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Canadian Society of Civil Engineers.

INCORPORATED 1887.

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THE CONSTRUCTION OF A SMALL TUNNEL.

By J. G. G. Kerry, A. M. Can.Soc.C.E.

To be read Thursday, 15*th March*, 1894.

INTRODUCTION.

The West Virginia & Pittsburgh R.R., a feeder of the B. & O. system, was built to open up the sparsely settled and formerly inaccessible counties of Central West Virginia. Topographically, these counties show series of heavy narrow parallel ridges with deep dividing valleys; these ridges run roughly east and west, and are some of the many chains of mountains comprising the great Alleghany range; the valleys are drained by tributaries of the Great Kanawha River, one of the main feeders of the Ohio. The slopes of these ridges are short and rough, and the line in its general course due southward cut directly across them, necessitating a difficult location with heavy grades and expensive work. At the divide between the Little Kanawha and Elk River valleys, it was found impossible to locate over the summit while maintaining the desired maximum grade of 1.5 per 100, and the tunnel whose construction is described in this paper was needed to pass this point.

The railroad was built by the West Virginia Improvement Co., of which Mr. J. A Fickinger was Chief Engineer and Manager, and the contract for this work was let in January, 1891, to T. J. Steers & Co. of Weston, W.Va.

LOCATION.

As finally located, the line passes through the north approach cut and into the tunnel on a 7° 30″ curve, the P.T. of which lies some 40 ft. beyond the portal; the remainder of the tunnel and the south approach cut are on the tangent to this curve. The tunnel is built on a 0.25 per 100 grade falling to the southward, and is on the summit between two 1.50 per 100 grades. The portals were laid out so that the cut on centre line at the head of the portal slope would be 50 feet, the distance between them being 624 feet.

MATERIAL.

The material through which the tunnel was driven was a soft blue clay shale, nearly dry, and showing little stratification. This shale rapidly disintegrated on exposure to the air, and tunneling through it without timbering would have been dangerous if not impossible. The company not being prepared to line the tunnel throughout with masonry at the time of construction, it was necessary to use a system of timbering amply strong for several years' service and large enough to contain the masonry when it should be built. The unusually large excavation section shown in Fig 1 (18.77 cub. yds. per lin. ft.) was rendered necessary by this double lining. The shale was overlaid with beds of heavy and strong sandstone dipping slightly toward the north and so low that near the north portal some of the sandstono had to be blown down to make room for the timbering.

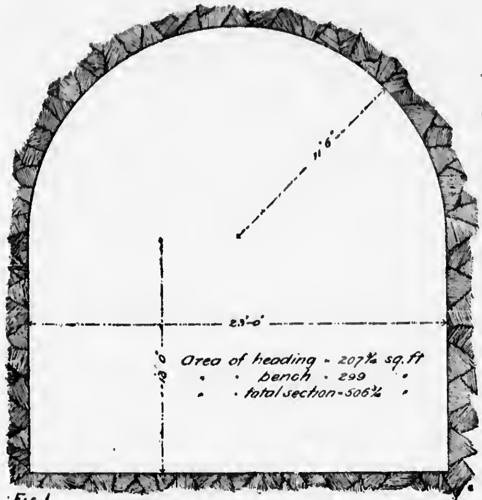

FIG. 1 EXCAVATION SECTION

METHOD OF EXCAVATION.

When the contractors had full forces, the excavation was carried on by day and night shifts, working ten hours each from both ends of the tunnel. It was but rarely, however, that full forces were employed, as the adjacent grading was more backward than the tunnel and the men were drawn off to it. The excavation was all done by hand work, no special tunnel machinery being employed, and it was conducted on the general principle that nothing is so expensive in tunneling as a cave-in

HEADING.

The shifts were divided into heading and bench gangs, the foreman of the bench gang being, however, subject to directions from the foreman of the heading. The heading gang consisted of a foreman, 8 miners, 6 muckers and a " nipper ; " and its work was to excavate the material from the bottom of the wall-plates up (7.70 cub. yds. per lin. ft.) to place the wall-plates in position, to erect the arches upon them, and to lag and pack the same.

Coming back into the heading after a blast, the miners first pulled down all dangerous material from the roof, then cleared away enough of the debris of the blast to give themselves working room, and proceeded with the drilling. Three sets of holes (two wet and one dry) were usually drilled in the face of the heading ; each set consisting of four holes about 4 ft. deep, the exact placing of each hole depending on the success of the last shot ; twenty-four lin. ft. of hole was considered a day's work for two miners. The holes were loaded with from 4 to 6 sticks ($\frac{1}{3}$ lb.) of dynamite apiece, and fired by battery or fuse, as might be desired ; as far as practicable, all blasts were fired at the end of the five hour spells, so that the dynamite fumes might dissipate during the idle hour ; the average fall from a heading blast was 2¼ ft.

While the drilling was progressing, the muckers cleaned up the heading, the scaffold car, Figs. 4, 5 and 6, being necessary for this purpose. This was a mounted platform, with height a little lower than the heading floor, and with its frame so arranged that dump cars could run right under it and be loaded through shoots from the platform above. It ran on a special track, and was provided with long detached planks which were laid from the platform on to the heading floor, the muck being wheeled down them and dumped through the shoots. The car was provided with a small derrick for handling timber, lagging and packing.

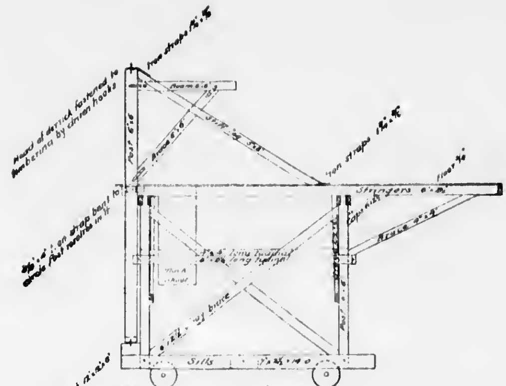

FIG 4 SIDE ELEVATION

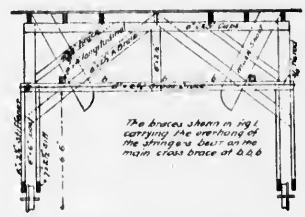

FIG 5 FRONT ELEVATION

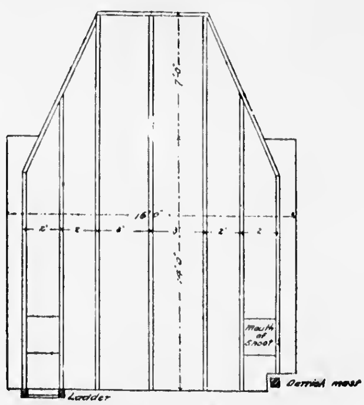

FIG 6 FLOOR PLAN

BENCH.

The bench gang consisted of a foreman, 8 drillers, 10 muckers and a "nipper"; and its work was to excavate the material remaining in the section (11.07 cub. yds. per lin. ft.), to place the plumb posts, and to lag and pack behind them.

After a bench blast, the whole gang was put at work cleaning off the rails of the scaffold car track, and pushing this up as way was made for it, it being always run back for safety before a blast. When the scaffold car was brought far enough ahead to communicate with the heading, the drillers cleared off places for their new set of holes, and went to work on them. The bench was shot down in four foot holds, two half-depth blasts being made for each hold; each blast consisted of four holes, two being centre holes and two drilled as nearly vertically under the inside edge of the wall-plate as possible; the charges were 10 sticks of dynamite to an outside hole and 15 to a centre one. The drilling and blasting of the bench though simple required skillful management, the points to be guarded against being: damage to plumb posts and arch timbers, danger of uncovering too great a length of the wall-plate at a single shot, and complete avoidance of any interference with the progress of the heading.

The muck was taken out to the dump in side-dumpers of about one yd. practical capacity run in trains of two, the heading muckers loading one through the scaffold car shoots, while the bench men loaded the other, the bench men having to clean up to the face of the bench before the next blast was ready. Where the rock shot down in large masses, progress was much aided by the use of stone flats mounted, so that the platforms were flush with the tops of their wheels, on to which heavy rock could be barred without blockholing or extra handling. The bench was kept about two wall-plate lengths behind the heading, and made the same average progress. This progress was about $2\frac{1}{2}$ ft. per shift; the actual excavation was made at a rate of 5 ft. per shift, but the time consumed in pointing down odd projections, timbering, lagging and packing being equal to that spent on rough excavation, the progress rate was only $2\frac{1}{2}$ ft. per shift.

PROGRESS OF EXCAVATION.

The north heading started under on April 17th, the south heading being delayed by a heavy approach cut until June 3rd. No record was kept of the monthly progress, the irregularities of the forces and delays occasioned by lack of timber rendered all such records valueless. The headings were holed on Sept. 17th, and the bench was finished by Oct. 15th, the work having been in progress for just six months. The heading was driven with great care, and no exceptional record was made until the night before the holing, when two gangs drove 20 ft. of heading of rapidly diminishing cross-section in a desperate effort to pierce the 24 feet remaining in the tunnel. The driving of the bench was of course limited by the heading, but after its completion the pick of the forces were placed on the bench, and with gangs increased to one foreman, 8 drillers, 12 muckers and nipper, the rate of progress rose to $3\frac{1}{2}$ feet per shift, the bench being blown in 6 ft. holds.

DIFFICULTIES IN EXCAVATION.

No trouble was experienced with the bench anywhere, but the heading was frequently in bad ground. At the north portal the top of the heading passed into a shattered bed of sandstone rock, which could not be shot down without disturbing a considerable amount of material on the portal slope. Here a 6′ x 8′ drift was made under the sandstone, and the heading expanded to its full section and timbered at the second wall-plate, and the first wall-plate length was driven outwards, the shattered rock being caught up by timbers as quickly as the excavation was completed.

As the tunnel grade fell and the sandstone rose to the southward, the heading was soon clear of the sandstone, which made an admirable roof for a season. The shale had very little adhesion to the sandstone, and when the sandstone bed and the tunnel section separated, it soon proved itself not sufficiently strong to hold up across the span by coming down in heavy falls, which left the bottom of the sandstone exposed. The material between the bottom of the sandstone and the top of the section was accordingly excavated, until its thickness grew such that the cost of its removal became an item of considerable expense when it was determined to hold it in place. This material where removed was classified as "fallen material."

Up to this point the system had been to drive a full heading for a wall-plate length, and then timber it up. This was now changed, and the heading was driven with an arched longitudinal section having full height at the end of the preceding wall-plate, and being barely high enough at the end of the new wall-plate to admit of its being easily placed. The new wall-plate being in position, the excavation necessary for each of its imposed arches was made separately, each being erected, blocked and partially packed before the excavation for the succeeding one was commenced. The last arch being up, the heading was again driven forward for a new wall-plate. Side drifting to place the wall-plates, on which the arches were then built as in the method just described, was tried, but was almost immediately abandoned as more costly than that method.

It is only just to remark that, owing to the great care thus taken by the contractors in all doubtful places, neither fatality nor accidental interruption occurred during the progress of the work.

TIMBER.

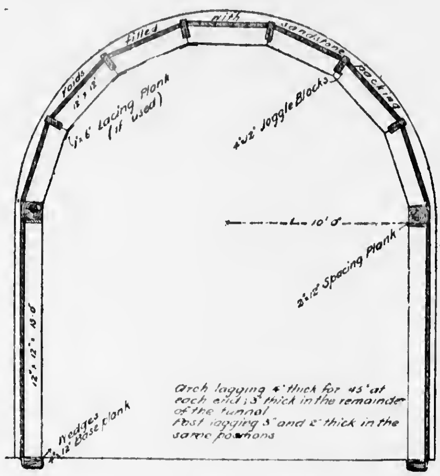

FIG 2 SECTION OF TIMBERING

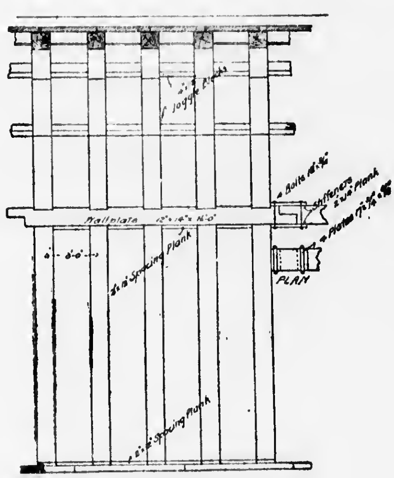

FIG 3 ELEVATION OF TIMBERING

The system of timbering is shown in Figs. 2 and 3. All timber was of white oak, and was carefully inspected; all sticks had to be in a thoroughly sound condition, and arch segments were rejected if they showed any sign of longitudinal cracking or splitting. The system of erection was as follows:—

The heading being ready, a pair of wall-plates were brought in, and the engineers were sent for, to superintend the placing of them. This operation is described further on. The wall-plates were 12″ x 14″ x 16′—0″, and as the theoretical springing of the arch was at the lower side of the wall-plate, radial beds were adzed on its upper side, to make bearings for the arch timbers; the wall-plates were jointed by halving for a foot at each end, and were made in pairs, right and left, so that the forward end when in position might always show the lower section of the half-joint, that being a material advantage in the placing of the plates. The wall-plates being in position and securely blocked against outward and downward movement, the joints were secured by tightening up the clamps. The detail of these clamps is shown in Fig 3. Stiffening planks 2″x 14″ x 2′–0″ were placed above and below the jointed plates, and drawn against them by tightening up bolts working through pairs of transverse straps. These bolts and straps are entirely outside the timber, and comprise all the permanent iron in the tunnel.

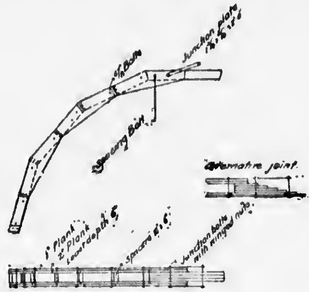

FIG 7 CENTRING FOR TIMBER ARCHES.

The arches were erected on the segment centres shown in Fig. 7. The arches are of 12″x12″ timber, in seven segments, the segments being cut to template, and were erected by simply laying each segment in place on the centres. The centres were erected by jointing the two segments by the bolts shown in Fig. 7, and then blocking up their feet to proper position; the long hook shown in the same Fig. was driven into the preceding arch, and served to hold the frame in position at its proper spacing; the second system of segment joint there shown proved the better in practice, being more readily handled. The arch segments being up, they were blocked solidly from the roof against all upward and outward movement, and 4″ x 12″ joggle-blocks with 8″ shoulders were placed between consecutive arches at each joint. The centres were then withdrawn and the lagging commenced. The lagging was close-laid in lengths equal to the arch spacing and the bottom piece bore on the projecting back of the wall-plate. All voids back of the lagging were filled with broken sandstone brought into the tunnel for the purpose, and hand-laid. The use of sandstone was insisted upon because it was feared that the shale would deteriorate in time and yield under pressure if used as packing, thus giving the masses above a chance to start moving. The lagging and packing were carried up simultaneously, the packing of the crown segment being completed from between the next arches; and the timbering was completed by nailing up the two lines of 1″x6″ lacing plank at each joint. These lacing planks were to protect the corners of the segments from blasts, and were torn down after the tunnel was completed. They had the demerit of hiding the condition of the joint, and were accordingly omitted in bad ground.

BENCH TIMBER.

As the bench was removed, the wall-plates were caught up on the plumb posts, due watch being kept that no length of the wall-plates was at any time left without ample support. The posts were underlaid by 4″x12″

plank in 6 feet lengths, and wedges bearing upon these planks were driven until the post took a full bearing against the wall-plate above. The posts were spaced by 2"x 12" plank at foot and head. The lagging and packing were carried up simultaneously from the floor level, but it was not considered necessary to keep this work right up as in the case of the arch logging, and it often fell considerably behind, the shale on such occasions proving itself amply strong to stand without support during the short period of exposure, the rate of disintegration being very slow in the unchanging atmosphere of the tunnel. No provision was made in this system for side long pressure, and no need of such provision was developed.

DIFFICULTIES AND ALTERATIONS OF TIMBERING.

The details of the system were varied to suit circumstances. The heaviest pressure (immediate and future) was anticipated at the portal, and the end wall-plates were accordingly carried well out, and all the ragged voids between the lagging and the portal slope filled with timber blocks; and for the first 45 ft. at the entrance 4" lagging was used over the arch, and 3" behind the plumb posts, these being reduced to 3" and 2" respectively for the remainder of the tunnel. The arch and plum. post spacing was 3 ft. centre to centre: a proposition to maintain the hickness of the lagging at the end of the first 45 ft. and to increase the bib spacing being considered and rejected.

As described hereafter, the wall-plates were set narrow, high and canted slightly inwards, the effect being to leave the segment joints open at the back and tight on the front, so that the joints would take a full bearing when the pressure came on and the edges yielded under it. Near the centre of the tunnel it was noticed that the joints of the arches on three wall-plates had opened at their lower edges indicating heavy downward pressure. The wall-plates were immediately dapped to receive extra arches; these were similar to the existing arches in every respect, except that one of the end segments was cut off short and wedges were placed between it and the wall-plate, by driving which the arch was forced to a full bearing against the lagging. For two wall-plates after this occurrence, seven arches were placed on a wall-plate instead of five; but as the indications of pressure then ceased, the five were again adopted.

GRADE AND ALIGNMENT.

By reason of the general plan of construction necessarily adopted, the company had to excavate a large and expensive section; but this section was reduced wherever practicable, and thus the clearance between the systems of lining was reduced to a minimum, necessitating very careful placing of the timbering. The wall-plates were the determining members of the timber system, and they were, therefore, placed by the engineering staff. The plan of operations was as follows:

Taking advantage of the fact that the main tangent in the tunnel passed out of the portal at the curved end well within the section, this line was established by five hubs, one over each portal, to serve as back-sights, one on the summit and one well away from each portal, in such position as to command a full view of it. These latter served as instrument stations, and from them the line could be run right into the heading when necessary. No permanent points were established in the tunnel, the line being always brought up from the outside points when required; the P.T. was established temporarily and the curve run in from the tunnel tangent. The signal used in the tunnel was a small miner's lamp with a plumb bob hung below the centre of the flame. When the tunnel was smoky, recourse was had to the gasoline lamps used to light the tunnel. These were known as "electric torches," and had a long pendant arm of gas pipe terminating in a bend and a small circular nest of burners, the plumb bob being attached to the centre of this nest. On very bad days for seeing, the speediest method was to establish points on the tangents as far as could be readily seen, and then to move the instrument up into the heading and get it into range with the points. When needed, the line was marked by a temporary point opposite the forward ends of the new wall-plates, the position of the last wall-plate being always tried as a check. The level was then set up in the heading, bench marks being established in the tunnel, and the wall-plate was alternately shifted in grade and alignment until both were satisfactory. A miner's lamp, held close to the face of the rod, proved sufficient to illuminate both it and the cross-hairs of the instrument. The wall-plates were normally set ½" narrow, ½" high, and canted slightly inwards, these allowances being made to provide for the unavoidable settlage under compression. When the heading was holed, the line and levels met within ¼ inch.

MEASUREMENT OF EXCAVATION.

At every set of timbers a regular series of offsets was taken by the inspector from the outside of the frame to the face of the rock, four measurements being made from each plumb post, one from every arch joint and one from the centre of each arch segment; the measurements of the sets on each wall-plate were averaged, and these averages were recorded as the measurements of that wall-plate length and the area and contents calculated therefrom; the recorded measurements read as if taken from the arch centre. The system of measurement proved very convenient; the step by step method of excavating and timbering would have seriously hampered any other system, but with this the inspector could always make his measurements whenever the excavation was complete and the timber frame in place, and the lagging and packing might immediately proceed. Any error in the relative placing of the timbers would, however, be reproduced in the measurements. These sections were taken as a precautionary measure, it being specified that the work would be paid for by theoretical dimensions.

COST.

The prices and costs were as follows:

11,726	Cy. Excavation	at $2.85	$33,419.10
742	Packing	1.75	1,298.50
256	Fallen Material	1.25	320.00
303,000	Ft. B.M.	30.00	9,090.00
	624 lin. ft. of tunnel		$44,127.60

these figures being contract prices, the actual cost being probably in the neighbourhood of $35,000. In the approaches the prices were solid rock, 80 cts. per cub. yd.; loose rock, 40 cts.; and earth, 20 cts. White oak timber was delivered on the ground for $15.00 per M., and cost $3.00 for framing. Common labour was worth $1.45 a day in the tunnel, and the miners were paid $1.75.

MASONRY.

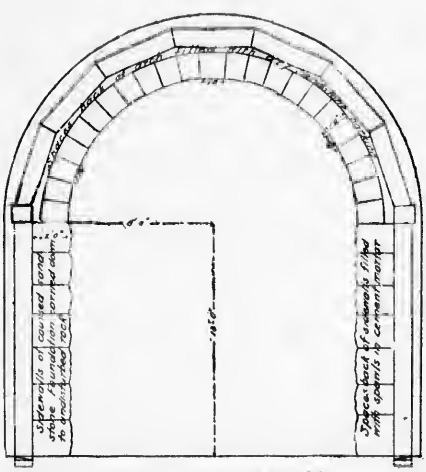

FIG 8 SECTION OF MASONRY

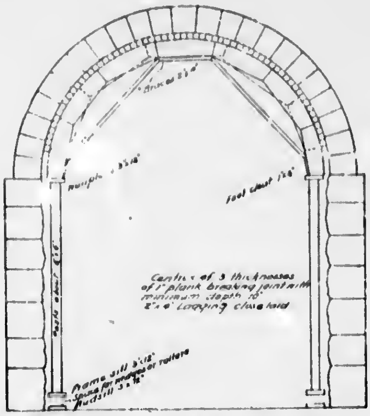

FIG 9 CENTRING FOR MASONRY

On considering the permanent stability of the tunnel it was thought that if any ground movement should occur such as would bring heavy pressure upon the lining, it would be in the vicinity of the portals, while the timbering would decay most rapidly at the same place. It was therefore determined to put in portals and to build the masonry lining for fifty feet at each end. The masonry section is shown in Fig. 8. It was built of red sandstone, very coarse in structure and well adapted to resist the action of heated gases. The sidewalls were laid in courses, all stones being two feet or more thick, and the bottom courses were extended into the tunnel, so that the ends of the courses might be racked off continuously from base to keystone, and the wall thus left in good condition for bonding on the resumption of work on the lining. The spaces between the plumb posts were filled with spawls in mortar. These walls were built with a small derrick set up without stiff-legs or guys, the pin at the top of the post being placed in an auger hole bored in the crown segment of one of the arches; and although the segment was not fastened in any way, the joint and lagging friction proved sufficient to overcome any stresses from the derrick tending to move the segment. The centring for the arch is shown in Fig. 9. The centres rested on a 3″ X 12″ wall-plate supported by rough 6″ X 6″ posts bearing on a 3″ X 12″ frame sill. The frame sill was carried by wedges working against a 3″ X 12″ mud-sill; the range of these wedges was large, so that the centres would be considerably lowered when the wedges were struck, and the whole section of cent[illegible] might then be run ahead on small rollers placed on the mud-sill. With that purpose in view the posts were set far enough away from the side-walls to clear the quarry face projections of the stones, and the first few pieces of lagging were omitted on each side of the centre. The section of centring used was about 25 ft long, the centres being spaced 3 ft. centre to centre; the centres were built of three thicknesses of 1″ plank breaking joint, and with a minimum depth at joint of 10 inches; the lagging was 2″ x 4″ laid on the flat; the consecutive posts were fastened together by irregular diagonal bracing. The masonry arch was 18″ deep, the voussoirs measuring $1' - 0\frac{3}{4}''$ on the intrados and the keystone $1' - 3''$; all joints were $\frac{1}{4}''$; and the voids between the masonry and the timbering were packed with dry sandstone, hand laid. By reason of the impracticability of the ordinary methods of handling stone in the confined space between the lagging of the centres and the timbering of the tunnel, special methods had to be resorted to. The method employed was to leave an opening in the crown lagging of ample size to pass any of the arch stones, above this opening a piece or two of the tunnel lagging was removed, and an iron bar placed upon the timber arches. A set of blocks were attached to this bar, and with their aid the arch stones were run up till they passed through the lagging, when they were swung off on to it. The difficulty was to get headway enough for the blocks to work in. Gas pipe rollers were placed under the stone, and it was run along on its side until it came opposite its destination. It was then canted upright, there being room to cant the stones at the joints of the timber arch only, and a single rope was passed round it. Six men were needed to bring it to place, two holding back on the rope from the opposite side of the centring, two aiding the slipping of the stone and guarding its edges from spawling, and two masons being below to receive it, throw off the rope and set the stone accurately, it requiring decided skill to bring the stone to its right place with an even mortar bed under it. The keystone was run into place dry and grouted. The head-wall of the portal was a rectan-

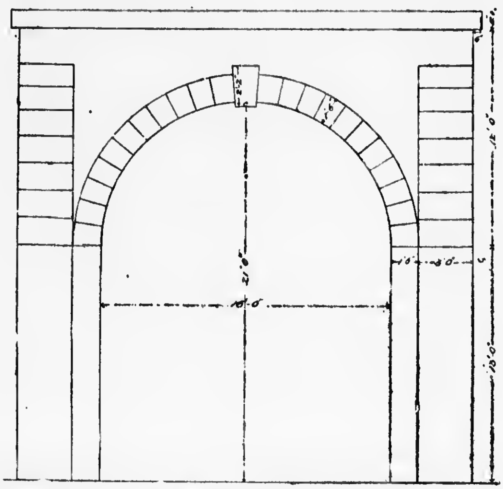

Fig 10 ELEVATION

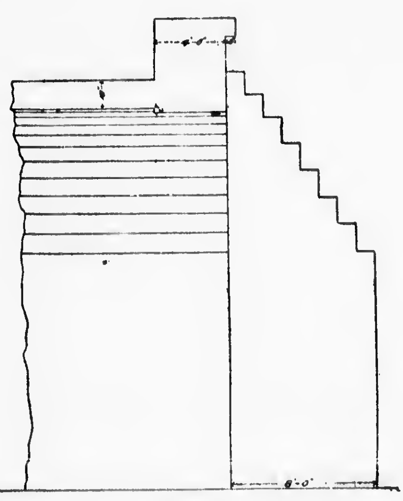

Fig 11 LONGITUDINAL SECTION

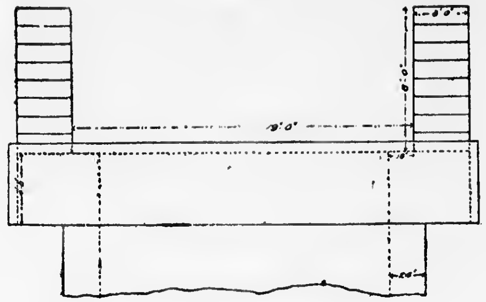

Fig 12

PLAN

gular block of masonry 25′ – 0″ X 26′ – 0″ X 4′ – 0″. It was laid as first class work, and the bond with arch was made by creepers. It was held that it was necessary to support these head-walls by buttresses, it being known that unsupported head-walls in tunnels in the same section of the State had failed under a gradually increasing movement of the material on the portal slope, this movement sometimes only commencing years after the completion of the work. The buttresses built were 8′ – 0″ X 3′ – 0″ in plan, and were stepped back towards the head-walls commencing at the springing level.

The prices on this work were $9.00 a cub. yd. for portal masonry, $8.00 for side-walls and $14.00 for arch sheeting. This cost was not included in the tunnel estimate before given, as the work was only partially done, and because the detail of the lining would probably be altered by the employment of a cheaper material when transportation facilities were obtained. The cost of one portal complete was:

76.5 cub. yds. portal masonry	@ $9.00...........	$688 50
6.1 arch masonry	@ 14.00...........	85.40
		$773.90

and the cost per lin. ft. of lining was:

Sidewalls	2.57 cub. yds.	@ $ 8.00................	$20.56
Arch	1.53	@ 14.00..................	21.42
Packing	1.19	@ 1.75................	2.08
		Lining per lin. ft........................	$44.06

In the estimate before given the cost of excavation, tinbering, etc., was $44,127.60 for 624 ft., so that the total cost per lin. ft. of completed tunnel would be (excluding portals, fallen material, etc.):

Excavation..	$53.55
Packing..	2.08
Timbering..	14.57
Side-walls..	20.56
Arch..	21.42
Packing..	2.08
	$114.26

The whole work was carried through in a style that was entirely satisfactory to the chief engineer. Mr. Jos. N. Allston was resident engineer in charge, and the management of the construction was in the hands of Mr. John E. Dongher of T. J. Steers & Co., and most of the practical points in the system above described were an outcome of his great experience as a tunnel builder.