If $n = 10$, the initial radius $r_1 = m_1 d = 0.80 \times 7.94 = 6.35$ ft.; $r_2 = \frac{10}{9} \times 6.35 = 7.05$ ft., $r_{10} = 10 \times 6.35 = 63.5$ ft. The half perimeter $= m_3 d = 1.51 \times 7.94 = 12.0$ ft., and $\theta = 71.5°$. The hydraulic radius $= m_5 d = 0.475 \times 7.94 = 3.76$ ft., or $= m_6 \sqrt{a} = 0.56 \sqrt{45} = 3.76$ ft. The tension $T = m_7 a w = 1.06 \times 45 \times 62.5 = 2980$ lb. per lin.ft.

Again, given $b = 12$ ft. and $p = 18$ ft., find d: From curve 8, with $\frac{b}{p} = \frac{12}{18} = 0.66$, read $\frac{b}{d} = 1.02$; then as $b = 12$ ft., $d = \frac{12}{1.02} = 11.62$ ft.

Fig. 4 gives the ordinates of the curve in terms of d, for values of b/d, and enables the construction of the curve to be made quicker than by construction in Fig. 1. When b/d is more than 0.63, the maximum ordinate is the top one, b_{10}; for values less than this, the maximum ordinate does not occur at the top, but at some intermediate point.

Comparing the hydrostatic catenary with the parabola and the arc of a circle, it will be found that for values of b/d about 1.0 and greater, it lies between the parabola and the arc of a circle, but when b/d is about 2.0 it lies outside the parabola in the upper part and inside it in the lower part.

The following is a comparison of the areas inclosed by the hydrostatic catenary, the circular segment, and the parabola, expressed in percentages of the inclosing rectangle, for varying values of b/d.

Ratio b/d	1.0	1.2	1.4	1.6	1.8	2.0
Inclosing rectangle	1.00	1.00	1.00	1.00	1.00	1.00
Area of hydrostatic catenary	0.73	0.708	0.693	0.682	0.672	0.667
Area of segment	0.785	0.75	0.731	0.716	0.706	0.698
Area of parabola	0.667	0.667	0.667	0.667	0.667	0.667

The application of this curve occurs in structures holding fluids, such as metal flumes, and large uncovered water pipes under a very low head. For spherical bottoms of water tanks and spheroidal gas-holder tanks (see ENGINEERING NEWS, Aug. 6, 1914), the above curves will give a close first approximation to the proper curve, and the correct curve can then be found from this by means of the funicular polygon.

Chicago Track Elevation; Rock Island Lines

SYNOPSIS—This work represents an expenditure of over $10,000,000. Its special problem was the elimination of a railway grade crossing in addition to the street crossings, necessitating an unusually high elevation (for tracks on two levels) and a five-span skew bridge over the lower tracks. Among the interesting features of the construction may be noted the following: (1) The high-level crossing; (2) the concrete-cased steel bridges; (3) the use of bin cars for the concreting trains and traveling forms for the retaining-walls; (4) the carrying of drainage from the fill to chambers formed in the retaining-walls and having sewer connections; and (5) the subway bridges, with steel columns, steel and concrete cross-girders and concrete slab spans.

One of the heaviest pieces of track-elevation work at Chicago is the extension of the track elevation of the Rock Island Lines from 72nd to 90th St., about 3 miles.

The Rock Island Lines were already elevated as far south as 76th St. and descended to the street level at about 78th St., but the high elevation required for a double-track crossing at 79th St., over the Chicago & Western Indiana tracks, made it necessary to begin the new work at 72nd St., increasing the present elevation on a grade of 0.5% to the summit, beyond which a similar grade descends to the normal level of the new elevated tracks. This new work will extend to 90th St., but the portion under construction during the past season only went to 84th St., as it was desired to concentrate the work on the complicated crossing at 79th St.

The work involves a total expenditure of about $10,000,000, and requires the placing of about 290,000 cu.yd. of concrete in walls, abutments and slab-deck bridges, besides about 15,000 concrete piles, aggregating over 300,000 lin.ft.

The special features in the execution of the work include: (1) Careful planning in advance; (2) rapid progress; (3) noninterference with a heavy regular traffic; (4) low cost of construction; (5) the organization and cost-keeping system.

Retaining Walls and Abutments

Between the bridges at street crossings, the tracks are carried on a solid fill of sand and gravel between heavy concrete retaining walls. This is typical of Chicago track-elevation work, but in this case the walls are of exceptional height, reaching a maximum of 42 ft. above the bottom of the foundation.

The foundations for the retaining walls and for the bridge abutments at subways are concrete piles, cast in place in the clay soil and having an average length of 22 ft. The heads of the piles are embedded in a heavy footing course, which forms the base of the wall, and has in it vertical lengths of old rails which project from the surface and thus form a mechanical bond with the wall proper. Load tests were made on the piles, and the actual load carried is 20 to 25 tons per pile.

In the design and construction of the retaining walls, a special effort was made to avoid the unsightly cracks which have developed in some other track-elevation work, and also to keep down cross-section area. The aggregate amount of concrete on the work is very great, and the wall design aims to secure the necessary strength with a minimum of material.

The walls vary in height from 20 to 36 ft., and a typical section is shown at the left in Fig. 1. The face is practically on the right-of-way line (with the toe of the footing projecting over the line). The face is vertical to the coping, while the back is stepped. At some points, however, the footing must be kept within the right-of-way line, and here the body of the wall is set back to allow of giving an outside toe. But the full roadbed width is retained nevertheless by forming a cantilever projection at the top of the wall, supported at 10-ft. intervals by triangular brackets. This form of wall is shown in the middle section in Fig. 1.

The walls are built in sections 35 ft. long, which is considered the maximum length that can be used without fear

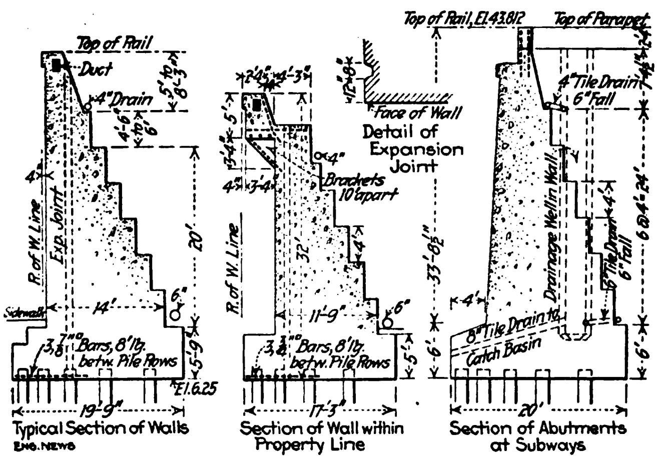

FIG. 1. SECTIONS OF RETAINING WALLS AND ABUTMENTS ON CHICAGO TRACK-ELEVATION WORK; ROCK ISLAND LINES

of cracks due to temperature movement. The sections have vertical keys at the expansion joints. In the top of each wall is a six-duct conduit for electric wires, cables and telegraph lines. Manhole chambers on the conduit are placed about 400 ft. apart, and are 6x3 ft., 4 ft. deep, with a reinforced-concrete slab cover having a 28-in. iron manhole.

An unusual feature is the provision of drainage wells in the ends of the retaining walls, adjacent to the abutments at the subway bridges. These are 3x3 ft., and extend to the bottom of the wall, as shown in the drawing of the abutment cross-section in Fig. 1. There are no weep holes through the retaining walls, but along the backs of the walls are laid inclined drains of 6-in. porous tile, on a grade of 0.5%, extending from subgrade level to 6-in. pipes which are embedded in the rear part of the walls and discharge into the drainage wells. Each well has an 8-in. connection to the catchbasin of a city sewer, as shown.

The waterproofing consists of a tar-pitch composition applied to the back of the wall, a strip of burlap and felt being placed over each expansion joint and well mopped with the composition. An ornamental concrete railing 4 ft. high will be placed upon the parapet over the subway.

At some of the cross streets the tracks were already elevated, but had to be raised still higher, due to the change in grade, as noted above. It was not considered desirable to increase the load on the old abutments, but instead of destroying them it was decided to build a heavy cross wall (pierced with rectangular openings) behind the abutment and supporting the new fill. The space between the two walls, about 17 ft., is covered with a deck of concrete slabs. In this way the load is transferred largely to the new wall, which extends between the retaining walls and has the usual pile foundation. In raising the height of the old abutment, a wall will be built upon it, the lower part of the wall sufficing to retain the toe of the fill and the slab behind it.

The fill is of sand and gravel, dumped from cars. Before the final surfacing to subgrade, the fill will be thoroughly soaked with water. This is done to reduce the amount of settlement after the work is completed and in service, as surfacing track under heavy traffic is difficult and costly.

SUBWAY BRIDGES

With the exception of the 79th St. crossing, noted below, the subways have slab deck spans of reinforced concrete. They are of the four-span type, with bents on each curb-line and at the middle of the street, as shown in Fig. 2. The two street spans are 20 to 23½ ft., with a clear headway of 13½ ft., while the sidewalk spans are 10 ft. The foundations are generally concrete footings on concrete piles. In a few cases, where soft ground was encountered, 44-in. to 60-in. open wells or caissons were sunk to rock (at depths of 40 to 50 ft.) and filled with concrete to form cylindrical foundation piers. In one case there were four piers, capped with a double row of steel box girders carrying the eight columns of the bent. In all other cases there was a pier under each column.

The columns are of steel, composed of an I-beam and two coverplates, with an angle at each corner and batten plates riveted across the angles. These are shown in Fig. 3. Where the height exceeds 25 ft., horizontal box-lattice struts extend between the columns (Fig. 2). All these steel members are wrapped with wire netting, and are filled and heavily cased with concrete. The concrete for this purpose is a 1:2:4 mix, using ¾-in.

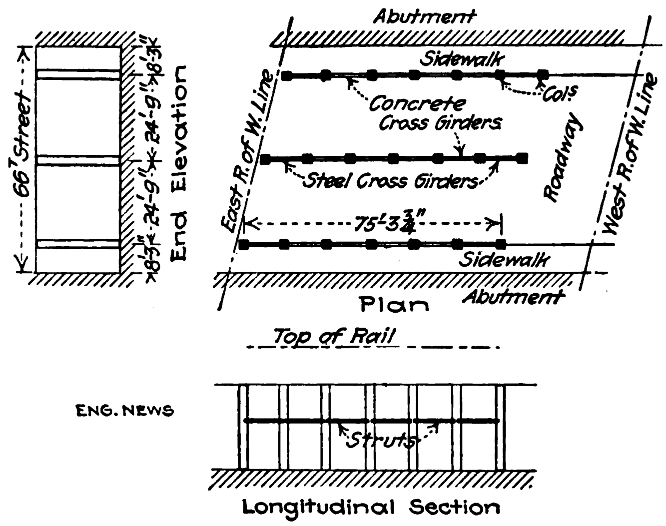

FIG. 2. TYPE OF SUBWAY BRIDGES

stone. Upon the columns of each bent are placed the cross girders, which are shown in Fig. 3. Those beneath the two outer tracks are steel box girders, while the others are of reinforced concrete, but the former are encased in concrete so that the difference is not apparent. The cross girders of the center bent have the under side curved or arched between the columns, but the shallower girders on the sidewalk bents are flat on top and bottom.

The deck slabs rest upon the abutments and the cross girders, and their construction is shown in Fig. 4. The largest slabs are 25x6 ft. and 44 in. thick, weighing about 46 tons each. The slabs of the shorter spans being thinner, are of L section, the ledge on the under side raising the slab so that its top is level with the top of the roadway spans. All the slabs for the sides of the deck are also of L-section, having parapet walls formed upon them to retain the ballast. The slabs are laid with ¼-in. joints, which are packed with asphaltic filler. Owing to the bridges being on a skew, the parapet slabs are of irregular shape in plan, and each has to be set in its proper position, as shown on the plans for each bridge.

The slabs are cast at a yard near 93rd St., a special organization being maintained for this work. Platforms are arranged on each side of a double-track spur, one track for the concrete mixer and the other for material cars. On these platforms are erected the slab forms, which are mainly of wood, but steel has been used for some parts and will be used more extensively. The concrete is a 1:2:4 mix. The slab gang consists of a foreman and 40 men, and turns out an average of 20 slabs per week.

The steel reinforcing bars (of deformed section) are purchased in commercial lengths, and cut and bent as required. For each cross-girder the reinforcement (including hook for handling) is assembled and wired together at the yard and set in the form as a unit. A concrete mixer with 1-yd. drum is mounted on a car and discharges the concrete into a chute leading to the form, where it is well stirred with paddles to insure thorough filling around the steel bars.

The viaduct crossing over 79th St. and the Chicago & Western Indiana R.R. (where the two roads intersect at an angle of about 17°) consists of five through-girder spans of about 90 ft., on concrete piers and abutments. The girders and floor-beams are incased in concrete, and the floor consists of a concrete slab embracing the top flanges of the floor-beams, while the lower flanges are embedded in a thinner slab, which serves to exclude the steam and gas from the locomotives. This structure will be described in a separate article.

Construction Methods and Plant

Concrete—The concrete is made of gravel which is washed, screened and graded into three sizes: torpedo sand, 1-in. stone and 2-in. stone. This material is obtained from a gravel pit and washing plant near Joliet, Ill. The proportions are 1:3:5 for the retaining walls and abutments, and 1:2:4 for deck slabs and all reinforced concrete.

The material for concrete is brought in by special trains, and in general the cars are dumped from high pile trestles which serve later for temporary tracks while traffic is being diverted. The cars are steel gondolas, with drop doors along each side, being regular freight cars assigned to this work. The temporary approaches to these trestles are of 3% grade. To a considerable extent the material for concrete is dumped directly into bin cars forming part of the concreting trains, the cars standing on a track parallel with the trestle, and the side of the trestle having an apron of proper slope, as shown in Fig. 5. The cement is delivered in sacks, but it is expected to make some trial of cement delivered in bulk.

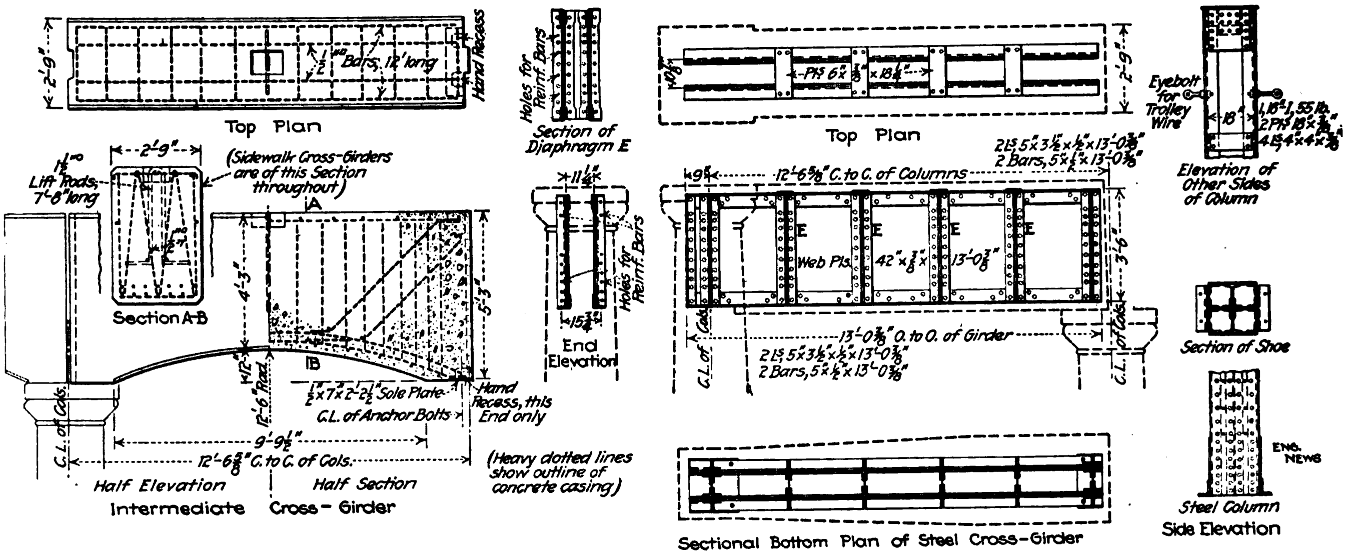

Fig. 3. Columns and Cross Girders of Subway Bridges; Rock Island Lines

Each concreting train, Fig. 5, consists of three steel flatcars. The head car carries a 1-yd. mixer, feed hoppers, measuring tank, and a bucket-elevator tower 60 ft. high with a hopper and jointed swinging chute to deliver the concrete into the forms. The trains building the foundation course around the heads of the piles had no towers, the mixers discharging either into buckets or directly into chutes. Behind the mixer car are two bin cars, each with capacity for 80 yd. of gravel and 80 yd. of sand. Below each main bin is a measuring hopper, beneath which runs a conveyor belt. The operator first opens the bin gate and fills the measuring hopper, and then opens the gate of the hopper, allowing the charge to fall upon the belt, which delivers it to the feed hopper above the mixer, carrying about 1 yd. of concrete material and 4½ bags of cement. The cement also is delivered to the feed hopper by a conveyor, and Fig. 5 shows the men dumping cement from sacks into a hopper over the conveyor.

The walls are built in traveling forms which straddle the site of the wall and are carried by wheels on either side. Both wood and steel forms of this type are used, each being long enough for a 35-ft. section and having grooved wheels riding upon two lines of rails. These are shown in Figs. 6 and 7.* The abutments are built in fixed forms of the usual type. Plank sheeting is used in both cases, and the two lines of sheeting are held together by tie-rods instead of wires. The rods are plain bars, not threaded, and are fitted with clamps instead of nuts.

*Steel forms, "Engineering News," Oct. 8, 1914.

When the clamp is in place, a setscrew jams the rod against a V-slot in the clamp, securing it rigidly in position (ENGINEERING NEWS, Sept. 10, 1914). Each rod is embedded in a tin tube, so that it can be withdrawn readily, the holes being then packed with stiff cement grout at each end.

The retaining walls are built in alternate blocks of 35 ft., with the traveling forms. It takes about 6 hours to fill the form, which is then left in place about 15 hours. It then takes about 20 hours to release the traveling forms, move 70 ft. forward and adjust them and the sheeting ready for the concrete. The use of the traveling forms has enabled the work to be done in about 25% of the time required with the ordinary forms (from the building to the removal of the form), and at about 50% of the cost (including erecting, pouring and dismantling).

The deck slabs for subway spans were hauled to the site on flat cars at the level of the bridge floor and set in place by wrecking cranes or locomotive cranes. The steel girders of the 79th St. span (weighing about 44 tons) were shipped complete and hoisted into place by locomotive cranes standing on the tracks below; these cranes also placed the floor-beams. All the steelwork of this bridge is encased in concrete, applied by the cement gun.

The filling between the retaining walls was done with trains of 40-ton ballast cars having side doors hinged at the top, the material being plowed off by a rapid unloader. The width of right-of-way is 100 ft., and practically all the work is kept within these limits.

The work-train service is handled by a special trainmaster who is a member of the construction organization, and works in consultation with the operating trainmaster and the dispatcher. The trains bringing in concrete material and filling are operated on a regular schedule. The construction work has been facilitated also by linking up and rearranging a number of separate sidings and industry tracks so as to form a continuous running track for construction trains, on the east side of the line, from the work to the material and slab yard at 93rd St. Thus all work trains and supply movements can be handled over this section of the line without interference with the main tracks.

For purchasing materials, complete estimates were made in advance so that the purchasing department could get the advantage of purchasing material in bulk. Then requisitions are made in such a way as to keep an ample stock in hand, the purchasing department obtaining the material in quantities as required, drawn against the total amount.

The main or running tracks are shifted as required, but only at long intervals. The shifting of the old track crossing at 79th St. was a difficult matter, as it included interlocking plant. The work was prosecuted first along the east side of the right-of-way, leaving the other side free for traffic. It was planned to get this part completed for three tracks over the crossing, with a 1½% run-off from the south end to the present level at 85th St. Then traffic was diverted to these three elevated tracks, and the construction work shifted to the west side of the right-of-way. The traffic over the crossing was controlled by hand-operated switches and signals during construction.

ORGANIZATION

All the work is being done by the railway company, except for the heavy steel erection and cement-gun work at 79th St., which are done by contract. The railway work, however, is not being done by the ordinary force-account method, but by a special organization which handles this one job alone and which estimates and carries on the work as a contracting organization might do. Bids were taken on different sections, and the "organization" bids were always lowest, while the work is being done at a cost below these bids. Part of the saving has been sacrificed, however, in expediting the work. The construction is carried on night and day, and the men receive time and a half for all overtime and holidays.

It is considered, however, that this sacrifice in first cost is well warranted by the advantages of getting the work promptly completed for traffic. In some cases track-elevation work of this kind has been in progress from four to seven years and trains are still being detoured to leave the construction free

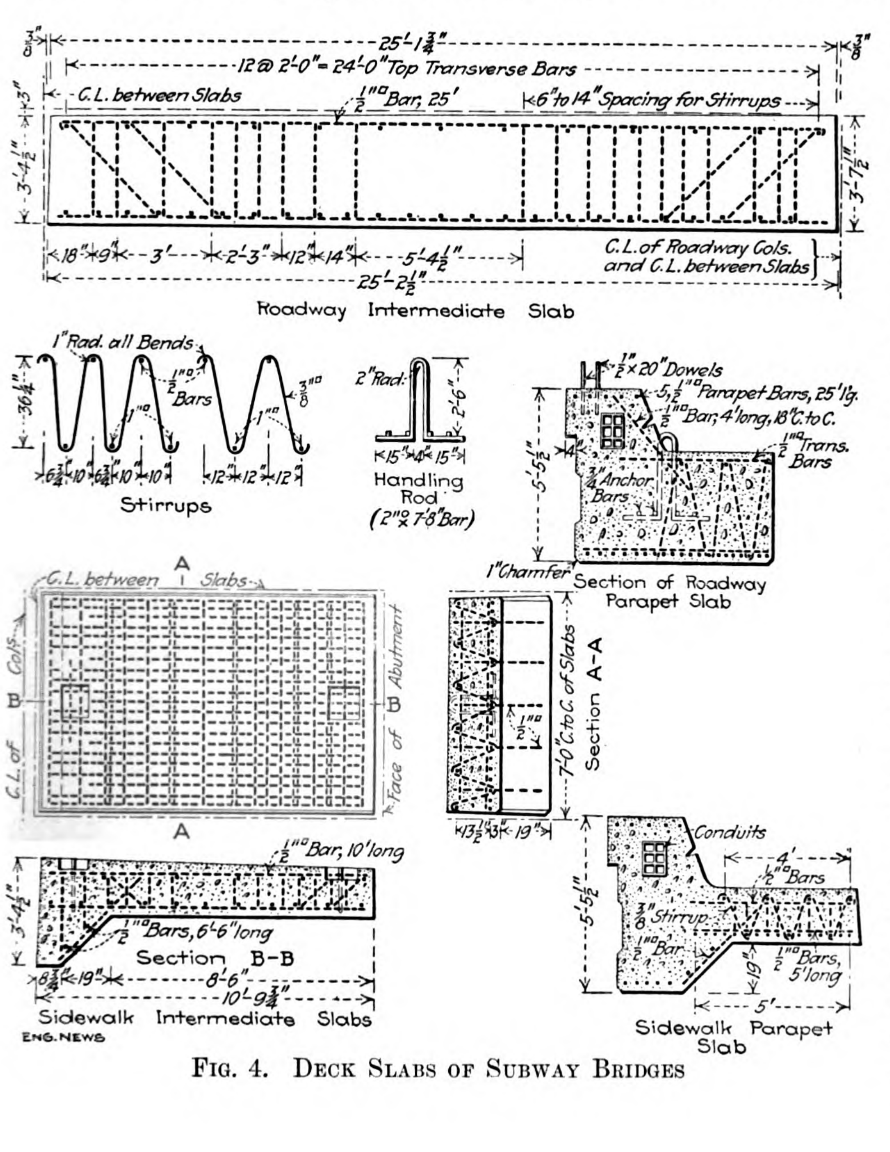

FIG. 4. DECK SLABS OF SUBWAY BRIDGES

of interruption; but in this particular case all traffic is being carried over it (with 400 to 500 trains daily over the crossing), and the work is being pushed with the greatest possible rapidity.

The organization headquarters are at the site, and comprise an office car and an engineers' car. There is also a hospital car, where a company doctor is in attendance daily to attend to minor injuries, and he can be called in emergency, but this work is mainly of the "first-aid" character. This car is operated in connection with the insurance company which insures the workmen under the employers' liability law.

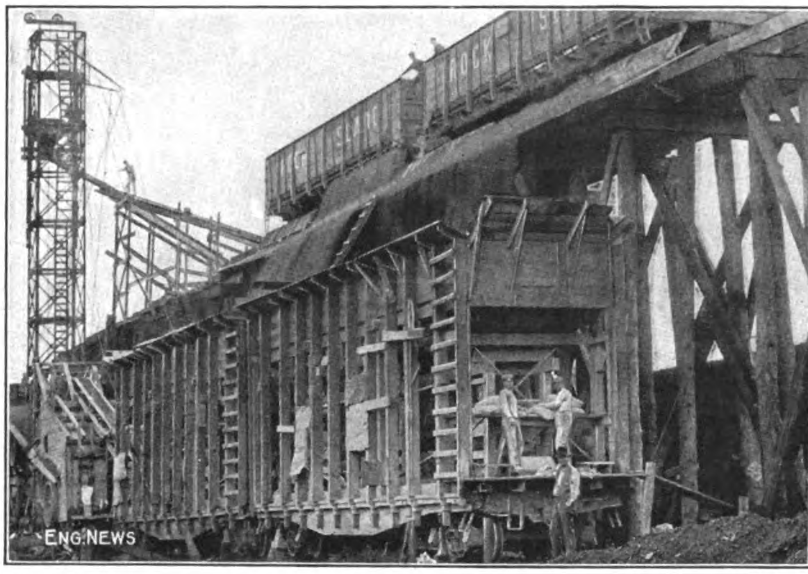

FIG. 5. CONCRETING TRAIN ON TRACK-ELEVATION WORK AT CHICAGO; ROCK ISLAND LINES

(The train consists of a mixer car, with hoist, tower and spouts, and two bin cars. Sand and gravel are delivered to the bins direct from cars on the high trestle. The materials are carried to the mixer car by belt conveyors.)

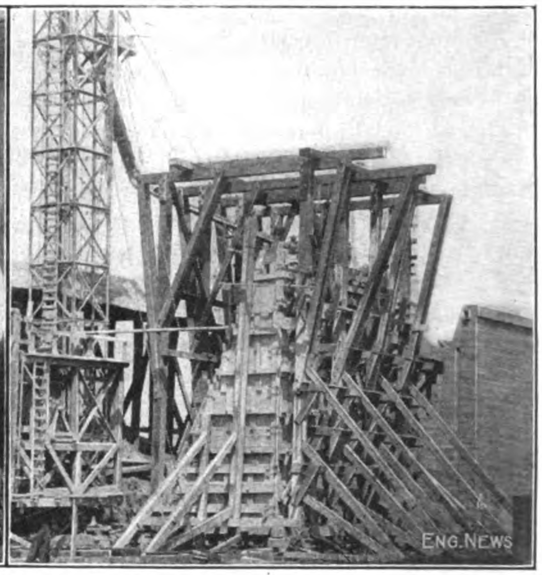

FIG. 6. BUILDING CONCRETE RETAINING WALLS IN TRAVELING TIMBER FORMS

The office car is an old mail car, remodeled, and has desks for the engineer in charge, office assistant, cost engineer, stenographers, etc. It is equipped with desk, file cases and other requirements, and has coat, wash and toilet rooms, the latter being connected to a city sewer.

The working force is varied as required, and ranges from 200 to 500 men. A special feature of the organization system is that each foreman employs his own assistants, and the assistants employ their gang foremen, while these last employ their own men, the appointments being in each case subject to the approval of the immediate superior. The gang foreman is allowed certain limits of pay for his men, so that he can adapt the pay to the market conditions and can also engage men of more or less skill according to his requirements. These gang foremen make daily reports on blank forms. The laborers are hired by the day, so that the force is continually being adjusted to meet the conditions.

The head of this special organization is Robert H. Ford, Engineer of Track Elevation (who reports to C. A. Morse, Chief Engineer of the Chicago, Rock Island & Pacific Ry.). Directly reporting to Mr. Ford are the general foreman, the chief clerk, the cost engineer, the assistant engineer (who is practically the resident engineer, and under whom are the inspectors and field engineers), and the trainmaster (in charge of work-train service). The general foreman has three assistant foremen, in charge of concrete, erection, and track and filling, respectively. Each is practically in entire charge of his work, the purpose being to give each man authority and responsibility, while the general foreman and engineer of track elevation have oversight of the whole force.

In addition, there are inspecting engineers on the work representing the city and the Chicago & Western Indiana R.R. (which latter pays a share of the cost of the 79th St. crossing). The principal officers are as follows: Engineer of track elevation, R. H. Ford; assistant engineer, C. P. Richardson; cost engineer, J. M. Weir; chief clerk, F. J. Nevins; trainmaster, G. R. Speer; general foreman, T. E. Reilly; assistant general foreman in charge of concrete work, A. L. Greenabaum; assistant general foreman in charge of erection, P. Franz; assistant general foreman in charge of track and filling, C. B. Teller.

COST-ACCOUNTING SYSTEM

A very complete cost-accounting system has been adopted for the purpose not only of keeping record of the unit and total cost, but also to see that the work is

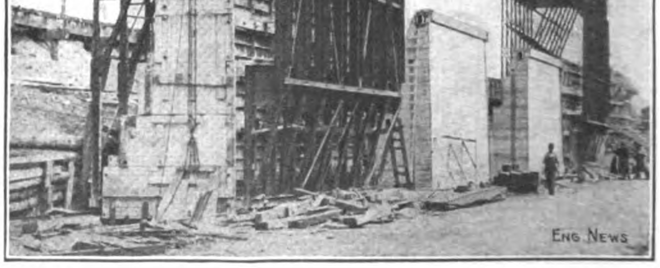

FIG. 7. BUILDING CONCRETE RETAINING WALLS IN 35-FT. SECTIONS IN TRAVELING STEEL FORMS; ROCK ISLAND LINES

done with the highest economy. For this latter purpose the cost engineer spends a good part of his time on the work, studying the methods and conferring with the foremen with a view to devising or suggesting ways in which cost may be reduced and economies effected.

An account is kept (and bulletined) of the amount of work done each week by each gang in the same class of work. In concreting, for instance, there is rivalry between the subforemen to make and maintain good records in this respect, and to do a maximum of work with a minimum of force and payroll. If the cost of any particular item shows an increase, the cost engineer makes an investigation as to the cause and its remedy. He has no authority to order any changes, however, and if the foreman should dissent from the suggestions made, the matter is submitted to the engineer of track elevation.

The reports of the gang foreman are handed to the cost engineer each morning, and he works out the total and unit costs, so that the exact results are known daily.

Concrete-Unit Building Construction at Cedars Rapids*

The large buildings of the Cedars hydro-electric development furnish a good example of the possible fields for the employment of concrete-unit members, molded and cured before placing in the superstructure.

The chief advantage of this scheme from the structural standpoint is the securing of factory conditions for manufacture, inspection and test, giving increased economy and reliability. In this case there were other practical conditions involved which opened the way for the use of this construction. The original plans of the power company called for steel-frame buildings with brick walls, but there were known to be necessarily many troubles and expenses in transportation of the brick since there was no direct railroad connection with the site and carload shipments had to be transported by car ferry on the Soulanges Canal. Straight reinforced-concrete construction was undesirable for the generator house, partly because of the need of using the frame of the building for cranes before concrete members would be sufficiently set. Moreover, the power-house structure was set on a long narrow dam serving also as the turbine casings and generator foundations, so that it was desirable to take as much work off the dam and out of the power house as possible, in order to facilitate the erection of the very heavy machinery. This was possible since the company owned plenty of shore land.

Before the decision was reached to use concrete inset units with the steel frame, the steelwork had already been designed for brick curtain walls, but the details did not require great change. The contractor for the unit construction undertook the erection of the steel, which, however, was furnished by the power company.

Power-House Construction

Walls—The exterior wall panels are 12 in. thick and are formed by two independent concrete slabs, 4 in. thick, with air space between. This provision of double walls was carried throughout the building (even double glazing was used in the windows) and was dictated by the severe winter conditions met with in this locality.

On the steel wall-column angles were riveted where necessary to form slots down which the concrete slabs were lowered. After two opposite slabs had been set (with mortared joints) they were held apart by a piece of 1-in. board slipped into notches in the slab as shown in Fig. 2. This served as a spacer for the slabs and a dam for the grout which was poured between column and slab. A concrete pilaster was cast in place after a wall panel had been completed. The window sills and some of the window jambs were made solid, 12 in. thick.

The crane girders and the main columns were designed to carry two 150-ton traveling cranes. The steelwork over the gates was designed for a single 30-ton crane. The roof trusses were designed for a load of 100 lb. per sq.ft.

Roof—The roof is made up of unit slabs, shown in Fig. 2. Each consists of a 3-in. reinforced-concrete plate, cast with integral beams along all four sides. Each roof-slab is designed as a beam between trusses, the flange reinforcement taking tension and the entire slab taking compression. A 1½-in. space was left between the ends of slabs over the center line of the trusses. These intervals, as well as the smaller ones between the sides of the slabs themselves, were filled with grout. Reinforcing bars 3 ft. long were placed in the spaces between units, passing over the roof trusses as a tie saddle.

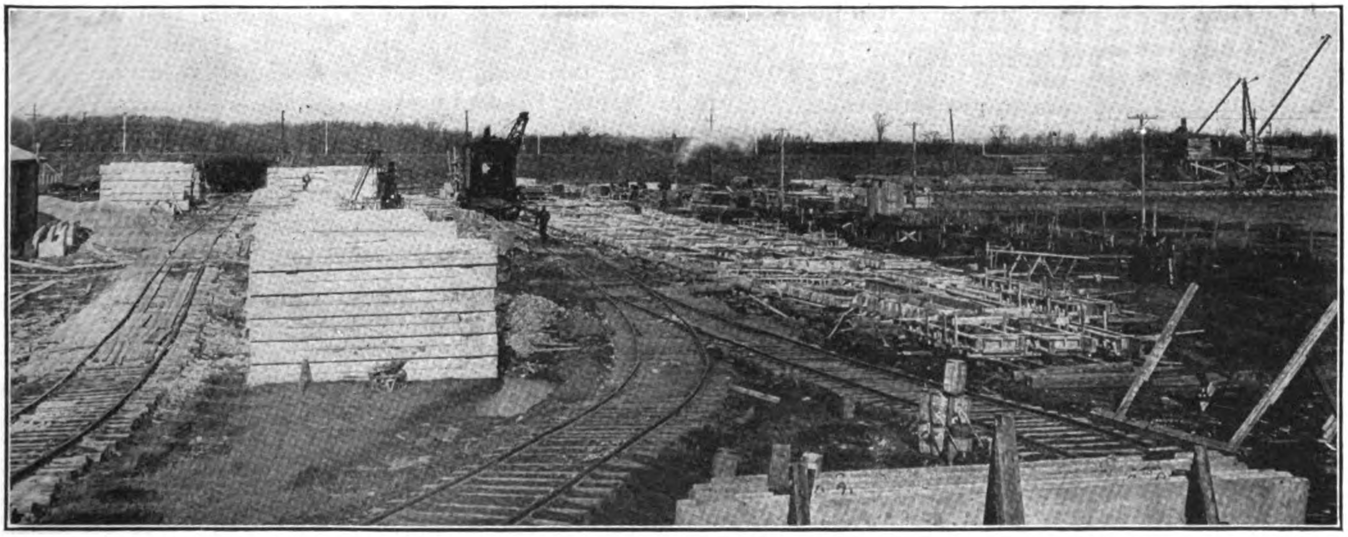

Fig. 1. Unit Casting Yard for Cedars Development

*The general design and construction of the Cedars hydro-electric works was presented in "Engineering News," Mar. 25, 1915. The turbines and electrical equipment were described Apr. 1.