Engineering & Contracting

Devoted to the Economics of Civil Engineering Design and to Methods and Costs of Construction

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VOLUME XXXVI

July-December, 1911

THE MYRON C. CLARK PUBLISHING CO.

537 South Dearborn St., Chicago, Ill.

posed improvement with the ability of farmers to stand the cost.

A preliminary design made by the writer for a pumping plant operated by hydraulic and electric power, is shown by Fig. 2. In this design the aim was substantial construction, with small maintenance cost, together with convenience and accessibility. It provides for concrete headworks and flash-board supports on the main canal, the cross-section of which is reduced as it passes the branch canal, at the head of which the plant could be located. The water goes through the trash racks, through the forebay (above which is to be carried a road which parallels the main canal), and through the head-gates to the various pipes. There are two gates supplying the turbine penstock; one gate supplying bypass, feeding water to the branch canal if turbine is not discharging the necessary amount; and one gate supplying the pumps.

The turbine speed at the given head is so low as to require either very large pump impeller, or a multi-stage pump, to raise the water to the proper height. The motor-driven pump, however, can be a single-stage, because of the ample speed of the motor. Aside from other advantages, the centrifugal type of pump is particularly adapted to this service, because of the large amount of silt carried by the water in this canal.

In case of accident to the electric supply or apparatus, the turbine would be the sole motive power. The emergency belt connection shown makes it possible in such an event, to use either pump and shut off the other for repairs or other necessary attention. When not in use, the belt and shafting do not waste any power in friction as provision is made for disconnecting them at the couplings.

As a considerable portion of the excavation at the site is already made, the excavation cost for this plant would not be as great as might appear from the drawing.

Greater compactness of the plant might be attained, at the sacrifice of certain features which it was desired to embody in this design. It should also be borne in mind that this does not represent a final, perfected design, but is merely a preliminary plan.

STEAM AND ELECTRIC RAILWAY SECTION

The Steel Arch Bridge Over the St. Croix River; Minneapolis, St. Paul & Sault Ste. Marie Ry.

Contributed by Pierce P. Furber, Assistant Engineer to C. A. P. Turner, Consulting Bridge Engineer Minneapolis, St. Paul & Sault Ste. Marie Ry.

In June, 1911, the construction of a new bridge, Fig. 1, over the St. Croix River about six miles above Stillwater was completed for the Minneapolis, St. Paul & Sault Ste. Marie Ry. This bridge is the most important part of reconstruction work undertaken by the Soo Line upon securing control of the Wisconsin Central Railway in April, 1909. This line is now known as the Chicago Division. Several cutoffs were planned between Chicago and Minneapolis, the new bridge being included in what is known as the New Richmond cutoff. Grade and curvature reductions were the primary objects of the work, although the length of the line has been materially lessened by the revisions. The Wisconsin Central crossed the St. Croix upon a bridge built about 25 years ago, located five miles above Stillwater, Minn. This bridge was found upon investigation by the Soo Line engineers to be too light for the present traffic. The new line between Withrow Junction and New Richmond, Wis., was located about a mile up-stream from the old bridge, calling for a new bridge over the river. The new line has no curve greater than 1° 30′, while the old road had curves up to 6°. A total of 1,223 degrees of curvature was eliminated on this cutoff in the 17.73 miles. Grades were reduced from a maximum of 1.3 per cent to 0.5 per cent.

The new bridge is a single track structure, consisting of five three-hinged arch spans of 350 ft. each, with steel trestle approaches made up of 40 ft. towers and 80, 90 and 100-ft. girders, the total length of bridge aggregating 2,682 ft.

The St. Croix at this point flows through a valley with bluffs on each side averaging about 200 ft. in height. The main channel is about 300 ft. wide, though at times of extreme high water, the valley is submerged for its full width of about 1,800 ft. Borings indicated that the rock which outcropped on the face of the bluffs dipped under the bed of the river to a depth of about 130 ft. The rock surface is overlaid with gravel and sand, interspersed with fine silt. Economy dictated the use of piles for foundations which were a very important consideration in the determination of the type of bridge to be built.

The profile showed base of rail at an elevation of practically 185 ft. above ordinary water. Several types of bridge were considered for the crossing. Concrete arches, steel arches, steel trestle, and steel trusses were studied. Concrete was abandoned as uneconomical, and impractical for a single-track structure of so great a height. Finally designs were prepared for a steel trestle, consisting of girders and towers and also for the steel arch bridge as built. Bids were invited on these designs and alternate designs were also requested. Several bridge companies submitted designs for viaducts of the latticed girder type, supported on steel towers. Comparison of the tenders showed a considerable saving of metal for the plate girder design over the arch, while the latticed girder bridge was between these two. Foundations, however, figured cheapest for the arch bridge. It was finally decided to build the arch bridge as the estimates showed this design to be the most economical as a whole.

Foundations for the arch spans were built on piles, the length varying from 70 to 85 ft. They were driven with a steam hammer to a depth of 50 to 80 ft., driving being continued to refusal or until the penetration did not exceed ¼ in. On account of the height, the trusses were battered, making a spread of about 60 ft. at the shoes. Independent piers were built on this account, making a total of eight pile foundations. One hundred and ten piles were driven for each pier and the tops were allow to project into the concrete for about 5 ft. The piers were riprapped very thoroughly to protect them from possible scour. Piers were built about 8 ft. above high water, bringing them 15 ft. above ground, all but one of them being on dry land except during high water. The piers for the end arches and also for the trestle posts were founded on solid sand rock.

Concrete plants were constructed at each end of the bridge. A timber trestle built a few feet up-stream from the piers, and several feet higher than their tops carried a track upon which half-yard cars were operated to deliver material to the piers. At the west end concrete was ferried over the main channel on a cableway, and then deposited in the cars. A chute delivered concrete to a hopper at the east end, and the hopper dumped into the car.

It is in the superstructure that this bridge presents features which are out of the ordinary and on that account of particular interest. The use of the three-hinged arch in a railway bridge is unusual in the first place. A bridge of this type requires a location that will allow sufficient rise for the arch, and also provide solid foundations to take the thrust. Comparison of two-hinged and three-hinged arches shows some points of advantage in favor of each type. The former is admittedly stiffer, but is statically indeterminate and is also subject to temperature stresses. Absolutely secure foundations are an essential with this type of structure. On the other hand, the three-hinged arch is simple of calculation, and free from temperature stresses, while it has been generally considered so lacking in rigidity that it has been used but little for railway bridges. This last idea has been a result of the ordinary design of arches. Most of the bridges of this type have been so shallow at the crown that rigidity under load has been almost impossible. Sufficient depth will give the arch greater stiffness than can be secured by the use of simply supported spans.

These various questions were well considered in the design of the St. Croix River Bridge. The arches are of the three-hinged type, with the attendant advantages of certainty of stress distribution and elimination of temperature stresses. The depth of truss at the crown was made 25 ft. for a span of 350 ft. and rise of 124 ft., considerably more than is usual, thus giving the required stiffness. In addition to this an ingenious device was designed to impart the advantages of the two-hinged arch to the structure when under

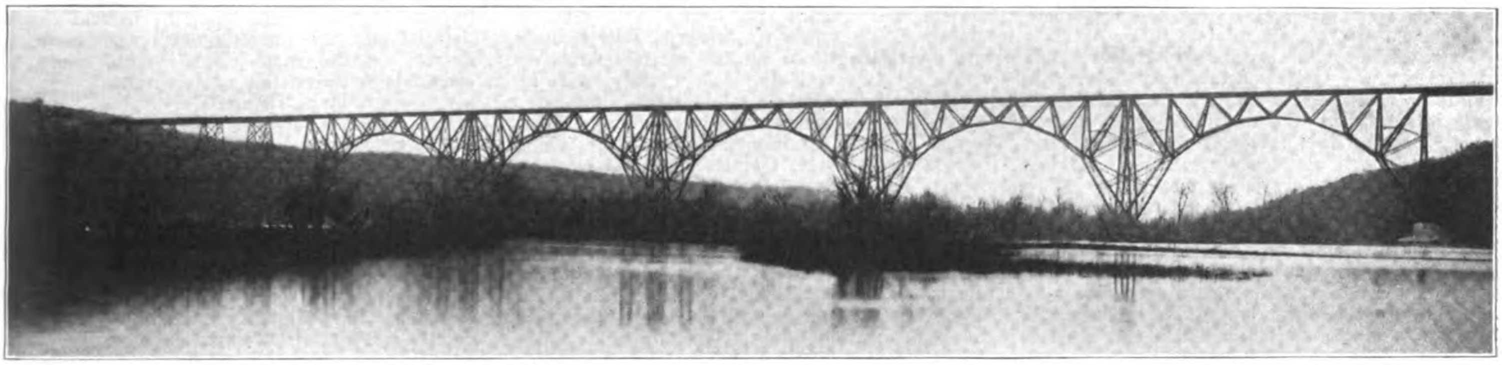

Fig. 1—General View of St. Croix River Bridge, Minneapolis, St. Paul & Sault Ste. Marie Railway.

live load. As will be seen by the drawing of Fig. 3, the middle panel of the top chord is provided at each end with sliding bearings on the adjacent chords. The latter extend a short distance beyond the panel points to receive the middle girder, which is not a part of the truss proper, being suspended between the bearings, and over the crown hinge. The bearings consist of five plates, three of steel and two of phosphor bronze which serve as a friction joint. Under dead load only, this middle panel is free to move with changes of temperature, and the arch is truly three-hinged. When the live load comes upon the span, the plates are locked together, making the frame act as a two-hinged arch. The computations for live load showed very little difference in stress intensities whether the arch be considered as two or three-hinged. While the expansion joint removed the necessity to consider temperature stresses.

As noted above, the trusses were battered, Fig. 2, the plane of trusses being inclined 2 to 12 with the vertical. Effect of wind in stressing the truss members was thereby greatly reduced. Of course, the detailing stressing was rendered a little more difficult as a result of the inclination. The top chords were designed to stand in a vertical plane, connection plates being bent below the bottom flanges to receive the inclined web members. The bottom lateral plates at panel joints were cut on the line of intersection of top flanges of adjacent bottom chords, to allow simple bends to be made.

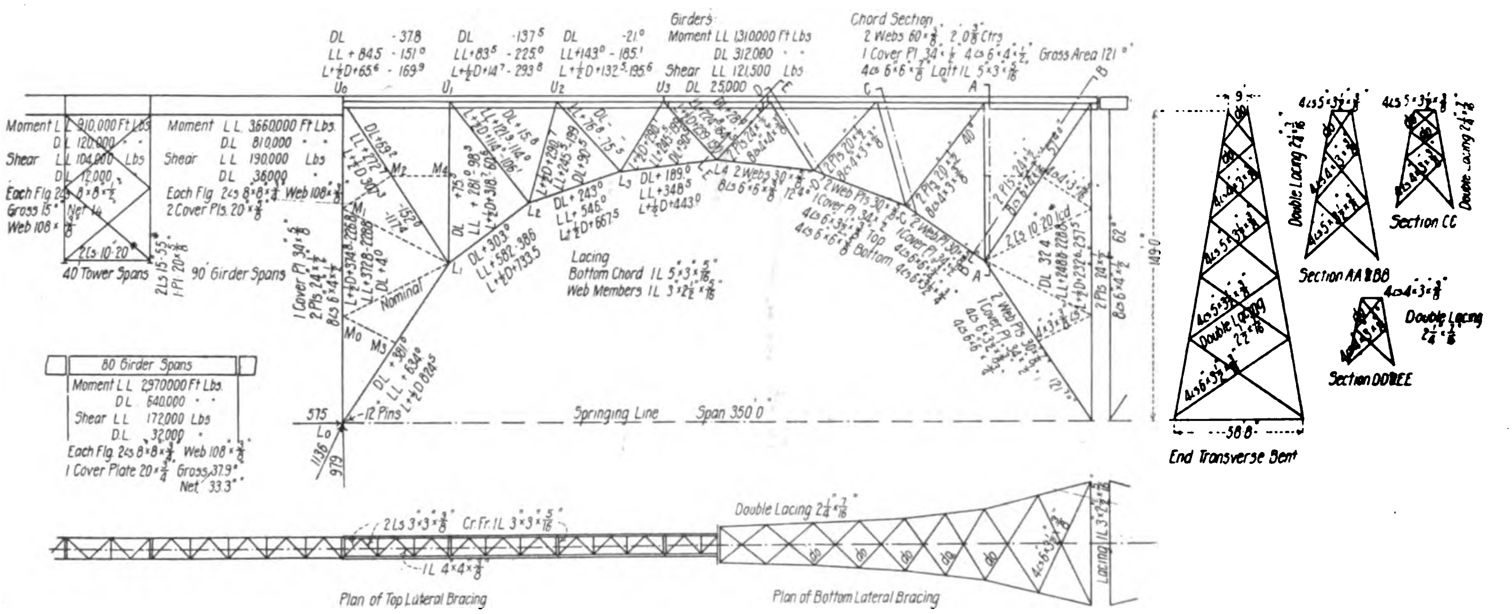

Fig. 2—Stress Sheet for Arch Span, St. Croix River Bridge.

The track is carried on the top chord, doing away with stringers and floor beams. Top chords were made of heavy box girders, spaced 9 ft. center to center. The span is one panel length of 50 ft., each girder consisting of two web plates 5 ft. deep, a 34 in. cover plate and four angles on each flange.

The shoes of the arches were given a horizontal bearing on cast steel bolsters, which were bolted to steel frames concreted into the piers. The back of the shoe thrusts against a series of vertical channels projecting above the pier. These channels were riveted to horizontal channels set directly on top of the piers, and anchored to the mass concrete by means of angles riveted to connection plates which were in turn riveted to the webs of the horizontal channels. The angles were inclined at 45° and projected down into the pier. They were tied together with horizontal rods. The anchorage after being riveted up, was hoisted to place within the forms, and the piers were concreted to the level of the underside of horizontal channels. Holes were left in the cast bolster, through which grout was poured, filling the spaces between the channels. The shoe could then be put into place on the bolster.

As it was necessary to provide for adjustment of the span, an opening of 9 ins. was left between the back of the shoe and the channel thrust block. A screw wedge, Fig. 4, designed to move the shoe horizontally was inserted into this opening before commencing erection of the span. This wedge could be operated to move the center of span up or down as might be required.

The necessity for clearance at the skewbacks was apparent in erecting the end arches. These spans were erected from the shore end, falsework being used for the entire span. Due to a settlement of the falsework, the end bottom chords were thrown several inches beyond the proper point to make connections with shoes on the river piers. The wedges could not be entered until the span was raised. By taking advantage of temperature changes this was effected very readily. This part of the work was done in March, at which time of the year the temperature has a considerable range. The shoe could be forced away from the block slightly in the morning by wedging. Increase of temperature during the day lifted the span off the falsework. Shims could then be driven between falsework and bottom chords. This

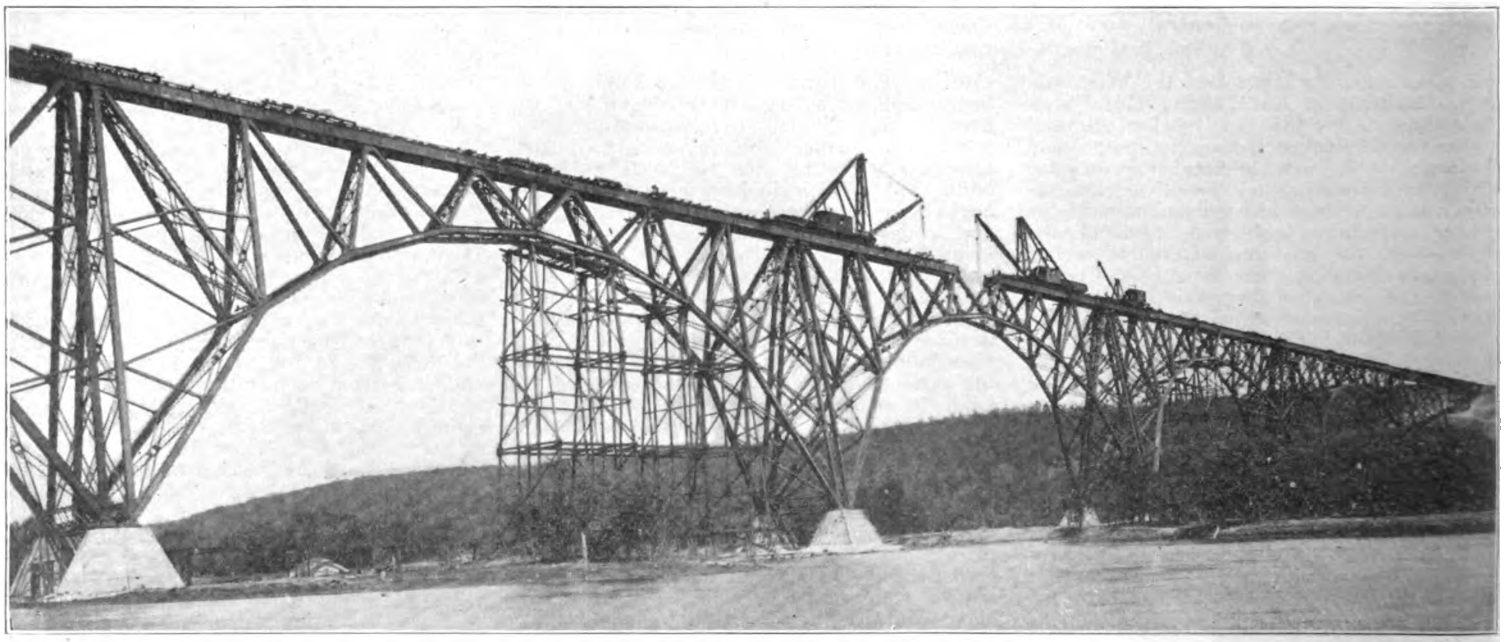

Fig. 5—View Showing Derricks Erecting, St. Croix River Bridge.

prevented the arch from returning to the original position, and the clearance at the shoe was consequently increased with a fall of the thermometer. This clearance was maintained by driving shims behind the shoe. By thus taking advantage of temperature changes, the wedge was finally entered and the arch adjusted.

motion to the bolt was set up around the bolt before concreting. This was merely a precaution against possible discrepancy between column base and foundation.

The work was completed in about one year's time. Foundation work was begun in the summer of 1910. Erection of metal was commenced in October, 1910. The bridge was finished in June, 1911, and the first train went over on June 3.

Mr. Thomas Greene, chief engineer of the Minneapolis, St. Paul & Sault Ste Marie Ry., directed the work, Mr. C. N. Kalk, assistant engineer, having immediate supervision. Mr. C. A. P. Turner, consulting bridge engineer to the railway company designed the structure. The American Bridge Co. fabricated the metal, which weighed a little over 5,000 tons. The superstructure was erected by the Kelly Atkinson Construction Co. of Chicago. Foundation work, with the exception of piling, was done by the railway company, Mr. R. G. Hase, masonry superintendent, being in charge. About 10,000 cu. yds. of concrete were required in the piers. The contract for pile driving, which amounted to 60,670 lin. ft., was executed by George W. Oakes & Co. of St. Paul. Robert W. Hunt & Co. looked after the inspection of metal for the railway company.

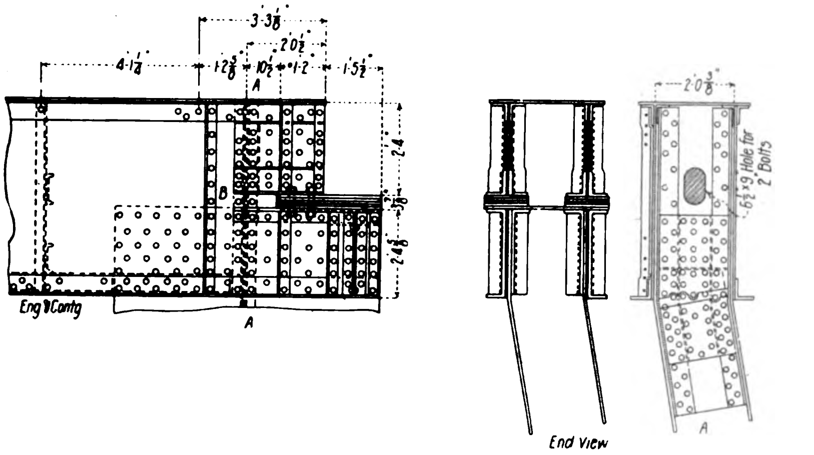

Fig. 3—Sliding Connection for Ends of Center Panel Top Chords of Arches.

The bridge was erected with ordinary derrick cars, Fig. 5, with timber booms 70 ft. long, and of fifty tons' capacity. Erection from both ends toward the middle required two complete plants to carry on the work. Two cars were used at each end, one to unload and store the material, the second to erect it as it was received from the first car.

Falsework was used to support the entire first arch at each end. The next spans were erected as cantilevers from the shore end toward the middle and the other half erected on falsework. The falsework was lowered from the derrick car and erected one panel in advance of the steel. The middle span was erected as a cantilever from both ends.

In cantilevering, the end post was tied to the adjacent end post of the completed arch with large bolts, the heads bearing on timber blocks, until one panel of the truss was erected, when "hitch" angles could be bolted to top chords and securely anchor the cantilever.

After the difficulty experienced in getting the end spans adjusted no trouble was encountered in the erection, the cantilever portion of the work being a much more rapid operation than erection on falsework.

The design and construction of the trestle approaches contained no unusual features, except that a single anchor bolt was used to anchor the columns. This bolt was 2½ ins. in diameter, and buried 9 ft. in the concrete pedestal. Two 8x8-in. angles at the bottom were used in lieu of an anchor plate, or washer. A conical tube of sheet iron, 8 ins. in diameter at its top to allow freedom of motion to the bolt was set up around the bolt before concreting.

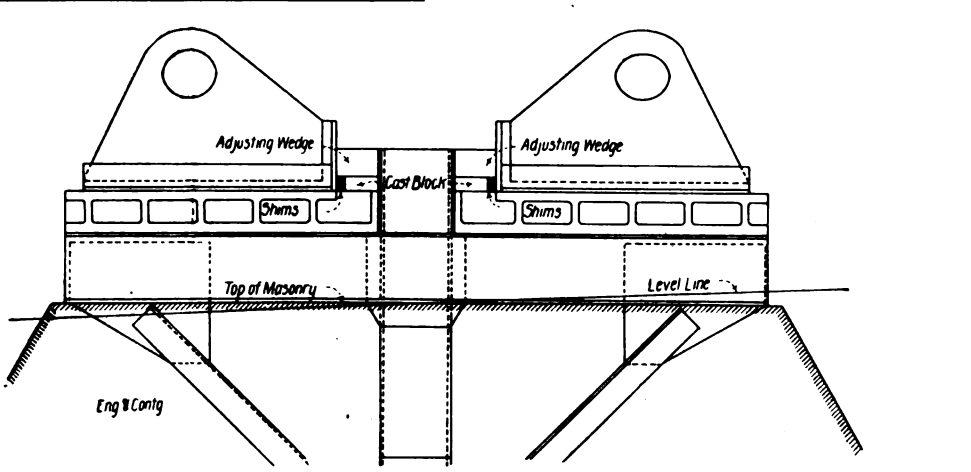

Fig. 4—Sketch of Anchorage Between Arches, Showing Methods of Adjustment.

TABLE I.—MONTHLY AND YEARLY AVERAGE PRICE OF LAKE COPPER BARS, 1883-1910.
In cents per pound.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly avge.
1883	....	....	....	....	....	....	15¼	15½	15¼	15¼	15	15	.....
1884	15	15	15	15	14½	14½	14⅛	14	13¾	13⅛	13	11⅞	14.03
1885	11¼	11¼	11	11	11½	11⅜	11⅛	11⅛	11⅛	11	11	11¼	11.17
1886	11½	11½	11½	11½	10⅞	10¼	10⅛	10⅜	10¾	11⅜	12	12	11.15
1887	11⅝	11	10¾	10½	10	10	10⅝	10¾	10½	10½	12⅝	17	11.32
1888	16½	16⅜	16	16⅝	16⅝	16½	16¾	16¾	17¼	17¼	17½	17¼	16.78
1889	17⅛	16¾	16½	16½	12½	12¼	12	12	11½	11	12½	14¼	13.74
1890	14½	14¼	14¼	14½	15	16¼	17	17	17	17	17	16	15.81
1891	15	15	14	14	13½	13	13	12⅜	12½	12¼	11½	11	13.09
1892	11	10¾	11¼	11⅞	12	12	11¾	11⅝	11¼	11¾	12	12¼	11.63
1893	12⅛	12	11⅞	11½	11	10⅞	10⅜	9¾	9¾	9¾	10	10⅜	10.78
1894	10	9¾	9¾	9½	9⅜	9¼	9⅛	9⅛	9½	9¾	9½	9⅞	9.54
1895	10	9⅞	9⅝	9⅝	10½	10¾	11⅛	12	12	12	11½	10¾	10.81
1896	10	10¾	11	10⅞	11⅛	11⅝	11¼	11	10¾	10¾	11¼	13⅜	10.98
1897	11⅞	12	11¾	11½	11	11¼	11⅛	11¼	11¼	11⅛	10⅞	11	11.33
1898	11⅛	11⅜	12	12	12	11⅞	11⅝	12	12⅜	12½	12⅞	13	12.06
1899	15	18	18	18¾	18½	18¼	18½	18½	18½	18	17¼	16¾	17.80
1900	16½	16¼	16⅝	17	16¾	16¼	16⅝	16⅝	16¾	16¾	16⅞	17	16.66
1901	16⅞	17	17	17	17	17	16¾	16¾	16¾	16¾	16¾	14⅞	16.73
1902	11⅝	12¾	12⅜	12¼	12⅜	12½	12	12	12	11⅞	11¾	11¾	12.14
1903	12½	13⅛	14⅜	15¼	15	14¾	13⅝	13⅝	13⅝	13⅜	13¼	12½	13.79
1904	12¾	12½	12¾	13⅜	13¼	12¾	12¾	12¾	12¾	13⅜	14⅞	15⅛	13.25
1905	15½	15½	15½	15¾	15¼	15⅛	16	16	16¾	16¾	17¼	19	16.09
1906	19⅜	18⅝	18⅝	18¾	18⅞	18⅞	18¾	18¾	19⅜	22¼	22¾	23⅜	19.87
1907	25½	25¾	26	25⅜	25¼	24⅞	20⅞	20⅞	16¾	14⅛	14⅛	13⅝	21.30
1908	13⅞	13⅛	13	13	13⅞	13⅞	13¾	13¾	13¾	13⅝	13⅜	14½	13.50
1909	14⅜	13¼	12⅞	13	13¼	13½	13½	13½	13¼	13⅛	13⅝	13¾	13.42
1910	13⅞	13⅞	13¾	13¼	13	12¾	12¾	12¾	12¾	12⅞	13	13	13.14

Monthly Average Price of Copper Bars from 1883 to 1910 and Copper Wire from 1900 to 1911.

(Staff Article.)

Both in appraising plant values and in estimating probable future costs it is desirable to have at hand the prices of materials for a long term of years. This is particularly true of copper, which has been subject to violent price fluctuations.

Table I is based upon price records kept by the American Steel and Wire Co., and shows the price per pound of bar copper (Lake) at the Atlantic seaboard. It will be noted that the average prices of copper bars were as follows:

	Cts. per lb.
Average of 27 years (1884-1910)	13.78
Average of 20 years (1891-1910)	13.90
Average of 10 years (1901-1910)	15.32
Average of 5 years (1906-1910)	16.25

These are not weighted averages. In other words, the pound price has not been multiplied by the number of pounds sold—and the

TABLE II.—BASE PRICE OF COPPER WIRE, 1900-1911, IN CENTS PER POUND.

Date.	Cts. per lb.
1900.	
Aug. 29	17¾
1901.	
Jan. 31	17⅞
Feb. 16	18⅝
Sept. 24	17¾
Dec. 2	17½
Dec. 16	16½
Dec. 19	14¼
1902.	
Jan. 3	13¼
Jan. 11	12¼
Jan. 21	12⅜
Jan. 31	14¼
Feb. 3	14¾
Feb. 5	14¼
Feb. 19	14½
May 21	13½
May 29	13⅝
June 5	13⅞
June 19	13¾
June 23	13½
July 7	13⅜
July 22	13¼
Aug. 7	13
Aug. 26	12¾
Sept. 6	13⅛
Sept. 25	12¾
Oct. 30	12⅞
Nov. 15	12¾
Dec. 3	13⅝
Dec. 6	12¾
1903.	
Jan. 2	13⅜
Jan. 24	13⅝
Feb. 2	13¾
Feb. 9	13⅞
Feb. 11	14
Feb. 26	14½
Mar. 2	15
Mar. 9	15⅜
Mar. 12	15⅝
Mar. 19	15¾
Mar. 24	16
June 1	15½
June 29	14¾
July 20	14⅜
Aug. 17	14½
Oct. 2	14⅜
Oct. 9	14
Oct. 19	13⅞
Nov. 3	14¾
Nov. 7	14⅝
Nov. 16	14¼
Nov. 17	14
Nov. 24	13½
Dec. 4	13
Dec. 9	13½
Dec. 23	13¼
Dec. 31	13½
1904.	
Jan. 4	13¾
Jan. 7	13⅞
Jan. 11	14
Jan. 28	13¾
Feb. 2	13½
Feb. 5	13¼
Feb. 11	13⅜
Feb. 17	13½
Mar. 18	13⅝
Mar. 21	13⅞
Mar. 30	13¾
Apr. 8	14⅛
Apr. 11	13¾
Apr. 21	13¾
Aug. 2	13½
Aug. 16	13⅝