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TUNNELS.

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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 greatest in number, do not appear. For example, on a railroad having a present length of a little over two thousand miles, there were added since 1904 for the construction of branch lines twelve tunnels having an aggregate length of 7863 feet, the maximum length of any single tunnel being 4770 feet; while those added in connection with double-track and improving lines and on low grade lines numbered thirty-two, having an aggregate length of 32,251 feet, the maximum length of any single tunnel being 3291 feet.

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 feet long. Completed January, 1915.

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

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

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

The Mount Royal tunnel, on the Canadian Northern Railroad, Montreal, Canada, which is a double-tracked tunnel having a length of 17,000 feet, 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 feet.

The American Railway Engineering Association in its Manual of 1911 publishes therein, as representing good practice for new construction, single-track tunnels 16 feet wide, with a clear height from base of rail of 22½ feet; 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 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.

SNOQUALMIE TUNNEL.

On Change of Line at Snoqualmie Pass, Cascade Mountains, Sixty Miles East of Seattle, Washington; Chicago, Milwaukee & St. Paul Ry.

Single-track tunnel, 11,890 feet long, opened for traffic in January, 1915. Length of new line, including tunnel, 4.5 miles. The object of building this tunnel is to shorten length of line 3.7 miles; reduce Summit Hill, and eliminate 443.5 ft. of rise and fall (made up of westbound 4.7 miles of 2.2% grade, eastbound 4.4 miles of 2.75% 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 on Plate I, which also shows the location with plan and profile of tunnel.

Plate II shows method of excavation and plan of doing the work.

Plate III shows the completed cross-section of tunnel.

The width of the completed tunnel section is 16 feet; area to subgrade, 352 sq. ft.; area above track, 337 sq. ft.; crown of arch to base of rail, 22 ft. 5 in. (see Plate III). Average section excavated, about 517 square feet, 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 feet, 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 feet 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 on Plate II.

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 four feet above subgrade, four holes being drilled below the bar, acting as lifters, and all others above the bar.

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 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 ten feet per day, bonus 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 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 feet 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 feet at 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 feet top heading. June 1, 1912, to August 4, 1914—6971 lineal feet of bottom heading. Average per day, 9.5 feet. Maximum progress per day, 25 feet; 77 days shut down to wing out. Average progress per shot, 6.1 feet. Average time between shots, 15.5 hours. Maximum monthly progress (March, 1913), 455 lineal feet.

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

Bench progress for the west end is as follows: average progress, 7.7 feet. Maximum monthly progress (November, 1914), 658 lineal feet. For the east end: average progress, 10.3 feet. Maximum monthly progress (November, 1914), 644 lineal feet.

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 on Plate III, a comparatively simple section to build, and concrete was easily placed from the high-line timbers. Concrete lining in the tunnel averages about 6.1 cubic yards 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 feet of the face to allow its quick removal at time of firing a shot.

SANDY RIDGE TUNNEL.

On Elkhorn Extension of Carolina, Clinchfield & Ohio Ry., at Dante, Virginia.

Single-track tunnel, which was completed in 1914; length, 7804 feet. The permanent lining of the tunnel is in progress.

Plate IV contains a profile of the tunnel showing the line of cleavage between sandstone and slate, the two materials mostly encountered. It also shows the monthly progress from the time the excavation was started, in October, 1912. Sketches on Plate V indicate the method of excavation adopted, the top center heading system having been used, working from each end of the tunnel.

The minimum width of the lined tunnel section will be eighteen feet; maximum, nineteen feet. The minimum square feet of area is 364; maximum, 378.

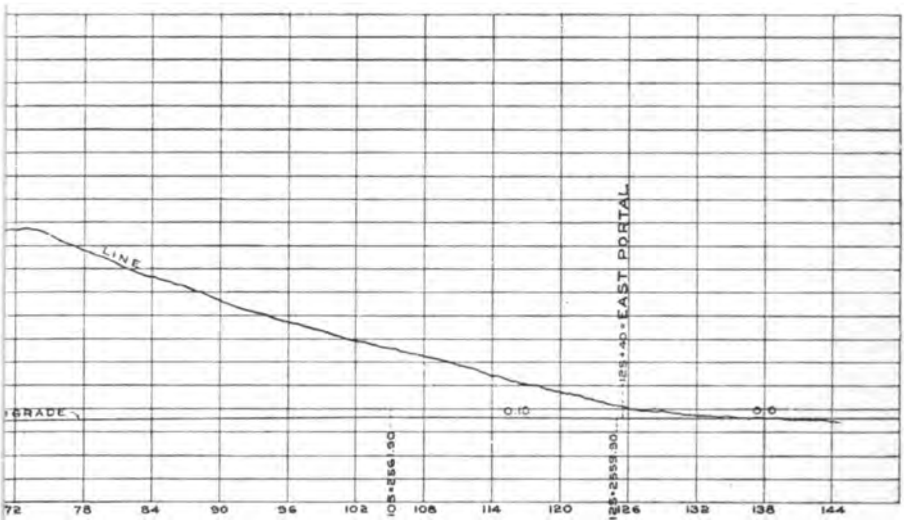
The average area of the excavation made, including falls, was 625 square feet, requiring the removal of 23 cubic yards per lineal foot of tunnel.

The average area of heading removed was 85 square feet, or 3.1 cu. yds. per lineal foot of tunnel, but where timber lining was required the excavation of heading material was increased to 6.5 cu. yds. per lineal foot of tunnel.

The area of the sub-bench removed averaged 132 square feet. The work was planned to keep the sub-bench about 8 feet behind the heading; and the drilling to progress in such a manner that the holes in heading, in the sub-bench, and the full bench could be fired in a series of shots that would result in an advance of the full tunnel section of from 7 to 8 feet.

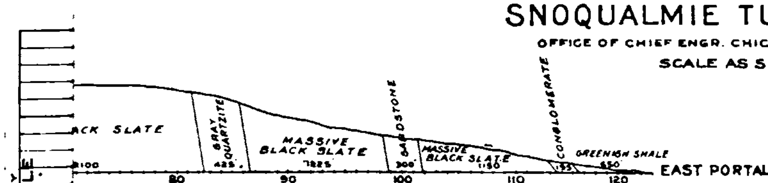
Figure 1, on Plate V, illustrates the methods of drilling and shooting. Ordinarily, 22 to 24 holes were placed in the heading, using the V-cut method. Twelve-foot drills were run in the cut holes, starting about eight feet apart at the face of the heading and bottoming from 12 to 18 inches apart. Ten-foot drills were run in the side rounds. From seven to eight feet were removed as a result of one blast. Two rows of vertical holes, twelve in all, were drilled in the sub-bench, the length of drills being eight feet. Four holes were drilled in the full bench, with two side holes at times. The two center holes were sprung three times, and the side holes twice, to form a powder chamber. All other holes were shot straight. This method of springing full-bench holes is responsible for some additional breakage in the side walls, but was adopted in order to secure the greatest possible rate of progress. Up to September, 1913, the benches were carried immediately behind each heading, and a weekly progress of 45 feet was made in each end of the tunnel. In September, 1913, the bench was kept 80 feet behind the headings. This method was followed until February, 1914, making a weekly progress of 50 feet at each end of the tunnel. At this date it was decided, on account of ventilation, to stop work on benches temporarily and drive the headings alone. This course was followed, the headings meeting on May 20, 1914. Work was resumed on the benches in May, 1914, and excavation was completed in November, 1914, notwithstanding more temporary timbering was required than anticipated.

The work in this tunnel was in progress almost continuously, the men being under pay about 22 hours per day for six days in the week. The labor worked in two shifts of ten hours per day.



OF TUNNEL

C.M & ST. P. RY.
PLAN & PROFILE
SNOQUALMIE TUNNEL. WASH.
OFFICE OF CHIEF ENGR. CHICAGO, ILL. NOV. 21-1914
SCALE AS SHOWN



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