(Paper No. 4077.)

“Steel Forms for Reinforced-Concrete Conduit, Catskill Aqueduct, New York.”

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THE Catskill Aqueduct is designed to add 500 million gallons daily to the water-supply of the City of New York, through a concrete conduit about 90 miles in length. Most of this was cast on steel travelling-forms or centering, the most complex type of which was used in constructing a reinforced-concrete section about $2\frac{1}{4}$ miles long known as the Kensico by-pass. A cross-section of the by-pass is shown in *Fig. 1*. The selected type of forms and method of working adopted met the severe conditions satisfactorily and with speed and economy.

The location of the by-pass was on moderately rough hill-side, the centre profile varying between 5 feet fill and 20 feet cutting, with the larger part of the alignment on curves of 200 feet radius. The trench in which the by-pass was to be built was excavated nearly to shape by steam-shovels, in material ranging from loam and gravel through soft to hard rock, soft rock being the characteristic material. The specifications required that the roughly-excavated trench be brought to exact form by careful hand-work immediately before placing a thin concrete sheet or cradle, on which reinforced concrete was to be cast. This trimming was tedious, expensive, and one of the limitations to the speed of the work.

Contiguous to the conduit a 3-foot construction railway was built to handle the steam-shovel cars, the distribution of concrete from the mixer, and the supply of material to it, as well as the general service for other construction beyond the by-pass. This railway was a busy line, and the other demand interrupted the best service to the by-pass.

Between the construction railway and the conduit, space was left for a crane travelling by its own power and swinging a complete

circle. A concrete-mixing plant was built at convenient points, with elevators and bins for sand, stone and cement, the mixer delivering concrete to drop-bottom buckets, holding about 1 cubic yard each. The buckets were filled whilst on the cars, and then moved by the railway to the travelling crane, which lifted and swung them over the forms. The concrete was dumped along and at the top of the forms, the material falling on the inside forms between and around the reinforcing bars, to be then thoroughly spaded and tamped over the space between the inner and outer steel forms. The mixer plant was rebuilt when the transportation between it and the forms exceeded $\frac{1}{2}$ mile.

Fig. 1.

The governing conditions were: that there should be expansion-joints in the conduit not more than 75 feet apart; that between joints concrete should be cast around the reinforcement in a continuous process to make a monolith of the section; that the system of forms should work on both straight and curved alignment; and that no man should work more than 8 hours in 24, this being a strictly enforced provision of the contract, rendering very difficult the arrangement of a sequence of operations so to employ forces as to complete their work in 8 hours without waste of time. The inside forms were to be supported on small concrete pedestals or pillars, built in advance, thin enough to pass from foundation up to

the shell of the inside form, between adjacent planes of reinforcement, the cast concrete incorporating these pillars in the monolith.

Before the by-pass forms were designed, much experience was gained in the working of steel forms for the unreinforced graded aqueduct in open cut. As a result, it was decided to do without interior cross-bracing, and make the periphery of the form stiff enough to support the casting of concrete, but by a hinge system to enable the forms after the concrete on them was set to be slacked off, collapsed upon a travelling carriage, and moved through the units on which concrete was depositing to a point in front, where the moving units were expanded and bolted to units already placed ;

Fig. 2.

so that, at least theoretically, there were always in continuous steel ahead enough forms for a new cast before the cast in progress was completed.

For the aqueduct in open cut, the design was comparatively simple, in that travelling forms were required only for the upper or arched part of the conduit, the arch resting and the forms travelling upon a concrete invert cast in advance. For the by-pass there was no invert, and the entire cross-section was cast in the same operation. This involved the handling of relatively more form in less space, much alteration of detail, and greater complexity of working. *Fig. 2* shows forms ready to receive concrete; *Fig. 3* shows an

inside form unit collapsed and ready to move on the carriage, and *Fig. 4* illustrates the order in which work was done.

The system adopted required two kinds of forms, an outside or saddle form and a many-hinged inside form. The outside forms were adjusted on wooden blocking supported by the cradle. The inside form was adjusted to line and gradient when it came to a bearing on the pillars PP (*Fig. 2*). The forms were held to proper spacing, and prevented from spreading during a cast, by the tapered bolts T, which are carefully turned and polished so as to be easily knocked out after a cast. The hole left was closed by grouting from the outside.

Both outside and inside forms were composed of units $7\frac{1}{2}$ feet long. The outside form in this length has four 4-inch channel-iron ribs, connected longitudinally by angles, all riveting to $\frac{1}{4}$ -inch plates. These plates do not cover the whole space, but are omitted at many regular intervals, for which there are removable shutters or doors, to be placed in position from time to time as the concrete rises in the forms. The upper middle part of the form has neither plate nor doors, the slope being flat enough to finish the concrete in the open. The object of the doorways is to permit men at successive levels to stand in them and on the concrete, and thoroughly work it round the reinforcement and to the forms.

The hinged sections of the inside forms are built each with three intermediate I beam ribs and a channel at each end, all riveting to $\frac{1}{4}$ -inch plates, which form the cylindrical outside of the form. Both outside and inside forms finish with the channel ribs machined to fit adjacent units. Slotted holes through the channels permit slight adjustment, and the units are held together lengthways by bolts through these holes, a withdrawal of these bolts being the preliminary to slacking off the form.

To slack the inside forms the temporary stiff connections at the hinges C and D (*Fig. 2*) are removed. The segments C-D are then rotated until they approach the main rib. Prior to this the cantilever beam of the carriage is advanced, the temporary arms

Fig. 3.

attached at B, and the main ribs are then drawn in and lowered, the final position being shown in *Fig. 3*, with the collapsed form swung from the carriage in readiness for removal to the front.

Referring to *Fig. 4*, AB shows finished concrete supported on forms, and BC shows a section where forms and reinforcement are ready to receive concrete. The plane of the forward end C of each cast must be closed by a steel bulkhead, held during the cast by bolts to the outside and inside forms.

The bulkhead is separable into a number of pieces to permit easy detachment, and leaves room for and supports a steel expansion-plate 6 inches by $\frac{1}{2}$ inch, which forms through the bulkhead the annular tie between two casts. Inside form units are lowered to the carriage, withdrawn from the A end, moved through BC to the D end, there to receive the reinforcement ring, to be expanded, bolted up, and generally got in readiness for the next cast. The final preparation is the removal by the travelling crane of outside forms from the A end to a new place at the D end.

The inside forms being in shape short cylinders, it is necessary on curves to assume the centre line as a succession of short chords to the curve. To take up the wedge-shaped space between adjacent form-units on different chords, short forms or fillers were used. At first the fillers were wood, under the belief that greater facility of adjustment would result. Wood did not work well, principally on account of the long bolts necessary, and the design was changed to a steel filler, with the same connection by short bolts as that of the several units to each other.

As elsewhere described, the reinforcing-bars were bent into rings, which were generally conveyed by hand to the trench, and strung on the inside form-units as they were advanced. When the forms were expanded and bolted up, the reinforcement in the same plane was spaced by fixing each bar in a slot, each slot cut half out of a

small timber, the two timbers, when drawn together by a bolt, locking the bars in their slots at the correct distance from each other and from the forms. These timber struts were placed at the horizontal diameter and above, and successively unbolted and withdrawn as the concrete rose to their level. The several planes of reinforcement were spaced horizontally 18 inches C to C, and held by wiring to twisted steel longitudinals.

Sufficiently careful shop-work can be done on the forms to make any unit fit and match any other. Every unit, however, has three hinges and the centre joint, each requiring some little play in the stiffening pieces which cover, so that the form tends to sag at the top and spread at the middle diameter. Temporary wooden posts with screw ends were used for vertical and turn-buckle rods for horizontal adjustment. It was regarded as necessary to retain these adjustments while the concrete was casting, and to that extent the purpose was defeated of having at all times free passage through the forms. The interruption was not thought to cause either delay or expense in completing the conduit in the present instance, and it could be obviated if desirable. The adjustments held the inside form within a limit of $\frac{1}{8}$ inch of true position and shape.

The number of inside form-units required for a particular length of cast will vary with the time required to set the concrete, and with the speed attainable in moving and reinforcing the forms. The latter operations are very much slower than casting. Sixty-five feet have been cast in 6 hours, and it would not have been difficult to have maintained 100 feet in 8 hours. In practice, the length generally cast on the by-pass was about 45 feet, that distance being fixed by the rate at which the forward work could be got ready for another cast. There were in use 22 inside form-units, making 165 feet. On curves the total was increased by the fillers, so that the amount of inside form available was between 165 and 180 feet, or three and a half to four times the length of the cast. Very much fewer outside forms are needed.

The by-pass reinforcement consisted of two bars in the same plane, each bar of $1\frac{1}{8}$ -inch square steel twisted. The inside bar was at a uniform distance from the inside of the conduit and therefore concentric with it, while the outside bar approximated the outside of the concrete cross-section and was laid out with four centres. The bars could be made in either one or two pieces, the ends being joined either by welding or by lapping and wiring together. Welding by any process was too expensive, and it was thought that a single bar for the whole circumference with ends

lapped was not only the most economical in labour and material, but rendered a ring sufficiently rigid against side-deformation to make it easy to handle and place in position.

It was determined experimentally that twisted steel bars bent round a drum of smaller radius could be made to set to any desired radius. In the case of the $1\frac{1}{8}$ -inch bars the drums were about $\frac{7}{10}$ ths of the final radius.

For the actual bending, level places were selected from time to time. A timber platform not too heavy for transport was framed, and on it were laid out curves with radii $\frac{7}{10}$ ths of those of the reinforcement in place. These curves were defined by timber lips about 6 inches high, with their faces protected against wear by sheet iron. One end of a bar was held to the curve by a temporary pin. Six men then walked round with the free end of the bar, holding it against and bending it to the sheet-iron curves. After one half was bent the bar was reversed, the straight end placed at the pin and the other half of the bar bent. The bars being cut to exact lengths, the ends were lapped an exact amount and wired together, and the ring was in final and correct shape. There were other sections of reinforced circular conduit as large as 17 feet in internal diameter, where the bars were $1\frac{3}{8}$ inch square and 65 feet, and even 70 feet, in length. The same bending process was effective, but it was found here that the proper drum radius was about $\frac{6}{10}$ ths, and eleven men were required for bending instead of six.

The concrete was mixed wet, 1 part cement, 2 parts fine and 4 parts coarse aggregate, the latter mainly stone broken to pass a 2-inch ring.

The weight per foot of inside forms was 620 lbs., of outside forms 425 lbs., and of reinforcement 262 lbs., making a total weight of 1,307 lbs. per lineal foot measured along the conduit.

From the fact that the average cast was estimated to be made in 5 to 6 hours, during which time concrete deposited wet attained a height of about $12\frac{1}{2}$ feet above the bottom of the inside form, it was at first thought that the pressures induced would float the inside forms, and provision was made to weight them during the casting. In practice, applied weights were found unnecessary, the weight of the forms and reinforcement being sufficient to hold the forms firmly to their support.

Prior to a cast, all the hinge and other joints were caulked with oakum or clay, and there was much of this to be done. There was always some leakage of concrete water, principally at the bottom and in the earlier part of the cast. In the beginning of the work, the presence of the water led to an attempted correction by a drier

concrete. It was found difficult to compact this around the reinforcing bars, and such leakage as remained tended to showing cavities next to the forms. A return was made to the wet mixture, and observation shows a solid, generally smooth, finished concrete, unaffected by the leakage which may have occurred.

The construction was in charge of a general foreman, aided by foremen and labourers for each of the several operations of trimming excavation, mixing, transporting, bending-reinforcement, moving forms, placing reinforcement, and casting concrete. These men were not confined exclusively to their special work, but at times helped on other operations. None of these men worked more than an 8-hour day, although some worked at times when others did not. Most of the work was done between 8 a.m. and 4 p.m., but some men always worked between 4 and 8 a.m. and from 4 to 8 p.m., so as to co-ordinate the different operations.

TYPICAL WORKING FORCE FOR ONE 8-HOUR DAY.

	Number of Men.	Per Cent. of Expense.
General foremen	1	3
Trimming excavation (2 foremen, 2 skilled, 18 common labourers)	22	17
Bending reinforcement (1 foreman, 6 skilled labourers)	7	6
Moving forms and placing reinforcement (3 foremen, 1 hoisting engineer, 1 fireman, 4 carpenters, 30 skilled labourers)	39	38
Mixing concrete (1 foreman, 1 fireman, 9 skilled labourers)	11	10
Track-work and transporting concrete to forms (2 locomotive engineers, 2 brakemen, 2 skilled, 7 common labourers)	13	10
Casting and tamping concrete (1 foreman, 1 hoisting engineer, 1 fireman, 14 skilled labourers)	17	16
Total force	110	100

The average pay of foremen, carpenters, and engineers was a little more than twice that of common labour. The pay of skilled labour ranged from 10 per cent. to as much as 60 per cent. above the wages of common labour. A close approximation of the total labour expense can be made by reckoning the entire force at the rate for common labour and adding one-third. The above estimate is given with the reservation that no organization, installation, plant, general, or fuel and material expense is included, and that it is intended to indicate, for purposes of comparison, the average

labour required for the operations specifically stated, and under the conditions prevailing upon this work.

After gaining experience, such a force working the equivalent of an 8-hour day for every day in the month averaged about 1,000 feet per month of completed conduit, measuring about 3,100 cubic yards of concrete. The highest monthly progress was 1,138 feet, and the best season's work about 6,800 feet.

In the Author's judgment the best and most uniform finish to concrete surfaces is gained by casting against accurately shaped stiff steel plates. While it is apparent that the installation of travelling steel forms sufficient in number for rapid progress is an expense justified only by a certain magnitude of work, yet the forms do not deteriorate in accuracy and finish by heavy work for years, and if there be enough work, the cost of installation may be a small sum per cubic yard of the concrete placed. The Author believes that for most large conduits the first and operating cost combined of proper steel forms will be less than by any other method of support, with the incidental advantage of more rapid work and a concrete with the best attainable finish. If the conduit be monolithic between expansion joints, collapsing steel forms are almost a necessity, and if in addition the concrete is to be reinforced, telescopic forms permit the placing of reinforcing bars by a method which represents the minimum in simplicity and cost.

The Paper is accompanied by four tracings, from which the Figures in the text have been prepared.