little more than 26,250 feet. The great tunnel, with its length of more than 3 miles, is by far the longest in Turkey. It is only exceeded in length by the great tunnels in the Alps and elsewhere. Still, the technical difficulties which had to be overcome in piercing through have been just as great as those encountered in the Alps. In fact, for several hundred yards, the engineers encountered a rock of practically pure quartz, which was so hard that it was necessary to have recourse to boring machines of special construction."

The Railway Review has received a request from E. E. Betts, superintendent of transportation of the Chicago & Northwestern Ry., that further explanation be made of the fact that the article entitled "Promoting the Proper Handling of Equipment," appearing in our issue of October 16, with Mr. Betts as author, is the joint work of a committee of the General Superintendents' Association of Chicago, the several members of which are equally entitled to a share in the credit for its authorship. Included in this committee with Mr. Betts were: W. E. Beecham, car accountant, C. M. & St. P. Ry.; E. H. DeGroot, superintendent of transportation, C. & E. I. Ry.; L. M. Betts, car accountant, Chicago Belt Ry.; P. Meininger, assistant to the president, B. & O. Chicago Terminal R. R., and F. C. Schultz, chief interchange inspector, Chicago Car Interchange Bureau.

If the subscriber from Jacksonville, Fla., whose interesting communication on the subject of a method of setting the Walschaert valve gear has been received, will kindly disclose his identity to this office we will gladly arrange for the publication of his remarks and solicit a discussion pertaining thereto at an early date. It is contrary to the policy of this paper to make use of communications of unknown authorship.

Modern Methods in Railway Tunnel Construction

By Charles S. Churchill, Assistant to President, Norfolk & Western Ry.

Methods employed in later years in the excavation and lining of railway tunnels. The examples used are long tunnels recently constructed or now under way. The Sandy Ridge tunnel, of the Carolina Clinchfield & Ohio Ry., here omitted, was illustrated and described in the Railway Review of Sept. 11, 1915. Tunnel enlargement, also, is treated. From a paper presented at a meeting of the International Engineering Congress, San Francisco, Cal., Sept. 20-25, 1915.

Introduction.

The construction of tunnels in America in recent years has been much more rapid than is indicated by the increase in the mileage of the railroads themselves. Their need has arisen from three causes:

1. From the construction of new railroad lines.
2. From the improvement of alignment and grades; also in connection with the double-tracking of existing lines, and enlargement of sections that are considered small.
3. From the construction of important terminals.

While those of the first and third classes are generally described in the various engineering publications, many of those included in the second class, which are the more numerous, do not appear. For example, on a railroad having

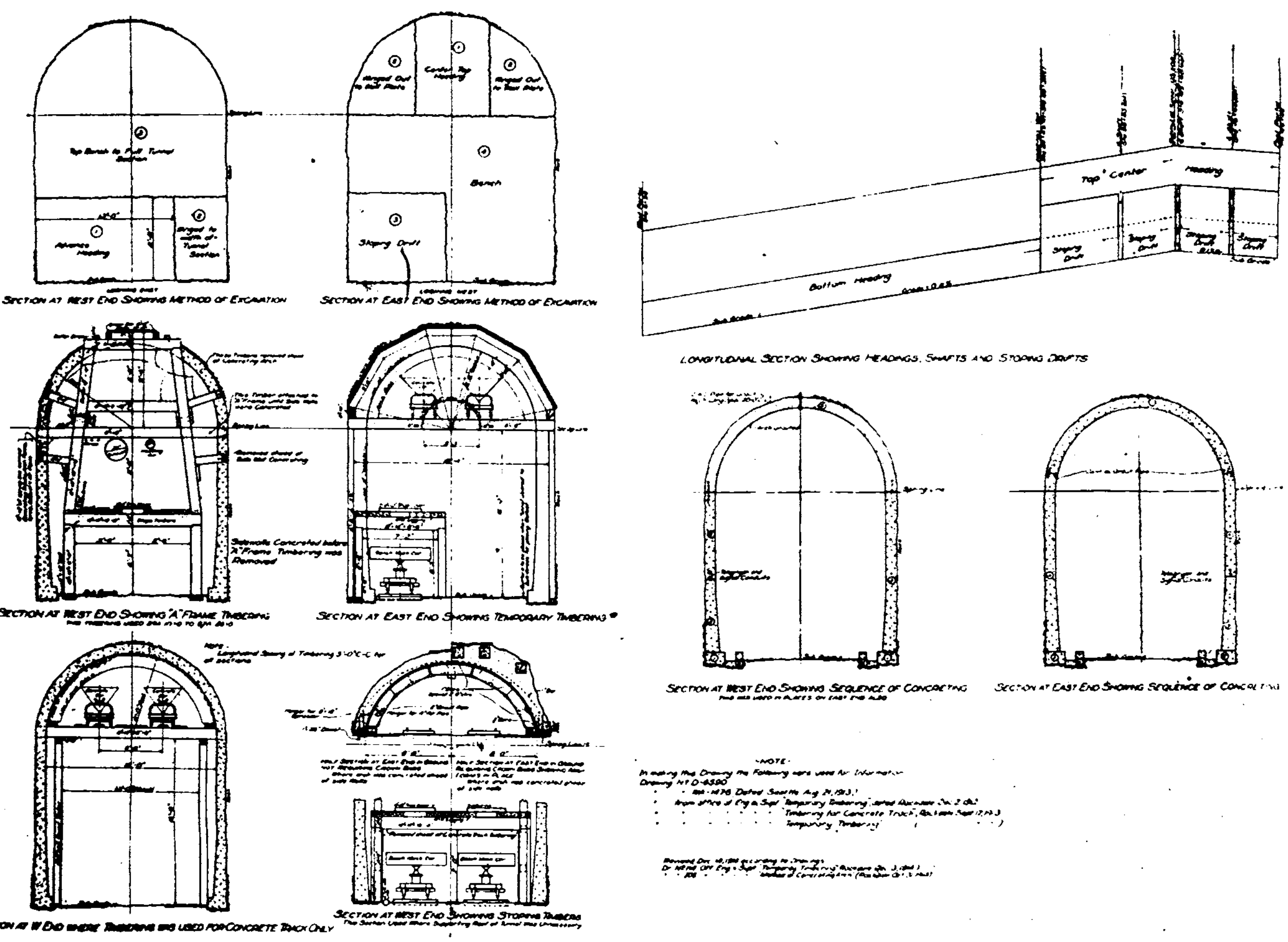

Fig. 2—Timbering Schemes and Stages in Excavation and Construction, Snoqualmie Tunnel, C. M. & St. P. Ry.

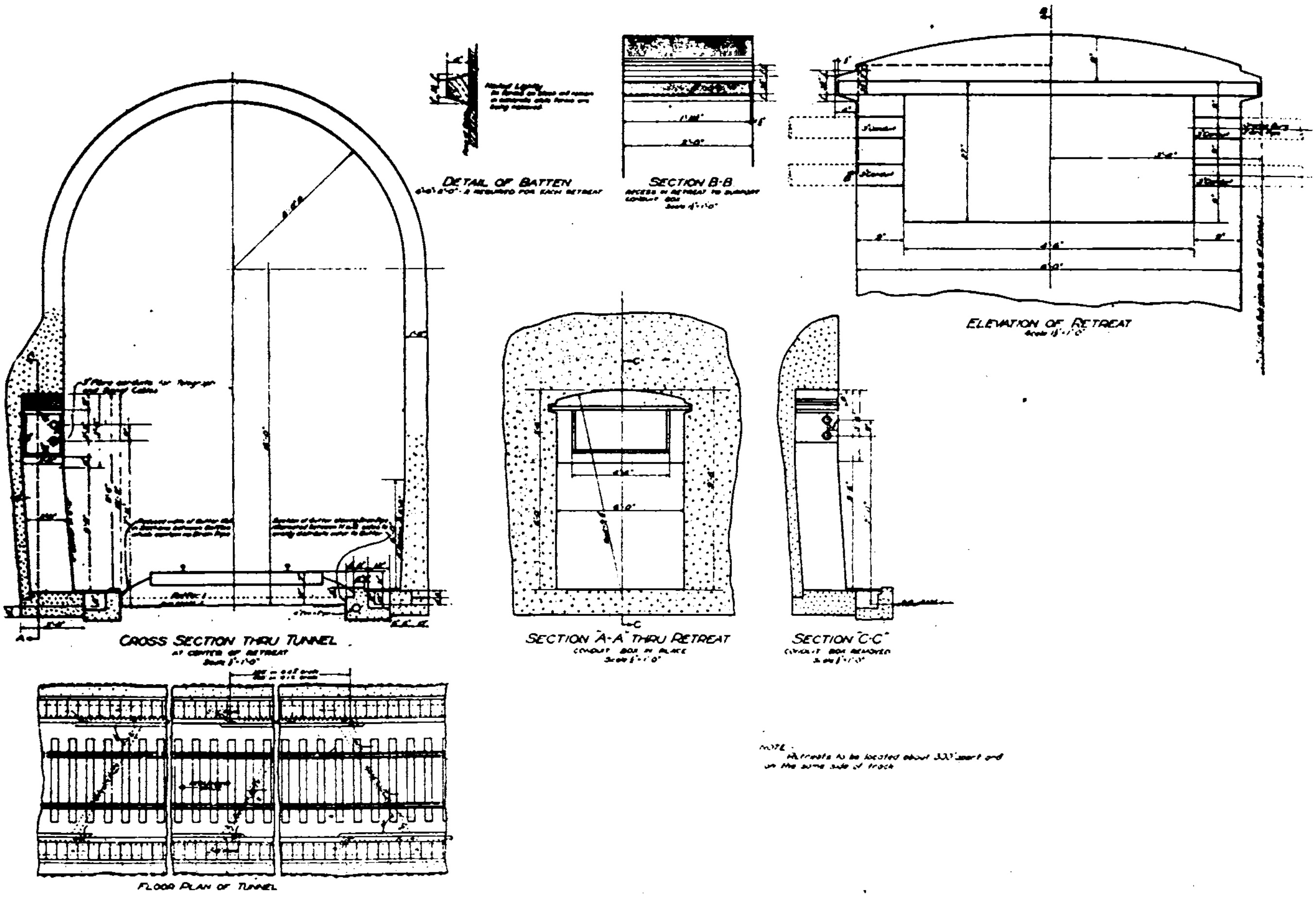

Fig. 3—Cross Section and Retreat Details, Snoqualmie Tunnel, C. M. & St. P. Ry.

a present length of a little over 2000 miles, there were added since 1904 for the construction of branch lines twelve tunnels of an aggregate length of 7863 ft., the maximum length of any single tunnel being 4770 ft.; while those added in connection with double-track and improving lines and on low grade lines, numbered thirty-two, of an aggregate length of 32,251 ft., the maximum length of any single tunnel being 3291 ft.

Some examples of tunnels constructed for these reasons and coming under the second class, are:

The Snoqualmie tunnel through the Cascade mountains (Chicago Milwaukee & St. Paul Ry.), 11,890 ft. long. Completed January, 1915.

The Rogers Pass tunnel on the Canadian Pacific Railroad, which will be a double-track tunnel five miles in length, the work on which was begun in 1913.

The Nicholson tunnel, on the Delaware Lackawanna & Western Railroad, a double-track tunnel 3630 ft. long, to be completed early in 1915.

Examples of the third class are the Seattle tunnel, which is a double-track tunnel for terminal purposes at Seattle; length, 5141 ft.; completed in 1905.

The Mount Royal tunnel, on the Canadian Northern Railroad, Montreal, Canada, which is a double-track tunnel 17,000 ft. long, built for the purpose of entering the terminal station at Montreal; completed in 1914.

The tunnels under Bergen Hill, North River, City of New York, and East River, which provide entrance into New York for the Pennsylvania Railroad System, and which have been in operation for some time, are built for two or more tracks for a length of 27,052 ft.

The American Railway Engineering Association in its Manual of 1911 publishes therein, as representing good practice for new construction, single-track tunnels 16 ft. wide, with a clear height from base of rail of 22½ ft.; double-track tunnels to furnish the same clear width outside of each track and the same height over the center of each track. The tunnels constructed during recent years approach these dimensions where steam locomotives are used exclusively, but where electric power is used much smaller cross-sectional area is followed in good practice. The Mount Royal tunnel referred to, at Montreal, and the Pennsylvania tunnels in New York present examples of these.

With the rapid increase in the use of electric power it is probable that not only will it become unnecessary to widen many existing tunnels, but tunnels that are built in the future will be of this smaller cross-sectional area; such, for example, as the single-track section of the Pennsylvania tunnels in New York, which has 225 square feet of area above the track. It may be said, therefore, that, so far as dimensions of cross-sections are concerned, the art of tunnel design is in a state of transition, in that those dimensions depend upon the probable style of power that will hereafter be used.

The methods of constructing tunnels, involving elements that make up the cost thereof, have also been in somewhat of a transitional state during recent years on account of the effort of every party interested therein to secure their construction at a comparatively high rate of speed and still at as low a total cost as was practicable. The brief outline which follows, of the methods used in constructing a number of recently built tunnels, has been compiled in order to call attention to, and bring out discussion of, the different typical methods of construction that have been followed in recent years, under the usual varying conditions met with in tunnel work—methods that have been used, primarily, for the purpose of securing speed, combined with safety, economy in construction, and the best means for securing proper ventilation.

In this outline, the areas of cross-sections are given, and the number of cubic yards of material removed per foot of advance of both heading and entire tunnel section are recorded, together with the rates of progress, in order that a correct comparison may be made of all the results secured under each method of procedure.

The Snoqualmie tunnel is on a change of line at Snoqualmie pass, Cascade mountains, 60 miles east of Seattle, Wash., on

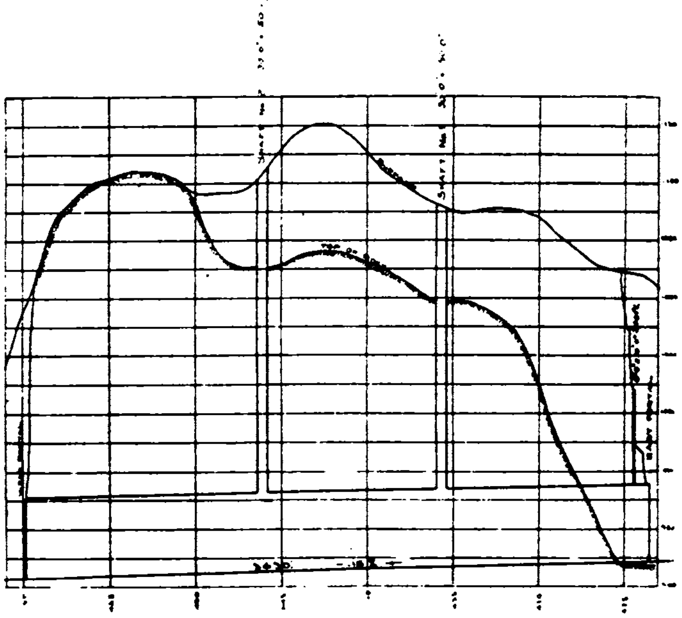

Fig. 4—Cross Section of Nicholson Tunnel, D. L. & W. R. R.

the Chicago Milwaukee & St. Paul Ry. It is a single-track tunnel, 11,890 ft. long, opened for traffic in January, 1915. The length of new line, including tunnel, is 4.5 miles. The object of building this tunnel is to shorten the length of line 3.7 miles; reduce the summit hill, and eliminate 443.5 ft. of rise and fall (made up of westbound 4.7 miles of 2.2 per cent grade, eastbound 4.4 miles of 2.75 per cent grade); to cut curvature 1239°; to decrease snow trouble resulting from a fall exceeding fifty feet in some seasons; to reduce pusher service to a minimum and save in operating cost.

For the greater portion of the distance the bore passes through bodies of massive black slate, intercepted by comparatively thin strata of grey quartzite, blue conglomerate and an andesite dike; all of which dip to the east with an angle of approximately 75 degrees to the horizontal. The formations are generally shown in Fig. 1, which also shows the location with plan and profile of tunnel.

Figure 2 shows method of excavation and plan of doing the work.

Figure 3 shows the completed cross-section of the tunnel. The width of the completed tunnel section is 16 ft.; area to subgrade, 352 sq. ft.; area above track, 337 sq. ft.; crown of arch to base of rail, 22 ft. 5 in. Average section excavated, about 517 sq. ft., making about 19.2 cu. yds. per foot of tunnel. Owing to the nature of the ground—there being much debris, fractured rock and water—the 436 ft. of the west end of the tunnel were driven by the top heading method, and enlarged and timbered to a standard section to allow concrete lining without removal of the timber. The remainder of the work from the west end was done by the bottom heading method, which was considered most economical, as providing means for trapping material from above directly into cars in the completed heading, and because progress in removal of the balance of the section was not dependent upon the use of shovel.

A heading 8x13 ft., requiring removal of about four cubic yards per foot advance, was driven at subgrade and along the north line of the tunnel section and was kept from 1000 to 2000 ft. in advance of the bench, the distance varying with the progress of the bench, which was dependent upon the labor situation. The order of procedure is shown in Fig. 2.

Work in the heading was carried on continuously, the crew consisting of three shifts of four machine runners, four helpers, ten muckers, two nippers and two shift bosses. The runners, helpers and muckers worked six-hour shifts, laying off twelve; the nippers and shift bosses worked twelve hours.

Fourteen to thirty 9-ft. holes were drilled for each shot depending on rock encountered, the drills being mounted on a cross bar, 4 ft. above subgrade, four holes being drilled below the bar, acting as lifters, and all others above the bar.

The average break per shot was about 6.1 ft.; average time between shots, 15.5 hours; and average daily progress, 9.5 ft.; maximum progress in any one day having been 25 ft.

These figures are averages for the entire distance of west heading; however, under favorable conditions a shot was fired about every twelve hours, the time being divided about as

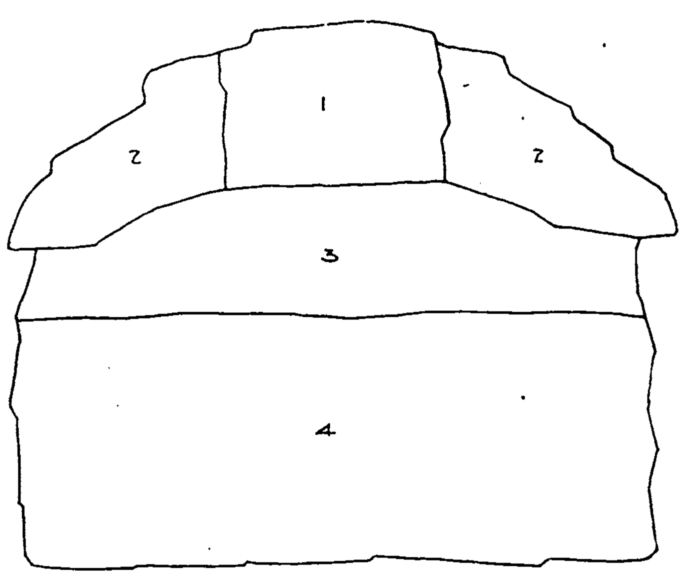

Fig. 5—Excavation in Rock, Nicholson Tunnel, D. L. & W. R. R.

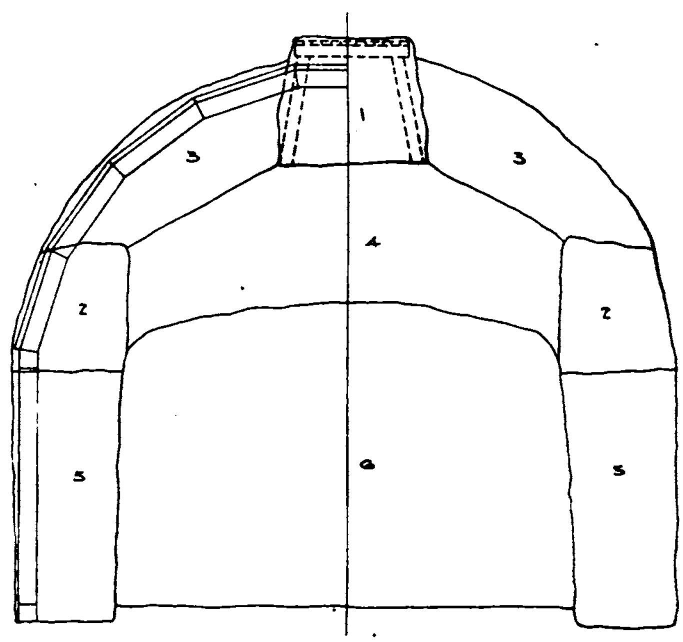

Fig. 6—Excavation in Soft Ground, Nicholson Tunnel, D. L. & W. R. R.

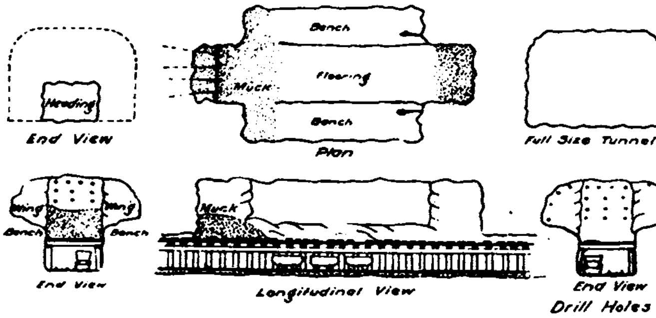

Fig. 7—Details of Construction, Mt. Royal Tunnel, Canadian Northern Ry.

follows: Two and one-half to three hours breaking down roof and mucking back; seven hours setting up cross-bar, drilling and mucking out; one hour taking down, clearing and shooting; and one hour waiting for the heading to clear of the gases. Many exceptions to the above were encountered, an example being the andesite dike where twenty four hours were taken to drill one round. Before a shot was fired, steel shoveling sheets were laid on the floor and up against the face of the heading so that the muck, which was broken finely, could easily be shoveled to the low heading cars of one yard capacity.

All heading work was considered "preferred" and carried a bonus to all directly connected; a bonus of one hour's time being given for each foot over 10 ft. per day, the bonus being paid every ten days.

Following the advance heading a crew winged it to full tunnel section width, after which the trap or stoping timbers were placed. Bench openings were then driven to full tunnel section at intervals of a hundred and fifty feet, from which the bench was worked both ways. As a usual thing the west end was standard tunnel timbering, to be concreted in place; the remainder of the work had stoping timbers, to take out the bench, and where the roof was at all treacherous, an "A" frame was built up from the stope bent and the roof held by crown bars, all to be removed ahead of the concreting; where the roof was good, the stoping timbers were taken down and moved ahead. "A" timbers were used from Station 10 to Station 26; remainder of tunnel, except in a few places, was not timbered, as the lining work followed the bench closely.

Work at the east end of the tunnel was not started until in 1913, and due to the fact that the approach cut was not completed the tunnel was driven by the center top-heading method. The amount excavated per foot advance in heading averaged about 2½ yards. The heading was winged to the wall plates; shafts were sunk to subgrade at several places and bottom drifts run both ways so that when the approach cut was complete the bench material could be stoped out, as on the west end, the material being used to make the fill for the railroad yard at the east end of the tunnel.

Driving data, west end, are as follows: prior to April 26, 1912—436 ft. top heading. June 1, 1912, to August 4, 1914—6971 lineal ft. of bottom heading. Average per day, 9.5 ft. Maximum progress per day, 25 ft.; 77 days shut down to wing out. Average progress per shot, 6.1 ft. Average time between shots, 15.5 hours. Maximum monthly progress (March, 1913), 455 lineal ft.

Driving data, east end: May 1, 1913, to August 4, 1914—4483 lineal ft. of heading; average per day, 10 lineal ft.; average progress per shot, 5.4 ft.; average time between shots 13.1 hours; maximum monthly progress (September, 1914), 433 lineal ft.

Bench progress for the west end is as follows: average progress, 7.7 ft.; maximum monthly progress (November,

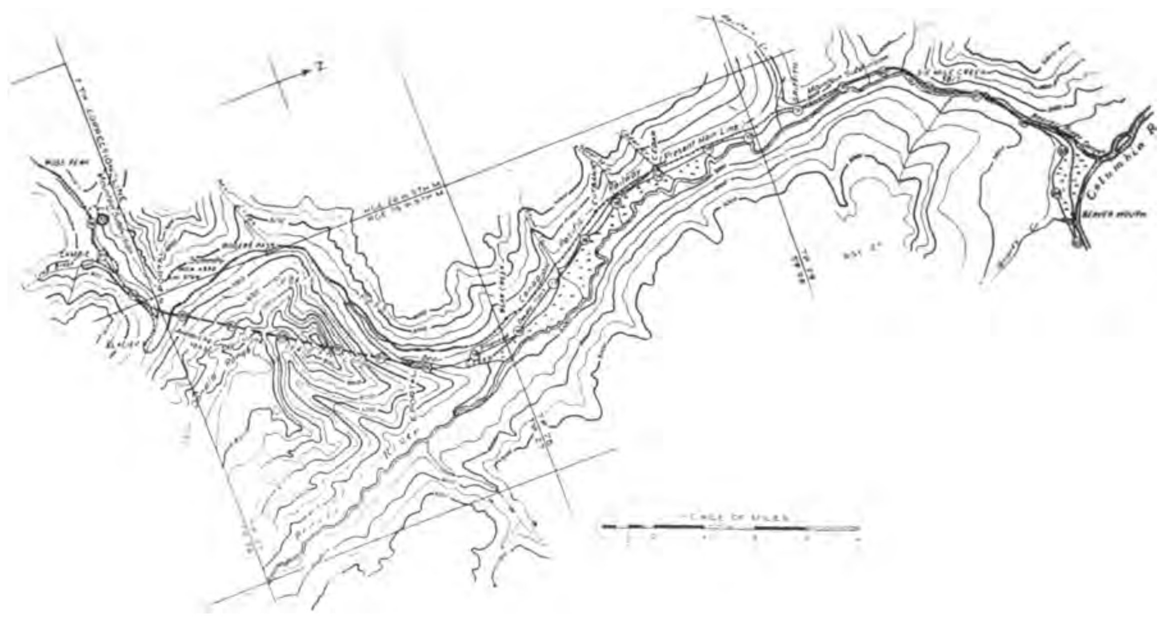

Fig. 8—Revised Alignment Between Ross Peak and Beavermouth, Showing Location of Rogers Pass Tunnel, Canadian Pacific Ry.

1914), 658 lineal ft. For the east end: average progress, 10.3 ft.; maximum monthly progress (November, 1914), 644 lineal ft.

Dynamite used per foot advance of tunnel, 55¼ lbs., costing $8.27. Quantity of dynamite used per cu. yd. of tunnel excavation, 2.8 lbs.

While the rock encountered was hard and unaffected by weather, it was so stratified, fractured and filled with soft talc seams that lining throughout was a necessity. The lining section is shown in Fig. 3, a comparatively simple section

the entire face was drilled and shot at one time, in that way giving the machine runners and muckers continuous work in each stope.

Average progress on the west-end bench was 7.7 ft. per day; however, this cannot be taken as a criterion as to what speed could be obtained, as the bench work was held up for some time due to the fact that the work was carried on with a limited payroll, and when labor was scarce the heading was pushed at the expense of the bench progress.

Several timbering schemes were used. The first 436 ft. at to build, and concrete was easily placed from the high-line timbers. Concrete lining in the tunnel averages about 6.1 cu. yds. per lineal foot.

The main concrete plant, capable of handling 150 cu. yds. of concrete in a day of ten hours, was built outside the tunnel at the west end, and the work of concreting from the west end progressed while tunnel excavation was in progress. Concrete work at the east end was started as soon as sufficient full section was excavated at that end. The east heading struck some bad ground, and to save timbering, the arch was concreted from the east concrete plant before the bench was removed, and in so doing a great saving was made in cost of timbering.

Ventilation at both ends of the work was accomplished by exhaust method, a large fan in the power house being connected to a 2-ft. ventilation pipe that opened at the end of the enlarged section. In addition to this, an auxiliary plant at each end forced air into the heading through a 10-inch pipe, a canvas section being used within 100 ft. of the face to allow its quick removal at time of firing a shot.

The Nicholson tunnel, on a change of line from Clark's summit to Hallstead, Delaware Lackawanna & Western R. R. is for double-track, the lining completed early in 1915. Length, 3630 ft. Figure 4 shows a longitudinal section of the tunnel, with location and dimension of the shafts that were used during construction, and which will be permanently lined and used for ventilating purposes. The rock met with was blue and grey sandstone, horizontally stratified, with soft material between the stratifications. The earth met with in the tunnel was heavy clay and gravel. The sectional area of arched tunnel down to subgrade is 660 sq. ft.; sectional area above the track being 608 sq. ft. The total area of the excavation removed approximated 964 sq. ft., equivalent to 35.7 cu. yds. per lineal ft. of tunnel.

The work was started by sinking Shaft No. 2, September, 1912, the excavation of this shaft being completed, April, 1913. Shaft No. 1 was started October, 1912, and completed June, 1913. About 0.58-lb. of dynamite was used per cubic yard of excavation in shafts.

The local cost of the shaft excavation was divided, approximately: Labor, 67 per cent; repairs and miscellaneous, 9 per cent; supplies, including explosives, 24 per cent.

Each shaft was sunk to a point about twelve feet below the top of the tunnel, and drifts or headings were then started.

Figure 5 shows the general method of construction, the top center heading method being followed; the headings being worked in two directions from each shaft, and also from the west end.

Headings (marked Sec. 1) were started in both directions from both shafts, working two ten-hour shifts per day of twenty-four hours, in each of the four headings, with an average progress of slightly less than eight feet per day in each heading. A heading, occupying the same position in the section, was started at the west portal in September, 1913, with approximately the same rate of progress. The number of holes drilled per shift in each heading varied from 18 to 24, each having an approximate depth of eight feet. There were always eight cut holes; the number of others varied with kind of material encountered. The average cost of drilling was 29 cents per foot drilled. The amount of material removed per lineal foot of heading from each of the five headings where work was in progress was about five cubic yards per lineal foot of tunnel. The second step in the process of tunnel excavation was the removal of sections marked 2, this work being done close behind the removal of the heading. Where the material was poor, Section No. 2 was not excavated until the advanced headings were joined, and the timbering was carried up immediately behind this excavation.

The cost of explosives per cubic yard of heading was 78 cents. The total cost of the heading, by percentages, was: Labor, 68.3 per cent; repairs, 1.5 per cent; supplies, including explosives, 26.6 per cent; miscellaneous, 3.6 per cent.

Top bench (marked 3) was drilled, shot and thrown by hand over top of main bench to the shovel, one shift ahead of the drilling of main bench (marked 4). All the material from both benches was removed by a No. 40 Marion shovel operated with compressed air.

In November, 1913, the shovel started to excavate Sections

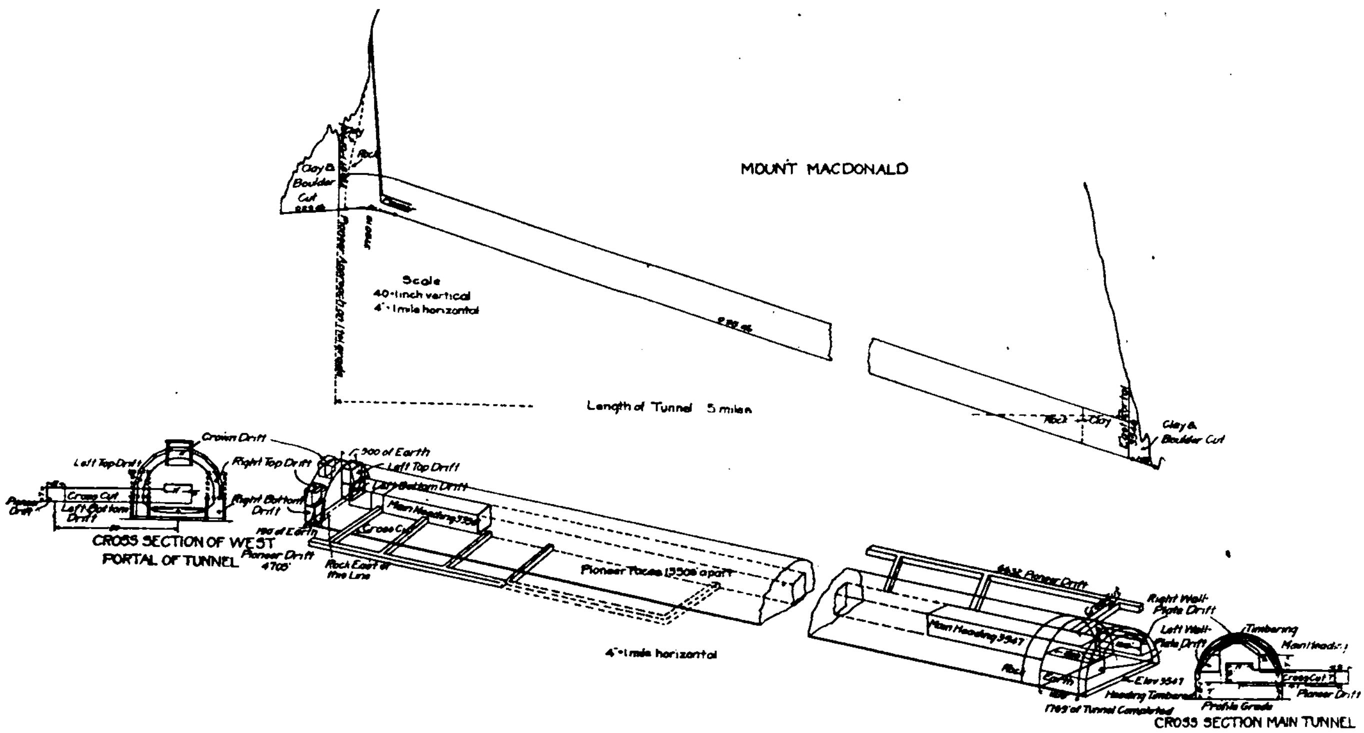

Fig. 9—Construction Plan of Rogers Pass Tunnel, Canadian Pacific Ry.