THE NEW SPANS OF THE PORTAGE VIADUCT, ERIE R. R.

The Portage viaduct, which for many years was famous as one of the highest railroad bridges in the world, is a single-track structure officially known as Bridge No. 16 of the Buffalo Division of the Erie Railroad. It consists of a series of spans connecting towers seated on low-masonry piers built on solid rock in a deep gorge with precipitous sides. It has a total length of 819 ft. between back walls and a height of 235 ft. 2 in. from the bed of the stream to the base of rail. The original structure was a timber trestle built in 1852, and replaced in 1875 by a light wrought-iron structure with pin-connected members, designed by the late G. S. Morison, then bridge engineer for the Erie Railroad. It contained about 639 tons of iron manufactured and erected by the Watson Bridge Co.

As the traffic of the road increased in weight and volume and the iron spans became inadequate, plans were made for replacing them with heavy riveted trusses and plate-girder spans for increasing traffic at a higher speed. They are proportioned for a train load of 4,000 lb. per lin. ft., preceded by two coupled 123½-ton locomotives with 53-ft. wheel bases and 35,000 lb. on each of four pairs of drivers on 4½ ft. centers. This train loading is nominally rather light in comparison with that adopted by some other important roads, but it is compensated for by the low unit stresses allowed, which result in the use of sectional areas that are much smaller than are found in any corresponding structure. The train load is considered to be, in reality, a matter of little consequence, since the longest span on the Erie system is only 223 ft., and is therefore nearly covered by the locomotives. There are bridges and viaducts of total lengths up to more than 2,000 ft., but they are all made up of spans shorter than that above mentioned, so that their severest stresses are caused by the locomotives. Longitudinal stresses are assumed at 2 per cent. of the maximum live load, and the wind pressure is assumed at 600 lb. per linear foot.

The old towers and foundations were carefully inspected and found to be in good condition, and as the former structure had been intended ultimately to carry two tracks, the substitution was considered adequate for the increased dead and live loads of a single track. All of the towers and masonry except one abutment were, therefore, retained, and the reconstruction consisted in the replacement of the old track, floor system, girders and trusses by new spans supported on the old towers. The old girders and trusses were seated directly on the caps of the tower columns and were spaced 19 ft. 10 in. apart on centers. The track was carried on 8x16-in. cross-ties 22 ft. long and 14 in. apart on centers which rested directly on the top flanges of the old girders and the top chords of the old trusses. The new structure was designed entirely to facilitate its substitution for the old spans without interrupting the regular train service, and the width of the old span enabled the new one to be erected complete between them and be supported on new transverse girders without adding to the stresses in the old spans or throwing the latter out of service until the new were ready to receive the traffic.

The new trusses and girders are spaced 14 ft. apart on centers, thus clearing the tower columns, and are seated on the top flanges of heavy new transverse girders. The upper chords are connected to the end lower-chord sections, which are riveted members two panels long. At one end of each 100-ft. span, the connections to the lower chord are made with bolts in 2x1-in. slotted holes. This is considered necessary in order to

The depth of the connection is calculated to afford sufficient stiffness to provide all necessary sway-bracing and compensate for the omission of diagonals in the upper panel of the tower. Each end of the girder is connected to the tower column by seventy-four ¾-in. field rivets at each end, exclusive of those in the brackets. The 50-ft. connecting girder spans are seated on solid-web transverse plate-girders 6 ft. deep, with similar double-web knee-plate brackets at both ends. These girders have forty-four ¾-in. field rivets at each end in the connections to the columns, and, like the other girders, have vertical web stiffeners under the loaded points only. The arrangement of field rivets is such that all of them could be easily driven.

The 100 and the 118-ft. spans have pin-connected Pratt deck trusses, respectively 14 and 15 ft. deep on centers. The details are substantially alike, and each is designed to carry the track ties directly on the top chord. Both top and bottom chords are connected at panel points by horizontal transverse struts with I-shaped cross-sections built of pairs of angles back-to-back. The horizontal struts are connected by pairs of X-brace angles riveted to the inner faces of the vertical posts. The upper struts have jaw-plates engaging the flanges of the chords. The upper jaw-plates in the top struts receive the pin connections for the clevis-ended, top-lateral diagonal rods. The lower-lateral struts clear the inner ends of the bottom-chord pins, and the latter are fitted with wing plates in vertical planes which receive the pin connections for the clevis-ended bottom-lateral panels. At each panel the top and bottom struts are connected by pairs of X-brace angles riveted between. The upper outrigger is seated on bracket plates below the upper transverse struts. The top chords are each made in three lengths connected by two field-riveted splices with double-web plate field-riveted to both members and single-cover-plate shop-riveted to one member.

The details of the vertical end posts are special in order to provide for the requirements of erection, which made it necessary to assemble and erect the span elements before their connection with the trusses. The upper member of these sway-bracing and compensate for the omission of diagonals in the upper panel of the tower. Each end of the girder is connected to the tower column by seventy-four ¾-in. field rivets at each end, exclusive of those in the brackets. The 50-ft. connecting girder spans are seated on solid-web transverse plate-girders 6 ft. deep, with similar double-web knee-plate brackets at both ends. These girders have forty-four ¾-in. field rivets at each end in the connections to the columns, and, like the other girders, have vertical web stiffeners under the loaded points only. The arrangement of field rivets is such that all of them could be easily driven.

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allow for temperature movements, because the vertical posts are rigidly attached to the fixed columns and no other adjustment is provided for the trusses.

The longitudinal girders, nominally 50 ft. long, vary in actual length back-to-back of angles from 48 ft. 4½ in. to 60 ft. 2½ in. They have a uniform depth of 6 ft. 9½ in. back to back of angles, and the webs are made in four sections with three field-riveted splices, each having 36 rivets in two vertical rows. The girders are braced at each splice by a vertical transverse frame with two panels of X-brace angles. The panels between these frames are X-braced with the top-lateral system of diagonal rods with screw ends, which pass through 4½-in. slotted holes in the web of the girder just below the top flange. Their nuts take bearing on bent plates riveted to the outsides of the girder webs.

Each girder is divided into panels of about 6 ft. by pairs of vertical web-stiffener angles and fillers. At the ends these angles in adjacent girders are field-riveted together through their outstanding flanges, so as to splice them rigidly and make them form continuous girders except at expansion points, where they are bolted into the viaduct developing abundant stiffness and rigidity under heavy train traffic.

The weight of new steel in the viaduct is about 500 tons. It was designed by Mr. Mason R. Strong, engineer of bridges, under the direction of Mr. C. W. Buchholz, then chief engineer and now consulting engineer of the Erie Railroad Co. The girders and trusses were built at the McClintock-Marshall bridge shops, and were erected by the railroad company's regular erection force in charge of Mr. W. H. Wilkinson, inspector of bridges.

A VERTICAL BLOWING ENGINE, Installed at the North-Eastern Steel Co., at Middlesbrough, England, and having compound steam cylinders 48 and 90 in. in diameter, and two 90-in. air cylinders, showed, according to indicator cards, an efficiency of compression of 92.5 per cent. and a mechanical efficiency of 84.1 per cent., making total efficiency, that is, the ratio of the ideal work required to compress the air isothermally to the actual work in the steam cylinders, 77.7 per cent. The engine, which was described in "Engineering," was built by Messrs. Davy Bros., Ltd., Sheffield.

Time Required for the Construction of Large Public Works.

In connection with the studies for the isthmian Canal and the various schemes proposed within the past year or two for the additional water supply of the city of New York, statements have from time to time been made in the technical and daily press as to the time required for the construction of the works. This time element is frequently a most important consideration, particularly in the case of additional water-works needed to supplement a system already outgrown, or nearly so. Estimates of the time which must elapse before a proposed scheme can be carried out, it is often the fact that a sufficient allowance is not made for the inevitable preliminaries of legislation and supervision, or due to possible strikes or litigations, or to the inefficiency or financial inability of contractors selected by the ancient and honored custom of awarding the work to the lowest bidder. Imponderables of this kind have been so fully described in this journal that very little explanation of them is necessary. It is merely proposed to point out in a general, approximate way the time consumed in preliminaries and in some of the unexpected and intentional delays, and the total calendar time that passed between the inception and the completion of the works, without going into the details of individual cases. It seems scarcely necessary to suggest caution against the unintentional and indiscriminate applications of, or deductions from, the facts here presented. Reasons for delays or for rapid progress can be found stated or suggested in the records of the works, to some extent.

In its session of 1892-93, the Massachusetts legislature directed the State Board of Health to investigate and report upon a scheme for public works to supply the Boston metropolitan district with water to supplement, and in some towns supplement, the then existing sources of supply. On June 5, 1895, "an Act to provide for a Metropolitan water supply" was approved by the Governor. Members of the Metropolitan Water Board were appointed soon after, met for organization July 19, and appointed a chief engineer July 24. The organization of an engineering record to present at this time the records of several large and very well known municipal undertakings.

The results of the study are set forth in the form of the following brief partial chronologies of the Massachusetts Metropolitan water-works, the New Croton system for the supply of New York City, the Boston subway, the New York Rapid Transit Railroad, the Massachusetts Metropolitan sewerage systems, and the Philadelphia filtration plants. These works have all been so fully described in this journal that very little explanation of them is necessary. It is merely proposed to point out in a general, approximate way the time consumed in preliminaries and in some of the unexpected and intentional delays, and the total calendar time that passed between the inception and the completion of the works, without going into the details of individual cases. It seems scarcely necessary to suggest caution against the unintentional and indiscriminate applications of, or deductions from, the facts here presented. Reasons for delays or for rapid progress can be found stated or suggested in the records of the works, to some extent.

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neering force was begun immediately, the chief engineer and most of his principal associates, as well as a number of the subordinates, having been connected with the preliminary investigations. About Aug. 1 the final location surveys for the Wachusett aqueduct were begun, and on Aug. 7 the final borings for the examination of the site of the Wachusett dam. On Feb. 14, 1896, eight months after the approval of the act, the first aqueduct contract was let, for the construction of a tunnel 2 miles long, and the last important contract for the aqueduct, for an open channel 3 miles long, was awarded Sept. 22, 1896, fifteen and a half months after the approval of the Metropolitan water act, and about twelve and a half years from the date of the beginning of the investigations by the State Board of Health.

Simultaneously with the construction of the Wachusett works, the Metropolitan Water Board built the 300,000,000-gal. Weston aqueduct to supplement the two old aqueducts conveying water to the distribution system from Lake Cochituate and the Sudbury River. In February, 1899, surveys and studies for this aqueduct were begun, but some preliminary studies, including a fairly careful location, had been made by the State Board of Health. On Sept. 24, 1900, the Weston aqueduct department of the engineering force was established to carry on the construction, and on May 9, 1901, the first contracts were let, two years and three months after the beginning of the final surveys. This aqueduct has a total length of 13.4 miles, comprising five tunnels aggregating 2.3 miles, 9.1 miles of cut-and-cover, 1 mile of pipe siphons, and 1 mile of open channel and equalizing reservoir. On Dec. 29, 1903, the first water was delivered into the district through the new aqueduct, four years and eleven months after the beginning of the final surveys, and two years and nine months having elapsed. This aqueduct has a capacity of 300,000,000 gal. per 24 hours, and its construction was pushed vigorously. Not until Oct. 1, 1900, was the principal contract for the Wachusett dam made, but the early construction of a temporary dam and flume as portions of the works for the control of the river during the building of the main dam rendered possible the partial utilization of the new source at the date given above.
On account of contractors who proved unequal and some trouble and delay were experienced on account of contractors who proved unequal to their tasks. The cost of constructing these works, exclusive of land and damages for water rights and other claims, will be about $26,000,000 in round figures.

Published reports of the new Croton works do not give their history in so much detail, but the principal steps in their progress can be briefly stated. After some preliminary agitation and investigation, the Aqueduct Act, so-called, was passed by the Legislature in June, 1883, and the commissioners met for the first time on Aug. 8. On Dec. 13, 1884, eighteen and a half months later, the contracts for the first sections of the New Croton aqueduct were awarded. On July 15, 1890, this aqueduct was first put into service, although not wholly finished, seven years and two months after the passage of the act; it is about 33 miles long, has a capacity of 300,000,000 gal. per day and cost about $25,000,000 for construction work.

On Feb. 7, 1887, the Aqueduct Commissioners adopted a resolution for investigating the design and location of the principal dam, and on March 7, 1888, the board of experts on the Quaker Bridge dam was appointed, four years and nine months after the act was signed. The experts reported Oct. 1, 1888, but it was not until Jan. 22, 1891, that the commissioners finished, seven years and two months after the act was signed. The experts reported Oct. 1, 1888, but it was not until Jan. 22, 1891, that the commissioners on March 7, 1888, the board of experts on the Quaker Bridge dam was appointed, four years and nine months after the act was signed. The experts reported Oct. 1, 1888, but it was not until Jan. 22, 1891, that the commissioners on March 20, 1890, the first contract was awarded, nearly three years and ten months from the date of the first act and eight and a half months from the final act. During September, 1897, a portion of the subway about 0.8 mile long was put into service. Subsequently other sections were put into service from time to time, and the East Boston tunnel was opened to travel on Dec. 30, 1892, a contract was made for building the New Croton dam, the Quaker Bridge site having been abandoned. Thus nine years and three months were consumed by investigations, delays, and the preparation of drawings and specifications for the principal dam. It is now confidently expected that the New Croton dam and reservoir will be completed by October, 1905.

Another example of well managed work is the Boston rapid transit system, but in this case, also, more time has passed between the beginning and the completion than would ordinarily be estimated as required. On June 3, 1891, by act of legislature a commission was created to promote rapid transit for the city of Boston and its suburbs. On April 5, 1892, the final act was passed by which the Boston Transit Company was incorporated. On Sept. 28, 1894, under which the Boston Transit Company was incorporated. On March 20, 1890, the first contract was awarded, nearly three years and ten months from the date of the first act and eight and a half months from the final act. During September, 1897, a portion of the subway about 0.8 mile long was put into service. Subsequently other sections were put into service from time to time, and the East Boston tunnel was opened to travel on Dec. 30, 1892, a contract was made for building the New Croton dam, the Quaker Bridge site having been abandoned. Thus nine years and three months were consumed by investigations, delays, and the preparation of drawings and specifications for the principal dam. It is now confidently expected that the New Croton dam and reservoir will be completed by October, 1905.
THE RECONSTRUCTION OF THE PORTAGE VIADUCT.

THE RECONSTRUCTION OF THE PORTAGE VIADUCT
AN EXPLANATION OF THE METHOD OF RECONSTRUCTION WITHOUT INTERRUPTING TRAFFIC

The Portage viaduct is officially known as bridge No. 16 of the Buffalo Division of the Erie R. R. It is a single-track structure 819 ft. long and about 235 ft. high from the bottom of the river to the base of rail. It consists of six towers supporting plate-girder and truss spans of from about 50 to 118 ft. long. Originally it was built of timber, and for a long time after its completion in 1853, was famous for its height and imposing appearance where it crosses a rocky chasm a short distance above a beautiful waterfall. It was replaced in 1875 by a light pin-connected wrought-iron structure carried by new transverse girders riveted to the top chords of the trusses, which were spaced about 20 ft. apart and were supported directly by the battered columns of the towers. It was originally intended to add at some time a second track on long and deep ties laid across the top chords of the trusses, which were spaced about 19 ft. 10 in. apart on centers, so as to have transverse bracing and had two cantilever guys. With it the track on the regular ties of the old bridge was made with very deep overhanging heads, from falsework trusses; suspending the old track from the new trusses; removing the old trusses; lowering the new trusses to final position and laying the permanent track on them. Operations were commenced by installing at the rear end of each jigger beam was anchored by a 22-h.p. Fairbanks-Morse gasoline engine. It had sufficient clearance for the train traffic to pass through it, and it could be left in any position where it was required without interrupting trains. It was made with very deep overhead transverse bracing and had two cantilever jigger beams, from which tackles were suspended about 3 ft. clear of the front bent. The rear end of each jigger beam was anchored by 1-in. vertical rods with welded loops at both ends; and workmen on them cut away the lattice-frames on the inner sides of the battered posts and drilled holes for the connections of the new transverse girders. These holes were scribed from cast-iron templates through which the holes in the girders had previously been drilled. The holes in the columns, except in inaccessible positions where they were ratcheted by hand, were drilled by pneumatic tools manufactured by the Chicago Pneumatic Tool Co. There were about 2,500 holes 15/16-in. in diameter, and they were drilled at the rate of ten per hour by the pneumatic tools and four per hour by hand. While this work was in progress a 20-ton der-
MARCH 4, 1905.

a 3/4-in. steel wire cable made fast to the old trusses.

The 10-ton transverse girders were delivered on trucks to the traveler, which lifted them by a single tackle hitched near one end of the girders and lowered them vertically between the ties of the old bridge floor. When they were clear underneath, a tackle from the other jigger beam was hitched to the opposite end of the girder and both tackles were operated to hoist the girder into a horizontal position and swing it to place between the tower columns, to which it was immediately connected by assembling bolts through all of the field-fast holes. Riveting girders closely followed the erectors and replaced the bolts by rivets, most of which were driven by pneumatic hammers. A girder was put in position and bolted up without obstructing the track more than about one hour.

and the work was done at intervals between trains when it occasioned no interruption to traffic.

A sort of braced gallow-frame with longitudinal sills and inclined stiff-legs and having an overhang of 24 in. was built and equipped with two four-part Manila tackles corresponding to those on the traveler. This was called a jack-bent and was seated on one side of the tower, while the traveler was seated on the opposite side of the tower. A sufficient interval between trains was selected and the girders for the tower span were separately delivered and unloaded by the traveler and jack-bent main tackles which landed them alongside the track without releasing them from the tackles. The rails and cross-ties were removed from the old tower span by two whip lines attached to the traveler, and two attached to the jack bent, and were loaded on trucks and carried a short distance away. The top laterals and sway-bracing were then removed from the old span, leaving the bottom struts and laterals in position. The two new girders were then simultaneously lowered to their seats on the new transverse girders, their way frames being bolted in place and their lateral rods were put in with the aid of the whip lines, which afterwards replaced the old ties and track on the new girders. The whole operation required about 2½ hr. from the time the old span was out of service to the time the new span was in service. Afterwards the old trusses and bottom lateral and transverse struts were removed piecemeal by the whip lines and the traveler and jack bent were advanced another span and so on. All of the tackles and the whip lines were operated by a two-drum-four-spool Liigderwood hoisting engine located most of the time near the center of the viaduct, but occasionally moved for convenience.

While the 50-ft. spans were being erected, the falsework Howe trusses were framed in the storage yards, and after the 50-ft. spans were erected they were assembled on the cross-ties outside of the track at the west end of the viaduct. After they were braced together by the overhead struts which afforded clearance for trains to pass between them, each truss was seated on six solid steel rollers at each end and rolled forward on tracks made with three lines of rails spiked to the old ties. The trusses raised them about 3 ft. above their final position. All of the bracing except the top laterals was connected to the trusses and the working platform was removed, the suspenders extended and the platform replaced below the lower chords of the old trusses, where it served to support them during their removal. Before the old trusses were removed, the 8x16-in. cross-ties 22 ft. long, which had rested on their top chords, were suspended from the new top chords which just cleared them, by pairs of U-bolts, and the spans being thus shortened, their strength was increased to carry the traffic from the new trusses and release the old trusses. After the old trusses were removed, transverse lifting girders were connected to the ends of the new
Reconstructing Piers of a Railroad Bridge in Service.

A rather unusual piece of substructure work has recently been successfully accomplished in Replacing two piers and repairing one abutment of a railroad bridge under traffic where Exceptional difficulties were encountered.

The bottom of the river was very much obstructed, the river was subject to sudden high floods and to dangerous ice gorges, and one new pier had to be built in the same position as the old one. The work was executed with ordinary plant and involved interesting features in the method of supporting the spans over the replaced pier, and novel devices for supporting the service track, driving the concrete mixer, and handling concrete buckets where there was not sufficient clearance to operate a derrick.

The Wabash River bridge, of the Cleveland, Cincinnati, Chicago & St. Louis Ry., at Terre Haute, Ind., consisted of one curved-chord, 230-ft. span, one 78-ft. girder span, and three 125-ft. Pratt truss spans, resting on limestone masonry piers. From the base of rail to low water is about 40 ft. The old piers were built in 1865, when the road was constructed. They were 22 ft. in length by 6 ft. in width under the coping, and were square ended, with a batter of 1 in. on each end, and 3 ft. 6 in. at the foot.

There seems to be no record of the foundations of these piers, but they were supposed to rest Simply on timber grillage and were supported by an inch with one 10-in. and one 6-in. centrifugal pumps. On further investigation it was found that the whole river bottom was filled with rip-rap of sizes running from one-man stones up to 3-ton stones, and, in addition to this, there were two old bridge spans, a locomotive and 40 old freight cars, the remnants of three wrecks on the bridge, besides old falsework plies that had been cut off below low water.

On account of so much debris in the river, and also because the range between high and low water in the Wabash at this point is about 27 ft., and the ice gorges in the spring are very severe, the first plan for replacing the three east spans was abandoned and it was decided to put in two piers resting on pneumatic caisson foundations and two 134-ft. Warren truss spans, thus giving a greater waterway between the piers, and less chance for the ice to gorge than by the other plan.

The Foundation Company, 35 Nassau St., New York, was called in consultation and given a contract to construct these new piers and rebuild the east abutment. They designed the caissons, which were approved by the chief engineer.

The caissons were built of 12x12-in. yellow-pine timber, the walls being 24 in. thick and the deck 36 in. thick, with a 4-in. oak shoe on the cutting edge. They were 38 ft. 6 in. in length by 16 ft. 6 in. in width, with a working chamber 6 ft. 4 in. high, with 35 ft. of 12x12-in. rows of sizes running from one-man stones up to 4-ton stones and, in addition to this, there were two old bridge spans, a locomotive and 40 old freight cars, the remnants of three wrecks on the bridge, besides old falsework plies that had been cut off below low water.

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