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CONSTRUCTION OF THE HOOSAC TUNNEL 1855 to 1876

By
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Dedication

This paper is dedicated to my father, the late Harry W. Brierley, who took the author as a young boy to visit the west portal of the Hoosac Tunnel. Although we did not know it at the time, that visit represented the beginning of a fascination for me with the Hoosac Tunnel which led to the preparation of this paper.

I. Introduction

The Hoosac Tunnel is a truly great civil engineering accomplishment. Constructed through Hoosac Mountain in Northwestern Massachusetts from 1855 to 1876, the 4 and ¾-mile route has been used continuously since then as a railroad tunnel. It is currently owned and operated by the Boston & Maine Corporation.

Tunneling the "Mighty Hoosac" was significant for two principal reasons. First was the herculean efforts which were required to overcome natural obstacles such as a fault zone and large water flows. Nearly 200 construction workers lost their lives in the tunnel! Second was the substantial strides that were made in hard rock tunneling technology during construction of the tunnel. To quote Sandstrom (1963), ". . . out of the Hoosac mess would ascend the American compressed air industry which . . . took an unchallenged leadership in developing and providing the mining and construction industries with the only types of tools and machines hitherto capable of mechanized work underground."

The following paper presents a brief history of the tunnel and discusses construction methods, costs and time durations. The construction history is summarized in Chapter III and there is a discussion of contemporary tunneling technology in Chapter IV. Chapter V contains a description of specific construction activities at the Hoosac Tunnel. Other chapters provide additional general information. In the Epilogue is a discussion of how a tunnel like the Hoosac might be constructed today in accordance with modern requirements and construction methods.

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II. Early History

Following the Revolutionary War, Massachusetts enjoyed a period of economic prosperity. Sailing fleets from her eastern seaports travelled the world reaping large profits for their owners. Embargoes associated with the War of 1812, however, placed severe hardships on the shippers. Then followed agricultural development in the "West" (New York and Pennsylvania) where conditions for farming were more favorable than in rocky Massachusetts. Completion of the Erie Canal in 1825 from Lake Erie to the Hudson River made New York City the busiest port on the eastern seaboard. By 1830, when Massachusetts celebrated the bicentennial year of the Massachusetts Bay Colony, it was obvious that her economic growth was lagging behind that of her northeastern neighbors (Salsbury, 1967). Hoosac Mountain in Western Massachusetts was one of the things that prevented significant commercial interaction between Boston and the country's new commercial center.

An engineering study was commissioned by the Massachusetts General Court in 1825 under the direction of Loammi Baldwin, Jr. to determine the feasibility of constructing a canal from Boston to the Hudson River. Baldwin found two possible routes: one along southern Massachusetts through Worcester, Springfield and Pittsfield, and another more northerly route through Fitchburg, Greenfield, and North Adams which included a five-mile long tunnel through Hoosac Mountain (See Figure 1). Baldwin recommended the northerly route but the Legislature discarded the entire proposal. A canal was too expensive, could not be used during the winter, would require large amounts of water which were sometimes needed for farming, and, most significant, canals began to compare unfavorably with a new mode of transportation: the railroad.

In 1826, the Massachusetts Legislature began to receive requests for possible railroad route surveys across Massachusetts. In 1831, the Boston and Worcester Railroad was chartered and subsequently constructed from Boston to Worcester, Massachusetts as a private development. By 1842, this line was extended by the Western Railroad from Worcester to Greenbush, New York on the east bank of the Hudson River directly across from Albany. A branch line in Massachusetts from Pittsfield to North Adams was constructed in 1845 and 1846. These railroads produced some trade with New York, and, just as important, induced considerable industrial expansion on the extensive interior river system of Massachusetts.

Interest never waned, however, in the possibility of a railroad across Northern Massachusetts to Troy, New York along the route originally recommended by Baldwin. Troy was jealous of the railroad connection of her southern neighbor, Albany. Massachusetts' northern residents wanted the same opportunities for development that existed along the southern route. Even Albany merchants became upset with the southern route because its steep gradients and excessive curvature sometimes resulted in long delays for shipping their produce. Lastly, Yankee pride was stung by the thought that only 4 and ¾ miles of rock stood in the way of this enterprise.

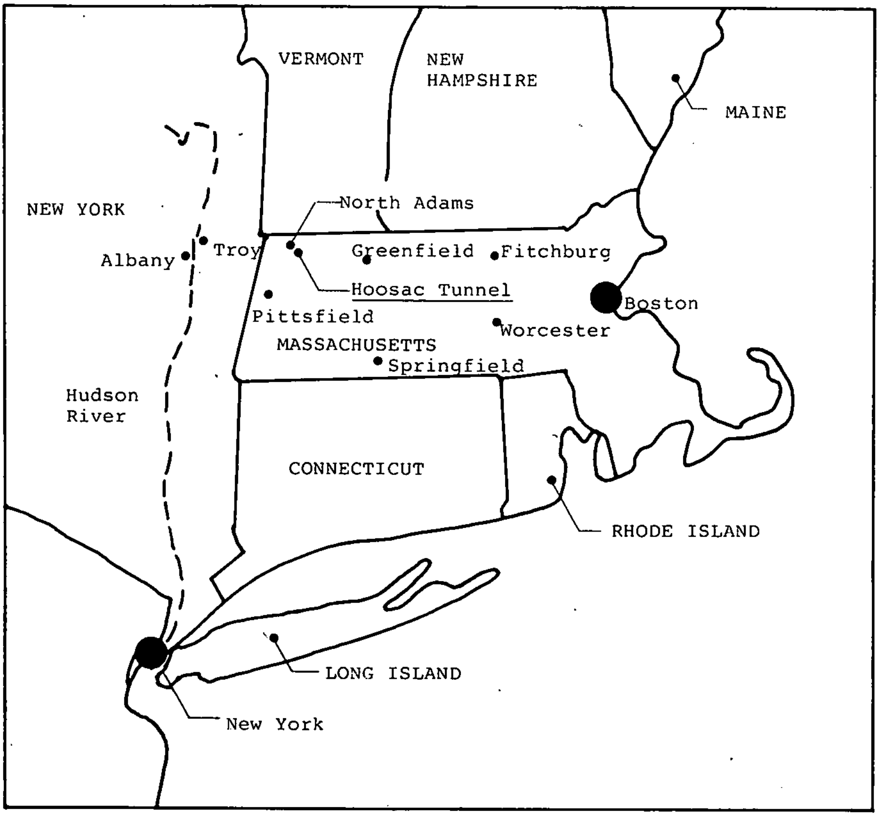


Figure 1. Hoosac tunnel project locus.

III. Construction History

A northern route was begun in the early 1840's with a railroad from Boston to Fitchburg, Massachusetts. This was extended by the Vermont and Massachusetts Railroad so that by 1848 a line was complete to Greenfield, Massachusetts. On May 10, 1848, the Massachusetts General Court chartered the Troy and Greenfield Railroad, including the Hoosac Tunnel, from Greenfield to the Massachusetts-Vermont border at Williamstown, Massachusetts. Soon thereafter, railroads were chartered in Vermont (Southern Vermont Railroad Company) and New York (Troy and Boston Railroad Company) to complete the link from Greenfield, Massachusetts to Troy, New York.

The location of the proposed Troy and Greenfield Railroad was filed in 1850 and a contract let on October 28 of that year to Gilmore and Carpenter for construction of railroad from North Adams westward to the State line. On January 7, 1851, directors of the Troy and Greenfield Railroad voted to break ground in North Adams.

As part of the early preparations for the tunnel, geologists were asked for opinions about the structure of Hoosac Mountain. The most notable of these was the State Geologist, President Edward Hitchcock of Amherst College. Professor Hitchcock had visited the mountain on numerous occasions, but never specifically to analyze the route of the proposed tunnel.

He correctly perceived that the mountain was composed of metamorphic rock (mica slate with some gneiss and occasional quartz veins) and that the mountain had been forced upward by high horizontal stresses. He was certain that no granite or trap would be found in the interior of the mountain. He had noticed some limestone "near the foot on the west side" but attached no particular significance to this observation. In general, he perceived the rock to be dipping steeply and striking nearly at right angles to the tunnel alignment, and felt that very little arching would be necessary. At a hearing before the Legislature on January 31, 1854, Hitchcock said, ". . . I do not believe that it (the tunnel) would require any more masonry for its support than would be necessary for a good sound stick of timber with an auger-hole bored through it." He even went so far as to volunteer to construct all required masonry for a few thousand dollars. Luckily, no one accepted his offer. Professor Hitchcock also had the "impression" that the tunnel would "go below where the groundwater percolated" and that it would be dry after tunneling in from the portals.

On the basis of this information, A.F. Edwards, the first Chief Engineer for the Troy and Greenfield Railroad, addressed himself to the feasibility of constructing the tunnel (since no tunnel of this size had been constructed in America) and, if feasible, to the cost and time for completion. True to his profession, he decided that the tunnel was indeed feasible. The cross-section recommended by Mr. Edwards is shown in Figure 2. If the tunnel were to be excavated manually from either portal, he estimated that it would cost $1,968,557 and that it would take 1556 working days to complete. With the use of two shafts, he estimated that the time for construction would be reduced to 1005 working days. Mr. Edwards felt that additional time reductions were possible if a tunnel boring machine then being tested at the east portal of tunnel (see Chapter IV) or various drilling machines could be made operable.

In 1854, the Massachusetts General Court agreed to loan the railroad corporation $2,000,000 to help with construction. Contracts with E.W. Serrell, Herman Haupt and others were let from 1855 to 1858 during which time the railroad from North Adams to Troy was finished and construction of the tunnel, and the railroad east of the tunnel begun. Construction continued until July 12, 1861 when W.S. Whitewell, a recently appointed chief engineer, refused to authorize an installment payment to the contractor and work ceased. The State took complete possession of the railroad on September 4, 1862 following mortgage payment default by the Troy and Greenfield Railroad.

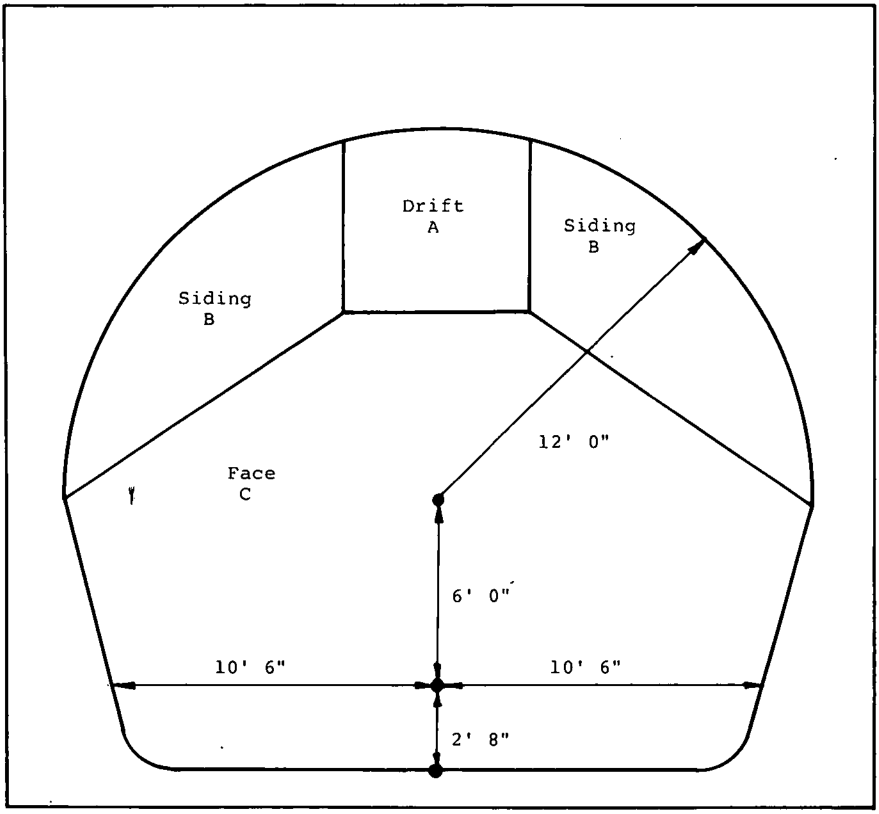


Figure 2. Tunnel cross-section recommended by A. F. Edwards, Chief Engineer, 1851.

There followed an interesting interlude in the construction of the tunnel from 1862 to 1868 when the State became the general contractor and appointed a three-man commission to oversee the project. One of the commissions' first official functions was to send Charles S. Storrow to Europe to study contemporary European tunneling methods. The commissioners also appointed Thomas Doane as their first Chief Engineer; he was responsible for many of the innovative tunneling procedures tried at the tunnel.

Work under State control proved to be very expensive; although in fairness to State officials, allowance must be made for cost escalation during the Civil War and for considerable research and development activities. During this period, a dam was constructed across the Deerfield River to provide water power for machinery, a central shaft was begun, compressed-air rock drills were introduced to the tunnel, nitroglycerine supplemented black powder as a blasting compound, electric blasting caps were used for detonation, and new surveying instruments were manufactured to improve tunnel alignment methods. The State supervised construction of the dam and machine shop near the east portal, the hoisting equipment at the central shaft, and the nitroglycerine factory and brick kiln at the west end. Toward the end of this period, successful contracts were let to B.N. Farren for open-cut excavation and brick arching along the west end of the tunnel and for construction of the railroad east of the tunnel to Greenfield. A contract for construction of the tunnel except the west end was let to Messrs. Dull, Gowan & White in 1867, but was terminated after a disastrous fire at the central shaft.

In June, 1868, Walter and Francis Shanly of Canada received a letter from Consulting Engineer Benjamin H. Latrobe, Jr. informing them that the tunnel was going out to bid and asking them to submit a proposal. This they did, and immediately became involved in the greatest undertaking of their career. It took two distinct types of courage to face the Hoosac: the first was to face the mountain itself, and the second was to face Massachusetts politicians who had shown a propensity for rough treatment of contractors associated with the project. The Shanlys overcame both obstacles with equal fortitude and energy.

The Shanlys were well pleased with the contract they had negotiated in the face of opposition. Originally it called for a lump sum deposit of $500,000 and payment of 80 percent of earned income for the duration of the project. This was a very large sum of money to commit. The Shanlys were able to change this so that instead of a $500,000 deposit, they were to perform $500,000 worth of work (which they thought they could do for $400,000). Their bid price was reduced from $4,623,069 to $4,594,268, largely on account of work performed by the State or omitted from the contract during the negotiation period. Payment was to be received by the Shanlys on a monthly basis at 80 percent of the payment schedule outlined in Table I. The Shanlys also agreed to the stringent rates of progress shown in Table II. The contract was signed December 24, 1868.

The Shanlys capitalized on the experiences of those that had come before and pushed the tunnel through to final hole-through on November 27, 1873. Although the Shanlys completed most of the tunnel excavation, they were apparently not interested in finishing the entire project. When they reached a provisional settlement of their contract on December 22, 1874, considerable tunnel enlarging and lining construction remained to be done. A great deal of open-cut excavation was also necessary west of the west portal.

On November 19, 1874, the Commonwealth of Massachusetts entered into a contract with B.N. Farren for $300,000 "... to do and perform all such work and furnish all necessary materials as may be required to complete enlargement and arching of the Hoosac Tunnel and the facade and stone-arch at the *eastern* portal . . .". The compensation schedule for work performed, with the usual 20 percent deduction for security deposit, is given in Table III. Payments were to be made monthly.

TABLE I
COMPENSATION SCHEDULE — SHANLY CONTRACT

East End Section	
Tunnel Enlargement	$16/cu. yd.
Heading Enlargement	$ 9/cu. yd.
Full-Size Tunnel Excavation	$11/cu. yd.
Central Drain Construction	$13/lin. ft.
Single-Track Construction	$14,000/mile
Central Section	
Fire-Proof Door Erection	$2,000
Shaft Repair	$5,830
Shaft Excavation	$395/lin. ft., or $33.62/cu. yd.
Iron Pipe Placement	$10/lin. ft.
Full-Size Tunnel Excavation	$14/cu. yd.
Central Drain Construction	$13/lin. ft.
Single-Track Construction	$14,000/mile
West End Section	
Heading Enlargement	$9.75/cu. yd.
Full-Size Tunnel Excavation	$12/cu. yd.
Brick Arch Construction	$22/1000 brick
Central Drain Excavation Only	$4.35/lin. ft.
Central Drain Construction	$13/lin. ft.
Central Drain Construction West of West Shaft	$3/lin. ft.
West End Stone Arch and Facade	$49,000
Haupt Tunnel Maintenance	$8,500
Single-Track Construction	$14,000/mile

TABLE II
RATES OF PROGRESS — SHANLY CONTRACT

	Feet/Month
East End Heading Advance and Tunnel Excavation	75
East End Full-Size Tunnel Excavation	125
Central Shaft Complete by May, 1870	---
Central Section Full-Size Tunnel Excavation	80
West End Full-Size Tunnel Excavation	100

TABLE III
COMPENSATION SCHEDULE — FARREN CONTRACT

Enlargement Excavation	$10.00/cu. yd.
Brick or Stone Masonry	$11.50/perch*
Eastern Portal Facade & Stone Arch	$25.00/cu. yd.
Foundation Masonry	$ 7.50/cu. yd.
Dry Packing Behind Arch	$ 2.75/cu. yd.
Wing Walls	$ 7.50/cu. yd.
Facing of Stone Walls	$ 0.50/sq. ft.

*1 Perch = 25 cu. ft.

The contract also provided for the use of the State's brickyard and for passage of trains through the tunnel. Farren apparently made a few extra dollars by agreeing to haul trains through the tunnel with his own locomotive. In case of controversy, the specification provided for the appointment of a three-man arbitration board, whose decisions were to be "final and conclusive."

Farren attacked the project with vigor, laying more brick and completing more lining than anyone thought possible at the time. He was greatly aided in this work by the fact that the Shanlys had intentionally overexcavated in some areas at the request of the State to allow room for lining. Farren laid more than 1,000,000 brick per month and completed 4922 ft of lining by June 30, 1876, at which time he turned the tunnel over to the State. The tunnel was officially dedicated and opened for business on July 1, 1876.

Farren was justifiably proud of the work he had done at the Hoosac; he completed all his work on or before schedule and never claimed as much as one penny in extra compensation. The Hoosac construction was exceptional in that it had three great contractors on it: Herman Haupt, Walter Shanly, and Bernard Farren.

A summary of the construction schedule is given in Table IV showing the time periods and activities of the major contractors. Additional discussion of construction activities at the four working areas of the tunnel (east end, central shaft, west shaft, west end) is given in Chapter V.

IV. Contemporary Tunneling Technology

When plans for the Hoosac Tunnel were first seriously considered around 1850, tunnel excavation procedures had not advanced very much in the preceding 200 years. Gunpowder had been known to Western man since the early 1300's and successfully applied to mining by placement in drill holes in the early 1600's in Germany. Drill holes were shallow and placed individually so that each shot would have the greatest advantage for moving the largest possible volume of rock. All drilling and mucking was done by hand. Ignition of the powder was done by a powder trail or simple fuse, preferably by someone who could run fast.

TABLE IV
SUMMARY OF CONSTRUCTION ACTIVITIES

Period	Contractor	Remarks
1850 to 1853	----------	Preliminary layout and railroad construction.
1854	----------	Commonwealth of Massachusetts loans $2 million to the Troy and Greenfield Railroad.
1855 to July 12, 1861	E.W. Serrell, Herman Haupt and others	2399 ft. of 14 x 6 ft. heading and 2129 ft. of 14 x 18 ft. full-size tunnel completed at east end, west shaft sunk to grade, 450 ft. of tunnel completed at west end (later abandoned).
1862 to 1868	Commonwealth of Massachusetts	Studied contemporary European technology, placed the tunnel on one straight line, built power dam and machine shop at east end, developed practical compressed air rock drill, introduced nitroglycerine for general heading advance, enlarged Haupt's tunnel at east end to double track dimensions and carried heading 5282 ft. from east portal, began excavation of central shaft, tunneled 1609 ft. east from west shaft, completed extensive work on west end of tunnel.
1866 to 1869	B. N. Farren	Excavated and lined 931 ft. of double track tunnel at west end under most difficult working conditions and completed drainage adit from west end to west shaft.
Aug., Sept. & Oct. 1867	Messrs. Dull, Gowan and White	Continued excavation at east end, carried central shaft to a depth of 583 ft., continued excavation eastward from west shaft with a top heading rather than the bottom heading which was used at the east end. This brief contract was voluntarily withdrawn following the central shaft fire on Oct. 19, 1867.
Dec. 24, 1868 to Dec. 22, 1874	Walter and Francis Shanly	Carried central shaft to full depth, holed through at east end on December 12, 1872, holed through at west end on November 27, 1873, firmly established the center cut system of heading advance.
1873 to 1874	Messrs. McClallan, Son & Walker	Constructed railroad from west portal to North Adams, including extensive rock excavation near west portal along abandoned Haupt tunnel.
Nov. 19, 1874 to June 30, 1876	B. N. Farren	Completed enlarging and lining of tunnel, laid track in tunnel.

Initially rock excavation at the Hoosac Tunnel was similar to the description above. Holes were drilled with a small sledge by one man striking a drill held by himself, or, if room allowed and the holes were to be advanced more than about three feet, by one, two or even three men striking a drill held by another person. Hole locations were selected individually by the foreman based on the rock mass configuration and observed geologic discontinuities.

After drilling several holes (8 to 10), the men were withdrawn behind heavy wooden parapets, the holes charged with powder, and fuses lighted. The fuse in this case was probably the Bickford Safety Fuse developed by William Bickford in 1831. It consisted of a powder thread spun in jute yarn and waterproofed with coal tar. It burned at approximately 2 to 3 feet per minute. When a blast occured, the parapet behind which the men and mules were protected was showered with rock, every lamp in the tunnel was extinguished by the air blast, and the tunnel was filled with dust and acrid smoke. During the blast, the foreman would carefully count the number of explosions to be certain that none of the fuses had been cut or that a hole was not "hanging fire". Very often the men had to stay behind the parapet until the reason for a misfire could be ascertained. Upon receiving an all-clear signal, the men returned to the face to begin loading broken rock into mule cars for removal from the tunnel and drilling more blast holes.

Initial attempts to improve the rate of progress with the techniques described above led to experiments with tunnel boring machines. For those who think tunnel boring machines are a recent idea, it will come as a surprise to learn that the first tunnel boring machine was proposed by Monsieur Mauss in 1845 for use at the Mont Cenis Tunnel (Drinker, 1878.). By 1850 his idea had been given up as impracticable.

In 1851, the Wilson Patent Stone-Cutting Machine was constructed by Richard Munn & Company of South Boston for use at the east portal of Hoosac Tunnel. The machine was designed to cut a 24-foot outside diameter, 13-inch wide groove in the rock by means of revolving cutters with a small-diameter cylindrical borehole at the center. After drilling approximately two feet, it was planned to withdraw the machine and remove the center core by blasting or wedging. During various trials, the machine actually cut rock at the rate of 14 to 24 inches per hour to a total depth of approximately 10 feet. The machine's greatest flaw was apparently in the cutter bearings which could not take the pressure. In addition, the machine was run by steam and it is highly unlikely that steam could have been piped very far in from the portal without condensing.

A second machine tried at the west portal was introduced by Herman Haupt in 1857. It was constructed by the Novelty Iron Works in New York at a cost of $25,000 and was reportedly patterned after a machine then in use in California. The machine was designed to cut an 8-foot-diameter bore which was to be used as the heading. A report by Henry Cartwright dated September 20, 1857 describes a trial run of the machine at Hoosac Tunnel in fractured limestone near the west portal. Mr. Cartwright was pleased with the performance of the machine and expected a rate of progress of between

15 and 24 inches per hour as soon as the competent mica slate in the interior of the mountain was encountered. Haupt & Company never had the chance to try the machine under those conditions, however, because their contract was terminated. Although additional tunnel boring machines were tried at various tunneling projects following the Hoosac experiment, none could be made to operate efficiently.

At the same time that experiments were proceeding with tunnel boring machines, other attempts were being made to mechanize the tunneling process. The two most important results of those experiments were the development of a practical compressed air rock drill, and the development of blasting compounds more powerful than gunpowder.

The first mechanical percussion drill was invented by J. J. Couch of Philadelphia in 1849. It consisted of a machine that hurled a "lance" at the rock and was quickly found to be terribly inefficient. One of his assistants, however, J. W. Fowle, developed a technique for direct impact of drills held against the rock; this was to prove a key to later success. Despite his partial success, Fowle did not continue to develop a practical drill.

One of the primary responsibilities of Charles S. Storrow, on a trip to Europe under the auspices of the Commonwealth of Massachusetts, was to visit the famous Mont Cenis Tunnel between France and Italy and investigate a compressed air rock drill which had been introduced there in 1861. The Mont Cenis project was important because it demonstrated the use of a drill, the concept of a drill carriage for supporting several drills at the face, and, most important of all, it demonstrated the power of compressed air as a power source. Prior to this time, steam had been the primary source of mechanical power, but steam condensed when it was piped great distances outdoors. At Mont Cenis, it was shown that compressed air could be piped long distances without losing its "elastic force". Although Storrow was pleased to discover that the Mont Cenis drill had increased the rate of advance of the tunnel, he also discovered that the drill had not reduced the *cost* of tunneling. The cost remained high because the drill was expensive to manufacture, very heavy and cumbersome to work with in the tunnel, and subject to excessive maintenance. Storrow was confident that a more efficient drill could be developed by American machinists.

The first attempt at compressed air rock drilling at the Hoosac Tunnel was at the east end in the Summer of 1866. The drill, known as the Brooks, Gates and Burleigh Drill, had been developed under the direct supervision of State authorities at the Putnam Machine Company in Fitchburg, Massachusetts. It was used at the tunnel for six months and proved a failure. To quote Thomas Doane in his annual report for 1866, "They were beautiful machines, light in weight, compact in form, and automatic, but proved themselves in a few days to be deficient in the very necessary quality of strength."

Charles Burleigh had made extensive observations of this machine and proceeded to invent another drill, known as the Burleigh Drill, which was introduced to the tunnel on November 1, 1866. (Mr. Burleigh used the idea of J. S. Fowle mentioned earlier and had to purchase Mr. Fowle's patent later for $10,000.) The drill was an immediate success and was used at the tunnel continuously until completion. Walter Shanly purchased 60 of these drills from the Putnam Machine Company at a cost of $625 each at the beginning of this contract. The drill reportedly weighed over 500 pounds and advanced a two-inch-diameter hole at two inches per minute to depths up to 13 feet. The drill itself had a hole in its center through which water was pumped to cool the bit and clear dust from the hole. In a letter dated February 26, 1872, Walter Shanly said he estimated "the savings in time by use of these drills at fully fifty percent." The compressed air rock drill was the first important component of a more rapid tunneling technique.

Another compressed air rock drill, referred to as the Wood & Robinson Drill, was used at the tunnel during the Dull, Gowan & White contract in 1867. The fear that this drill infringed on Burleigh's patent rights caused its use to be discontinued, although it was subsequently used on other projects with great success.

The second important development toward more rapid tunneling was an invention by Ascanio Sobrero in 1847 in Italy; it was nitroglycerine. Nitroglycerine was several times more powerful than gunpowder, but highly susceptible to sudden detonation with the slightest disturbance. Careless handling of the material had resulted in many accidents and in the deaths of many innocent bystanders. Several countries had passed laws prohibiting its manufacture and shipment and the United States had severe restrictions on interstate shipment.

Alfred Nobel had begun experimenting with nitroglycerine in Europe in the early 1860's. His American representative, Colonel Tal P. Schaffner, actually conducted the first experiments with nitroglycerine at the east heading of the west shaft on the Hoosac Tunnel in 1866. In 1867, George W. Mowbray was invited to come to North Adams, Massachusetts to help with the Hoosac Tunnel project.

Professor Mowbray had become familiar with nitroglycerine by using it to enlarge oil wells near Titusville, Pennsylvania. He came to North Adams, (reportedly when his business interests in Pennsylvania had taken a turn for the worse) and constructed a plant for manufacturing nitroglycerine near the west end of the tunnel. Actual production began in January, 1868 and continued throughout construction of the tunnel during which time more than 500,000 pounds of nitroglycerine were manufactured. Some of it was shipped outside the North Adams area.

Mowbray manufactured nitroglycerine by mixing glycerine, drop by drop, with nitric and sulfuric acids while the entire solution was bathed in ice and stirred continuously by a cold stream of bubbling air. The air apparently removed from the mixture impurities which were liable to cause spontaneous decomposition and explosion. Following manufacture, the nitroglycerine was placed in stone jars, immersed in water at 60° to 70°F for several days, and skimmed of impurities which collected at the top. Then the nitro was placed in paraffin-lined metallic containers and frozen. During freezing a "reddish liquid" accumulated at the top which was "uncrystallizable" and highly explosive. The reddish liquid was also carefully removed.

It was found out quite by accident at the Hoosac that frozen nitroglycerin was more difficult to explode than the liquid form; the opposite had been believed prior to this time. William Granger was determined to bring nitroglycerine over the mountain to the east end during the winter of 1868-69 to remove anchor ice from the canal. During the trip, his sleigh was upset and the nitro cartridges spilled out onto the snow and were frozen. Despite his thinking the material now highly explosive, Mr. Granger continued to the east end and found out, to his surprise, that he could detonate the nitro only after it had been thawed. From then on, all nitroglycerine was transported in a frozen state.

Prior to blasting, the nitroglycerine was placed in metallic tubes 1-1/2 inch in diameter and 4 to 6 feet long. These were placed in the drill hole together with an exploder, wired together with all other charges, and detonated with electric blasting caps. Mowbray laid down stringent rules about handling nitro which made it reasonably safe, but any slight degree of carelessness left little margin for survival. Many miners were killed or maimed by the explosive. The biggest advantage of nitroglycerine was that it fractured harder rock and much more rock than gunpowder. It also had the beneficial side effect of not producing as much smoke and fumes as gunpowder.

A third, but somewhat auxiliary development which contributed to a more rapid tunneling rate and which was used extensively at the Hoosac Tunnel was electrical ignition or detonation. Moses Shaw had patented the idea of simultaneous *ignition* of several charges of gunpowder with electricity in 1831 and the technique was apparently used in mining operations. Electrical ignition had the beneficial effects of eliminating the smoke of common fuses, of allowing all the men to be withdrawn before firing any charges, and of much more dependable performance than the common fuse which was sometimes cut by early explosions or simply failed to ignite the gunpowder. The first use of electrical ignition at the Hoosac Tunnel was at the east end working area in the summer of 1865. By 1866, the technique was in general use.

With the advent of nitroglycerine, electricity was used together with blasting caps for *detonation* as well. At the Hoosac Tunnel, blasting caps (exploders) were made by Charles A. and Isaac S. Browne in a small factory near the west end of the tunnel. As many as 30,000 caps a month were produced at the height of construction. The cap consisted of a small wooden plug with two wires, between which was placed a small quantity of fulminate of copper. This plug was inserted into a larger outer shell containing fulminate of mercury, all of which constituted the blasting cap. Later improvements of the cap were made to eliminate the too-sensitive fulminate of copper. Charles Browne, in fact, was blinded by a premature explosion of fulminate of copper.

All of the above developments, together with drill carriages designed by

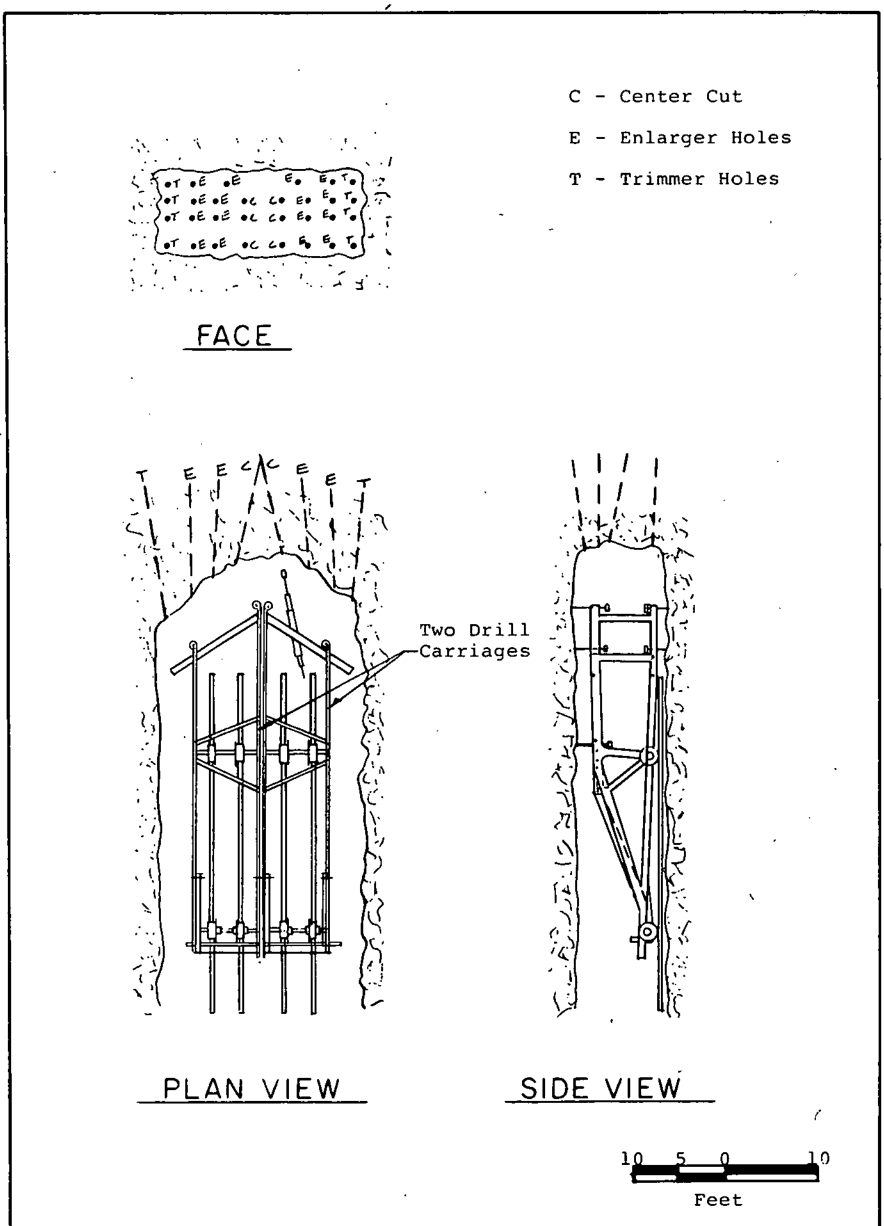


Figure 3. Center-cut system of heading advance.

Thomas Doane, were combined at the Hoosac Tunnel in the so-called "center-cut system" of heading advance, Figure 3. The V-shaped set of holes at the center was drilled first, followed by enlarger and trimmer holes. Each set of holes was loaded and shot before drilling the next set. The drilling advance was increased from the three feet possible by hand drilling to ten feet and Walter Shanly estimated that tunneling progress was increased five-fold with the center-cut system. A comparison of Shanly's and Haupt's work shows this to be the case. Significantly, Shanly's average production rate was even 50 percent greater than at the Mont Cenis Tunnel in terms of cubic yards of rock removed per month from a heading opening to a portal.

The center cut system of heading advance represents the Hoosac tunnelers' chief contribution to tunneling technology. To quote Gillette (1904), "The center-cut system of drilling was first used in the celebrated Hoosac Tunnel in Massachusetts . . . .". Even as late as 1969, Dupont's *Blaster's Handbook* said: "The V or wedge cut is one of the oldest of the angled cuts and is still commonly used." To the Hoosac tunnelers belongs the distinction of having firmly established a new method of underground excavation which, with some modifications, has been used in almost every rock tunnel constructed in the world until recently.

Another significant contribution of the Hoosac tunnelers was the demonstration of modern surveying accuracy. There is a popular misconception to the effect that Herman Haupt had made a mistake with his survey control and that he was excavating two tunnels. This is not true. Herman Haupt was actually excavating one tunnel along two headings with slightly different bearings, so that when the headings met and the alignment was found to be off by several feet (as was common) the lines could be connected by a simple curve. At the Mont Cenis Tunnel referred to earlier, closure was quoted as excellent, although the discrepancy was nearly 18 in.

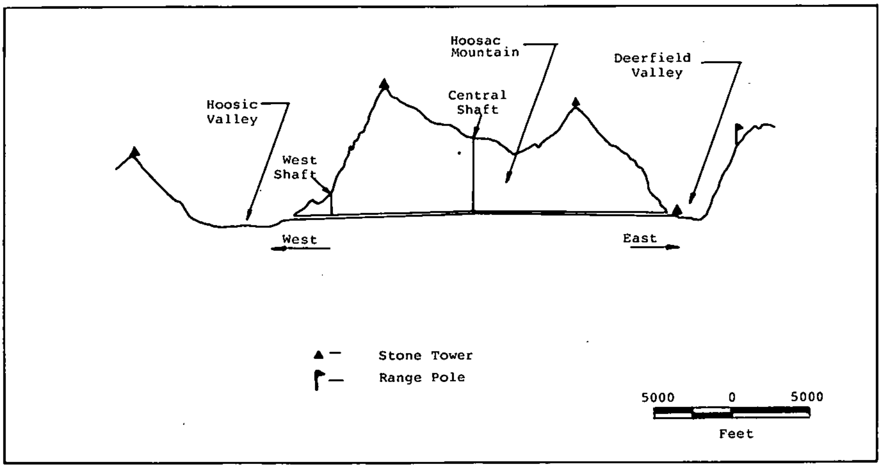


Figure 4. Profile of Hoosac Mountain showing survey control layout.

When the State took control of the Tunnel in 1862, Thomas Doane was said to have "boldly" re-established control and set the tunnel on a single tangent. This was "bold" because if the two portions of the line did not meet at the center, it would require an S-type curve to connect them. Shown in Figure 4 is the survey control established by Tom Doane. It consisted of eight signal stations: one at each portal, one at each of two shafts, one at each summit of Hoosac Mountain, and one on each mountain opposite the portals. Four of the stations were permanent 10-foot-square stone towers. The averaging of numerous observations in different weather conditions was used to obtain accuracy.

At the central shaft, the surveyors had to contend with a vertical drop of 1030 feet and a base length of only 23 feet. Air currents, water infiltration, equipment vibrations and normal pendulum action caused considerable motion of the lines at the bottom of the shaft. However, complete enclosure of the plumb lines, suspension of the plumb bobs in water, and numerous repetitions of observations resulted in a very successful survey. Closures at the Hoosac Tunnel were 5/16 inch and 9/16 inch at the two hole-throughs. These closures would be satisfactory even by today's standards and represented an order of magnitude improvement over contemporary procedures.

V. Construction Activities at the Hoosac Tunnel

Chapter V contains a discussion of specific construction activities at the Hoosac Tunnel which can be used together with information in Chapter III for an overall understanding of the Hoosac Tunnel project. Figure 5 is a cross-section of Hoosac Mountain showing the four principle working areas of the tunnel. Discussion in Chapter V is divided on the basis of these working areas beginning with the east end and proceeding westward. Each

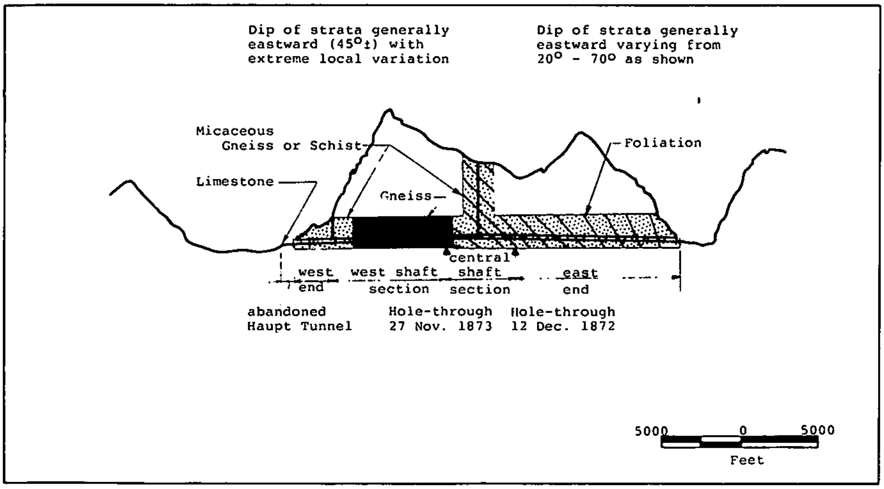


Figure 5. Construction working areas and general geologic information.

working area is described from beginning of construction to hole-through in that area to avoid extensive cross-referencing of contractors associated with the project. Reference to Table IV in Chapter III may help to clarify the chronological sequence of contractor involvement.

Also shown in Figure 5 is simplified geologic information for Hoosac Mountain. This information is based on geologic mapping of the tunnel immediately after excavation in conjunction with proposals for lining the tunnel. In general, bedrock from the east end to beyond the central shaft and near the west end was described as a micaceous gneiss or schist. Rock foliation dipped generally to the east being steepest near the east end (70°) and decreasing rather uniformly toward the center of the mountain. Dips of 20° to 30° were noted west of the central shaft. Dips along the west portion of the tunnel were noted as generally eastward (45°+), but were subject to extreme local variation.

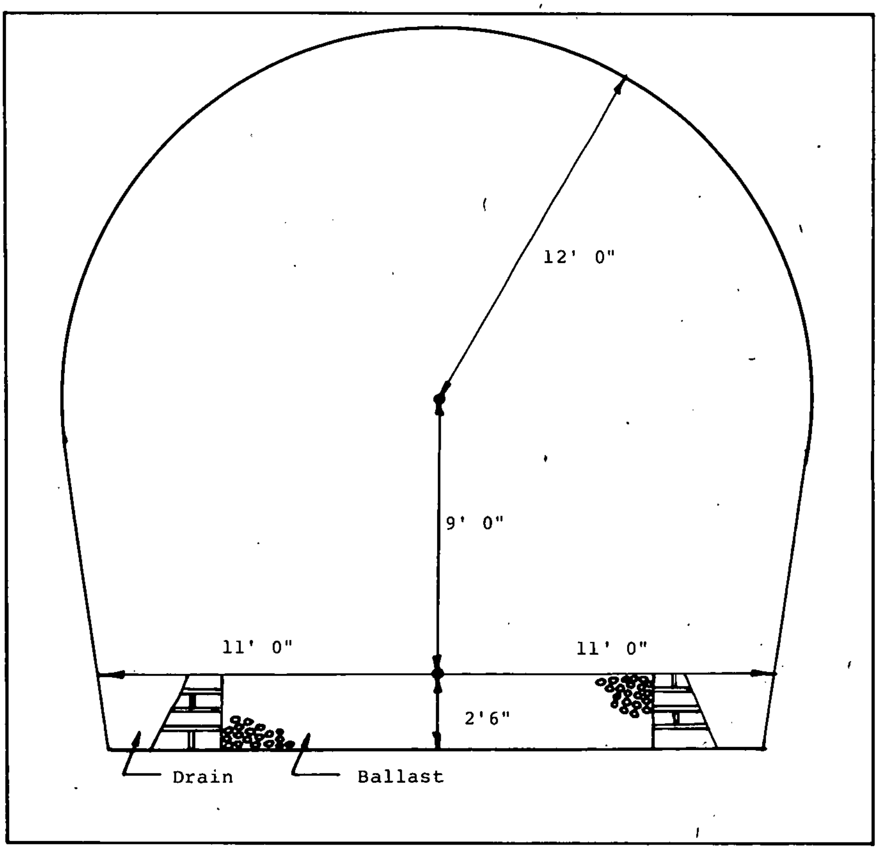


Figure 6. Tunnel cross-section recommended by State Commissioners, 1863.

The west-central portion of the mountain contained a rock described as a gneiss or granitoid gneiss. It was more coarsely textured and harder than the rock described above.

The mountain was apparently intersected throughout with hard seams of quartz varying in thickness from a few inches to several feet. The mountain also contained numerous shear zones parallel to the foliation with fractured rock and clay gouge, and seams of weathered feldspar. These weak areas generally had the greatest instability and inflow of groundwater.

Conditions at the west end were greatly complicated by a thrust fault which caused an abrupt change in rock type at the west portal from schist or gneiss to limestone. This, together with hydrothermal alteration resulted in a rock mass that was severely weathered, fractured and disintegrated. It was referred to in contemporary terminology as "demoralized" (See West End Working Area).

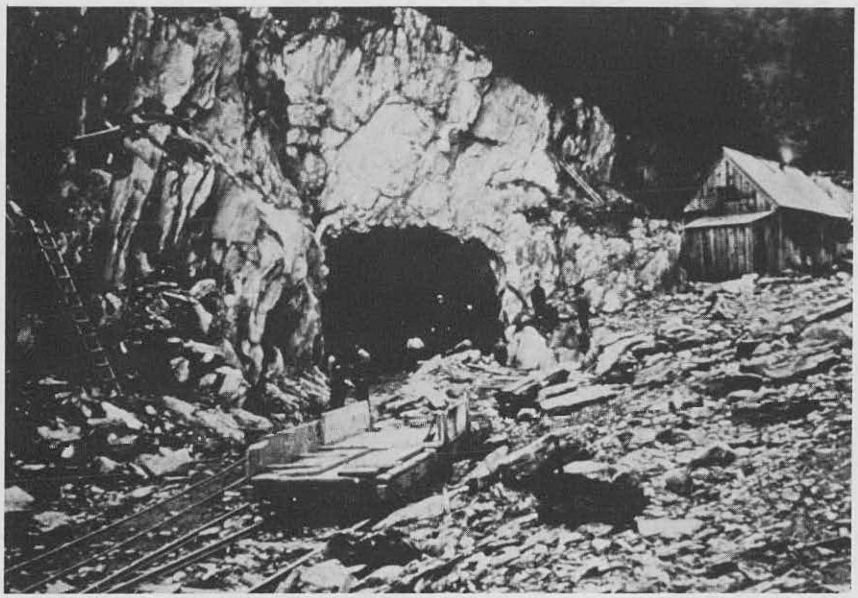
East End Working Area

The first productive work on the Hoosac Tunnel was accomplished by Herman Haupt from 1855 to July 12, 1861. At the east end, Haupt excavated 2399 ft of 14-foot by 6-foot heading; 2129 feet of which were enlarged by means of two, 6-foot high benches to full, *single-track* dimensions of 14 x 18 feet. A single-track tunnel was allowed in Haupt's contract with the Troy and Greenfield Railroad with provisions for later enlargement to double-track dimensions at the railroad's discretion. A reasonable, average advance rate for the east end heading was 50 feet per month. Haupt estimated the cost of the completed tunnel at $50 per foot or $5 per cubic yard.

When the State took over the tunnel in 1862, a three-man commission was appointed to oversee construction. One of their recommendations was to enlarge the tunnel to double-track dimensions as shown in Figure 6. Work actually began on the enlargement in 1863 and was completed in March, 1865. As the work progressed, it became obvious that a brick arch would not be used at the east end, and the tunnel was excavated to a rectangular shape; 24 feet wide and 20 feet high. Work on the enlargement was estimated to have cost $10.64 per cubic yard.

With the enlargement complete, the State began excavating a new heading near the bottom of the tunnel as shown in Figure 7. It was felt that the bottom heading would result in more efficient drainage, continuous mucking to the heading, and the possibility of enlarging the tunnel in any desired configuration. The heading was driven by three shifts of eight hours each. Each shift consisted of five holders and five strikers with one foreman, who was "in the habit of relieving one of the men for a few moments, now and then". Five 1⅜-inch-diameter holes were drilled and blasted every two hours resulting in an average daily advance rate of 2½ feet.

Extensive work was also undertaken during this period on a dam-canal-machine shop complex for use with compressed air rock drills which were then in the development stage. Although the dam at the east end was quite an accomplishment in its own right at the time, especially in a river as wild as



East end of Hoosac Tunnel during construction. Portal erected here in 1877 by B. N. Farren.

the Deerfield River, it never really fulfilled its expectations. Originally, it was planned to pipe compressed air to all the working faces from the east end, and to maintain the dam after construction of the tunnel to furnish power for a small manufacturing facility. Ice jams in the winter and low flows in the summer resulted in intermittent power, however, and all power produced by the water was needed at the east end. In fact, steam compressors had to be erected at the east end to provide supplementary power. Maintenance costs for the dam were also high because of perennial, violent floods in the Deerfield River, especially during spring ice flows.

As stated in Chapter IV, the successful Burleigh Drill was finally introduced at the east end of the tunnel in November, 1866. With this drill, heading advance at the east end was twice as much in 1867 (1187 feet) as in 1866 (570 feet). This was the case even though the heading had been progressively enlarged from 15 feet by 7 feet to 24 feet by 8 feet, so there was an even better improvement in terms of cubic yards of rock removed. The monthly working rate was still further improved during 1868 although the total advance (575 feet) was less because work was performed for only 5½ months. The primary causes for delay were lack of power from the dam and decreased activities preparatory to turning the work over to the Shanlys. By the time the State ceased work in 1868 the heading had been advanced 5282 feet from the portal, and the tunnel was complete or nearly complete for 2635 feet.

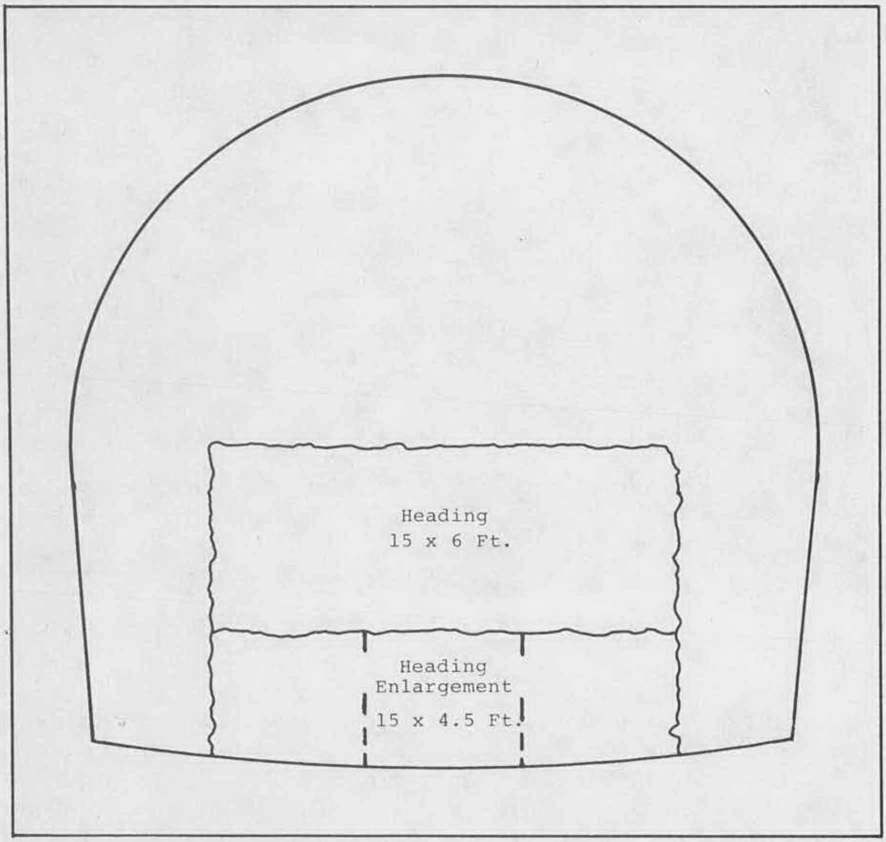
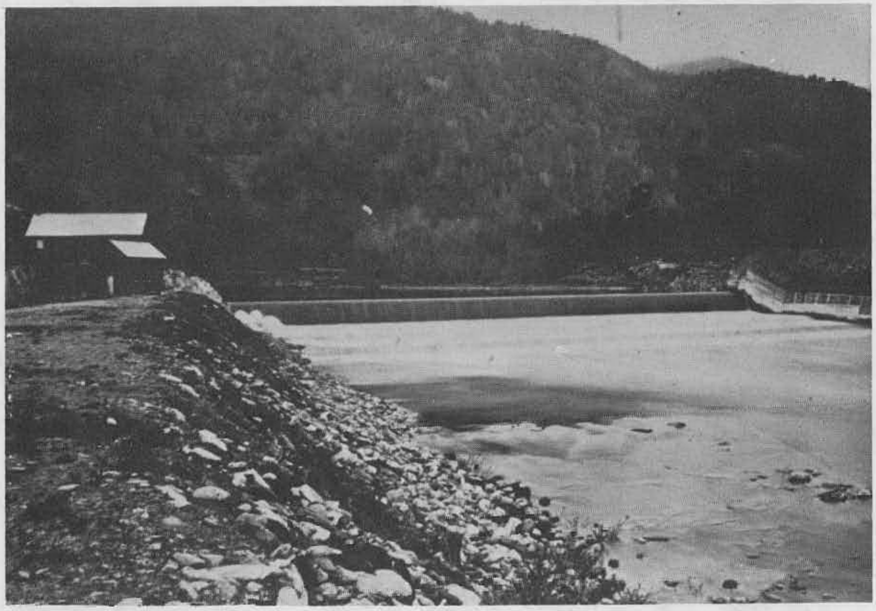


Figure 7. Heading advance at east end and first portion of eastward heading from west shaft, 1865. Note: Heading moved to crown on west side by Dull, Gowan & White in 1867.

Work began in earnest by the Shanlys in April, 1869. At the east end, the Shanlys erected new steam driven compressors to supplement water power from the Deerfield River. They also began using a small locomotive to remove muck from the enlargements. Tunnel advance was made with a 24 foot by 8 foot bottom heading and two, 6-foot overhead enlargements for a total of 20 vertical feet. Gunpowder was used in the heading as an economy measure and nitroglycerine in the overhead enlargements. Compressed air rock drills and drill carriages were used continuously at the heading; work proceeded as smoothly as could be expected. A total of three 8-hour shifts, 15 men each shift, worked at the east end heading 6 days per week. Advance rates increased to as much as 167 feet per month as the work progressed. Hole-through of the east-end heading with the heading driven eastward from the central shaft occurred on December 12, 1972, 11,274 ft from the east portal.

Machine shop near east end of tunnel. Note "muck" pile in the background.



Famous Deerfield Dam constructed under supervision of Thomas Doane, Circa 1864.

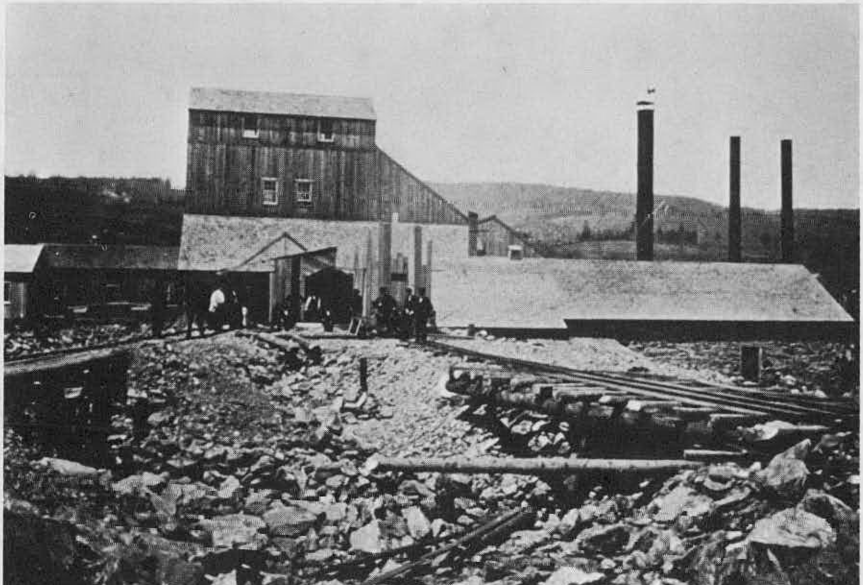
Central Shaft Section

The 15-foot by 27-foot elliptical, central shaft was started by the State in December, 1863. The reasons for the shaft were to provide for two new headings and to provide ventilation for the completed tunnel. The shaft was sunk through 25 feet of soil and 47 feet of rock by September, 1864 when worked ceased temporarily. Rock removed from the shaft was used to construct a thick masonry retaining wall in the soil portion and to extend it to 10 feet above ground surface.

By the end of 1865, the shaft reached a depth of 232 ft. An attempt was made during the spring of 1865 to introduce "Mr. Harsen's" steam-driven drilling machines but the drills became too hot to handle, filled the shaft with "hot vapor", and were removed. A "Mackenzie" blower was used for ventilating the shaft after a blast; clearing the air could reportedly be accomplished in five minutes. In October, a "naphtha" gas apparatus was installed by a firm from Meriden, Connecticut for lighting the shaft.

The shaft was worked by three shifts of eight hours each. Drill holes were made by hand to an average depth of three feet. Each gang loaded and shot its own holes at the end of the shift. All rock was removed by hand and water by bailing. It was reported that water infiltration in 1865 averaged 5 gallons per minute.

Work proceeded smoothly at the shaft throughout 1866, and the shaft reached a depth of 393 feet by the end of December. The average advance rate for nine months of active excavation was 17 feet per month. The other



Central shaft working area.

three months were consumed installing new hoisting equipment. In October, 1866, the common fuse was replaced by the Abel fuse which was fired by electricity. Reportedly, one or two holes had been lost on every shift when using the common fuse. Average water infiltration during 1866 was 11 gallons per minute. It is interesting to note that even at this low rate of infiltration two to ten tubs of water had to be removed from the shaft for every tub of rock.

Work continued quite smoothly during 1867 until the fire at the shaft on October 19, 1867. Work at that time was under the direction of Messrs. Dull, Gowan & White. The fire was caused by the accidental ignition of naphtha gas used to light the shaft. By this fire, almost every structure at the shaft was destroyed, along with thousands of board feet of lumber. More than a year was needed to reconstruct the buildings and recover the bodies of the thirteen men lost at the bottom of the shaft, then at a depth of 583 feet. The cost of excavating the shaft during the period of State control was placed at approximately $25.00 per cubic yard.

Work by the Shanlys at the central shaft began early in 1869 and was plagued by the usual problems of insufficiency or malfunction of equipment. The Shanlys spent considerable time and money upgrading these works. Hand methods were used for both drilling rock and removing water. Various attempts to introduce drilling machines into the shaft were unsuccessful. Blasting was by nitroglycerine and electrical blasting caps. The shaft was carried to its full depth of 1030 feet by August, 1870.

As the tunnel headings started away from the shaft, the Shanlys installed pumps to remove water. Apparently, pumps were placed at 270 foot vertical intervals in the shaft, each with its own tank to receive water pumped up from below. All of the water was pumped into a small adit 1009 feet from the floor which emptied into a nearby ravine. The maximum pumping rate was approximately 225 gallons per minute.

During shaft sinking, rock and water were removed in one-cubic-yard buckets. Upon completion of the shaft, the walls were trimmed and flooring strengthened to accept three-cubic-yard buckets and vertical guides. It is not known whether these buckets and guides were designed or installed by the celebrated Otis Brothers & Company or not. Otis Elevator Company, which is still in business in Yonkers, New York, has no currently available record of such an installation although the record may have been lost or destroyed. The fact that the cars were confined to their "own vertical channel by guides built into a rigid framework" would not qualify them as Otis elevators, because Otis had patented a safety mechanism which stopped cars from plummeting to the bottom in case of supporting cable failure, and three men were killed at the central shaft in October, 1870 for this very reason. A vague reference to many "inventors" having visited the site (Walker, 1957) suggests that one of the Otis brothers may have visited the Hoosac. The vertical rise at the Hoosac was impressive, however, for any type of elevator at the time. By way of comparison, Otis did not install an elevator in a building with more than 1000 feet of travel until 1929.

The final attack on the tunnel began with the advance of two headings, east and west, from the central shaft. Hand methods were used for mining until the headings were approximately 300 feet apart and room existed to introduce drilling machines. No sooner were these machines introduced, however, then the west heading began to penetrate a water-bearing zone with some seams producing as much as 50 gallons per minute. The Shanlys decided to abandon this heading, over strong objections of the State, and make a through connection to the east to allow water to drain out of the tunnel. This they did, with the east side headings meeting on December 12, 1872 at a point 1563 feet east of the central shaft. Advance rates for the heading east of the central shaft increased to as much as 148 feet per month.

With a path now complete for water to drain from the tunnel, the Shanlys attacked the west heading with vigor. Advance rates varied from 131 to 184 feet per month during 1873 until November 27, 1873 when final hole-through occurred at a point 2056 feet west of the central shaft.

West Shaft Section

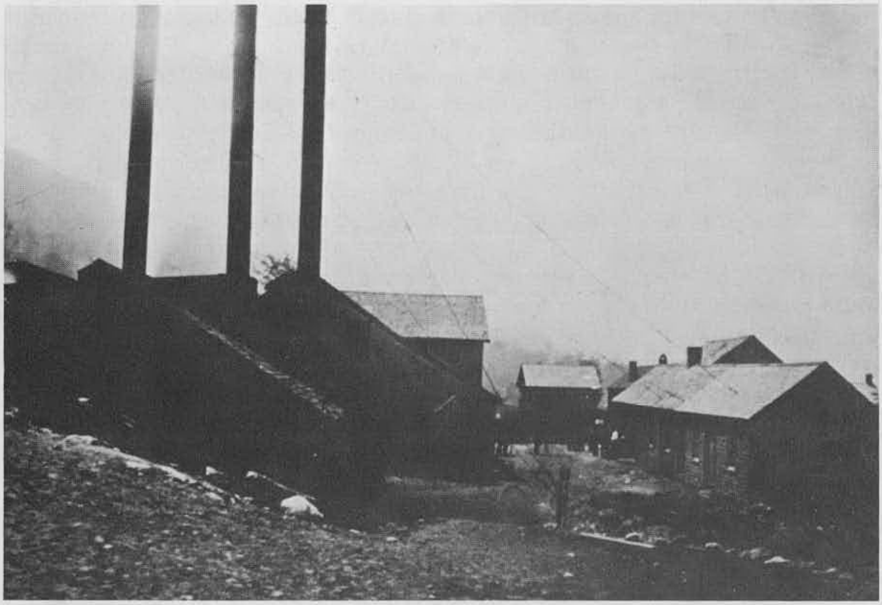
Work on the west shaft began in the late 1850's under the direction of Herman Haupt. Haupt excavated the west shaft in order to open a productive working face at the west end of the tunnel. Earlier, Haupt had discovered the loose, weathered rock and large water flows near the west portal which were to "embarrass" work in that area for years to come. When Haupt's contract was terminated on July 12, 1861, the west shaft had been sunk to grade at a depth of 320 feet, and 50 feet of tunnel had been excavated easterly from the bottom of the shaft.

Tunneling at the west shaft was performed rather haphazardly by the State during the latter part of 1863 and throughout 1864. By the end of 1864, 128 feet had been driven to the east and 155 feet to the west. Early in 1865, several buildings at the west shaft were burned by striking workmen, further delaying the work.

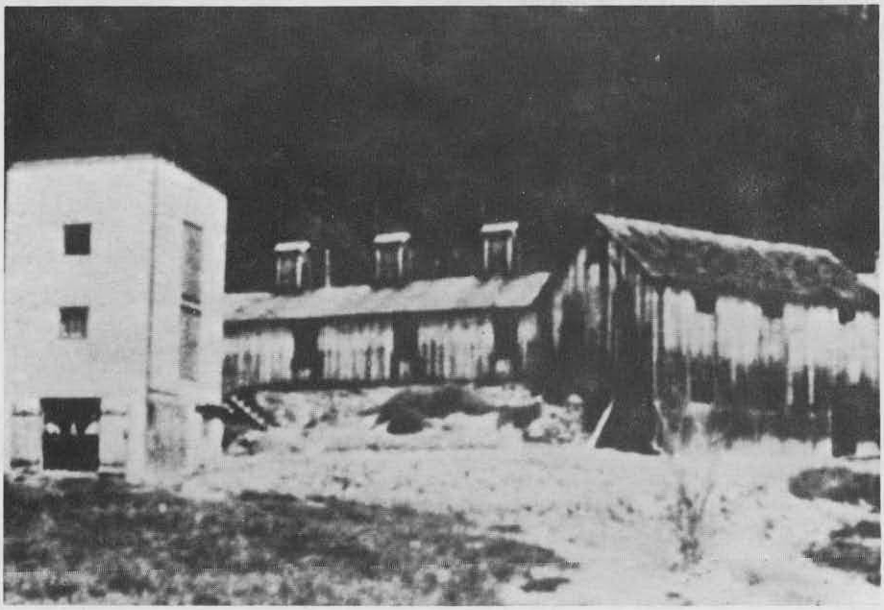
Work on the east heading was begun in earnest on June 1, 1865 at which time the bottom heading was increased in size from 11 feet by 5 feet to 15 feet by 6 feet. Progress from June 1, 1865 to the end of 1866 was approximately 870 feet. The first nitroglycerine experiments were tried at this heading by Colonel Schaffner in August and October of 1866. Early in December, 1866, all of the men were driven from the heading by a great influx of water (estimated at 250 gallons per minute) and no work was performed here again until June, 1867. Total water flow from the west shaft at this time was estimated at 1000 gallons per minute.

In 1867, some of the work at the west shaft was performed under contract by Messrs. Dull, Gowan & White. It was during this time that the eastward heading from the west shaft was raised to the crown, (See Figure 7) and increased in size again to 24 feet by 8 feet. Progress during 1867 was 290 feet.

In 1868, the State made the final introduction of "modern" tunneling appliances to the east heading of the west shaft preparatory to turning the



West shaft working area.



Professor Mowbray's nitroglycerine factory.

work over to the Shanlys. These included the introduction of drilling machines into the heading in June and the final adoption of nitroglycerine for general heading advance in August. Mowbray's nitroglycerine factory was located approximately 1000 feet south of the west shaft. A drift connection was also made with the west end allowing water to flow out of the tunnel. No longer would progress be delayed because of insufficient pumping capacity at the shaft. By the time work ceased directly for the State in 1868, the main heading had been extended 1609 feet eastward from the west shaft.

In 1869, the Shanlys spent considerable time and money upgrading and repairing the buildings and equipment at the west shaft preparatory to beginning excavation eastward and westward from the bottom of the shaft. Work on the eastward heading from the west shaft proceeded with a 24 foot by 8 foot top heading and two 6-foot-high benches. Drilling was done with Burleigh compressed air rock drills. Finally on November 27, 1873, the eastward heading from the west shaft met the westward heading from the central shaft at a point 10,188 feet from the west portal to herald the final hole-through for the tunnel.

West End Working Area

In this paper the term "west end" refers to the section from the west portal to the west shaft. The section changed its length several times during construction. When Haupt started construction at the west end in 1855, his contract did not contain a pay item for general excavation. He, therefore, wanted to make the tunnel as long as possible and his portal was 3008 feet from the west shaft. By the time his contract was terminated in 1861, he had excavated 450 feet eastward under very difficult tunneling conditions.

When State officials took over construction in 1862, they decided to move the portal 561 feet eastward and 20 feet northward of the original location to avoid some bad tunneling ground and to line up with Tom Doane's new straight-line alignment for the tunnel. As a result, all of Haupt's tunnel was abandoned although it was used for years to gain access to the new west end portal.

At the new portal, the State immediately began a deep open-cut and encountered great quantities of quicksand, water, boulders and "demoralized rock". Descriptions of the "demoralized rock" indicate that it was a classic example of saprolite, which is a rock completely weathered to soil, but which retains the structural features of the parent material such as foliation, joints, etc. Costs for various kinds of excavation were estimated as follows:

Earth, quicksand	$1.05/cu. yd.
Loose rock	$1.22/cu. yd.
Solid rock	$2.50/cu. yd.

Work at the west end was slow during 1865 because of the difficult working conditions and because the State was not anxious to complete this portion of the work. Money managers felt that considerable amounts of interest could be saved by delaying expenditure on this portion of the work until its completion was needed to finish the entire tunnel. The west heading from the west shaft was stopped on August 2, 1865 at an advance of 281 feet because it appeared that the heading was about to enter the "demoralized rock" and water flow increased from 25 to 65 gallons per minute. No chance could be taken on flooding the eastward heading which had far to go. A small drift was attempted from the west portal to the west heading but it collapsed with the great flow of water and had to be reclaimed by extending the open cutting.

Several test pits were excavated at this time to better define subsurface conditions. One of these indicated that the west heading could be extended by another 1000 ft. Prior to any heading advance, however, the existing heading was enlarged for 298 feet to 15 feet by 10.5 feet and a supplementary shaft was sunk 264 feet west of the west shaft. The supplementary shaft was used to improve alignment and as a pumping shaft. In December of 1866, work ceased at the west shaft until April, 1867 because of a great influx of water.

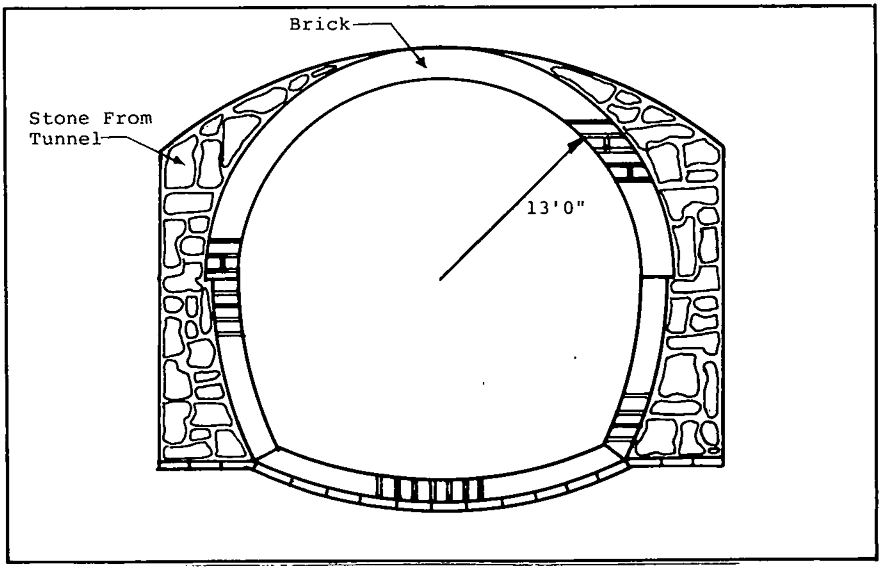


Figure 8A. Structure used by Farren in cut-and-cover area.

In the Spring of 1866, B.N. Farren amazed everyone by agreeing to excavate the west end under contract. He agreed to construct 174 feet of enclosing structure in cut-and-cover area and 200 feet of full-size tunnel lining underground within one year. Cross-sections of the linings used by Farren are shown in Figures 8A and 8B. The State agreed to provide all necessary supplies and materials at cost. Eventually, Farren had to excavate adits along and outside of the tunnel to drain the rock mass prior to excava-

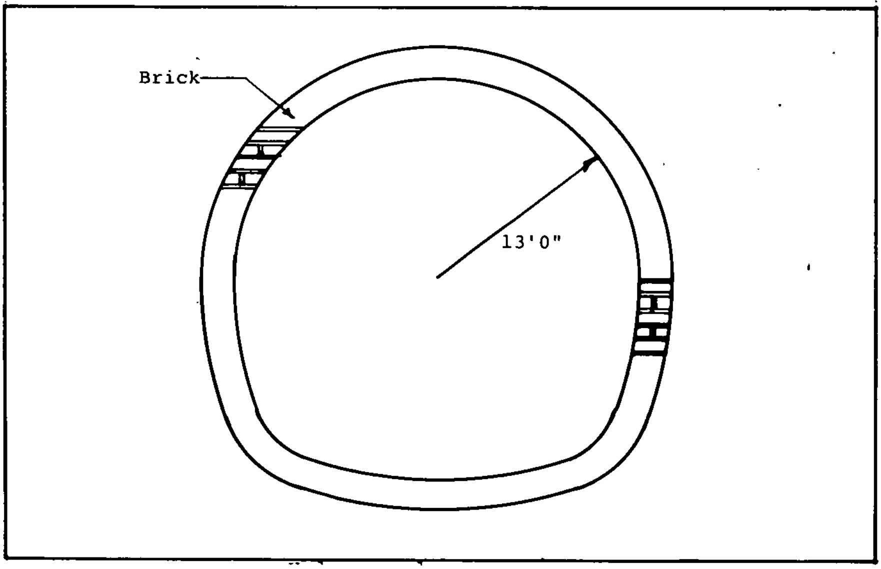


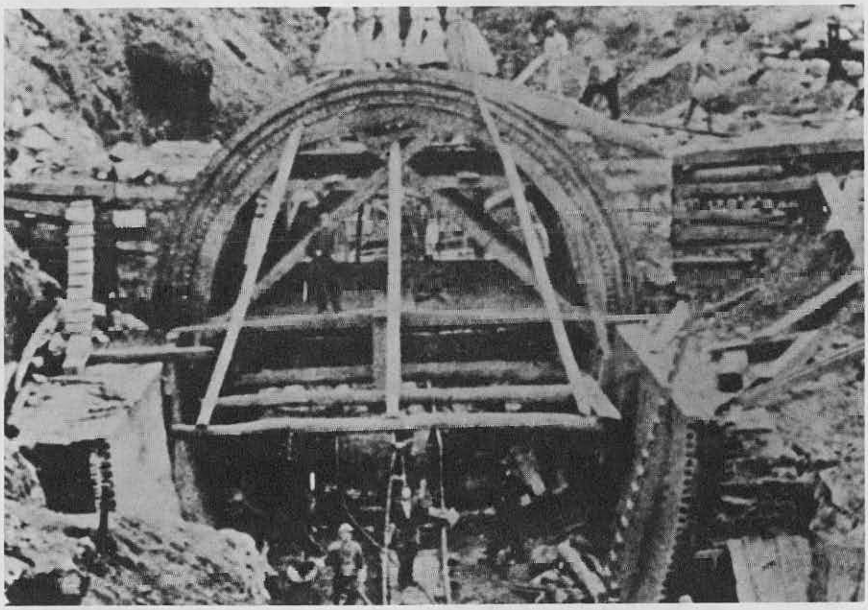
Figure 8B. Tunnel lining used by Farren underground.

tion. Upon draining, heavy timber bracing was constructed and the brick arch placed inside the timbering.

In 1867, Farren successfully completed his first contract and agreed to construct another 500 feet of full-size tunnel lining. He also agreed to construct 500 feet of adit from the west shaft heading in an attempt to provide a through-going adit along the west end. This adit was badly needed to allow water to drain freely from the tunnel workings. Water was being pumped from the west shaft at this time at an estimated rate of 700 to 1000 gallons per minute.

Delays from the water continued into 1868 necessitating completion of the adit. To assist with the work, Test Well No. 4 was enlarged and used as a shaft for adit construction. A through-going connection was finally made on October, 1868. In addition to the above, B.N. Farren continued to erect the full-size lining with vigor. He extended the portal 60 feet eastward in open cut and 500 feet westward into the mountain. At a point approximately 800 feet from the portal, he encountered rock sufficiently strong to serve as a footing for the lining and was able to dispense with the "inverted arch" at the bottom. In all, he completed 931 feet of lining by early in 1869.

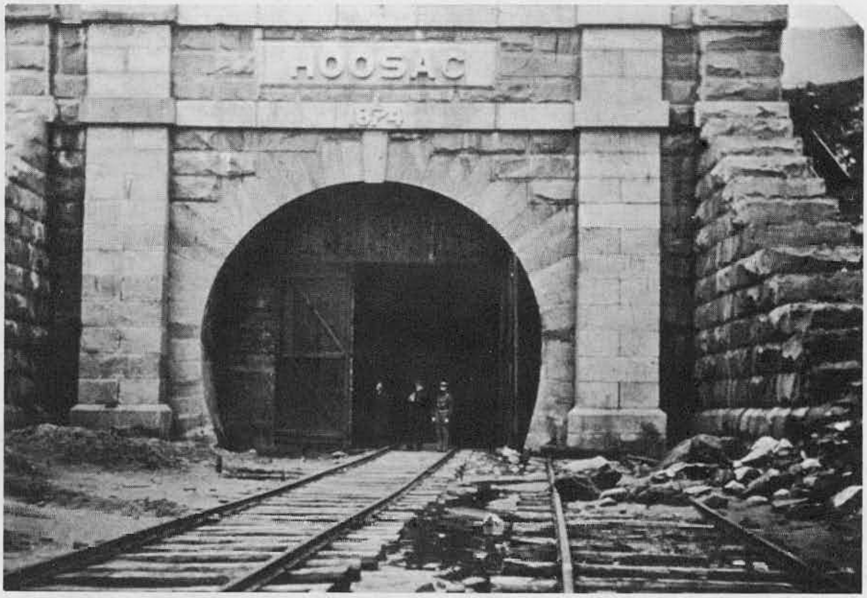
Farren had demonstrated how to conquer the west end, and work proceeded relatively smoothly under Shanly's supervision, the work having been let to Holbrook and Hawkins. In 1871, a contract was let to Messrs. McClallan, Son & Walker to excavate soil and rock along the abandoned Haupt tunnel. Eventually, the entire distance from the west portal to the west shaft (2447 feet) was lined with brick by early in 1873. The work was not without difficulties, however. On October 3 and 4, 1869, a rainstorm of "unparalleled severity" occurred in Western Massachusetts. Total rainfall was measured as 6 inches at Williams College with the most intense rain falling on the afternoon of October 4. A brook crossing the tunnel next to the west end overflowed its banks, dammed the Haupt tunnel with a great quantity of debris, and completely flooded the west end workings. It took nearly a month to clean up the mess and this severely interrupted Shanly's progress.



West end lining being constructed by B. N. Farren, Circa 1867.

In another instance, a major crown failure occurred in the tunnel on March 30, 1870 at about station 12+00. It was estimated that 1200 to 1400 cubic yards of material collapsed into the tunnel, crushing timber supports and approximately 25 feet of completed lining. Clean-up required three months. The lining was reconstructed three feet thick in this vicinity.

Following complete excavation of the tunnel, a decision had to be made as to how much brick lining would be necessary in addition to that already in place from the west portal to the west shaft. To assist with this decision, the railroad asked two geologists and three civil engineers to view the tunnel and render opinions. A fourth civil engineer, Edward S. Philbrick, was asked to analyze their reports and make a final recommendation. Mr. Philbrick recommended that 1600 feet be lined in addition to approximately 2500 feet already lined, that 3500 feet be more thoroughly examined and probably lined, and that the entire remaining 17,500 feet of tunnel be carefully stripped of all loose rock. Eventually, 7573 feet of the tunnel was lined with brick and a 50-foot masonry extension was added to the portal at the west end.



Famous West Portal of the Hoosac Tunnel constructed by Francis and Walter Shanly in 1874.

VI. Claims For Extra Compensation

There were three principal claims for extra compensation arising from the tunnel work. The first was by Herman Haupt who requested compensation for his being thrown off the job in 1861. There is no doubt that Haupt could have finished the tunnel, and that he was dealt with very harshly by the State. Haupt went on to become one of the great engineers and contractors of his time.

Haupt worked diligently on the tunnel and related railroad, but the result was not up to the standards of a finished road. Haupt insisted, with some justification, that his early work on the railroad was intended primarily to allow him to proceed with excavation of the tunnel which was the key to completion of the entire operation. The State, however, in the form of Chief Engineer Whitwell, insisted on each foot being finished prior to payment. Haupt had already invested so much of his own or borrowed money into the enterprise by this time that he was unable to make the necessary improvements and ceased work.

It was not until 1868 that Haupt received $75,814 as a final settlement. He placed his damages by that time in excess of $600,000 including actual payments made on the tunnel and interest on his money with no allowance for "pain and suffering". The fact that he was able to survive such a loss and continue to maintain the trust of individuals who knew him is a measure of his character and fortitude. His family insisted to his dying day that he was permanently scarred by his experiences in Massachusetts.

Another individual who was dealt with quite harshly by the State was Charles Burleigh. He first became involved with the tunnel while an employee and stockholder of the Putnam Machine Company, having helped one of the commissioners, J.W. Brooks, design a drill. This drill was known as the Brooks, Gates and Burleigh Drill, was introduced to the tunnel early in 1866, and proved a failure. The State had invested a good deal of money in development of this drill, however, and had obtained its use free of charge.

After investigating the causes of the failure of the first drill, Burleigh proceeded to design a new one, and it worked well. He patented the drill and allowed it to be used in the tunnel under a *verbal* agreement with Mr. Crocker that he "should receive no payment whatever at the time, but the State should have the full use of the machine, and when it could be determined of how much value the invention was to the State, he should be fairly and fully rewarded". In order to obtain clear title to the drill, he had to pay $10,000 to obtain rights to another patent. Putnam Machine Company provided sixteen drills for the State at cost. These drills were turned over to the Shanlys in 1869 along with other State equipment and the Shanlys proceeded to purchase another 60 drills at $625 apiece.

It should be borne in mind that it was not possible to sue the State for just compensation. The only recourse was to file a bill and hope that it would be passed by the Legislature and not vetoed by the Governor. People like Mr. Burleigh and Mr. Haupt were at the complete mercy of the legislative process. Although Burleigh did not name a specific figure for his claim he demonstrated that the State had saved millions of dollars by using his drill and that he would be satisfied with $100,000. He received $10,000 and a pat on the back.

A claim by the Shanlys in 1875 involved a classic example of "changed condition". Upon tunneling westward from the central shaft, the Shanlys intersected a water bearing zone which threatened to flood the shaft. They decided that it would be better to finish the eastward heading so that water could drain from the tunnel by gravity. The State insisted on pushing westward, however, under any circumstances and threatened nonpayment if it was not done. With this threat, the Shanlys invested months of time and thousands of dollars installing pumping equipment in the shaft. It was as if, as Walter Shanly said, "The engineers seemed to say, 'Never mind the *rock*, get all the *water* you can and bring *it* up.' " It was estimated that during 1872 the Shanlys lifted 13,800 tons of rock and 316,000 tons of water from the central shaft!

The Shanlys eventually received (in 1875) $147,000 in addition to $141,894.83 which was paid to them for payment items in excess of their bid price. A further claim for $129,495.62, although approved by the Legislature, was vetoed by Governor Butler in 1888.

VII. Closing and Conclusions

There is considerable disparity in the published literature about the time for completion and about the cost of the Hoosac Tunnel. There were four principal working stages of the tunnel beginning with Haupt in 1855, proceeding through the State control to the Shanlys, and ending with Farren who completed the tunnel, 1874 to 1876. Total working time during these 21 years was approximately 186 months or 15½ years. The average rate of advance for 25,081 feet of full-sized tunnel with the necessary lining was 135 feet per month.

The cost of the tunnel has been reported at anywhere from 7 to 20 million dollars, the most common figure being 14 million dollars. Analysis of the costs, however, shows Drinker (1878) to be the most accurate. He set the cost of tunnel construction at 10 million dollars, the cost of the associated railroad from Greenfield to the Vermont state border at Williamstown at 4 million dollars, and the cost of interest paid on the debt during construction at 3.3 million dollars. The railroad had cost almost $100,000 per mile and the tunnel $400 per foot of $2,000,000 per mile.

A question asked frequently is, "Was the tunnel worth it?" There is no doubt that the tunnel has paid for itself over the last 100 years and that it has generated considerable business for towns in its vicinity and for Boston, but it did not lower freight rates and it did not open the "west" as was originally intended. By the time the tunnel was finished, it had cost so much that freight rates had to remain high to pay for it, and the "west" by that time had moved from New York to California with completion of the transcontinental railroad in 1869. The tunnel is an interesting, but somewhat auxiliary episode in the history of railroad development in America.

The tunnel's chief contribution was to tunneling technology, including the firm establishment of the center-cut system of heading advance, the incorporation of simultaneous ignition or detonation electrically, the generalized use of nitroglycerine, and the use of compressed air rock drills and drill carriages. The Hoosac tunnelers' use of two tunnel boring machines and a 1000-foot elevator at the central shaft must be considered highly innovative. In addition, the Hoosac tunnelers achieved modern surveying accuracy. It might all have been done at a different time, during construction of some other tunnel, but it wasn't. It was done at the "Mighty Hoosac" when Francis and Walter Shanly put "Daylight Through the Mountain."

Epilogue

People sometimes wonder how the tunnel would be constructed today under modern requirements and with modern construction methods; how much it would cost; and how long it would take to build. Below are a few comments about what might happen if the tunnel were constructed today, although it is emphasized that there is really no way to form an accurate picture. As always, conduct of the project would depend on the *people* involved and their ability to deal with problems.

The tunnel certainly would not be built on the basis of "opinions" about the subsurface conditions. The actual site of the tunnel would be carefully surveyed and investigated, probably with aerial photographs, test borings and other methods of exploration. The fault at the west end would be discovered and no one would suppose that the tunnel "would go below where the ground water percolated". Properly describing the subsurface conditions, however, is not the same thing as correctly evaluating their potential impact on tunnel construction. It is still possible that more trouble at the west end and more water in the tunnel would be encountered than anticipated.

If constructed today, the tunnel would probably be shorter, larger in cross-section, and built without shafts. The open-cut at the west end would be more extensive with the portal moved as far eastward as possible. The tunnel cross-section would be more like 30 feet in diameter rather than 26 feet, for double track dimensions. No shafts would be necessary for a tunnel which by today's standards would be comparatively short. Ventilation during construction would be provided by pipes or conduits laid within the tunnel.

Excavation of the tunnel would be by either a tunnel boring machine or by drill and blast procedures. Large diameter machines are available today which bore their way through rock at rates which, under favorable conditions, exceed in a day what the Shanlys accomplished in months. A tunnel boring machine, however, might not be used at the Hoosac. Delivery time for a machine is long; the tunnel is relatively short; and those quartz veins in Hoosac Mountain are difficult to penetrate even with today's equipment.

If the contractor were to use drill and blast procedures, his basic approach would not be much different than that of the Shanlys although the headings would be larger and the process more highly mechanized. Compressed air rock drills today, for instance, penetrate the rock at one to two *feet* per minute rather than one to two inches.

It is estimated that the tunnel would take 3-1/2 years to construct and cost $75,000,000 for a full double-track cross-section. It is possible that a single-track cross-section could be provided at a cost of approximately $60,000,000. This cost escalation is not as great as it seems when you consider that wages for miners have increased from two dollars a day to nine dollars an hour.

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