.00**

——Power Plants: their Design, Efficiency, and Power Costs. 2 vols. ....In Press.

——Power Plant Papers.. Form I. The Steam Power Plant. Pamphlet (8x13) .....net, **$1.50**

LUNGE, G., Ph.D. Coal-tar and Ammonia: being the third and enlarged edition of "A Treatise on the Distillation of Coal-tar and Ammoniacal Liquor," with numerous tables, figures and diagrams. Thick 8vo, cloth, illustrated. ....net, **$15.00**

——A Theoretical and Practical Treatise on the Manufacture of Sulphuric Acid and Alkali with the Collateral Branches.

Vol. I. Sulphuric Acid. In two parts, not sold separately. Second Edition, revised and enlarged. 342 illus. 8vo, cloth **$15.00**

Vol. II. Salt Cake, Hydrochloric Acid and Leblanc Soda. Second Edition, revised and enlarged. 8vo, cloth **$15.00**

Vol. III. Ammonia Soda, and various other processes of Alkali-making, and the preparation of Alkalis, Chlorine and Chlorates, by Electrolysis. 8vo, cloth. New Edition, 1896. .... **$15.00**

——and HURTER, F. The Alkali Maker's Hand-book. Tables and Analytical Methods for Manufacturers of Sulphuric Acid, Nitric Acid, Soda, Potash and Ammonia. Second Edition. 12mo, cloth **$3.00**

LUPTON, A., PARR, G. D. A., and PERKIN, H. Electricity as Applied to Mining. With tables, diagrams and folding plates. Second Edition, revised and enlarged. 8vo, cloth, illustrated. ....net, **$4.50**

LUQUER, L. M., Ph.D. (Columbia Univ.). Min-erals in Rock Sections. The Practical Method of Identifying Minerals in Rock Sections with the Microscope. Especially arranged for Students in Technical and Scientific Schools. Revised Edition. 8vo, cloth, illustrated, net, **$1.50**

MACKIE, John. How to Make a Woolen Mill Pay. 8vo, cloth ....net, **$2.00**

MACKROW, C. The Naval Architect's and Ship-builder's Pocket-book of Formulae, Rules, and Tables; and Engineers' and Surveyors' Handy Book of Reference. Ninth Edition. 16mo, limp leather, illustrated **$5.00**

MAGUIRE, E., Capt., U.S.A. The Attack and Defense of Coast Fortifications. With maps and numerous illustrations. 8vo, cloth, **$2.50**

——Wm. R. Domestic Sanitary Drainage and Plumbing Lectures on Practical Sanitation. 332 illustrations. 8vo **$4.00**

MARKS, E. C. R. Notes on the Construction of Cranes and Lifting Machinery. With numerous diagrams and figures. New and enlarged edition. 12mo, cloth ....net, **$1.50**

——Notes on the Construction and Working of Pumps. With figures, diagrams and engravings. 12mo, cloth, illustrated ......net, **$1.50**

——G. C. Hydraulic Power Engineering. A Practical Manual on the Concentration and Transmission of Power by Hydraulic Machinery. With over 200 diagrams and tables. 8vo, cloth, illustrated **$3.50**

MARKHAM, E. R. Steel Worker, The American. A twenty-five years experience in the selection, annealing, working, hardening and tempering of various kinds and grades of steel. 8vo, cloth. Illus. Second Edition **$2.50**

MARSH, C. F., and DUNN, W. Reinforced Con-crete. With full-page and folding plates, and 512 figures and diagrams. Third Edition, revised and enlarged. 4to, cloth, illus., net, **$7.00**

MAURICE, WM. Electric Blasting Apparatus and Explosives: with Special Reference to Colliery Practice. 8vo, cloth.

MAVER, W. American Telegraphy: Systems, Apparatus, Operation. 450 illustrations. 8vo, cloth **$5.00**

MAYER, A. M., Prof. Lecture Notes on Physics. 8vo, cloth **$2.00**

McCULLOUGH, R. S., Prof. Elementary Treatise on the Mechanical Theory of Heat, and its application to Air and Steam-engines. 8vo, cloth. **$3.50**

——E. Engineering Work in Towns and Small Cities. With valuable tables, diagrams, and formulae. 12mo, cloth, illustrated **$3.00**

McINTOSH, J. G. Technology of Sugar. A Prac-tical Treatise on the Manufacture of Sugar from the Sugar-cane and Sugar-beet. With diagrams and tables. 8vo, cloth, illustrated. ....net, **$4.50**

——Industrial Alcohol. A Practical Manual on the Production and Use of Alcohol for Industrial Purposes and for Use as a Heating Agent, as an Illuminant and as a Source of Motive Power. With plans and engravings. 8vo, cloth, ill. 252 pp., London, 1907 .....net, **$3.00**

——Manufacture of Varnishes and Kindred In-dustries, Based on and including the "Drying Oils and Varnishes," of Ach. Livache. Volume I. Oil Crushing, Refining and Boiling, Manufacture of Linoleum, Printing and Lithographic Inks, and India-rubber Substitutes. Second

greatly enlarged English Edition. 8vo, cloth, illustrated ....net, **$3.50**
(To be complete in three volumes.)

McMECHEN, F. L. Tests for Ores, Minerals and Metals of Commercial Value. 8vo, cloth, illustrated. .... In Press.

McNEILL, B. McNeill's Code. Arranged to meet the requirements of Mining, Metallurgical and Civil Engineers, Directors of Mining, Smelting and other Companies, Bankers, Stock and Share Brokers, Solicitors, Accountants, Financiers and General Merchants. Safety and Secrecy. 8vo, cloth **$6.00**

McPHERSON, J. A., A. M. Inst. C. E. Water-works Distribution. A practical guide to the laying out of systems of distributing mains for the supply of water to cities and towns. With tables, folding plates, and numerous full-page diagrams. 8vo, cloth, illustrated, **$2.50**

MELICK, C. W., Prof. Dairy Laboratory Guide. .... In Press.

MERCK, E. Chemical Reagents; Their Purity and Tests, 250 pp. ....net, **$1.50**

MERRITT, Wm. H. Field Testing for Gold and Silver. A Practical Manual for Prospectors and Miners. With numerous half-tone cuts, figures and tables. 16mo, limp leather, illustrated **$1.50**

METAL TURNING. By a Foreman Pattern-maker. Illustrated with 81 engravings. 12mo, cloth **$1.50**

MICHELL, S. Mine Drainage; being a Complete Practical Treatise on Direct-acting Underground Steam Pumping Machinery. Containing many folding plates, diagrams and tables. Second Edition, rewritten and enlarged. Thick 8vo, cloth, illustrated **$10.00**

MIERZINSKI, S., Dr. Waterproofing of Fabrics. Translated from the German by Arthur Morris and Herbert Robson. With diagrams and figures. 8vo, cloth, illustrated .... net, **$2.50**

MILLER, E. H. (Columbia Univ.). Quantitative Analysis for Mining Engineers. 8vo, cloth, Second Ed. Revised ....net, **$1.50**

MILROY, M. E. W. Home Lace-making; a Hand-book for Teachers and Pupils. With plates and diagrams. 12mo, cloth, illustrated. ....net, **$1.00**

MINIFIE, W. Mechanical Drawing. A Text- book of Geometrical Drawing for the use of Mechanics and Schools, in which the Definitions and Rules of Geometry are familiarly explained; the Practical Problems are arranged from the most simple to the more complex, and in their description technicalities are avoided as much as possible. With illustrations for drawing Plans, Sections, and Elevations of Railways and Machinery; an Introduction to Isometrical Drawing, and an Essay on Linear Perspective and Shadows. Illustrated with over 200 diagrams engraved on steel. Tenth Thousand, revised. With an Appendix on the Theory and Application of Colors. 8vo, cloth **$4.00**

——Geometrical Drawing. Abridged from the Octavo edition, for the use of schools. Illustrated with 48 steel plates. Ninth Edition. 12mo, cloth **$2.00**

MODERN METEOROLOGY. A Series of Six Lectures, delivered under the auspices of the Meteorological Society in 1870. Illustrated. 12mo, cloth **$1.50**

MOORE, E. C. S. New Tables for the Complete Solution of Ganguillet and Kutter's Formula for the flow of liquids in open channels, pipes, sewers and conduits. In two parts. Part I, arranged for 1080 inclinations from 1 over 1 to 1 over 21,120 for fifteen different values of (n). Part II, for use with all other values of (n). With large folding diagram. 8vo, cloth, illustrated ....net, **$5.00**

MOREING, C. A., and NEAL, T. New General and Mining Telegraph Code. 676 pages, alphabetically arranged. For the use of mining companies, mining engineers, stock brokers, financial agents, and trust and finance companies. Eighth Edition. 8vo, cloth ...**$5.00**

MOSES, A. J. The Characters of Crystals. An Introduction to Physical Crystallography, containing 321 illustrations and diagrams. 8vo. ....net, **$2.00**

——and PARSONS, C. L. Elements of Mineral- ogy, Crystallography and Blowpipe Analysis from a Practical Standpoint. Fourth Enlarged Edition. 8vo, cloth, 336 illustrations, net, **$2.50**

MOSS, S. A. Elements of Gas Engine Design. Reprint of a Set of Notes accompanying a Course of Lectures at Cornell University in 1902. Second Edition. 16mo, cloth, illustrated. (Van Nostrand's Science Series) **$0.50**

——The Lay-out of Corliss Valve Gears. (Van nostrand's Science Series.) 16mo, cloth, illustrated $0.50

MULLIN, J. P., M.E. Modern Moulding and Pattern-making. A Practical Treatise upon Pattern-shop and Foundry Work: embracing the Moulding of Pulleys, Spur Gears, Worm Gears, Balance-wheels, Stationary Engine and Locomotive Cylinders, Globe Valves, Tool Work, Mining Machinery, Screw Propellers, Pattern-shop Machinery, and the latest improvements in English and American Cupolas; together with a large collection of original and carefully selected Rules and Tables for every-day use in the Drawing Office, Pattern-shop and Foundry. 12mo, cloth, illustrated $2.50

MUNRO, J., C.E., and JAMIESON, A., C.E. A Pocket-book of Electrical Rules and Tables for the use of Electricians and Engineers. Sixteenth Edition, revised and enlarged. With numerous diagrams. Pocket size. Leather. $2.50

MURPHY, J. G., M.E. Practical Mining. A Field Manual for Mining Engineers. With Hints for Investors in Mining Properties. 16mo, cloth. $1.00

NAQUET, A. Legal Chemistry. A Guide to the Detection of Poisons, Falsification of Writings, Adulteration of Alimentary and Pharmaceutical Substances, Analysis of Ashes, and Examination of Hair, Coins, Arms and Stains, as applied to Chemical Jurisprudence, for the use of Chemists, Physicians, Lawyers, Pharmacists and Experts. Translated, with additions, including a list of books and memoirs on Toxicology, etc., from the French, by J. P. Battershall, Ph.D., with a preface by C. F. Chandler, Ph.D., M.D., LL.D. 12mo, cloth $2.00

NASMITH, J. The Student's Cotton Spinning. Third Edition, revised and enlarged. 8vo, cloth, 622 pages, 250 illustrations $3.00

NEUBERGER, H., and NOALHAT, H. Technology of Petroleum. The Oil Fields of the World: their History, Geography and Geology. Annual Production, Prospection and Development; Oil-well Drilling; Transportation of Petroleum by Land and Sea. Storage of Petroleum. With 153 illustrations and 25 plates. Translated from the French by John Geddes McIntosh. 8vo, cloth, illustrated, net, $10.00

NEWALL, J. W. Plain Practical Directions for Drawing, Sizing and Cutting Bevel-gears, showing how the Teeth may be cut in a Plain Milling Machine or Gear Cutter so as to give them a correct shape from end to end; and showing how to get out all particulars for the Workshop without making any Drawings. Including a Full Set of Tables of Reference. Folding plates. 8vo, cloth **$1.50**

NEWLANDS, J. The Carpenters' and Joiners' Assistant: being a Comprehensive Treatise on the Selection, Preparation and Strength of Materials, and the Mechanical Principles of Framing, with their application in Carpentry, Joinery and Hand-railing; also, a Complete Treatise on Sines; and an Illustrated Glossary of Terms used in Architecture and Building. Illustrated. Folio, half morocco **$15.00**

NIPHER, F. E., A.M. Theory of Magnetic Meas-urements, with an Appendix on the Method of Least Squares. 12mo, cloth **$1.00**

NISBET, H. Grammar of Textile Design. With many diagrams and figures. 8vo, cloth, illustrated. 276 pp., London, 1907 ......net, **$3.00**

NOLL, Augustus. How to Wire Buildings: A Manual of the Art of Interior Wiring. With many illustrations. Fourth Edition. 8vo, cloth, illustrated **$1.50**

NUGENT, E. Treatise on Optics; or, Light and Sight Theoretically and Practically Treated, with the Application to Fine Art and Industrial Pursuits. With 103 illustrations. 12mo, cloth **$1.50**

O'CONNOR, H. The Gas Engineer's Pocket-book. Comprising Tables, Notes and Memoranda relating to the Manufacture, Distribution and Use of Coal-gas and the Construction of Gasworks. Second Edition, revised. 12mo, full leather, gilt edges **$3.50**

OLSEN, J. C., Prof. Text-book of Quantitative Chemical Analysis by Gravimetric, Electrolytic, Volumetric and Gasometric Methods. With Seventy-two Laboratory Exercises giving the Analysis of Pure Salts, Alloys, Minerals, and Technical Products. With numerous figures and diagrams. Second Edition, revised. 8vo, cloth ....net, **$4.00**

OSBORN, F. C. Tables of Moments of Inertia, and Squares of Radii of Gyration; supplemented by others on the Ultimate and Safe **Strength of Wrought-iron Columns, Safe**

Strength of Timber Beams, and Constants for readily obtaining the Shearing Stresses, Reactions and Bending Moments in Swing Bridges. Fifth Edition. 12mo, leather ......net, **$3.00**

OUDIN, M. A. Standard Polyphase Apparatus and Systems. With many diagrams and figures. Fifth Edition, revised and enlarged. Fully illustrated. 8vo, cloth, 370 pp. ...**$3.00**

PALAZ, A., Sc.D. A Treatise on Industrial Photometry, with special application to Electric Lighting. Authorized translation from the French by George W. Patterson, Jr. Second Edition, revised. 8vo, cloth, illustrated, **$4.00**

PAMELY, C. Colliery Manager's Handbook. A Comprehensive treatise on the Laying-out and Working of Collieries. Designed as a book of reference for colliery managers and for the use of coal-mining students preparing for first-class certificates. Fifth Edition, revised and enlarged. Containing over 1,000 diagrams, plans, and engravings. 8vo, cloth, illustrated ....nėt, **$10.00**

PARR, G. D. A. Electrical Engineering Measuring Instruments, for Commercial and Laboratory Purposes. With 370 diagrams and engravings. 8vo, cloth, illustrated, net, **$3.50**

PARRY, E. J., B.Sc. The Chemistry of Essential Oils and Artificial Perfumes. Being an attempt to group together the more important of the published facts connected with the subject; also giving an outline of the principles involved in the preparation and analysis of Essential Oils. With numerous diagrams and tables. 8vo, cloth, illustrated ......net, **$5.00**

——and COSTE, J. H. Chemistry of Pigments. With tables and figures. 8vo, cloth, net, **$4.50**

——L. A., M.D. The Risk and Dangers of Various Occupations and their Prevention. A book that should be in the hands of manufacturers, the medical profession, sanitary inspectors, medical officers of health, managers of works, foremen and workmen. 8vo, cloth, net, **$3.00**

PARSHALL, H. F., and HOBART, H. M. Armature Windings of Electric Machines. With 140 full-page plates, 65 tables and 165 pages of descriptive letter-press. 4to, cloth **$7.50**

——Electric Railway Engineering. With numerous tables, figures, and folding plates. 4to, cloth, 463 pp., illus. ....net, **$10.00**
This is undoubtedly the most comprehensive

work on a rapidly growing and immensely important branch of engineering, and is likely to remain for long the standard book on the subject.

——and PARRY, E. Electrical Equipment of Tramways ....In Press.

PASSMORE, A. C. Handbook of Technical Terms used in Architecture and Building, and their Allied Trades and Subjects. 8vo, cloth. ....net, **$3.50**

PATERSON, D., F.C.S. The Color Printing of Carpet Yarns. A useful manual for color chemists and textile printers. With numerous illustrations. 8vo, cloth, illustrated, net, **$3.50**

——Color Matching on Textiles. A Manual intended for the use of Dyers, Calico Printers, and Textile Color Chemists. Containing colored frontispiece and 9 illustrations, and 14 dyed patterns in appendix. 8vo, cloth, illustrated ....net, **$3.00**

——The Science of Color Mixing. A Manual intended for the use of Dyers, Calico Printers, and Color Chemists. With figures, tables, and colored plate. 8vo, cloth, illustrated, net, **$3.00**

PATTEN, J. A Plan for Increasing the Humidity of the Arid Region and the Utilization of Some of the Great Rivers of the United States for Power and other Purposes. A paper communicated to the National Irrigation Congress, Ogden, Utah, Sept. 12, 1903. 4to, pamphlet, 20 pp., with 7 maps **$1.00**

PATTON, H. B. Lecture Notes on Crystallography. Revised Edition, largely rewritten. Prepared for use of the students at the Colorado School of Mines. With blank pages for note-taking. 8vo, cloth ....net, **$1.25**

PAULDING, C. P. Practical Laws and Data on the Condensation of Steam in Covered and Bare Pipes; to which is added a translation of Péclet's "Theory and Experiments on the Transmission of Heat Through Insulating Materials." 8vo, cloth, illustrated, 102 pages. ....net, **$2.00**

——Transmission of Heat Through Cold-storage Insulation: Formulas, Principles, and Data Relating to Insulation of Every Kind. A Manual for refrigerating engineers. With tables and diagrams. 12mo, cloth, illustrated. ....net, **$1.00**

PEIRCE, B. System of Analytic Mechanics. 4to, cloth $10.00

PERKIN, F. M. Practical Methods of Inorganic Chemistry. With figures and diagrams. 12mo, cloth, illustrated, 152 pp. ....net, $1.00

PERRIGO, O. E. Devices, Change Gear. Showing the Development of the Screw Cutting lathe and the Methods of obtaining various pitches of Threads. Cloth $1.00

PERRINE, F. A. C., A.M., D.Sc. Conductors for Electrical Distribution: their Manufacture and Materials, the Calculation of Circuits, Pole Line Construction, Underground Working and other Uses. With numerous diagrams and engravings. Second Edition, revised. 8vo, cloth, illustrated, 287 pages ....net, $3.50

PERRY, J. Applied Mechanics. A Treatise for the Use of Students who have time to work experimental, numerical, and graphical exercises illustrating the subject. 8vo, cloth, 650 pages ....net, $2.50

PHILLIPS, J. Engineering Chemistry. A Prac-tical Treatise for the use of Analytical Chemists, Engineers, Iron Masters, Iron Founders, students and others. Comprising methods of Analysis and Valuation of the principal materials used in Engineering works, with numerous Analyses, Examples, and Suggestions. Illustrated. Third Edition, revised and enlarged. 8vo, cloth ....net, $4.50

——Gold Assaying. A Practical Handbook giv-ing the Modus Operandi for the Accurate Assay of Auriferous Ores and Bullion, and the Chemical Tests required in the Processes of Extraction by Amalgamation, Cyanidation, and Chlorination. With an appendix of tables and statistics and numerous diagrams and engravings. 8vo, cloth, illustrated, net, $2.50

PHIN, J. Seven Follies of Science. A Popular Account of the most famous scientific impossibilities and the attempts which have been made to solve them; to which is added a small Budget of Interesting Paradoxes, Illusions and Marvels. With numerous illustrations. Second Edition. 8vo, cloth, illustrated. ....net, $1.25

PICKWORTH, C. N. The Indicator Handbook. A Practical Manual for Engineers. Part I. The Indicator: its Construction and Application. 81 illustrations. 12mo, cloth $1.50

——The Indicator Handbook. Part II. The Indicator Diagram: its Analysis and Calculation. With tables and figures. 12mo, cloth, illustrated **$1.50**

——Logarithms for Beginners. 8vo, boards, $0.50

——The Slide Rule. A Practical Manual of In-struction for all Users of the Modern Type of Slide Rule, containing Succinct Explanation of the Principle of Slide-Rule Computation, together with Numerous Rules and Practical Illustrations, exhibiting the Application of the Instrument to the Every-day Work of the Engineer—Civil, Mechanical and Electrical. Seventh Edition. 12mo, flexible cloth, **$1.00**

PLANE TABLE, THE. Its Uses in Topographi-cal Surveying. From the Papers of the United States Coast Survey. Illustrated. 8vo, cloth. **$2.00**

"This work gives a description of the Plane Table employed at the United States Coast Survey office, and the manner of using it."

PLATTNER'S Manual of Qualitative and Quan-titative Analysis with the Blow-pipe. Eighth Edition, revised. Translated by Henry B. Cornwall, E.M., Ph.D., assisted by John H. Caswell, A.M. From the sixth German edition, by Prof. Friederich Kolbeck. With 87 woodcuts. 463 pages. 8vo, cloth ......net, **$4.00**

PLYMPTON, Geo. W., Prof. The Aneroid Bar-ometer: its Construction and Use. Compiled from several sources. Tenth Edition, revised and enlarged. 16mo, boards, illustrated, **$0.50**

POCKET LOGARITHMS, to Four Places of Deci-mals, including Logarithms of Numbers, and Logarithmic Sines and Tangents to Single Minutes. To which is added a Table of Natural Sines, Tangents, and Co-tangents. 16mo, boards **$0.50**

POPE, F. L. Modern Practice of the Electric Telegraph.. A Technical Handbook for Electricians, Managers and Operators. Fifteenth Edition, rewritten and enlarger, and fully illustrated. 8vo, cloth **$1.50**

POPPLEWELL, W. C. Elementary Treatise on Heat and Heat Engines. Specially adapted for engineers and students of engineering. 12mo, cloth, illustrated **$3.00**

——Prevention of Smoke, combined with the Economical Combustion of Fuel. With diagrams, figures and tables. 8vo, cloth, illustrated ....net, **$3.50**

Practical Compounding of Oils, Tallow and Grease, for Lubrication, etc. By an Expert Oil Refiner. 8vo, cloth ....net, **$3.50**

Practical Iron Founding. By the Author of "Pattern Making," etc. Illustrated with over 100 engravings. Third Edition. 12mo, cloth. **$1.50**

PRATT, HERBERT. Wiring a House. Pamphlet **$0.25**

PRAY, T., Jr. Twenty Years with the Indicator: being a Practical Text-book for the Engineer or the Student, with no complex Formulae. Illustrated. 8vo, cloth **$2.50**

——Steam Tables and Engine Constant. Compiled from Regnault, Rankine and Dixon directly, making use of the exact records. 8vo, cloth **$2.00**

PREECE, W. H. Electric Lamps .....In Press.

——and Stubbs, A. T. Manual of Telephony. Illustrations and plates. 12mo, cloth, **$4.50**

PRELINI, C., C.E. Earth and Rock Excavation. A Manual for Engineers, Contractors, and Engineering Students. With tables and many diagrams and engravings. Second Edition, revised. 8vo, cloth, illustrated ....net, **$3.00**

——Retaining Walls and Dams. 8vo, cloth, illustrated ....In Press.

——Tunneling. A Practical Treatise containing 149 Working Drawings and Figures. With additions by Charles S. Hill, C.E., Associate Editor "Engineering News." 311 pages. Third Edition, revised. 8vo, cloth, illus. **$3.00**

PREMIER CODE. (See Hawke, Wm. H.)

PRESCOTT, A. B., Prof. Organic Analysis. A Manual of the Descriptive and Analytical Chemistry of certain Carbon Compounds in Common Use; a Guide in the Qualitative and Quantitative Analysis of Organic Materials in Commercial and Pharmaceutical Assays, in the Estimation of Impurities under Authorized Standards, and in Forensic Examinations for Poisons, with Directions for Elementary Organic Analysis. Fifth Edition. 8vo, cloth. **$5.00**

——Outlines of Proximate Organic Analysis, for the identification, Separation and Quantitative Determination of the more commonly occurring Organic Compounds. Fourth Edition. 12mo, cloth **$1.75**

——and JOHNSON, O. C. Qualitative Chemical Analysis. A Guide in Qualitative Work, with Data for Analytical Operations, and Laboratory Methods in Inorganic Chemistry. Sixth revised and enlarged Edition, entirely rewritten, with an appendix by H. H. Willard, containing a few improved methods of analysis. 8vo, cloth ....net, $3.50

——and SULLIVAN, E. C. (University of Michigan). First Book in Qualitative Chemistry. For Studies of Water Solution and Mass Action. Twelfth Edition, entirely rewritten. 12mo, cloth ....net, $1.50

PRESS, A. Design of Electrical Machinery. 8vo, cloth. Illus. ....In Press.

PRITCHARD, O. G. The Manufacture of Elec- tric-light Carbons. Illustrated. 8vo, paper. $0.60

PROST, E. Manual of Chemical Analysis as Ap- plied to the Assay of Fuels, Ores, Metals, Alloys, Salts, and other Mineral Products. Translated from the original by J. C. Smith. Part I, Fuels, Waters, Ores, Salts, and other mineral industrial products; Part II, Metals; Part III, Alloys. 8vo, cloth ....net, $4.50

PULLEN, W. W. F. Application of Graphic Methods to the Design of Structures. Specially prepared for the use of Engineers. A Treatment by Graphic Methods of the Forces and Principles necessary for consideration in the Bridges, Trusses, Framed Structures, Wells, Bridges, Trusses, Framed Structures, Roofs, Dams, Chimneys, and Masonry Structures. 12mo, cloth, profusely illustrated, net, $2.50

PULSIFER, W. H. Notes for a History of Lead. 8vo, cloth, gilt top $4.00

PUTSCH, A. Gas and Coal-dust Firing. A Crit- ical Review of the Various Appliances Patented in Germany for this Purpose since 1885. With diagrams and figures. Translated from the German by Charles Salter. 8vo, cloth, illustrated ....net, $3.00

PYNCHON, T. R., Prof. Introduction to Chemi- cal Physics, designed for the use of Academies, Colleges and High Schools. Illustrated with numerous engravings, and containing copious experiments, with directions for preparing them. New Edition, revised and enlarged, and illustrated by 269 wood engravings. 8vo, cloth $3.00

RADFORD, C. S., Lieut. Handbook on Naval Gunnery. Prepared by Authority of the Navy Department. For the use of U. S. Navy, U. S. Marine Corps, and U. S. Naval Reserves. Revised and enlarged, with the assistance of Stokely Morgan, Lieut. U. S. N. Third Edition, revised and enlarged. 12mo, flexible leather. ....net, **$2.00**

RAFTER, G. W. Treatment of Septic Sewage (Van Nostrand's Science Series, No. 118). 16mo, cloth **$0.50**

——Tables for Sewerage and Hydraulic Engineers ....In Press.

——and BAKER, M. N. Sewage Disposal in the United States. Illustrations and folding plates. New Revised and Enlarged Edition. 8vo, cloth ....In Press.

RAM, G. S. The Incandescent Lamp and its Manufacture. 8vo, cloth ....net, **$3.00**

RAMP, H. M. Foundry Practice ......In Press.

RANDALL, P. M. Quartz Operator's Handbook. New Edition, revised and enlarged, fully illustrated. 12mo, cloth **$2.00**

RANDAU, P. Enamels and Enamelling. An introduction to the preparation and application of all kinds of enamels for technical and artistic purposes. For enamel-makers, workers in gold and silver, and manufacturers of objects of art. Third German Edition. Translated by Charles Salter. With figures, diagrams and tables. 8vo, cloth, illustrated .....net, **$4.00**

RANKINE, W. J. M. Applied Mechanics. Comprising the Principles of Statics and Cinematics, and Theory of Structures, Mechanism, and Machines. With numerous diagrams. Seventeenth Edition, thoroughly revised by W. J. Millar. 8vo, cloth **$5.00**

——Civil Engineering. Comprising Engineering Surveys, Earthwork, Foundations, Masonry, Carpentry, Metal-work, Roads, Railways, Canals, Rivers, Water-works, Harbors, etc. With numerous tables and illustrations. Twenty-first Edition, thoroughly revised by W. J. Millar. 8vo, cloth **$6.50**

——Machinery and Millwork. Comprising the Geometry, Motions, Work, Strength, Construction, and Objects of Machines, etc. With nearly 300 woodcuts. Seventh Edition, thoroughly revised by W. J. Millar. 8vo, cloth ..**$5.00**

——**The Steam-engine and Other Prime Movers.** With diagram of the Mechanical Properties of Steam. Folding plates, numerous tables and illustrations. Fifteenth Edition, thoroughly revised by W. J. Millar. 8vo, cloth **$5.00**

——**Useful Rules and Tables for Engineers and** Others. With Appendix, Tables, Tests and Formulae for the use of Electrical Engineers. Comprising Submarine Electrical Engineering, Electric Lighting and Transmission of Power. By Andrew Jamieson, C.E., F.R.S.E. Seventh Edition, thoroughly revised by W. J. Millar. 8vo, cloth **$4.00**

——**and BAMBER, E. F., C.E. A Mechanical** Text-book. With numerous illustrations. Fifth Edition. 8vo, cloth **$3.50**

RAPHAEL, F. C. Localization of Faults in Elec-tric Light and Power Mains, with chapters on Insulation Testing. With figures and diagrams. Second Edition, revised. 8vo, cloth, illustrated ,........................net, **$3.00**

RATEAU, A. Experimental Researches on the Flow of Steam through Nozzles and Orifices, to which is added a note on the Flow of Hot Water. (Extrait des Annales des Mines, January, 1902.) Authorized translation by H. Boyd Brydon. With figures, tables, and folding plates. 8vo, cloth, illus. ....net, **$1.50**

RAUTENSTRAUCH, W., Prof. Syllabus of Lec-tures and Notes on the Elements of Machine Design. With blank pages for note-taking. 8vo, cloth, illustrated ....net, **$1.50**

——**and WILLIAMS, J. T. Machine Drafting and** Empirical Design. 8vo, cloth ....In Press.

RAYMOND, E. B. Alternating-current Engin-eering Practically Treated. With numerous diagrams and figures. Second Edition. 12mo, cloth ....net, **$2.50**

RAYNER, H. Silk Throwing and Waste Silk Spinning. With numerous diagrams and figures. 8vo, cloth, illus. ....net, **$2.50**

RECIPES for the Color, Paint, Varnish, Oil, Soap and Drysaltery Trades. Compiled by an Analytical Chemist. 8vo, cloth **$3.50**

RECIPES FOR FLINT GLASS MAKING. Being Leaves from the mixing-book of several experts in the Flint Glass Trade. Containing up-to-date recipes and valuable information as to Crystal, Demi-crystal, and Colored Glass in its many varieties. It contains the recipes for cheap metal suited to pressing, blowing, etc., as well as the most costly Crystal and Ruby. British manufacturers have kept up the quality of this glass from the arrival of the Venetians to Hungry Hill, Stourbridge, up to the present time. The book also contains remarks as to the result of the metal as it left the pots by the respective metal mixers, taken from their own memoranda upon the originals. Compiled by a British Glass Master and Mixer. 12mo, cloth ....net, **$4.50**

REED'S ENGINEERS' HANDBOOK to the Local Marine Board Examinations for Certificates of Competency as First and Second Class Engineers. By W. H. Thorn. With the answers to the Elementary Questions. Illustrated by 358 diagrams and 37 large plates. Seventeenth Edition, revised and enlarged. 8vo, cloth, **$5.00**

——Key to the Seventeenth Edition of Reed's Engineers' Handbook to the Board of Trade Examination for First and Second Class Engineers, and containing the workings of all the questions given in the examination papers. By W. H. Thorn. 8vo, cloth **$3.00**

——Useful Hints to Sea-going Engineers, and How to Repair and Avoid "Breakdowns;" also appendices containing Boiler Explosions, Useful Formulae, etc. With 42 diagrams and 8 plates. Third Edition, revised and enlarged. 12mo, cloth **$1.50**

——Marine Boilers. A Treatise on the Causes and Prevention of their Priming, with Remarks on their General Management. 12mo, cloth, illustrated **$2.00**

REINHARDT, C. W. Lettering for Draftsmen, Engineers, and Students. A Practical System of Free-hand Lettering for Working Drawings. Revised and enlarged edition. Twenty-fourth Thousand. Oblong boards **$1.00**

——The Technic of Mechanical Drafting. A Practical guide to neat, correct and legible drawing, containing many illustrations, diagrams and full-page plates. 4to, cloth, illus. **$1.00**

REISER, F. Hardening and Tempering of Steel, in Theory and Practice. Translated from the German of the third and enlarged edition, by Arthur Morris and Herbert Robson. 8vo, cloth, 120 pages **$2.50**

——**N. Faults in the Manufacture of Woolen** Goods and their Prevention. Translated from the second German edition, by Arthur Morris and Herbert Robson. 8vo, cloth, illustrated. .... net, **$2.50**

——**Spinning and Weaving Calculations with** special reference to Woolen Fabrics. Translated from the German by Chas. Salter. 8vo, cloth, illustrated ....net, **$5.00**

RICE, J. M., and JOHNSON, W. W. On a New Method of Obtaining the Differential of Functions, with especial reference to the Newtonian conception of Rates or Velocities. 12mo, paper **$0.50**

RICHARDS, F., and COLVIN, F. H. Perspective, Practical, (Isometric). Flexible cloth ...**$0.50**

RIDEAL, S., D.Sc. Glue and Glue Testing, with figures and tables. 8vo, cloth, illustrated. ....net, **$4.00**

RIPPER, W. A Course of Instruction in Machine Drawing for Technical Schools and Engineer Students. With 52 plates and numerous explanatory engravings. Folio, cloth, ...net, **$6.00**

ROBERTS, J., Jr. Laboratory Work in Electrical Engineering, (Preliminary Grade.) A series of Laboratory Experiments for First and Second Year Students of Electrical Engineering. With Figures, Diagrams and Tables. 8vo, cloth, illustrated ....net, **$2.00**

ROBERTSON, L. S. Water-tube Boilers. Based on a short course of Lectures delivered at University College, London. With upward of 170 illustrations and diagrams. 8vo, cloth, illustrated **$3.00**

ROBINSON, J. B. A New System of Architectural Composition.. 8vo, cloth, illus. ... In Press.

——**S. W. Practical Treatise on the Teeth of** Wheels, with the theory and the use of Robinson's Odontograph. Third Edition, revised, with additions. 16mo, cloth, illustrated. (Van Nostrand's Science Series.) **$0.50**

ROEBLING, J. A. Long and Short Span Railway Bridges. Illustrated with large copperplate engravings of plans and views. Imperial folio, cloth **$25.00**

ROLLINS, W. Notes on X-Light. With 152 full-page plates. 8vo, cloth, illustrated, net, **$7.50**

ROSE, J., M.E. The Pattern-makers' Assistant. Embracing Lathe Work, Branch Work, Core Work, Sweep Work and Practical Gear Constructions, the Preparation and Use of Tools, together with a large collection of useful and valuable Tables. Ninth Edition. With 250 engravings. 8vo, cloth **$2.50**

——Key to Engines and Engine-running. A Practical Treatise upon the Management of Steam-engines and Boilers for the use of those who desire to pass an examination to take charge of an engine or boiler. With numerous illustrations, and Instructions upon Engineers' Calculations, Indicators, Diagrams, Engine Adjustments and other Valuable Information necessary for Engineers and Firemen. 12mo. cloth. Illus. **$2.50**

ROUILLION, LOUIS. Cams. The Drafting of. Pamphlet **$0.25**

——Manual Training. The Economics of. A Study of the Cost of Equipping and Maintaining Hand Work in the Elementary and Secondary Schools. 8vo, cloth **$2.00**

ROWAN, F. J. The Practical Physics of the Modern Steam-boiler. With an Introduction by Prof. R. H. Thurston. With numerous illustrations and diagrams. 8vo, cloth, illustrated **$7.50**

SABINE, R. History and Progress of the Elec-tric Telegraph. With descriptions of some of the apparatus. Second Edition, with additions. 12mo, cloth **$1.25**

SAELTZER, A. Treatise on Acoustics in Con-nection with Ventilation. 12mo, cloth, **$1.00**

SALOMONS, Sir D., M.A. Electric-light Installa-tions. A Practical Handbook. With numerous illustrations. Vol. I., The Management of Accumulators. Ninth Edition, revised and mostly rewritten. 12mo, cloth **$1.50**

Vol. II. Seventh Edition, revised and enlarged, Apparatus. 296 illus. 12mo, cloth **$2.25**

Vol. III. Seventh Edition, revised and enlarged. Applications. 12mo cloth **$1.50**

——Management of Accumulators. A Practical Handbook. Ninth Edition, revised. (An edition, mostly rewritten, of Volume I of Electric Light Installations and the Management of Accumulators.) With figures and plates. 12mo, cloth, illustrated ....net, **$2.50**

SANFORD, P. G. Nitro-explosives. A Practical Treatise concerning the Properties, Manufacture and Analysis of Nitrated Substances, including the Fulminates, Smokeless Powders and Celluloid. Second Edition, revised and enlarged. 8vo, cloth ....net, **$4.00**

SAUNDERS, C. H. Handbook of Practical Mechanics for use in the Shop and Draughting-room; containing Tables, Rules and Formulae, and Solutions of Practical Problems by Simple and Quick Methods. 16mo, limp cloth, **$1.00**

SAUNNIER, C. Watchmaker's Handbook. A Workshop Companion for those engaged in Watchmaking and allied Mechanical Arts. Translated by J. Tripplin and E. Rigg. Second Edition, revised, with appendix. 12mo, cloth **$3.50**

SCHELLEN, H., Dr. Magneto-electric and Dynamo-electric Machines: their Construction and Practical Application to Electric Lighting, and the Transmission of Power. Translated from the third German edition by N. S. Keith and Percy Neymann, Ph.D. With very large additions and notes relating to American Machines, by N. S. Keith. Vol. I, with 353 illustrations. Second Edition. 8vo, cloth, **$5.00**

SCHERER, R. Casein: its Preparation and Technical Utilization. Translated from the German by Chas. Salter. 8vo, cloth, illustrated ....net, **$3.00**

SCHMALL, C. N. First Course in Analytic Geometry, Plane and Solid, with Numerous Examples. Containing figures and diagrams. 12mo, half leather, illustrated ......net, **$1.75**

——and SHACK, S. M. Elements of Plane Geometry. An Elementary Treatise. With many examples and diagrams. 12mo, half leather, illustrated ....net, **$1.25**

SCHMEER, Louis. Flow of Water: A New Theory of the Motion of Water under Pressure, and in Open Conduits and its Practical Application. 8vo, cloth, illustrated ....In Press.

SCHUMANN, F. A Manual of Heating and Ventilation in its Practical Application, for the use of Engineers and Architects. Embracing a Series of Tables and Formulae for Dimensions of Heating, Flow and Return Pipes for Steam and Hot-water Boilers, Flues, etc. 12mo, illustrated, full roan **$1.50**

SCHWEIZER, V. Distillation of Resins, Resinate Lakes and Pigments; Carbon Pigments and Pigments for Typewriting Machines, Manifolders, etc. A description of the proper methods of distilling resin-oils, the manufacture of resinates, resin-varnishes, resin-pigments and enamel paints, the preparation of all kinds of carbon pigments, and printers' ink, lithographic inks and chalks, and also inks for typewriters, manifolders, and rubber stamps. With tables and 68 figures and diagrams. 8vo, cloth, illustrated ....net, **$3.50**

SCIENCE SERIES, The Van Nostrand. (Follows end of this list.)

SCRIBNER, J. M. Engineers' and Mechanics' Companion. Comprising United States Weights and Measures, Mensuration of Superfices and Solids, Tables of Squares and Cubes, Square and Cube Roots, Circumference and Areas of Circles, the Mechanical Powers, Centres of Gravity, Gravitation of Bodies, Pendulums, Specific Gravity of Bodies, Strength, Weight and Crush of Materials, Water-wheels, Hydrostatics, Hydraulics, Statics, Centres of Percussion and Gyration, Friction Heat, Tables of the Weight of Metals, Scantling, etc., Steam and Steam-engine. Twenty-first Edition, revised. 16mo, full morocco **$1.50**

SEATON, A. E. A Manual of Marine Engineering. Comprising the Designing, Construction and Working of Marine Machinery. With numerous tables and illustrations reduced from Working Drawings. Fifteenth Edition, revised throughout, with an additional chapter on Water-tube Boilers. 8vo, cloth **$6.00**

——and ROUNTHWAITE, H. M. A Pocket-book of Marine Engineering Rules and Tables. For the use of Marine Engineers and Naval Architects, Designers, Draughtsmen, Superintendents and all engaged in the design and construction of Marine Machinery, Naval and Mercantile. Seventh Edition, revised and enlarged. Pocket size. Leather, with diagrams. **$3.00**

SEIDELL, A. (Bureau of Chemistry, Wash., D. C.). Solubilities of Inorganic and Organic Substances. A handbook of the most reliable Quantitative Solubility Determinations. 12mo, cloth, 367 pp. ....net, **$3.00**

SEVER, G. F., Prof. Electric Engineering Experiments and Tests on Direct-current Machinery. With diagrams and figures. Second edition, revised and enlarged. 8vo pamphlet, illustrated, 75 pp. ....net, **$1.00**

——and TOWNSEND, F. Laboratory and Factory Tests in Electrical Engineering. Second Edition, revised and rewritten. 8vo, cloth, illustrated, 269 pp. ....net, **$2.50**

SEWALL, C. H. Wireless Telegraphy. With diagrams and engravings. Second Edition, corrected. 8vo, cloth, illustrated ...net, **$2.00**

——Lessons in Telegraphy. For use as a Text-book in schools and colleges, or for individual students. Illustrated. 12mo, cloth **$1.00**

SEWELL, T. Elements of Electrical Engineer-ing. A First Year's Course for Students. Second Edition, revised, with additional chapters on Alternating-current Working and Appendix of Questions and Answers. With many diagrams, tables and examples. 8vo, cloth, illustrated, 432 pages ....net, **$3.00**

——The Construction of Dynamos (Alternating and Direct Current). A text-book for students, engineer-constructors, and electricians-in-charge. 8vo, cloth., illus., 316 pp. ..net, **$3.00**

SEXTON, A. H. Fuel and Refractory Materials. 8vo, cloth **$2.00**

——Chemistry of the Materials of Engineering. A Handbook for Engineering Students. With tables, diagrams and illustrations. 12mo, cloth, illustrated **$2.50**

SEYMOUR, A. Practical Lithography. With figures and engravings. 8vo, cloth, illustrated. ....net, **$2.50**

SHAW, P. E. A First-year Course of Practical Magnetism and Electricity. Specially adapted to the wants of Technical Students. Interleaved for note-taking. 8vo, cloth, illustrated. ....net, **$1.00**

——S. The History of the Staffordshire Potter-ies, and the Rise and Progress of the Manufacture of Pottery and Porcelain; with references to genuine specimens, and notices of eminent potters. A re-issue of the original work published in 1829. 8vo, cloth, illustrated. ....net, **$3.00**

——Chemistry of the Several Natural and Arti-ficial Heterogeneous Compounds used in Manufacturing Porcelain, Glass and Pottery. Reissued in its original form, published in 1837. 8vo, cloth ....net, **$5.00**

SHELDON, S., Ph.D., and MASON, H., B.S. Dynamo-electric Machinery: its Construction, Design and Operation, Direct-current Machines. Sixth Edition, revised. 8vo, cloth, illustrated. ....net, $2.50

——**Alternating-current Machines: being the** second volume of the author's "Dynamo-electric Machinery: its Construction, Design and Operation." With many diagrams and figures. (Binding uniform with volume I.) Fifth Edition. 8vo, cloth, illustrated ....net, $2.50

SHIELDS, J. E. Notes on Engineering Construction. Embracing Discussions of the Principles involved, and Descriptions of the Material employed in Tunneling, Bridging, Canal and Road Building, etc. 12mo, cloth ...$1.50

SHOCK, W. H. Steam Boilers: their Design, Construction and Management. 4to, half morocco $15.00

SHREVE, S. H. A Treatise on the Strength of Bridges and Roofs. Comprising the determination of algebraic formulas for strains in Horizontal, Inclined or Rafter, Triangular, Bow-string, Lenticular and other Trusses, from fixed and moving loads, with practical applications and examples, for the use of Students and Engineers. 87 woodcut illustrations. Fourth Edition. 8vo, cloth $3.50

SHUNK, W. F. The Field Engineer. A Handy Book of practice in the Survey, Location and Track-work of Railroads, containing a large collection of Rules and Tables, original and selected, applicable to both the Standard and Narrow Gauge, and prepared with special reference to the wants of the young engineer. Eighteenth Edition, revised and enlarged. With addenda. 12mo, morocco, tucks ...$2.50

SIMMS, F. W. A Treatise on the Principles and Practice of Leveling. Showing its application to purposes of Railway Engineering, and the Construction of Roads, etc. Revised and corrected, with the addition of Mr. Laws' Practical Examples for setting out Railway Curves. Illustrated. 8vo, cloth $2.50

——**Practical Tunneling. Fourth Edition. Re**vised and greatly extended. With additional chapters illustrating recent practice by D. Kinnear Clark. With 36 plates and other illustrations. Imperial 8vo, cloth $8.00

SIMPSON, G. The Naval Constructor. A Vade Mecum of Ship Design, for Students, Naval Architects, Ship Builders and Owners, Marine Superintendents, Engineers and Draughtsmen. 12mo, morocco, illustrated. 500 pages, net, **$5.00**

SINCLAIR, ANGUS., Mem. Am. Soc. Mech. Eng'rs. Development of the Locomotive Engine. Being a history of the growth of the locomotive from the most elemental forms, with biographical sketches of the eminent engineers and inventors. Half leather **$5.00**

SINDALL, R. W. Paper Technology. 8vo, cloth, 158 illus., 253 pp. ....net, **$4.00**

SLATER, J. W. Sewage Treatment, Purification and Utilization. A Practical Manual for the Use of Corporations, Local Boards, Medical Officers of Health, Inspectors of Nuisances, Chemists, Manufacturers, Riparian Owners, Engineers and Rate-payers. 12mo, cloth, **$2.25**

SMITH, F. E. Handbook of General Instruction for Mechanics. Rules and formulae for practical men. 12mo, cloth, illus., 324 pp., net, **$1.50**

——I. W., C. E. The Theory of Deflections and of Latitudes and Departures. With special applications to Curvilinear Surveys, for Alignments of Railway Tracks. Illustrated. 16mo, morocco, tucks **$3.00**

——J. C. Manufacture of Paint. A Practical Handbook for Paint Manufacturers, Merchants and Painters. With 60 illustrations and one large diagram. 8vo, cloth ....net, **$3.00**

——W. Chemistry of Hat Manufacturing; Lectures delivered before the Hat Manufacturers' Association. Revised and edited by Albert Shonk. 12mo, cloth, illustrated ....net, **$3.00**

SNELL, A. T. Electric Motive Power; The Transmission and Distribution of Electric Power by Continuous and Alternate Currents. With a Section on the Applications of Electricity to Mining Work. Second Edition. 8vo, cloth, illustrated ....net, **$4.00**

SNOW, W. G and NOLAN, T. Ventilation of Buildings. 16mo, cloth (Van Nostrand's Science Series.) **$0.50**

SODDY, F. Radio Activity; An elementary treatise from the standpoint of the disintegration theory. With 40 figures and diagrams. 8vo, cloth, illustrated ....net, **$3.00**

SOTHERN, J. W. The Marine Steam Turbine. A practical description of the Parsons Steam Turbine as presently constructed, fitted, and run, including a description of the Denny and Johnson Patent Torsion Meter for measuring the transmitted shaft horsepower, with diagrams, photographs and detail drawings. Second Edition. 8vo, cloth, illus., 163 pp. ..**$2.50**

SOXHLET, D. H. Art of Dyeing and Staining Marble, Artificial Stone, Bone, Horn, Ivory and Wood, and of imitating all sorts of Wood. A practical Handbook for the use of Joiners, Turners, Manufacturers of Fancy Goods, Stick and Umbrella Makers, Comb Makers, etc. Translated from the German by Arthur Morris and Herbert Robson, B.Sc. 8vo, cloth, 170 pages ....net, **$2.50**

SPANG, H. W. A Practical Treatise on Lightning Protection. With figures and diagrams. 12mo, cloth **$1.00**

SPEYERS, C. L. Text-book of Physical Chemistry. 8vo, cloth **$2.25**

STAHL, A. W., and WOODS, A. T. Elementary Mechanism. A Text-book for Students of Mechanical Engineering. Fifteenth Edition. 12mo, cloth **$2.00**

STALEY, C., and PIERSON, G. S. The Separate System of Sewerage: its Theory and Construction. Third Edition, revised and enlarged. With chapter on Sewage Disposal. With maps, plates and illustrations. 8vo, cloth, **$3.00**

STANDAGE, H. C. Leatherworkers' Manual: being a Compendium of Practical Recipes and Working Formulae for Curriers, Boot-makers, Leather Dressers, Blacking Manufacturers, Saddlers, Fancy Leather Workers, and all persons engaged in the manipulation of leather. 8vo, cloth ....net, **$3.50**

——Sealing Waxes, Wafers, and Other Adhesives. For the Household, Office, Workshop and Factory. 8vo, cloth, 96 pages, net, **$2.00**

——Agglutinants of all Kinds for all Purposes. 12mo, cloth, 267 pp. **$3.50**

STEWART, A. Modern Polyphase Machinery. With diagrams and engravings. 12mo, cloth, illustrated ....net, **$2.00**

——R. W. Text-book of Heat. Illustrated. 8vo, cloth **$1.00**

——Text-book of Magnetism and Electricity. 160 Illustrations and numerous examples. 12mo, cloth $1.00

STILES, A. Tables for Field Engineers. Designed for Use in the Field. Tables containing all the Functions of a One Degree Curve, from which a corresponding one can be found for any required Degree. Also, Tables of Natural Sines and Tangents. 12mo, cloth $1.00

STILLMAN, P. Steam-engine Indicator and the Improved Manometer Steam and Vacuum Gauges; their Utility and Application. New Edition. 12mo, flexible cloth $1.00

STODOLA, Dr. A. Steam Turbines. With an appendix on Gas Turbines, and the future of Heat Engines. Authorized translation by Dr. Louis C. Loewenstein (Lehigh University). With 241 cuts and 3 lithographed tables. 8vo, cloth, illustrated ....net, $5.00

STONE, HERBERT, F.L.S., F.R.C.I. The Timbers of Commerce and their Identification. With 186 Photo-Micrographs. 8vo, cloth $3.50

——R., Gen'l. New Roads and Road Laws in the United States. 200 pages, with numerous illustrations. 12mo, cloth $1.00

STONEY, B. D. The Theory of Stresses in Girders and Similar Structures. With Observations on the Application of Theory to Practice, and Tables of Strength and other Properties of Materials. New revised edition, with numerous additions on Graphic Statics, Pillars, Steel, Wind Pressure, Oscillating Stresses, Working Loads, Riveting, Strength and Tests of Materials. 777 pages, 143 illus. and 5 folding-plates. 8vo, cloth $12.50

SUFFLING, E. R. Treatise on the Art of Glass Painting. Prefaced with a Review of Ancient Glass. With engravings and colored plates. 8vo, cloth ....net, $3.50

SWEET, S. H. Special Report on Coal, Showing its Distribution, Classification, and Costs delivered over Different Routes to Various Points in the State of New York and the Principal Cities on the Atlantic Coast. With maps. 8vo, cloth $3.00

SWOOPE, C. W. Practical Lessons in Electricity: Principles, Experiments, and Arithmetical Problems. An Elementary Text-book. With numerous tables, formulae, and two large instruction plates. 8vo, cloth, illustrated. Eighth Edition ....net, $2.00

TAILFER, L. Practical Treatise on the Bleaching of Linen and Cotton Yarn and Fabrics. With tables and diagrams. Translated from the French by John Geddes McIntosh. 8vo, cloth, illustrated ....net, **$5.00**

TEMPLETON, W. The Practical Mechanic's Workshop Companion. Comprising a great variety of the most useful rules and formulae in Mechanical Science, with numerous tables of practical data and calculated results facilitating mechanical operations. Revised and enlarged by W. S. Hutton. 12mo, morocco. **$2.00**

THOM, C., and JONES, W. H. Telegraphic Connections: embracing Recent Methods in Quadruplex Telegraphy. 20 full-page plates, some colored. Oblong, 8vo, cloth **$1.50**

THOMAS, C. W. Paper-makers' Handbook. A Practical Treatise. Illustrated .....In Press.

THOMPSON, A. B. Oil Fields of Russia and the Russian Petroleum Industry. A Practical Handbook on the Exploration, Exploitation, and Management of Russian Oil Properties, including Notes on the Origin of Petroleum in Russia, a Description of the Theory and Practice of Liquid Fuel, and a Translation of the Rules and Regulations concerning Russian Oil Properties. With numerous illustrations and photographic plates and a map of the Balakhany-Saboontchy-Romany Oil Field. 8vo, cloth, illustrated ....net, **$7.50**

——E. P., M.E. How to Make Inventions: or, Inventing as a Science and an Art. A Practical Guide for Inventors. Second Edition. 8vo, boards **$0.50**

——Roentgen Rays and Phenomena of the Anode and Cathode. Principles, Applications, and Theories. For Students, Teachers, Physicians, Photographers, Electricians and others. Assisted by Louis M. Pignolet, N. D. C. Hodges and Ludwig Gutmann, E.E. With a chapter on Generalizations, Arguments, Theories, Kindred Radiations and Phenomena. By Professor Wm. Anthony. 50 diagrams, 40 half-tones. 8vo, cloth **$1.00**

——W. P. Handbook of Patent Law of All Countries. Thirteenth Edition, completely revised, March, 1905. 16mo, cloth **$1.50**

THORNLEY, T. Cotton Combing Machines. With Numerous tables, engravings and diagrams. 8vo, cloth, illustrated, 343 pages. ....net, **$3.00**

THURSO, J. W. Modern Turbine Practice and Water-Power Plants. With eighty-eight figures and diagrams. 8vo, cloth, illustrated. Second Edition, revised ....net, **$4.00**

TINNEY, W. H. Gold-mining Machinery; its Selection, Arrangement, and Installation. A Practical Handbook for the use of Mine Managers and Engineers. With a chapter on the Preparation of Estimates of Cost. 8vo, cloth, illustrated, 308 pp. ....net, **$5.00**

TITHERLEY, PROF. A. W. Laboratory Course of Organic Chemistry, including Qualitative Organic Analysis. With figures. 8vo. Cloth. Illustrated ....net, **$2.00**

TOCH, M. Chemistry and Technology of Mixed Paints. With 60 Photo-micrographs and Engravings. 8vo, cloth., illus., 166 pp., net, **$3.00**

TODD, J., and WHALL, W. B. Practical Seamanship for Use in the Merchant Service: including all ordinary subjects; also Steam Seamanship, Wreck Lifting, Avoiding Collision, Wire Splicing, Displacement and everything necessary to be known by seamen of the present day. Fifth Edition, with 247 illustrations and diagrams. 8vo, cloth, net, **$7.50**

TOMPKINS, A. E. Text-book of Marine Engineering. Second Edition, entirely rewritten, rearranged, and enlarged. With over 250 figures, diagrams, and full-page plates. 8vo, cloth, illustrated ....net, **$6.00**

TOOTHED GEARING. A Practical Handbook for Offices and Workshops. By a Foreman Patternmaker. 184 illus. 12mo, cloth ...**$2.25**

TRATMAN, E. E. R. Railway Track and Trackwork. With over 200 illus. 8vo, cloth ...**$3.00**

TRAVERSE TABLE, Showing Latitude and Departure for each Quarter Degree of the Quadrant, and for Distances from 1 to 100, to which is appended a Table of Natural Sines and Tangents for each five minutes of the Quadrant. (Reprinted from Scribner's Pocket Table Book.) Van Nostrand's Science Series. 16mo, cloth **$0.50**
Morocco **$1.00**

TRINKS, W., and HOUSUM, C. Shaft Governors. 16mo, cloth, illustrated. (Van Nostrand's Science Series.) **$0.50**

TUCKER, J. H., Dr. A Manual of Sugar Analysis, including the Applications in General of Analytical Methods to the Sugar Industry. With an Introduction on the Chemistry of Cane-Sugar, Dextrose, Levulose, and Milk-Sugar. Sixth Edition. 8vo, cloth, illus. ..$3.50

TUMLIRZ, O., Dr. Potential and its Application to the Explanation of Electrical Phenomena, Popularly Treated. Translated from the German by D. Robertson. 12mo, cloth. ill. $1.25

TUNNER, P. A. Treatise on Roll-turning for the Manufacture of Iron. Translated and adapted by John B. Pearse, of the Pennsylvania Steel Works, with numerous engravings, wood-cuts. 8vo, cloth, with folio atlas of plates $10.00

TURBAYNE, A. A. Alphabets and Numerals. With 27 plates. 4to, boards $2.00

UNDERHILL, C. R. The Electro-Magnet. New and revised edition. 8vo, cloth, illustrated. ....net, $1.50

URQUHART, J. W. Electric Light Fitting. Embodying Practical Notes on Installation Management. A Handbook for Working Electrical Engineers. With numerous illustrations. 12mo, cloth $2.00

——Electro-plating. A Practical Handbook on the Deposition of Copper, Silver, Nickel, Gold, Brass, Aluminum, Platinum, etc. Fourth Edition. 12mo $2.00

——Electrotyping. A Practical Manual Forming a New and Systematic Guide to the Reproduction and Multiplication of Printing Surfaces, etc. 12mo $2.00

——Electric Ship Lighting. A Handbook on the Practical Fitting and Running of Ship's Electrical Plant. For the Use of Ship Owners and Builders, Marine Electricians and Sea-going Engineers-in-Charge. Illus. 12mo, cloth, $3.00

UNIVERSAL TELEGRAPH CIPHER CODE. Arranged for General Correspondence. 12mo, cloth $1.00

VAN NOSTRAND'S Chemical Annual, based on Biedermann's "Chemiker Kalender." Edited by Prof. J. C. Olsen, with the co-operation of Eminent Chemists. First year of issue 1907. 12mo, cloth, illustrated ....net, $2.50

——Engineering Magazine. Complete Sets, 1869 to 1886 inclusive. 35 vols., in cloth ...$60.00
35 vols., in half morocco $100.00

—— **Year Book of Mechanical Engineering Data.** With many tables and diagrams. (First year of issue 1907.) ....In Press.

VAN WAGENEN, T. F. Manual of Hydraulic Mining. For the Use of the Practical Miner. Revised and enlarged edition. 18mo, cloth. **$1.00**

VEGA, VON (Baron). Logarithmic Tables of Numbers and Trigonometrical Functions. Translated from the 40th, or Dr. Bremiker's thoroughly revised and enlarged edition, by W. L. F. Fischer, M.A., F.R.S. Eighty-first Edition. 8vo, half morocco **$2.50**

VILLON, A. M. Practical Treatise on the Leather Industry. With many tables and illustrations and a copious index. A translation of Villon's "Traite Pratique de la Fabrication des Cuirs et du Travail des Peaux," by Frank T. Addyman, B.Sc. 8vo, cloth, illustrated ....net, **$10.00**

VINCENT, C. Ammonia and its Compounds: their Manufacture and Uses. Translated from the French by M. J. Salter. 8vo, cloth, illustrated ....net, **$2.00**

VOLK, C. Haulage and Winding Appliances Used in Mines. With plates and engravings. Translated from the German. 8vo, cloth, illustrated ....net, **$4.00**

VON GEORGIEVICS, G. Chemical Technology of Textile Fibres: their Origin, Structure, Preparation, Washing, Bleaching, Dyeing, Printing, and Dressing. Translated from the German by Charles Salter. With many diagrams and figures. 8vo, cloth, illustrated. 306 pages ....net, **$4.50**

Contents:—The Textile Fibres; Washing, Bleaching, and Carbonizing; Mordants and Mordanting; Dyeing, Printing, Dressing and Finishing; Index.

—— **Chemistry of Dyestuffs. Translated from** the Second German edition by Chas. Salter. 8vo, cloth, 412 pages ....net, **$4.50**

WABNER, R. Ventilation in Mines. Translated from the German by Charles Salter. With plates and engravings. 8vo, cloth, illustrated, 240 pages ....net, **$4.50**

WADE, E. J. Secondary Batteries: their The-ory, Construction and Use. With innumerable diagrams and figures. 8vo, cloth, illustrated, 492 pages ....net, **$4.00**

WALKER, F., C.E. Aërial Navigation. A Prac- tical Handbook on the Construction of Dirigible Balloons, Aërostats, Aëroplanes and Aëromotors. With diagrams, tables and illustrations. 8vo, cloth, illustrated, 151 pages. ....net, $3.00

——Electricity in Homes and Workshops. A Practical Treatise on Electrical Apparatus. With 205 figures and diagrams. Fourth Edition, entirely rewritten and revised. 12mo, cloth, illustrated ....net, $2.00

——Electric Lighting for Marine Engineers, or How to Light a Ship by the Electric Light and How to Keep the Apparatus in Order. Second Edition. 103 illus., 8vo, cloth $2.00

——SYDNEY F., M.I.E.E., Assoc. M.I.C.E., &c., &c. A Pocket Book of Electric Lighting and Heating. Comprising Formulae, Tables, Rules, and Data for use in daily practice by electrical engineers engaged in central station work and otherwise. 12mo, cloth. Illus.

——SYDNEY F., M.I.E.E., M.I.Min.E., Assoc. M.I.C.E., &c. Electricity in Mining. 8vo, cloth. Illus. $3.50

——W. H. Screw Propulsion. Notes on Screw Propulsion; its Rise and History. 8vo, cloth. $0.75

WALLING, B. T., Lieut. Com. U.S.N., and MAR- tin, Julius. Electrical Installations of the United States Navy. With many diagrams and engravings. 8vo, cloth, illustrated ..In Press.

WALLIS-TAYLER, A. J. Bearings and Lubrica- tion. A Handbook for Every user of Machinery. Fully illustrated. 8vo, cloth $1.50

——Modern Cycles, a Practical Handbook on Their Construction and Repair. With 300 illustrations. 8vo, cloth $4.00

——Motor Cars, or Power Carriages for Common Roads. With numerous illustrations. 8vo, cloth $1.80

——Motor Vehicles for Business Purposes. 8vo, cloth, illustrated ....net, $3.50

——Pocket Book of Refrigeration and Ice Mak- ing. Fourth Edition, enlarged. With 31 diagrams and numerous tables. 12mo, cloth, illustrated $1.50

——**Refrigerating and Ice-making Machinery.** A Descriptive Treatise for the use of persons employing refrigerating and ice-making installations, and others. 8vo, cloth, illus., $3.00

——**Refrigeration and Cold Storage: being a** Complete practical treatise on the art and science of refrigeration. 600 páges, 361 diagrams and figures. 8vo, cloth ......net, $4.50

——**Sugar Machinery. A Descriptive Treatise,** devoted to the Machinery and Apparatus used in the Manufacture of Cane and Beet Sugars. 12mo, cloth, illustrated $2.00

WANKLYN, J. A. A Practical Treatise on the Examination of Milk and its Derivatives, Cream, Butter and Cheese. 12mo, cloth, $1.00

——**Water Analysis. A Practical Treatise on the** Examination of Potable Water. Tenth Edition. 12mo, cloth $2.00

WANSBROUGH, W. D. The A B C of the Dif-ferential Calculus. 12mo, cloth $1.50

WARD, J. H. Steam for the Million. A Popular Treatise on Steam, and its application to the Useful Arts, especially to Navigation. 8vo, cloth $1.00

WARING, G. E., Jr. Sewerage and Land Drain-age. Illustrated with woodcuts in the text, and full-page and folding plates. New Edition ....In Press.

——**Modern Methods of Sewage Disposal for** Towns, Public Institutions and Isolated Houses. Second Edition, revised and enlarged. 260 pages. Illustrated. Cloth, $2.00

——**How to Drain a House. Practical Infor-**mation for Householders. Third Edition, enlarged. 12mo, cloth $1.25

WARREN, F. D. Handbook on Reinforced Con-crete. 16mo, cloth, illustrated .....net, $2.50

WATSON, E. P. Small Engines and Boilers. A Manual of Concise and Specific Directions for the Construction of Small Steam-engines and Boilers of Modern Types from five Horsepower down to model sizes. Illustrated with Numerous Diagrams and Half-tone Cuts. 12mo, cloth $1.25

WATT, A. Electro-plating and Electro-refining of Metals: being a new edition of Alexander Watts' "Electro-Deposition." Revised and largely rewritten by Arnold Philip, B.Sc. With numerous figures and engravings. 8vo, cloth, illustrated, 680 pages ....net, $4.50

——Electro-metallurgy Practically Treated. Eleventh Edition, considerably enlarged. 12mo, cloth $1.00

——The Art of Soap-making. A Practical Handbook of the Manufacture of Hard and Soft Soaps, Toilet Soaps, etc. Including many New Processes, and a chapter on the Recovery of Glycerine from Waste Lyes. With illustrations. Fifth Edition, revised and enlarged. 8vo, cloth $3.00

——Leather Manufacture: being a Practical Handbook, in which the Operations of Tanning, Currying and Leather Dressing are Fully Described, and the Principles of Tanning Explained, and many Recent Processes Introduced. With numerous illustrations. Fifth Edition, thoroughly revised and enlarged ....net, $4.50

WEALE, J. A Dictionary of Terms Used in Architecture, Building, Engineering, Mining, Metallurgy, Archaeology, the Fine Arts, etc., with explanatory observations connected with applied Science and Art. Fifth Edition, revised and corrected. 12mo, cloth $2.50

WEBB, H. L. A Practical Guide to the Testing of Insulated Wires and Cables. Illustrated. 12mo, cloth $1.00

——The Telephone Handbook. 128 Illustrations. 146 pages. 16mo, cloth $1.00

WEEKES, R. W. The Design of Alternate Current Transformers. Illus. 12mo, cloth ...$1.00

WEISBACH, J. A Manual of Theoretical Mechanics. Ninth American edition. Translated from the fourth augmented and improved German edition, with an Introduction to the Calculus by Eckley B. Coxe, A.M., Mining Engineer. 1,100 pages and 902 woodcut illustrations. 8vo, cloth $6.00
Sheep $7.50

——and HERRMANN, G. Mechanics of Air Machinery. Authorized translation, with an appendix on American practice by A. Trowbridge. With figures, diagrams, and folding plates. 8vo, cloth, illustrated ......net, $3.75

WESTON, E. B. Tables Showing Loss of Head Due to Friction of Water in Pipes. Fourth Edition. 12mo, cloth $1.50

WEYMOUTH, F. M. Drum Armatures and Commutators. (Theory and Practice.) A complete Treatise on the Theory and Construction of Drum Winding, and of commutators for closed-coil armatures, together with a full résumé of some of the principal points involved in their design, and an exposition of armature reactions and sparking. 8vo, cloth. **$3.00**

WHEELER, J. B. Prof. Art of War. A Course of Instruction in the Elements of the Art and Science of War, for the Use of the Cadets of the United States Military Academy, West Point, N. Y. 12mo, cloth **$1.75**

——Field Fortifications. The Elements of Field Fortifications, for the Use of the Cadets of the United States Military Academy, West Point, N. Y. 12mo, cloth **$1.75**

WHIPPLE, S., C.E. An Elementary and Prac-tical Treatise on Bridge Building. 8vo, cloth. **$3.00**

WHITE, W. H., K.C.B. A Manual of Naval Ar-chitecture, for use of Officers of the Royal Navy, Officers of the Mercantile Marine, Yachtsmen, Shipowners and Shipbuilders. Containing many figures, diagrams and tables. Thick, 8vo, cloth, illustrated **$9.00**

WILKINSON, H. D. Submarine Cable-laying, Repairing, and Testing. 8vo, cloth. New Edition ....In Press.

WILLIAMSON, R. S. On the Use of the Baro-meter on Surveys and Reconnaissances. Part I. Meteorology in its Connection with Hypsometry. Part II. Barometic Hypsometry. With illustrative tables and engravings. 4to, cloth **$15.00**

——Practical Tables in Meteorology and Hyp-sometry, in connection with the use of the Barometer. 4to, cloth **$2.50**

WILSON, G. Inorganic Chemistry, with New Notation. Revised and enlarged by H. G. Madan. New Edition. 12mo, cloth **$2.00**

WILLSON, F. N. Theoretical and Practical Graphics. An Educational Course on the Theory and Practical Applications of Descriptive Geometry and Mechanical Drawing. Prepared for students in General Science, Engraving, or Architecture. Third Edition, revised. 4to, cloth, illustrated ....net, **$4.00**

——**Note-taking, Dimensioning and Lettering.** 4to, cloth, illustrated ....net, $1.25

——**Third Angle Method of Making Working** Drawings. 4to, cloth, illustrated, net, $1.25

——**Some Mathematical Curves, and Their** Graphical Construction. 4to, cloth, illustrated. ....net, $1.50

——**Practical Engineering, Drawing, and Third** Angle Projection. 4to, cloth, illustrated. ....net, $2.80

——**Shades, Shadows, and Linear Perspective.** 4to, Cloth, illustrated ....net, $1.00

——**Descriptive Geometry—Pure and Applied,** with a chapter on Higher Plane Curves, and the Helix. 4to, cloth, illustrated ....net, $3.00

WINKLER, C., and LUNGE, G. Handbook of Technical Gas-Analysis. With figures and diagrams. Second English edition. Translated from the third greatly enlarged German edition, with some additions by George Lunge, Ph.D. 8vo, cloth, illustrated, 190 pages, $4.00

WOODBURY, D. V. Treatise on the Various Elements of Stability in the Well-proportioned Arch. With numerous tables of the Ultimate and Actual Thrust. 8vo, half morocco. Illustrated $4.00

WORDEN, E. C., Prof. The Nitro-cellulose Industry. A practical treatise on Nitro-cellulose, Pyroxylin, Collodion, Celluloid, Colloids, Plastics, Lacquers, Synthetic Leather, Artificial Silk, etc., including the manufacture of Films, Viscose, Amyl Acetate, Amyl Alcohol, and the Solvents and Non-solvents of substituted Cellulose, together with a complete résumé of the United States, English, French and German Patents relating to the subject. 8vo, cloth. ....In Press.

WRIGHT, A. C. Analysis of Oils and Allied Substances. 8vo, cloth, illustrated, 241 pages. ....net, $3.50

——**Simple Method for Testing Painters' Ma**terials. 8vo, cloth, 160 pages .....net, $2.50

——**H. E. Handy Book for Brewers: Being a** practical guide to the art of brewing and malting. Embracing the conclusions of modern research which bear upon the practice of brewing. Third Edition, thoroughly revised and enlarged. With figures and folding tables

8vo, cloth, illustrated, 562 pp., New York, 1907 ....net, **$5.00**

——T. W., Prof. (Union College). .Elements of Mechanics, including Kinematics, Kinetics and Statics. With applications. Seventh Edition, revised. 8vo, cloth, illustrated **$2.50**

——and HAYFORD, J. F. Adjustment of Ob-servations by the Method of Least Squares, with applications to Geodetic Work. Second Edition, rewritten. .8vo, cloth, illustrated. ....net, **$3.00**

YOUNG, J. E. Electrical Testing for Telegraph Engineers. With Appendices consisting of Tables. 8vo, cloth, illus. **$4.00**

——The teaching of Mathematics in the Elemen-tary and the Secondary School. 12mo. Cloth. Illus. 351 pp. New York, 1907 ...... net, **$1.50**

YOUNG SEAMAN'S MANUAL. Compiled from Various Authorities, and Illustrated with Numerous Original and Select Designs, for the Use of the United States Training Ships and the Marine Schools. 8vo, half roan, **$3.00**

ZEUNER, A., Dr. Technical Thermodynamics. Translated from the Fifth, completely revised German edition of Dr. Zeuner's original treatise on Thermodynamics, by Prof. J. F. lein, Lehigh University. 8vo, cloth, two volumes, illustrated, 900 pp. ....net, **$8.00**

ZIMMER, G. F. Mechanical Handling of Mater-ial. Being a treatise on the handling of material, such as coal, ore, timber, etc., by automatic and semi-automatic machinery, together with the various accessories used in the manipulation of such plant, also dealing fully with the handling, storing, and warehousing of grain. With 542 figures, diagrams, full-page and folding plates. Royal 8vo, cloth, illustrated ....net, **$10.00**

ZIPSER, J. Textile Raw Materials, and Their Conversion into Yarns. The study of the Raw Materials and the Technology of the Spinning Process. A Text-book for Textile, Trade and higher Technical Schools, as also for self-instruction. Based upon the ordinary syllabus and curriculum of the Imperial and Royal Weaving Schools. Translated from the German by Chas. Salter. 8vo, cloth, illustrated ....net, **$5.00**

No. 45. THERMO-DYNAMICS. .**New edition, in** press.

No. 46. ICE-MAKING MACHINES. From the French of M. Le Doux. Revised by Prof. J. E. Denton, D. S. Jacobus, and A. Riesenberger. Sixth edition, revised.

No. 47. LINKAGES: THE DIFFERENT FORMS and Uses of Articulated Links. By J. D. C. De Roos.

No. 48. THEORY OF SOLID AND BRACED Elastic Arches. By William Cain, C.E.

No. 49. MOTION OF A SOLID IN A FLUID. By Thomas Craig, Ph.D.

No. 50. DWELLING-HOUSES: THEIR SANI-tary Construction and Arrangements. By Prof. W. H. Corfield.

No. 51. THE TELESCOPE: OPTICAL PRINCI-ples Involved in the Construction of Refracting and Reflecting Telescopes, with a new chapter on the Evolution of the Modern Telescope, and a Bibliography to date. With diagrams and folding plates. By Thomas Nolan. Second edition, revised and enlarged.

No. 52. IMAGINARY QUANTITIES: THEIR GE-ometrical Interpretation. Translated from the French of M. Argand by Prof. A. S. Hardy.

No. 53. INDUCTION COILS: HOW MADE AND How Used. Eleventh American edition.

No. 54. KINEMATICS OF MACHINERY. By Prof. Alex. B. W. Kennedy. With an introduction by Prof. R. H. Thurston.

No. 55. SEWER GASES: THEIR NATURE AND Origin. By A. de Varona. Second edition, revised and enlarged.

No. 56. THE ACTUAL LATERAL PRESSURE of Earthwork. By Benj. Baker, M. Inst., C.E.

No. 57. INCANDESCENT ELECTRIC LIGHTING. A Practical Description of the Edison System. By L. H. Latimer. To which is added the Design and Operation of Incandescent Stations, by C. J. Field; and the Maximum Efficiency of Incandescent Lamps, by John W. Howell.

No. 58. VENTILATION OF COAL MINES. By W. Fairley, M.E., and Geo. J. André.

No. 59. RAILROAD ECONOMICS; OR, NOTES With Comments. By S. W. Robinson, C.E.

No. 60. STRENGTH OF WROUGHT-IRON Bridge Members. By S. W. Robinson, C.E.

No. 61. POTABLE WATER, AND METHODS OF Detecting Impurities. By M. N. Baker. Second, ed., revised and enlarged.

No. 62. THEORY OF THE GAS-ENGINE. By Dougald Clerk. Third edition. With additional matter. Edited by F. E. Idell, M.E.

No. 63. HOUSE-DRAINAGE AND SANITARY Plumbing. By W. P. Gerhard. Twelfth edition.

No. 64. ELECTRO-MAGNETS. By A. N. Mans-field.

No. 65. POCKET LOGARITHMS TO FOUR Places of Decimals. Including Logarithms of Numbers, etc.

No. 66. DYNAMO-ELECTRIC MACHINERY. By S. P. Thompson. With an Introduction by F. L. Pope. Third edition, revised.

No. 67. HYDRAULIC TABLES FOR THE CAL-culation of the Discharge through Sewers, Pipes, and Conduits. Based on "Kutter's Formula." By P. J. Flynn.

No. 68. STEAM-HEATING. By Robert Briggs. Third edition, revised, with additions by A. R. Wolff.

No. 69. CHEMICAL PROBLEMS. By Prof. J. C. Foye. Fourth edition, revised and enlarged.

No. 70. EXPLOSIVE MATERIALS. By Lieut. John P. Wisser.

No. 71. DYNAMIC ELECTRICITY. By John Hopkinson, J. N. Shoolbred, and R. E. Day.

No. 72. TOPOGRAPHICAL SURVEYING. By George J. Specht, Prof. A. S. Hardy, John B. McMaster, and H. F. Walling. Third Edition. revised.

No. 73. SYMBOLIC ALGEBRA; OR, THE ALGE-bra of Algebraic Numbers. By Prof. William Cain.

No. 74. TESTING MACHINES: THEIR HIS-tory, Construction and Use. By Arthur V. Abbott.

No. 91. LEVELING: BAROMETRIC, TRIGONO-metric, and Spirit. By Prof. I. O. Baker. Second edition.

No. 92. PETROLEUM: ITS PRODUCTION AND Use. By Boverton Redwood, F.I.C., F.C.S.

No. 93. RECENT PRACTICE IN THE SANI-tary Drainage of Buildings. With Memoranda on the Cost of Plumbing Work. Second edition, revised and enlarged. By William Paul Gerhard, C.E.

No. 94. THE TREATMENT OF SEWAGE. By Dr. C. Meymott Tidy.

No. 95. PLATE-GIRDER CONSTRUCTION. By Isami Hiroi, C.E. Fourth edition, revised.

No. 96. ALTERNATE CURRENT MACHINERY. By Gisbet Kapp, Assoc. M. Inst., C.E.

No. 97. THE DISPOSAL OF HOUSEHOLD Wastes. Second edition. By W. Paul Gerhard, Sanitary Engineer.

No. 98. PRACTICAL DYNAMO-BUILDING FOR Amateurs. How to Wind for Any Output. By Frederick Walker. Fully illustrated. Third edition.

No. 99. TRIPLE-EXPANSION ENGINES AND Engine Trials. By Prof. Osborne Reynolds. Edited with notes, etc., by F. E. Idell, M.E.

No. 100. HOW TO BECOME AN ENGINEER; or, The Theoretical and Practical Training necessary in Fitting for the Duties of the Civil Engineer. By Prof. Geo. W. Plympton.

No. 101. THE SEXTANT, and Other Reflecting Mathematical Instruments. With Practical Hints for their Adjustment and Use. By F. R. Brainard, U. S. Navy.

No. 102. THE GALVANIC CIRCUIT INVESTI-gated Mathematically. By Dr. G. S. Ohm, Berlin, 1827. Translated by William Francis. With Preface and Notes by the Editor, Thomas D. Lockwood, M.I.E.E. Second edition.

No. 103. THE MICROSCOPICAL EXAMINATION of Potable Water. With Diagrams. By Geo. W. Rafter. Second edition.

No. 104. VAN NOSTRAND'S TABLE-BOOK FOR Civil and Mechanical Engineers. Compiled by Prof. Geo. W. Plympton.

No. 105. DETERMINANTS. An Introduction to the Study of, with Examples and Applications. By Prof. G. A. Miller.

No. 106. COMPRESSED AIR. Experiments upon the Transmission of Power by Compressed Air in Paris. (Popp's System.) By Prof. A. B. W. Kennedy. The Transmission and Distribution of Power from Central Stations by Compressed Air. By Prof. W. C. Unwin. Edited by F. E. Idell. Third edition.

No. 107. A GRAPHICAL METHOD FOR SWING Bridges. A Rational and Easy Graphical Analysis of the Stresses in Ordinary Swing Bridges. With an Introduction on the General Theory of Graphical Statics, with Folding Plates. Second edition. By Benjamin F. La Rue.

No. 108. SLIDE-VALVE DIAGRAMS. A French Method for Constructing Slide-valve Diagrams. By Lloyd Bankson, B.S., Assistant Naval Constructor, U. S. Navy. 8 Folding Plates.

No. 109. THE MEASUREMENT OF ELECTRIC Currents. Electrical Measuring Instruments. By James Swinburne. Meters for Electrical Energy. By C. H. Wordingham. Edited, with Preface, by T. Commerford Martin. With Folding Plate and Numerous Illustrations.

No. 110. TRANSITION CURVES. A Field-book for Engineers, Containing Rules and Tables for Laying out Transition Curves. By Walter G. Fox, C.E. Second edition.

No. 111. GAS-LIGHTING AND GAS-FITTING. Specifications and Rules for Gas-piping. Notes on the Advantages of Gas for Cooking and Heating, and Useful Hints to Gas Consumers. Third edition. By Wm. Paul Gerhard, C.E.

No. 112. A PRIMER ON THE CALCULUS. By E. Sherman Gould, M. Am. Soc. C. E. Third edition, revised and enlarged.

No. 113. PHYSICAL PROBLEMS and Their Solution. By A. Bourgougnon, formerly Assistant at Bellevue Hospital. Second ed.

No. 114. USE OF THE SLIDE RULE. By F. A. Halsey, of the "American Machinist." Fourth edition, revised and enlarged.

No. 115. TRAVERSE TABLE. Showing the ference of Latitude and Departure for tances Between 1 and 100 and for Angl Quarter Degrees Between 1 Degree ar Degrees. (Reprinted from Scribner's P Table Book.)

No. 116. WORM AND SPIRAL GEARING. printed from "American Machinist." B A. Halsey. Second revised and enla edition.

No. 117. PRACTICAL HYDROSTATICS, Hydrostatic Formulas. With Numerou lustrative Figures and Numerical Exam By E. Sherman Gould.

No. 118. TREATMENT OF SEPTIC SEWA with Diagrams and Figures. By Geo. Rafter.

No. 119. LAY-OUT OF CORLISS VALVE GEA With Folding Plates and Diagrams. Sanford A. Moss, M.S., Ph.D. Repri from "The American Machinist," with r sions and additions. Second edition.

No. 120. ART OF GENERATING GEAR TEE By Howard A. Coombs. With Figures, I grams and Folding Plates. Reprinted fr the "American Machinist."

No. 121. ELEMENTS OF GAS ENGINE I sign. Reprint of a Set of Notes accompai ing a Course of Lectures delivered at C nell University in 1902. By Sanford Moss. Illustrated.

No. 122. SHAFT GOVERNORS. By W. Tri and C. Housum. Illustrated.

No. 123. FURNACE DRAFT: ITS PRODUCTI by Mechanical Methods. A Handy Referen Book, with figures and tables. By Willi Wallace Christie. Illustrated. Second e tion, revised.