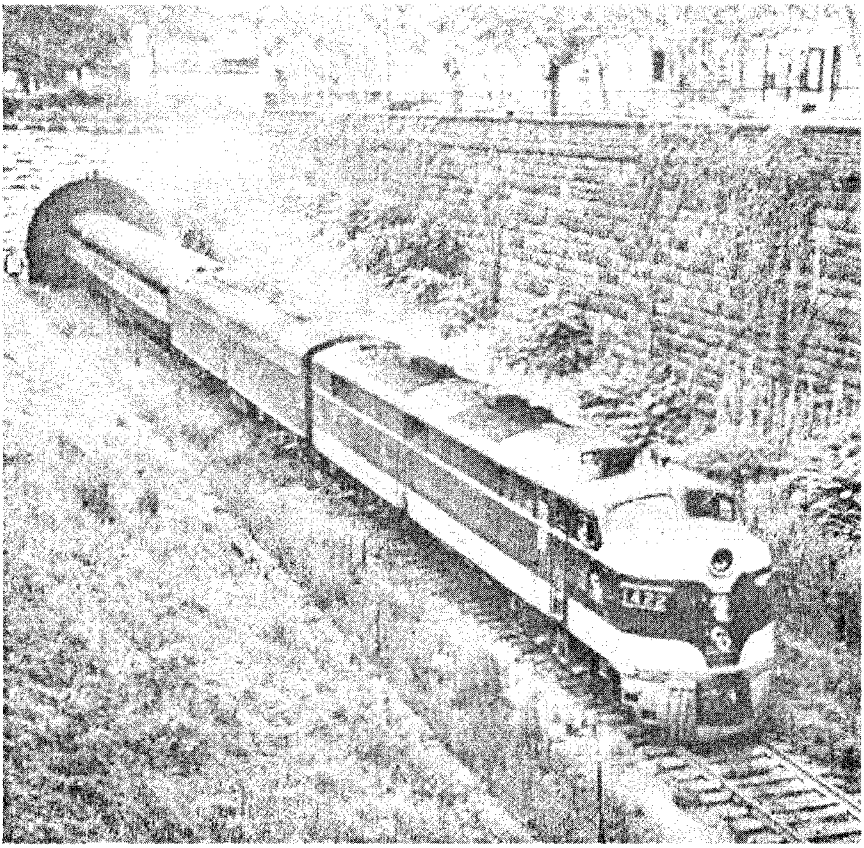
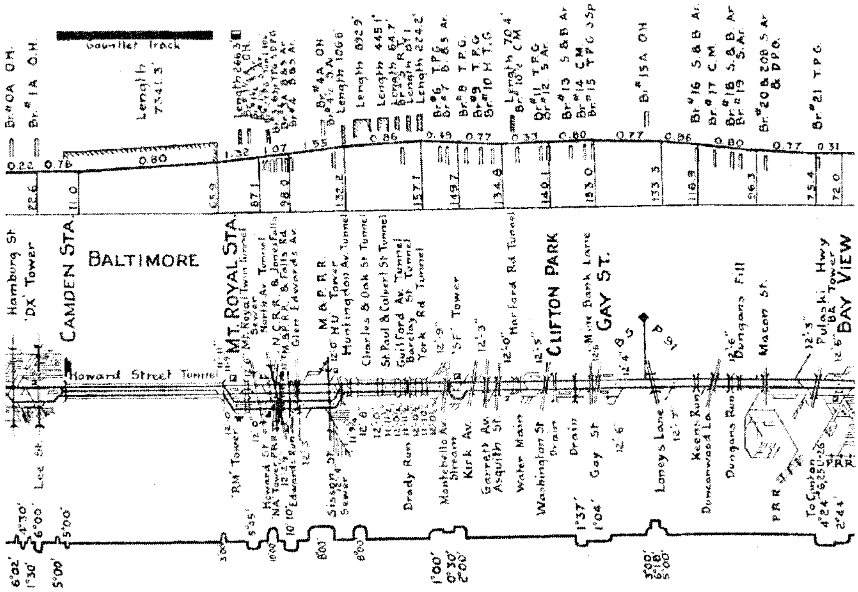


Figure 5. *An eastbound train emerges into a cut from one of the tunnels between 25th and 26th streets. The electrification and second track had been removed prior to this 1967 view, but the stonework survives. (H. H. Harwood, Jr.)*



TRACK CHART, BALTIMORE BELT RAILROAD, 1949

Figure 6. *Among many other details, this 1949 track chart of the Belt Line shows the line's grades, curves, tunnels, and bridges. Note the gauntlet track through the Howard Street Tunnel. (B&O Historical Society)*

miles (11.6 kilometers), but with ten tunnels totaling 9,605 feet (2,927.6 meters)—one-fourth of the line's length—these would be most expensive miles (kilometers) the B&O ever built. Initial estimates put the total cost at around $5 million, a figure that immediately began to increase.[8]

By 1890, the B&O was not in the best financial shape, so raising the necessary capital took several months and a little imagination. Railroad officers and some local investors formed the Maryland Construction Company, and this organization was able to attract the needed funds through a $6-million bond issue. The first construction contracts were issued on September 4, 1890, with Ryan and McDonald, a company that had built some of the B&O's line to Philadelphia, selected to be the primary contractor. A local firm, L. B. McCabe and Brother, won some of the work on the north side. The project was divided into four sections: Hamburg Street to Mount Royal Avenue [2.0 miles (3.2 kilometers), including Howard Street Tunnel]; Mount Royal Avenue to Guilford Avenue [1.2 miles (1.9 kilometers), including six tunnels]; Guilford Avenue to Belair Road [2.0 miles (3.2 kilometers), including three tunnels]; and Belair Road to Bay View Junction [2.0 miles (3.2 kilometers) and the junction].[9]

Construction of the three portions from Mount Royal Avenue to Bay View Junction proceeded smoothly, except for some delaying litigation over right of way near 26th Street. Even the complicated arrangement around North Avenue and across Jones Falls Valley went into place without serious difficulties, thanks in no small part to Rea's meticulous attention to its details. But as expected, the long tunnel under Howard Street proved to be the most time-consuming and problematic part of the whole undertaking. It was something of an excursion into the unknown.

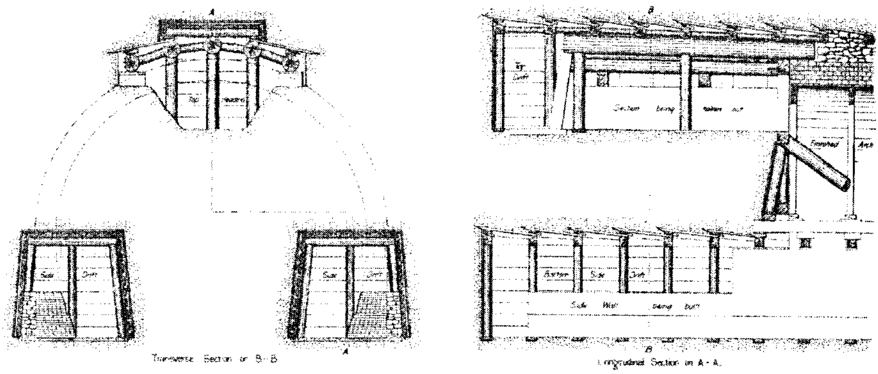
The shear size of this tunnel alone made it daunting: 7,339-feet (2,236.9-meters) long, 27-feet (8.2-meters) wide, and 22-feet (6.7-meters) high at its crown, with an expansion at its northern end to allow for the two tracks running through most of its length to increase to four. Since these were finished inside dimensions, the excavation would have to be some five to eight feet (1.5 to 2.4 meters) greater in size to allow room for the lining structure. The tunnel would be fully lined with between five and eight layers of brick, as it would be entirely in soft soil and gravel and need the structural strength. The depth of earth over the crown varied from three to about 50 feet (0.9 to 15.2 meters).

Although this would be a soft-ground tunnel, the nature of the soil left much to be desired, and far less was known about it before starting work than would now be the case. Primarily sand of varying degrees of coarseness, the soil also contained seams of loam, clay, gravel, and what one article in *Engineering News* referred to as "a layer of rotten rock three to four feet thick." One stratum of gravel, about 8-feet (2.4-meters) thick, underlay most of the route, and it contained a large amount of water. Baltimore had a minimal sewer system, and it was common practice for individual buildings to have a well down to this stratum into which sewage was dumped. Water percolated readily through the gravel, generally from east to west, which solved the sewage disposal problem, but this generated considerable concern for the tunnelers. Not only did the water have to be dealt with during construction and after completion, no one knew whether it would pose any health risks to the workers. As it turned out, the workers encountered clear, odor-free water, and no related illnesses were reported.[10]

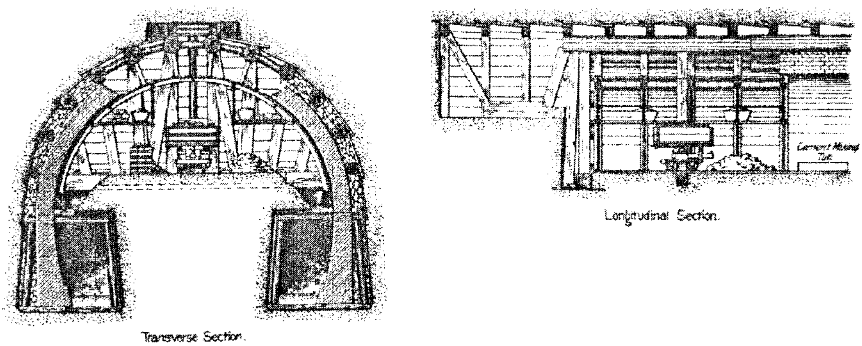
The soft soil presented stability problems as well. While there were a couple of sections of hard clay that even required blasting, cave-ins posed a greater concern. Howard Street was lined with three- to eight-story buildings, and a horse-drawn street railway ran most of the length over the tunnel. In addition, a cable railway had recently begun operation over three blocks along the south end, where the tunnel was at its shallowest depths. The railroad and contractors were, of course, responsible for any damage to these existing structures caused by the construction.

The city insisted that tunnel work disrupt traffic and activity on the street as little as possible, so access shafts for worker entry and muck removal had to be carefully planned and located. Ryan and McDonald ultimately sank five intermediate shafts, allowing ten working faces for drifts in addition to the two sections that utilized cut-and-cover techniques near the ends. Four of these shafts were struck horizontally from the basements of adjacent buildings or down and across from vacant lots to stay clear of the street itself, but Shaft Number 5 at German Street had to be sunk between horse car and cable railway tracks in the street. The hoist machinery was installed in a building to one side, however, with the hoist cables to the shaft supported high enough overhead to clear traffic. Shafts 1, 2, and 3 used steam elevator equipment furnished by Otis, while a steam-powered derrick built by Ryan and McDonald removed spoils and lowered support timbers in Shaft 4. A local firm, Bates and Company, provided the unusual hoist machinery for Shaft 5. Surviving drawings indicate that workers also drilled over 40 wells for water removal, most of them into the southern half of the bore.

Because of the unstable, water-laden soil, support for the tunnel during construction was crucial. Ryan and McDonald's general manager E. J. Farrell devised a technique that generally worked well. Prior to any excavation, teams drilled drainage wells to the work area and set up air-driven pumps. This substantially reduced water problems during excavation, and many of these pumps remained in service as the excavation progressed. At each face, workers dug a drift at the crown, supporting the roof with timbers. Simultaneously, other teams dug two parallel drifts for the lower portions of the sidewalls, also supporting these with timbers. These side drifts were bricked in and back-filled as soon as possible, with excavation and bricking typically progressing in 18-foot (5.5-meter) sections. (Figure 7) Each drift could accommodate two miners and a helper, and the side drifts generally advanced 20 to 25 feet (6.1 to 7.6 meters) ahead of the crown drift. The sides of the crown drift were then excavated, joining the three drifts to form an inverted "U," but leaving a substantial bench of earth along the center. This bench supported materials-handling carts and allowed masons to brick in the crown using only short scaffolds. (Figure 7) Only with the lining complete and—hopefully—stable, were the timbers removed, followed by the bench. During this late phase, there was enough room for workers to use a traveling derrick powered by compressed air to handle the heavy items. Several arrangements of increasingly complex timber supports were necessary as the work progressed and exposed more interior surface, and timbers were finally exchanged for iron bars with some adjustments that served as a form for the masons. Working two, ten-hour shifts per day, and barring unusual



EXCAVATION OF TOP AND SIDE DRIFTS



UNFINISHED ARCH WITH IRON CENTERING AND MASONS' SCAFFOLDS

Figure 7. *These two drawings show how most of the Howard Street Tunnel was dug in phases. The central bench was excavated after completion of the brick lining and removal of the temporary construction supports. (Engineering News)*

occurrences such as hitting a major inflow of water, this technique advanced the faces at between 50 and 90 feet (15.2 and 27.4 meters) per month.[11]

An 18-by-24-inch (457-by-610-millimeter) Ingersol-Sergeant air compressor located near Shaft 1 supplied a manifold that ran for over a mile (over 1.6 kilometers) along the street's curb to the other shafts. This furnished compressed air to drive the well pumps and hoists, but this air helped solve another problem as well. The atmosphere in the tunnel's confined spaces was humid at best, but high temperatures during the summer months made the work almost unbearable. Ryan and McDonald devised an ingenious solution to improve conditions. Instead of exhausting the air from the various pneumatic devices directly to the atmosphere, the company installed pipes to convey it to eductors on ventilation pipes leading from the workspaces up to the outside. Augmented with some supply air when necessary, this air induced a larger exhaust airflow from the spaces, which was replenished by fresh air drawn in through the access shafts. This ventilation system lowered the temperature in the tunnel 15 to 20 degrees Fahrenheit (8 to 11 degrees Celsius) in the hottest sections at very low cost. (Figure 8)

Even though the ground was soft and the tunnel's overburden shallow, this method generally produced a stable lining structure and caused little disturbance to the street and buildings above. In most instances, the crown of the lining settled between two and six inches when the supports were removed. Some of this can be accounted for by mortar compression, but the rather poor quality of much of the backfill behind the lining and the water content of the soil permitted greater distortion in some locations. In several places, the street surface settled by a foot or more. This resulted in numerous cracks in sewers, water and gas pipes, and the cable trough of the cable railway. Crews repaired these as they occurred with few serious outages or delays. By far the most serious incident involved the City College Building at Howard and Centre streets. Excavation here in 1893 tapped into a large pool of water that rapidly drained into the tunnel, undermining the building's foundation and damaging the structure so severely that it had to be demolished. According to the contract, Ryan and McDonald were responsible for replacing it, and they did so in an excellent fashion, completing an impressive new City College Building in 1899. It remains in service as an apartment building.[12]

A different kind of tunnel casualty was none other than Samuel Rea. Rea had thrown himself into the work with gusto, and long hours took their toll on his health. Seriously run-down and unable to oversee the work as he wished, Rea resigned in 1891, less than a year after construction work began. Fortunately for Rae, his strength returned during a long sabbatical, and he was able to return to railroading, rejoining the PRR's Engineering Department. He served as chief engineer for that railroad's massive Pennsylvania Station and Hudson River Tunnel project in New York City—where he apparently took better care of his health—and ultimately became president of the company in 1913.[13]

While almost 5,900 feet (1,798 meters) of the tunnel were bored, approximately 300 feet (91 meters) on the north end and 1,150 feet (350 meters) on the south end were very close to the surface, and Ryan and McDonald constructed these portions using cut-and-cover methods. The northern end featured a bell-mouth enlargement with turnouts inside the bore expanding the tunnel's two tracks to four to

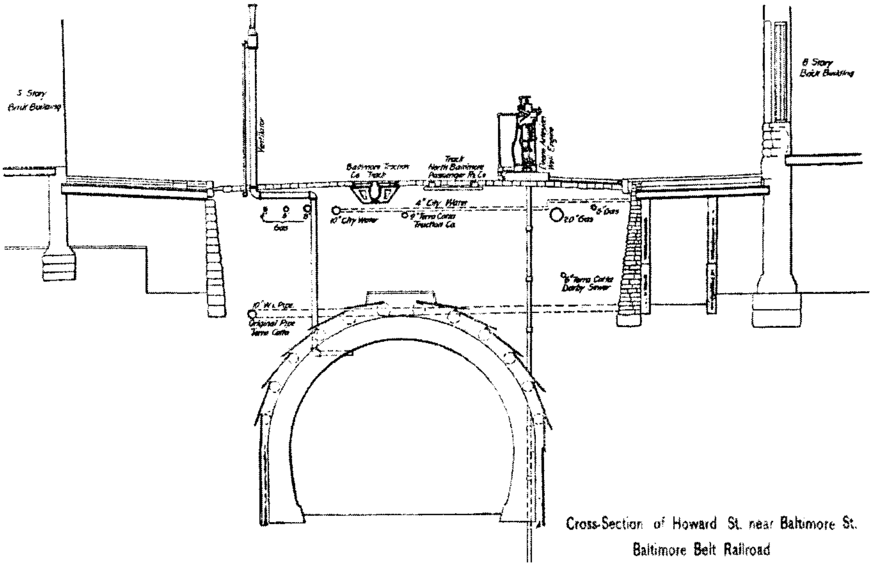


Figure 8. *The relation of the tunnel to other Howard Street structures is clear in this drawing, which also shows one of the venturi-driven ventilators used during construction. (Engineering News)*

serve the new Mount Royal Station's platforms and provide sufficient capacity to prevent the grade from becoming an undue operational bottleneck. The portal opening measured 51 feet, 7 inches (15.72 meters) wide by 27 feet, 8 inches (8.43 meters) high, and the lining thickness increased gradually from five to nine layers of brick to support the larger arch and overhead fill. South of Lombard Street, two designs were employed. Initially, the B&O planned to include a new station at Howard and Lombard streets to replace the ageing Camden Station, but a combination of financial pressures and the realization that trains going no farther north than the new Lombard Street Station would create serious operational problems in the south end of the tunnel convinced management to abandon the idea. Nevertheless, a portion of the tunnel near Lombard Street was built with an adjacent alcove intended to serve as access to underground platforms. To accommodate this alcove, steel girders on vertical brick and concrete walls replaced the standard brick-arch construction. (Most of these girders were covered in 1907 when the B&O "arched in" this area with brick. Except for openings to the alcove, this section now looks much like the remainder of the tunnel.) The southernmost 822 feet (250.5 meters) reverted to brick-arch, with an increase to six layers near the portal. Both portals were attractively finished in limestone, as were adjacent retaining walls. South of the portal, a cut continued alongside the Camden Station tracks for about five city blocks. Westbound trains ascended a 0.78 percent grade to reach the grade of the existing trackage at Henrietta Street.[14]

The remaining tunnels on the Belt Line, most of which were not much more than substitutions for bridges to carry overhead streets, were built using cut-and-cover methods similar to those employed in those portions of the Howard Street Tunnel. While less involved than the long bore, these nine tunnels, particularly the twin tunnels with internal bridges at North Avenue, were far from inconsequential, totaling over 2,254 feet (687 meters) in length. All of their portals were faced with cut stone. Substantial cuts stretched between the tunnels along 26th Street, and another major cut was required near what is now Edison Highway.

Solving the Power Problem

Building the Belt Line, while formidable, was only part of the B&O's problem. The road also had to figure out a way to run trains through the long tunnel without major health and pollution problems from steam locomotive smoke. Westbound trains (moving north to south through the tunnel) could coast down the grade with fires banked, so they presented no problem, but hard-working eastbound trains climbing the tunnel's grade seemed to defy solution. Realizing its dire need for a line through Baltimore, the B&O bravely embarked on construction in 1890 without knowing how the operational problems could be solved. Building tall chimneys along Howard Street held no attraction, and the company's managers gambled that they would not be necessary. What they needed was some new type of motive power that did not generate large amounts of smoke and gas.

The clean new power source that filled the bill was electricity, but both the B&O and a young manufacturing concern named General Electric (GE) took a substantial leap of technological faith when they signed a contract for electric locomotives, a generating plant, and a power distribution system for the Belt Line in spring 1892. Small electric rail vehicles had been demonstrated, including some 10-ton (9.1-tonne) units in London and a few pioneering electric streetcars,[15] but nothing close to the size and power required had yet been built. Interestingly, the B&O did have prior experience, albeit very limited, with electric traction on its own rails, having hosted an experiment 40 years earlier with a battery-powered locomotive designed by Charles G. Page. During April 1851, Page's primitive locomotive ran between Washington and Bladensburg, Maryland, achieving speeds up to 19 miles per hour (30.6 kilometers per hour). While Page's motor was small, he did demonstrate the ability of electric traction to pull trains, but his experiments also made it clear that batteries could not furnish the amount of power needed for commercially viable operation.[16]

General Electric proposed to supply three 96-ton (87.1-tonne) locomotives (Figure 9) that would receive direct-current (D.C.) power through an overhead rail (the running rails would serve as the ground side of the circuit), along with steam-engine-driven generators and electrical switching equipment to supply the power. The specifications called for each of these locomotives to pull a 500-ton (454-tonne) passenger train up the 0.8 percent grade through the tunnel at 35 miles per hour (56.3 kilometers per hour), or a 1,200-ton (1,089-tonne) freight train at 15 miles per hour (24.1 kilometers per hour). Both passenger and freight train consists included a non-working locomotive, with open cylinder cocks to minimize resistance. Locals hailed the decision to electrify the tunnel with praise that says much about the general faith at the time in technology, even unproven technology, to solve almost any problem. With unbridled optimism, one paper lauded the announcement thusly:

> When the Belt Railroad tunnel is completed and all trains are hauled back and forth by the subtle power of electricity, it will be one of the most wonderful events of the world. If it is a success, and there seems no doubt, it will completely revolutionize railroad power and be a great boon to all travelers.[17]

This naïve reporter may have had no doubt, but those more intimately involved at B&O and GE surely harbored some from time to time. Apparently unsure how their gamble might be received by shareholders, B&O management chose not to raise any undue questions until after the fact. The company's annual reports between 1890 and 1894 all included a section describing Belt Line progress, but they made no mention of electrification. The commitment to electrify had the power to make or break both B&O and GE, and everyone involved knew that a lot of new ground had to be covered in only three years to turn this proposal into a reliably functioning reality, so the less said the better. Fortunately, the GE engineers proved up to the challenge, but only after the system worked did it receive understated mention in the B&O's 1895 annual report.

No electric utility existed to furnish the necessary power in 1892, so the B&O built a new powerhouse designed by E. Francis Baldwin, a notable local architect already responsible for several B&O structures, alongside the track between Henrietta and Hill streets south of Camden Station. Steam from twelve 250-horsepower (186.4-

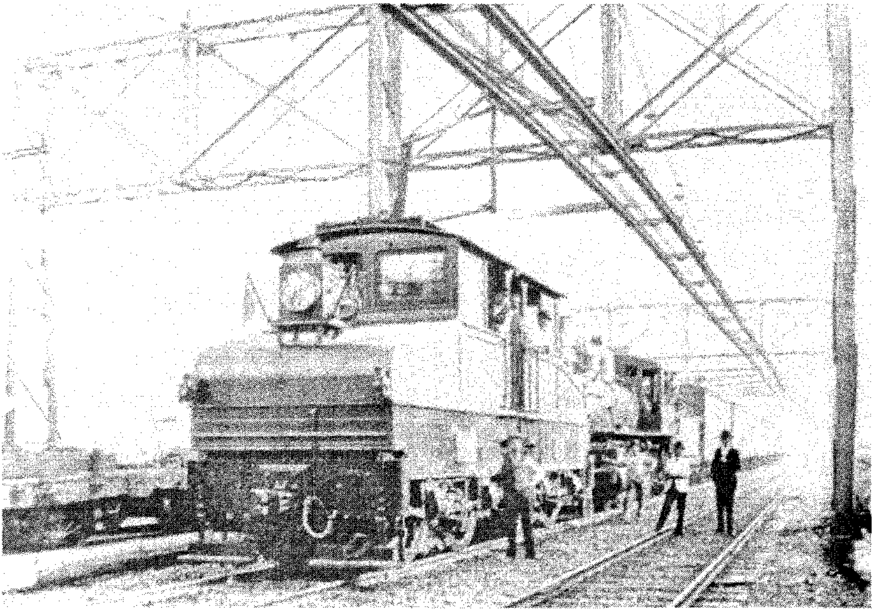


Figure 9. *B&O Number 1, class LE-1, with the first eastbound freight train to pass through the tunnel in June 1895. The original overhead electrical system is clearly visible. (Industrial Photo Service)*

