ROUTE 15 CORRIDOR IMPROVEMENT PLAN

BURLINGTON-ESSEX RAIL PROJECT

Burlington Rail Tunnel Assessment

Prepared for:
CHITTENDEN COUNTY METROPOLITAN PLANNING ORGANIZATION
VERMONT AGENCY OF TRANSPORTATION - RAIL DIVISION

Submitted by:
DMJM HARRIS
66 Long Wharf, Boston, MA 02110

May 2002
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I. Introduction

This report has been prepared to support the Environmental Assessment and Schematic Engineering Phase of the Burlington – Essex Rail Project for the Chittenden County Metropolitan Planning Organization (CCMPO) and the Vermont Agency of Transportation (VTrans). The Burlington Rail Tunnel is located at milepost 1.15 on the Winooski branch of the New England Central Railroad (NECR) line and is an integral component of the rail line.

The objectives of this phase of engineering are to:

- Perform a visual assessment of the Burlington Rail Tunnel and to evaluate the structural integrity of the tunnel to support the proposed passenger rail service.
- Review the applicable codes and regulations (NFPA\textsuperscript{1} 130 and the AREMA\textsuperscript{2} Manual for Railroad Engineering) to determine the areas where the tunnel is considered to be substandard to support passenger rail service.
- Identify the level of remediation required to satisfy the imposed loads as well as the current standards based on the site inspection and code review.
- Develop alternatives to address the structural condition of the tunnel and any code deficiencies and make recommendations.
- Prepare estimates of probable construction cost will be prepared for the alternatives presented at this level of engineering.

As the tunnel is considered eligible for the National Register of Historic Places, it is anticipated that any modifications to the tunnel through the subsequent design phase will be subject to additional review by the State of Vermont Division for Historic Preservation.

The Burlington Rail Tunnel, located at Milepost 1.15 of the NECR Winooski spur line, is a 340-foot long brick masonry horseshoe shaped tunnel that passes through the sandy ridge supporting North Street (Burlington) on a curve of approximately four degrees. North Street runs in a north to south direction while the tunnel runs approximately in an east to west direction (see Figure 1 for Site Plan and Figure 2 for Schematic Elevation). The tunnel, constructed in 1860, has an overall height of approximately 17 feet and a width of roughly 14 feet at the base, increasing to approximately 16 feet wide at approximately 9 feet above top of rail. The tunnel provides passage for a single track over ballast. The track grade is generally level.

The tunnel is considered to be of national historic significance as it was one of the earliest successful railroad tunnels in the United States. While several smaller tunnels were constructed during the 1830’s and 1840’s it was the beginning of construction of the Hoosac Tunnel on the Boston to Albans route, through western Massachusetts, in 1855 that marked the maturity of American tunneling technology. The next two important tunnel projects in New England were the Burlington Rail Tunnel and the Tunnel at Bellows Falls, in Vermont. The Vermont and Canada Railroad undertook the Burlington Rail tunnel project as part of an eight-mile spur to connect Lake Champlain with its main route through Essex Junction.

\textsuperscript{1} National Fire Protection Association
\textsuperscript{2} American Railroad Engineering and Maintenance of Way Association
FIGURE 2

SCHEMATIC ELEVATION OF BURLINGTON RAIL TUNNEL

WEST PORTAL

102'-0" ± ROAD

100'-0" ±

EL 218 ±

18'-0" T/R TO ROOF TUNNEL

APPROX. EL 138.00 ±

342'-0"

EAST PORTAL

STEPPED STONE BLOCK RETAINING WALL TYP.)
The ridge through which the tunnel was constructed consists of loose sands approximately 75 to 80 feet deep that had been blown off the east shores of Lake Champlain. The tunnel portals consist of stacked masonry block walls roughly thirty-five feet high and 19 feet wide at the base. Stepped stone block retaining walls, approximately 47 feet long, are located at each side of the track, supporting the embankment. Tunnel construction was accomplished by setting a vertical wooden shield through which holes were bored in a semi-circular shape. Poles were then driven through the holes to form the arch shape. The sands were then excavated from underneath the driven poles. As soon as the half-circle heading was completed, the sides were dug. Nearly 700,000 feet of lumber was needed to construct the wooden framework necessary to brace the excavation. After the heading and sides were dug, a foundation of limestone and concrete was constructed. As soon as there was room, a brick arch in the form of a horseshoe was built. The walls between the brick masonry and the wood formwork were packed solid with cement. Under the best conditions, the workers could construct approximately three feet of tunnel a day. Working day and night, the tunnel was constructed in just over six months.³

The materials in the tunnel are reportedly all of Vermont origin. The portals were constructed of hammer-dressed limestone from the Isle La Motte. The interior brick of the tunnel were obtained from a factory from the north side of Mallets Bay and the mortar was made with lime from Weathersfield, Vermont. Construction appears to be robust as the walls are reportedly four feet thick and the arch two feet thick. The bricks are arranged in a running bond pattern. It is noted during the site inspection the lack of bonder or header courses of brick, at least at the surface course of brick. The limestone foundation is exposed along the base of the tunnel as it protrudes above the track bed elevation approximately eight inches and away from the brick masonry arch by approximately eight inches.

During the beginning of the 20th century, up to 11 passenger trains a day would pass through the tunnel. By the early 1930’s, this number had dwindled to one passenger train per day. The last passenger train passed through the tunnel in June of 1938. Currently the tunnel only services transfer freight service by the New England Central Railroad to the Burlington yard operated by the Vermont Railway.

II. Site Inspection

On March 12, 2002, representatives from DMJM+HARRIS performed a visual assessment of the railroad tunnel. The purpose was to assess the physical condition of the tunnel and to evaluate its ability to support passenger rail service. No core borings through the tunnel arch or soil borings of the embankment were taken at this phase of the project.

The findings of the assessment, beginning at the west portal and working towards the east are described below and illustrated with photographs. (Additional photographs are contained in Appendix A.)

The stones that make up the west portal (photo 1) appear solid and plumb. The stones that line the portal are all intact. There is light mortar loose between stones. Step type cracking is noted beginning at the north side of the arch ring, two stones below the crown. The cracking works its way up and to the south through approximately six courses of stone. No additional

movement or displacement of stone has been noted. During a file search in the Saint Albans office of the New England Central Railroad, photos of the west portal taken during the 1960’s highlighted this same portal cracking. The condition does not appear to have changed over the years. The stone masonry retaining walls (photos 2 & 3) are also intact and plumb. There are occasional signs of missing mortar in joints and light vegetation growing from the wall. Graffiti is present along portions of each retaining wall as well as on the stones around the portal ring. The graffiti extends along the inside face of the tunnel lining.
3. Southwest Wing Wall

The stones that make up the portal ring extend between 30 to 36 inches from the face of the portal where they interface with the brick lining. There are several small spalls (approximately 2 to 3 feet square) through the face course of the brick lining located within the first three to four feet of the tunnel (photo 4). The brick below is weathered.

4. South Tunnel Wall at West Portal.  
*Note intermittent spalling of brick adjacent to portal stones*
There is a mortar or gunite patch measuring approximately eight feet wide that extends continuously along the crown of the tunnel for its entire length (photo 5 & 6). The patch is generally intact although there are signs of light cracking and efflorescence along the patch. This patch has discolored over the years, being a decidedly different color than other patches within the tunnel. It is therefore concluded that this patch may be much older than some of the other repair patches found in the tunnel.

Between approximately 2 feet and 12 feet from west portal, along the south side of tunnel from the base to approximately 10 feet up the side, a cement masonry unit facing has been installed (photo 7). From 12 feet to 16 feet, a five-foot tall patch of face brick located one
foot above the base has fallen away. The brick below is intact, having lost approximately one half inch of mortar within the joints.

7. South Tunnel Wall at West Portal
Note previous cement block masonry repair and additional loss of outer rug bricks.

Between 10 feet and 16 feet from the west portal, located approximately 6 feet above the north base, a patch of face brick seven feet high has fallen away (photos 8 & 9). The bricks below have bulged forward and when tapped upon, they exhibit a hollow sound, indicating they may not be intact with the backing brick.

8. North Tunnel Wall at West Portal
Note the loss of the outer ring bricks and the intermittent spalls closer to the portal
9. Wall Section with Delaminated Face Brick

At approximately 20 feet from the west portal, there is a vertical crack that makes its way around the inside perimeter of the tunnel. The crack moves through the mortar joint as well as through the brick and the top gunite patch.

Between 25 and 31 feet from the west portal, along the south base of the tunnel, a three-foot high patch of the face brick is displaced.

At 35 feet from the west portal, a vertical crack moves through the brick and mortar joint along the inside perimeter of the tunnel. There is slight displacement or bulging of the brick along the crack. This displacement is greater towards the south side of the tunnel.

Between approximately 35 feet and 53 feet from the west portal, located approximately 12 feet above the north base, a patch of missing face brick intersects an area of the center gunite patch (photo 10). There is a piece of wood forming left in place along the patch. Dripping water including the presence of icicles was visible along this interface.

10. Patch and Plywood Form at North Wall

*Note heavy leaking and efflorescence at patch.*
Between 35 and 40 feet from the west portal, approximately 5 feet from the south base, is a 3-foot width of brick is loose and has protruded forward.

Between 54 and 58 feet from the west portal, there is a 2 feet wide by 4 feet long patch approximately 14 feet above the south base where the face brick have fallen away. Over the next 14 feet, there is intermittent loss of the face brick at the same level of the tunnel.

Between 62 and 78 feet from the west portal, beginning approximately 12 feet above the north base, there is a cement or gunite patch measuring up to ten feet wide. The patch is reinforced with a series of anchors placed in a grid of approximately two feet on center (photo 11). There is a row of four bolts, two rows of eight bolts, a row of nine bolts, a row of seven bolts and a single bolt at the sixth row. From fallen sections of other patches, it appears the patch would be approximately one and one-quarter inch deep with a layer of welded wire fabric placed towards the inside face. This patch runs into and overlaps the previously described patch located along the top inside face of the tunnel. Over the next 20 feet, a one-foot wide strip where the face brick was displaced has been patched. This patch is located approximately 16 feet above the north base of the tunnel (photo 12).
Within the middle half of the tunnel, the loss of areas of the brick face is reduced. The face brick is considered to be generally intact with intermittent loss of brick or broken or spalled face brick estimated over roughly 5% of the inside tunnel surface. There is one area located approximately 132 to 140 feet from the west portal, roughly 14 feet above the north base, where the face brick has fallen away from an area, approximately 6 feet high by 8 feet long.

Between 160 and 185 feet from the west portal, approximately two/third's of the inside surface of the tunnel is covered with a light to medium thick cover of efflorescence and the mortar joints between the bricks have experienced a mortar loss to almost two inches deep. Beyond this depth, the remaining mortar appears to be intact and hard when scratched. Between 185 feet and 220 feet from the west portal, the affected area drops to between 25 and 33 per cent of the interior surface area, with isolated areas experiencing a heavier concentration of face spalling within the brick.

Between 230 and 260 feet, there is a band of bricks between 10 feet and 16 feet above the north base that exhibits heavier weathering of the face over an estimated 50 to 75 per cent of the brick, as well as deeper mortar lose within the joints. Within the same region of the tunnel, the bricks between 10 and 16 feet above the south base have a heavier cover of efflorescence. These areas tend to blend into the center patch of the tunnel.

Between 260 feet and 325 feet from the west portal, the heavier weathering of the face brick extends lower along the north side (extending from the north base to 16 feet above). Within this region, approximately 50 % of the surface is covered with efflorescence and mortar loss between bricks is approximately one inch deep. Roughly, 20% of the brick is affected by weathering or loss of face brick. Heavier cracking is noted within the center patch.

At 325 feet from the west portal (approximately 20 feet from east portal), there is a vertical crack that moves through the inside perimeter of the tunnel. The crack moves through the joints and bricks and has a width of approximately one-quarter inch. The remaining 20 to 25 feet of tunnel approaching the east portal appears to be heavily distressed. At approximately seven feet above the south base and four feet from the east portal, a three to four foot wide by four foot high section of face brick has fallen away from the tunnel lining (photo 13). The distressed areas extend off from this area to more than triple its size. The distress includes loose and delaminated bricks, additional cracking between the brick and a heavy efflorescence cover. The distress continues to the top of the tunnel arch where the gunite patch exhibits significant cracking and efflorescence cover (photo 14). The heavy efflorescence and loss of brick continues along the northern wall where its condition is only marginally better than the south wall (photo 15).
13. South Tunnel Wall at East Portal
*Note loss of outer ring brick, heavy cracking and efflorescence.*

14. South Tunnel Wall at East Portal
15. North Tunnel Wall at East Portal

The east portal (photo 16) and retaining walls (photos 17 & 18) that support the embankment are considered to be in good condition. The eleventh stone from the north base in the portal ring has been displaced outward by approximately one inch. This is most likely a result of the distress experienced along the inside edge of the tunnel. Otherwise, there are no signs of stone movement, settlement or rotation. Joints between stones exhibit isolated areas of mortar loss. A skim coat of mortar has been applied over some joints along the south wingwall. Light vegetation is present throughout.

16. East Tunnel Portal
At the southeast embankment, significant erosion of the sandy slope is noted (photo 19). Preventive actions are required to provide long-term stabilization of the embankment.
Summary of Visual Assessment

In summary, the first 35 feet of the tunnel from the west portal and the first 25 feet from the east portal are considered heavily distressed. Cracking through the brick as well as significant loss of face brick is prevalent throughout these areas. The lack of bonder or header courses of brick has allowed for significant delamination of the face brick away from the backing courses. Water infiltration is thought to be the primary cause of the deterioration.

From examination of the site topography and geology, it is anticipated that the groundwater level will be found to be located below the level of the tracks. Thus, the only water the embankment experiences collect from surface runoff after snow and rain. This runoff is directed down the embankment where the ground soil cover over the tunnel is reduced. It is these end sections of the tunnel that have taken the brunt of the storm water runoff impacts over the years, which may have affected the structural integrity of the tunnel. It is unknown what the condition of the original tunnel formwork behind the brick arch is, and how potential deterioration has impacted the condition of the tunnel. At the next stage of design, cores through the masonry are recommended to determine this impact.

Beyond these heavily impacted end regions of the tunnel, the remaining portion of the tunnel is considered to be in generally fair condition. There are still moisture concerns as mortar leaching, efflorescence and weathering of the face brick have occurred over a significant section of the tunnel. As part of the next phase of design, additional investigation will be performed to determine whether this source of this water is infiltrating groundwater or
external condensation. Otherwise, the tunnel is considered to be generally intact, loss of brick is minimal and the general shape of the tunnel is considered to be good, as no notable sags or bulges were noted.

The tunnel portals and wingwalls at each embankment approach are also considered to be in generally good condition. Occasional cracking and isolated movement of stones has been noted that can be addressed with minor remediation. Of greater concern is the overall stability of the embankment. Heavy erosion has been noted at the southeast embankment and stabilizing efforts are deemed necessary.

III. Tunnel Clearance and Equipment Envelope

The available clear space within the tunnel measures approximately 17 feet high to the tunnel crown and the width varies between roughly 14 feet at the base, increasing to approximately 16 feet wide at approximately 9 feet above top of rail. The available clearance envelope falls short of the current AREMA requirements for new tunnel construction as depicted in AREMA Figure 1-3, the clearance diagram for a Single Tangent Track Railway Tunnel (see Figure 3).

The applicable freight equipment diagram for the Burlington to Essex line is AREMA Figure 2-3 or Plate C, Equipment Diagram for Limited Interchange Service. Plate C is representative of the freight service that currently makes limited usage of the tunnel. The passenger car envelope that has been provided for this phase of the study is based on a Virginia Railway Express Cab Car diagram. AREMA Figure 2-3, Plate C is depicted in Figure 4 along with the passenger vehicle envelope. Figure 5 depicts how the Plate C Equipment Diagram and the passenger vehicle envelope fit within the existing tunnel cross-section. The freight service that currently makes limited use of the tunnel fits within the envelope with very little margin. The proposed passenger service through the tunnel is slightly narrower than the freight service envelope and not as tall, thus it fits within the tunnel with slightly greater clearances.

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4 Plate C confirmed as maximum clearance envelope in phone conversation with Mike Olmsted, New England Central Railroad, by Mike Cook, DMJM+HARRIS, April 4, 2002.
TANGENT TRACK
CLEARANCE DIAGRAM FOR SINGLE-TRACK RAILWAY TUNNELS – NEW CONSTRUCTION
AREMA MANUAL
FIGURE 1–3
VEHICLE ENVELOPE

* AREMA MANUAL PLATE C
EQUIPMENT DIAGRAM FOR LIMITED INTERCHANGE SERVICE

FIGURE 4
CLEARANCE ENVELOPE
WITHIN TUNNEL
IV. Code Requirements for Fire, Lighting, Ventilation and Life Safety Issues

A. Applicable Codes

The National Fire Protection Association’s 2000 edition of the Standards for Fixed Guideway Transit and Passenger Rail Systems (NFPA 130) is the governing standard for the life safety issues that affect the Burlington Rail Tunnel as well as the other structures within the Burlington to Essex rail corridor. The NFPA 130 standard is not applicable for freight rail systems and thus its requirements currently do not apply to the components of the rail line. Reintroducing passenger rail service to the line will require compliance with the provisions of the NFPA 130 code. Although NFPA 130 is intended to apply to new construction, it has been used as the basis for upgrading fire-life safety systems in many existing systems. Applicable provisions of the code that impact the rail line are summarized below and a more detailed review of the code language has been included in Appendix B at the end of this report.

The other major governing code for railroad tunnels is the American Railroad Engineering and Maintenance of Way Association (AREMA) Manual for Railroad Engineering. A primary difference between the NFPA 130 and the AREMA Manual is that NFPA 130 is a national standard, while the AREMA Manual is published as “a recommended practice to railroad and others concerned with the engineering design and construction of railroad fixed properties”.

B. Summary of Code Review

The Burlington Rail Tunnel currently does not have any provisions for life and fire safety issues. To be compliant with current regulations (NFPA 130), the tunnel will need to be equipped with emergency lighting and communication provisions as well as a water source for fire fighting, either at the portals, or in the form of a dry standpipe system within the tunnel.

While there does not appear to be adequate room to provide for a dedicated emergency walkway through the tunnel (NFPA 130, Article 3.2.6) due to the inadequate clearance envelope, preparing the track level surface for a walkway will be explored. The passenger service as currently envisioned is anticipated to be a two-car train-consist with doors located at the front and rear of the train car where passengers can pass freely from carriage to carriage as shown in Figure 6. In the event of an emergency where passengers have to unload the train within the tunnel, passengers will exit the train through the door away from the incident, will step to the track level between the car and tunnel sidewall and then step to beyond the limits of the train and be able to walk away from the event. A two car consist will measure approximately 170 feet in length which is equivalent to one half of the tunnel length. The maximum walking distance within the tunnel will be no more than the remaining 170 feet of tunnel. The need for refuge niches per the AREMA Manual will also be discussed with railroad operations. Considering the low volume of traffic on the line, a design exception may be able to be obtained to waive their need.
The tunnel has no provision for mechanical ventilation. Natural ventilation due to the piston-effect of the train passing through the tunnel is the primary source of tunnel ventilation under normal operation conditions. The tunnel with a length of 340 feet falls into the length parameters covered by NFPA 130, Article 4-1.2.3 where an engineering analysis to determine the need for an emergency ventilation system is required. It is currently envisioned that given the short length of tunnel, the low train volume and the inclusion of the other NFPA 130 fire-life safety measures, that the risk of incident in the tunnel is considered remote and that passenger service can operate safely without mechanical ventilation. Given the current envelope of the tunnel, it appears unlikely that mechanical ventilation within the tunnel could be accommodated without significant disruption of the tunnel shell.

The primary function of the emergency ventilation system during a tunnel fire is to control the direction of smoke movement in order to provide a clear and safe path for evacuation of passengers and to facilitate firefighting operations. Without the aid of mechanical ventilation, it appears unlikely that the critical air velocity required to prevent back layering of the smoke during an event could be achieved. Therefore, the engineering analysis required would be a consideration of the risk from various scenarios. Given the limited train service (four morning trains and five afternoon trains) and the fact that freight operations will occur outside of the hours the passenger service operates, there is little chance of two trains being in the tunnel at any one time. This greatly reduces the risk of collision or the chance that one train would be trapped behind a disabled train within the tunnel. The inclusion of other fire-life safety requirements from NFPA 130 such as emergency lighting and communications, an egress walkway and a standpipe and hose system are also risk reducing measures that provide a safe and clear means to egress from the tunnel. The local fire officials and the rail line operators will need to be made aware of and ultimately accept or reject the risk of operating the tunnel without a ventilation system.

V. Remediation Alternatives

The visual assessment of the tunnel has revealed that the end regions of the tunnel are considered to be highly distressed. Over the end 35 feet at the west end of the tunnel and
approximately 25 feet at the east end of the tunnel, significant distress has occurred in the
form of cracking, extensive loss of face brick and associated delamination. Water runoff
down the embankments to an area where the tunnel has reduced ground cover has left this
region of the tunnel exposed to years of climate exposure that has taken its toll on the
overall structural integrity of the tunnel. Water has worked its way through the multi-wythe
brick construction and contributed to the deterioration of the mortar joints. As the brick
wythes are considered to be poorly bonded by the lack of header courses, the mortar joints
and the axial compression are the components holding the arch together. By weakening the
joints of a poorly bonded arch, the delamination of the exterior bricklayer was prevalent.
Away from the end regions, the physical condition of the tunnel is improved. Between 35
and 100 feet from the west portal, there are areas of missing or delaminated brick as well as
large areas that have been previously repaired. Throughout the remaining portion of the
tunnel there are still water issues to be addressed as loss of mortar within joints, weathering
of brick and efflorescence over the brick are commonplace. Left untreated, the deterioration
throughout the tunnel would continue and eventually, the collapse or failure of the end
regions of the tunnel would be an imminent possibility.

The following preliminary recommendations for tunnel repair are made based on the
information currently available. Further investigation and study, including core explorations
of the tunnel, are considered necessary in future phases of design to fully understand the
existing conditions.

**Alternative 1 – Internal Grouting of Tunnel**

The first alternative to be considered is cement or chemical grouting of the structure (see
cross section in Figure 7). The permeation of very low-viscosity cement or chemical grout
through ports drilled in the arch into the granular soil behind the arch improves the strength
and rigidity of the soil to limit ground movement. As a remedial tool, chemical grouting is
also effective in waterproofing leaking subterranean structures. Cement grouts consisting of
Portland and microfine cement are also effective in strengthening soil masses and sealing
water passages. The anticipated repair procedure is outlined below:

- Inject grout from inside the tunnel through a series of small diameter portholes drilled
  through the brick arch at centers of approximately 3 feet to 4 feet on center along the
  length of the tunnel. A study needs to be conducted to see how permeable the sand
  behind the tunnel liner is, how much pressure can be applied without damaging the
  masonry liner and to assess the advantages of cement or chemical grouts. If the soil
  surrounding the tunnel liner is permeable, it may be possible to create a structural
  liner behind the brick liner by injecting cement grout. The grout would also fill voids
  within the brick masonry and provide additional bonding between bricklayers. Other
types of grout can be used to form a water barrier outside the shell of the tunnel.

- Remove the damaged bricks and mortar patches. All delaminated sections of brick
  should be removed back to a sound and stable surface.

- Install new bricks matching the old ones as close as practical.
ALTERNATIVE 1
INTERIOR GROUT
• Clean the entire surface of the tunnel and remove the deteriorated mortars.

• Repoint the entire tunnel.

• To relieve future groundwater pressures that may build up behind the tunnel arch, weep holes on the order of 3” in diameter will be cored through the tunnel wall. Perforated PVC pipe wrapped in a geotextile fabric can be installed in the holes and sealed into place. Pipe spacing may be in the order of ten feet on center along the base of each wall. Runoff will be collected in an interior drainage system.

The Chettoogeta Mountain W & A Railroad Tunnel in Georgia was restored in a similar manner and was awarded the International Concrete Repair Institute’s honorable mention award for outstanding concrete repair project in 2000. This 1477 foot long brick arch with a span of 12’-6” and an overall height of 16 feet at the crown was restored for pedestrian traffic after it had deteriorated to a condition far worse than the Burlington Rail Tunnel. A hydrophobic polyurethane chemical grout was injected through the brick arch. The adhesive properties of the grout helped to bond the structure together, while the hydrophobic properties of the grout sealed the tunnel from water infiltration. Areas where the arch had failed or was missing brick were repaired with a dry shotcrete process. An artificial brick finish with “faux” joints was achieved by using a plaster coat over the shotcrete, colored to match the adjacent brick. This would also be an alternative for the Burlington Rail Tunnel if the cost of tuckpointing the new brick into the existing liner proves to be cost prohibitive.

**Alternative 2 – Jet Grout Crown over Tunnel**

Another alternative would be to stabilize the soils behind the arch at the damaged end regions of the tunnel to form a structural crown over the existing tunnel. The soil stabilization could be performed by jet grouting and would create a mass of self-supporting soils that would relieve the existing arch structure of the current imposed load (see cross section in Figure 8). Jet grouting techniques rely on the introduction of an engineered grout material mixed with the existing soils to form subsurface structural elements to support earth loads. Jet grouting can be accomplished by many methods, with a wide range of mixing tools and tool configurations available. The anticipated repair process is as follows:

• Jet-grout the soils 30 to 40 feet from both ends of the tunnel. The depth of overburden on the two ends of the tunnel is much lower than the center zone. A drill pattern of overlapping augured cores would be established from the ground surface at each embankment. As the auger approaches the tunnel, the mixing would begin to form a grouted column. By overlapping the augers a series of interconnected columns is formed that make up the arch over the existing tunnel. Internal monitoring of the existing arch would be ongoing during the process to control the external applied pressure to the brick masonry.

• Once the soil above has been strengthened, remove the damaged bricks and mortar patches along the interior of the tunnel. In addition to the loose delaminated brick, the spalled and cracked bricks, the previous mortar patches and concrete blocks installed as a repair can also be removed depending on the level of restoration that is being sought.
• Install new bricks matching the old ones as close as practical. Install a new brick face over the areas where damaged ones were removed.

• Clean the entire surface of the tunnel and remove the deteriorated mortars. Use water, chemicals, steam, or abrasives to clean the surface from graffiti, efflorescence, and the deteriorated mortars. The deteriorated mortar may need to be removed by chisel or some other mechanical methods. Most old brick masonries were fired at low temperatures and have a very thin outer glaze and a soft, powdery interior. If the glaze becomes damaged, old bricks begin to deteriorate rapidly. Methods such as sandblasting, power washing, and abrasive cleansers may be much too harsh for use in cleaning most historic masonry.

• Repoint the entire tunnel. Repoint the new and cleaned bricks with a mortar similar to the old mortar.

• In the center region of the tunnel where dampness or excessive wash of mortar is found to be a result of water leaching through the tunnel lining, cement or chemical grouts should be injected behind the masonry arch to produce an impermeable shield outside the tunnel shell as described in the first repair alternative presented above.

A similar soil stabilization program was recently successfully applied at the site of the Barus and Holly Building for Brown University in Providence, Rhode Island. The foundation for the building was located directly above an abandoned railroad tunnel. The surrounding buildings had been impacted by ground settlements of up to three inches that was attributed to voids in the soil resulting from the decomposition of the timber shoring used to support the tunnel arch during construction. A jet-grouting program was used to form a series of rib arches immediately above the tunnel to transfer the soil and building loads to the adjacent rock ledge.

**Alternative 3 – Interior Gunite Lining of Interior Tunnel Surface**

A third repair option is to install a shotcrete lining over the existing brick arch. The new lining would become the load-resisting element (see cross section in Figure 9). The anticipated repair process is as follows:

• As the tunnel clearance envelope is already severely restricted, further reductions in the clearance envelope would be extremely difficult to tolerate. However, as no header courses were observed in the exterior lining of the tunnel, there exists a possibility to strip the surface layer of bricks away and install a layer of reinforced shotcrete. The shotcrete layer can be reinforced with a layer of mesh or can be fiber reinforced for additional strength. Additionally, a membrane waterproofing layer can be installed between the remaining masonry arch and the shotcrete layer. Any infiltration through the arch would be captured by the membrane and funneled to a drainage collection system at the base of the tunnel wall.
ALTERNATIVE 2
JET GROUTING
ALTERNATIVE 3
INTERIOR SHOTCRETE LINER
• Such a plan could be implemented over the entire tunnel length or over the distressed end regions of the tunnel. In this case, the remaining portion of the brick liner would be cleaned and repointed as described above with local tuckpointing to make local repairs to broken, fractured or weathered brick.

• A concern with this type of remediation is that the available thickness for the shotcrete lining is equivalent to the thickness of the bricklayer that has been removed. A lining of this thickness may not provide an adequate level of strength to support the imposed loads. If this is the case, a series of soil anchors can be used below the gunite layer for added strength. This would be similar to the repair made previously within the tunnel along the north wall.

• The other significant concern with this type of repair is that many of the historic features of the tunnel will be covered with the shotcrete lining. While the portals remain unaffected, the brickwork along the interior of the tunnel could be completely covered. Such a remediation is anticipated to be the least favorable alternative by the Vermont Division of Historic Preservation.

Cost Estimate:

Cost estimates for the three repair alternatives have been developed for the conceptual engineering phase of the project. The repair costs for the three alternatives are as follows:

Alternative 1  (Internal Grouting of Tunnel) $2,400,000
Alternative 2  (Jet grout crown over Tunnel) $2,300,000
Alternative 3  (Interior Gunite Lining at Interior Tunnel Surface) $1,900,000

Spreadsheets with project construction costs are included as Figures 10, 11 and 12. Note that the estimate of probable cost for this stage of design is considered as a low-level budget estimate. A contingency multiplier of 40% has been included to reflect the preliminary nature of the estimate, the uncertainties of the existing conditions, and the degree of difficulty of the work.
**Figure 10 – Estimate of Probable Cost – Alternative 1**

**Alternative 1**  
Grouting through Inside of Tunnel

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Quantity</th>
<th>Unit price</th>
<th>Cost In Place</th>
</tr>
</thead>
<tbody>
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<td>Mobilization/Demobilization</td>
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<td>$75,000.00</td>
<td>$75,000.00</td>
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<td>Drill port holes</td>
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<td>1580</td>
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<tr>
<td>Old Track Removal</td>
<td>ft</td>
<td>342</td>
<td>$18.50</td>
<td>$6,327.00</td>
</tr>
<tr>
<td>Ballast Removal</td>
<td>Yd³</td>
<td>330</td>
<td>$8.50</td>
<td>$2,805.00</td>
</tr>
<tr>
<td>New concrete Base</td>
<td>Yd³</td>
<td>330</td>
<td>$250.00</td>
<td>$82,500.00</td>
</tr>
<tr>
<td>Install new rail/ballast/ties</td>
<td>L.f.</td>
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</tr>
<tr>
<td><strong>Portal Stone Work</strong></td>
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<td></td>
</tr>
<tr>
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<td>ft²</td>
<td>3500</td>
<td>$8.00</td>
<td>$28,000.00</td>
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<tr>
<td><strong>Emergency Lighting /</strong></td>
<td>Lump</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communications</td>
<td>Lump</td>
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</tr>
<tr>
<td>Fire Protection Stand Pipe</td>
<td>Lump</td>
<td>1</td>
<td>$191,000.00</td>
<td>$191,000.00</td>
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</tr>
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<td>4925</td>
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<tr>
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### Figure 11 – Estimate of Probable Cost – Alternative 2

**Alternative 2**  
Jet Grout Crown over Tunnel Liner

<table>
<thead>
<tr>
<th>Item</th>
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<th>Quantity</th>
<th>Unit price</th>
<th>Cost In Place</th>
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</thead>
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<td>$100,000.00</td>
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<tr>
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</tr>
<tr>
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<td>ft</td>
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<td>$6,327.00</td>
</tr>
<tr>
<td>Ballast Removal</td>
<td>Yd³</td>
<td>330</td>
<td>$8.50</td>
<td>$2,805.00</td>
</tr>
<tr>
<td>New concrete Base</td>
<td>Yd³</td>
<td>330</td>
<td>$250.00</td>
<td>$82,500.00</td>
</tr>
<tr>
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<td>L.f.</td>
<td>342</td>
<td>$92.50</td>
<td>$31,635.00</td>
</tr>
<tr>
<td><strong>Portal Stone Work</strong></td>
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<td></td>
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<td>4500</td>
<td>$2.00</td>
<td>$9,000.00</td>
</tr>
<tr>
<td>Repointing</td>
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<td>4500</td>
<td>$4.00</td>
<td>$18,000.00</td>
</tr>
<tr>
<td>Slope Stabilization</td>
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<td>$8.00</td>
<td>$28,000.00</td>
</tr>
<tr>
<td>Emergency Lighting / Communications</td>
<td>Lump Sum</td>
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<td>$191,000.00</td>
</tr>
<tr>
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<td>Lump Sum</td>
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<td>$10,000.00</td>
<td>$10,000.00</td>
</tr>
<tr>
<td><strong>Brick Work</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Cleaning (100%)</td>
<td>ft²</td>
<td>16500</td>
<td>$2.00</td>
<td>$33,000.00</td>
</tr>
<tr>
<td>Grout Removal (30%)</td>
<td>ft²</td>
<td>4925</td>
<td>$4.00</td>
<td>$19,700.00</td>
</tr>
<tr>
<td>New Brick Installation (35%)</td>
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<td>5750</td>
<td>$12.45</td>
<td>$71,587.50</td>
</tr>
<tr>
<td>Repointing (75%)</td>
<td>ft²</td>
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<td>$49,400.00</td>
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18% Design & Engineering $265,266.81  
40% Contingency $589,481.80  
Total $2,328,453.11
Figure 12 – Estimate of Probable Cost – Alternative 3

Alternative 3
Replacement of Existing Exterior Wyth of Brick with new Shotcrete Liner

<table>
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<tr>
<th>Item</th>
<th>Unit</th>
<th>Quantity</th>
<th>Unit price</th>
<th>Cost In Place</th>
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<td>$75,000.00</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Old Track Removal</td>
<td>ft</td>
<td>342</td>
<td>$18.50</td>
<td>$6,327.00</td>
</tr>
<tr>
<td>Ballast Removal</td>
<td>Yd³</td>
<td>330</td>
<td>$8.50</td>
<td>$2,805.00</td>
</tr>
<tr>
<td>New concrete Base</td>
<td>Yd³</td>
<td>330</td>
<td>$250.00</td>
<td>$82,500.00</td>
</tr>
<tr>
<td>Install new rail/ballast/ties</td>
<td>L.f.</td>
<td>342</td>
<td>$92.50</td>
<td>$31,635.00</td>
</tr>
<tr>
<td><strong>Portal Stone Work</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cleaning</td>
<td>ft²</td>
<td>4500</td>
<td>$2.00</td>
<td>$9,000.00</td>
</tr>
<tr>
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<td>ft²</td>
<td>4500</td>
<td>$4.00</td>
<td>$18,000.00</td>
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<tr>
<td>Slope Stabilization</td>
<td>ft²</td>
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<td>$8.00</td>
<td>$28,000.00</td>
</tr>
<tr>
<td><strong>Emergency Lighting / Communications</strong></td>
<td>Lump</td>
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<td>$191,000.00</td>
<td>$191,000.00</td>
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<tr>
<td><strong>Fire Protection Stand Pipe</strong></td>
<td>Lump</td>
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<td>$10,000.00</td>
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<td>$1,194,667.00</td>
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</table>

18% Design & Engineering $215,040.06
40% Contingency $477,866.80

Total = $1,887,573.86
VI. Next Steps

The information contained within this report was presented to representatives of the Vermont Agency of Commerce and Community Development, Division for Historic Preservation, and the Rail Division of the Vermont Agency of Transportation on April 18, 2002 at the Vermont Agency of Transportation offices in Montpelier.

Judy Erhlich of the Vermont Division for Historic Preservation stated that, because of its impact on the appearance of this historic structure, Alternative 3 (Gunite Lining) looked liked the least preferred alternative and that it would be considered an "adverse effect". Her preference was for Alternatives 1 and 2, since these options would incorporate restoration of the interior brick masonry. Ms. Ehrlich noted that “from a 4(f) perspective, Alternatives 1 and 2 would have to be shown to be infeasible, for Alternative 3 to be considered.”

At this stage of design, all three alternatives are considered technically equal. However, only Alternatives 1 and 2 will be further developed as the design advances in the subsequent phases, at which time, one of the alternatives may stand apart as being better suited to address the structural needs of the project, or a combination of the alternatives may prove to be appropriate.

To progress to the next phase of design, the following tasks are considered as necessary:

- Undertake a soil testing program to obtain the soil properties and strengths of the overlying soils
- Undertake a core boring program where core samples are obtained through the tunnel to better identify the tunnel cross sectional properties and the presence of the original left-in place timber forms and shoring.
- Meet with the rail operations personnel and local fire authority to review fire-life safety issues.
- Perform cross sectional analysis of the brick masonry tunnel.
- Further evaluate options for ground stabilization and tunnel restoration.

---

5 Section 4(f) of Department of Transportation Act of 1966 (49 USC 303) and implementing regulations (23 CFR 772), or Section 4(f), as it is commonly known, provides that the Secretary of Transportation may not approve a project that involves use of land from a significant publicly owned park, recreation area, wildlife or waterfowl refuge, or any significant historic site unless: (1) there is no feasible and prudent alternative to the use of the land; and (2) the proposed action includes all possible planning to minimize harm to the property from such use.
Appendix A
Photo Log
A1. View of Track from Top of West Embankment

A2. View of North Street Over Tunnel
A3. General View of Tunnel

A4. General View of Tunnel at Track Level
A5. Brick Detail, 1 of 2

A6. Brick Detail, 2 of 2

Note the spalled and fractured brick face.
A7. Graffiti at South Wall, East Portal

A8. General Wall View, 1 of 3

Note vertical cracking and heavy efflorescence.
Appendix B
Review of Applicable Codes
Appendix B – Review of Applicable Codes

A. NFPA 130 Standards for Fixed Guideway Transit and Passenger Rail Systems

The National Fire Protection Association’s 2000 edition of the Standards for Fixed Guideway Transit and Passenger Rail Systems (NFPA 130) is the governing standard for the life safety issues that affect the tunnel and other structures within the Burlington to Essex rail corridor. The scope of the standard defined in Article 1-1.1 is as follows:

This standard shall cover the fire protection requirements for passenger rail, underground, surface and elevated fixed guideway transit systems including trainways, vehicle, fixed guideway, transit stations and vehicle maintenance and storage areas; and for life safety from fire in fixed guideway transit stations, trainways, vehicles and outdoor vehicle maintenance and storage areas. Fixed guideway transit stations shall pertain to stations accommodating only passengers and employees of the fixed guideway transit and passenger rail system and incidental occupancies in the station. This standard establishes minimum requirements for each of the identified subsystem.

The NFPA 130 standard does not cover the requirements for freight rail systems (Article 1-1.2) and thus its requirements currently do not apply to the components of the rail line. Reintroducing passenger rail service to the line will require compliance with the provisions of the NFPA 130 code. Article 1.4.1 states that, “this standard shall apply to new fixed guideway transit and passenger rail systems and to extensions of existing systems”.

Applicability of NFPA130 to a rehabilitation project was confirmed with Mr. James D. Lake, a Senior Fire Protection Specialist with the NFPA International. Applicable provisions of the code that impact the rail line are as follows:

Chapter 2 – Stations – Provisions address station work not covered in the assessment of the Burlington Rail Tunnel.

Chapter 3 – Trainways

Trainways are defined in Article 1-5.47 as “That portion of the guideway in which the fixed guideway transit or passenger rail vehicle operates.” This system qualifies as a Passenger Rail System as defined in Article 1-5.32, “A transportation system, utilizing a rail guideway, operating on a right-of-way for the movement of passengers within and between metropolitan areas, and consisting of its rail guideways, passenger rail vehicles and other rolling stock, power systems; buildings; maintenance facilities; stations; passenger rail vehicle yard; and other stationary and moveable apparatus, equipment, appurtenances and structures”.

3-1.2 Occupancy It is anticipated that passengers will enter the trainway only in the event that it becomes necessary to evacuate a disabled train. Such evacuation shall take place only under the guidance and control of authorized trained transit system employees or other authorized personnel as warranted under an emergency situation.
3-1.5 **Blue Light Stations**  Blue light stations (a location along the trainway, indicated by a blue light, where emergency service or authorized personnel can communicate with central supervising station and disconnect traction power) shall be provided at the following locations:

1. End of station platforms
2. Cross passages (Not applicable)
3. Emergency access points
4. Traction power substations (Not applicable)

The tunnel portals would conform to Item (3), emergency access points, as defined under the provisions of Article 3-2.4 as described below. The requirements for the blue light station including provisions for emergency telephones shall be provided at each portal of the tunnel.

3-2 **Underground**

3-2.1 **Construction Materials**

3-2.1.1 Where line sections are to be constructed ...., perimeter walls and related construction shall not be less than Type I or Type II or a combination of Type I or Type II- approved noncombustible construction as defined in NFPA 220, Standards on Types of Building Construction.

3-2.1.3 Walkway surfaces designated for evacuation of passengers shall be constructed of noncombustible materials. Walkway surfaces shall have a slip resistant design.

The tunnel is currently constructed of non-combustible brick masonry. All interior rehabilitation will need to conform to this requirement.

3-2.4 **Emergency Exit Details**

3-2.4.1 Emergency exits shall be provided from tunnels to a point of safety.

A point of safety is defined in Article 1-5.34 as “An enclosed fire exit that leads to a public way or safe location outside the structure, or an at grade point beyond any enclosing structure, or another area that affords adequate protection for passengers”.

Article 3-2.4.2 states that emergency exits shall be provided throughout the tunnel and spaced so that the distance to an emergency exit shall not be greater than 1250 feet unless otherwise approved by the authority having jurisdiction. The tunnel portals would be considered a point of safety. As the tunnel length is only 340 feet, the maximum distance to a point of safety is 170 feet. No additional emergency exits are required.

3-2.4.7 **Emergency Lighting**

3-2.4.7.1 The requirements of 3-2.4.7 shall apply to all underground or enclosed trainways that are greater than 50 feet or one car length, whichever is greater.
The tunnel at 340 feet long meets the length parameters to require emergency lighting. Currently no electrical system is provided within the tunnel. An emergency lighting system will need to be provided.

3-2.6 Egress for Passengers The system shall incorporate means for passengers to evacuate a train at any point along the trainway and reach a safe area. System egress points shall be illuminated.

3-2.6.1 An effective emergency egress pathway shall be provided

3-2.6.2 Walking surfaces shall have a uniform slip-resistant design

3-2.6.4 Raised walkways, ramps and stairs shall be provided with a handrail that shall not obstruct egress from the train.

3-2.6.5 Crosswalks shall be provided at track level to assure walkway continuity. Crosswalks shall have uniform walking surface at top of rails.

3-2.6.6 Walkway continuity shall be maintained at special track sections.

The existing tunnel envelope allows for only minimal clearance between the edge of the passenger train and the tunnel lining. A raised walkway could not be accommodated in the current envelope. Consideration will be given to preparation of the track bed surface such that a walkway is available at this level. It is questionable if the walkway would provide adequate clearance to pass a disabled train. However, for the anticipated car type, doors are located at the front and back of the vehicle. Passengers could discharge from the end of the car to the track level and within a step or two, be clear of the train body and proceed to the egress point that would be the tunnel portal.

3-2.7 Protection

3-2.7.2 Standpipe and Hose System Standpipe for Class I and Class III service, as described in NFPA 14, Standards for the Installation of Standpipe, Private Hydrant and Hose Systems, shall be installed in all underground or enclosed trainways according to the following calculations. Due to the nature and length of underground or enclosed trainways, standpipes shall be permitted to be of the dry type with the approval of the authority having jurisdiction.

3-2.7.2.1 A fire standpipe system shall be provided for all underground or enclosed trainways if the length of the trainway, \( L_t \) is greater than the length allowable for participating agency personnel to reach every conceivable fire location within the trainway, according to the following calculated length:

\[
L_t > L_h - D_p
\]

Where:

- \( L_h \) = maximum length of fire hose permitted by the authority having jurisdiction
- \( D_p \) = maximum of the distance (measured along the route of the hose) from the trainway portal to the nearest fire hydrant or approved water source.
3-2.7.2.2 Underground or enclosed trainway standpipe lines shall be a minimum size of 4 inches in diameter, or sized by hydraulic calculations, and shall be increased in diameter as the length of pipe increases in order to deliver the rate of water flow at proper pressure, as specified by the authority having jurisdiction.

As the distance from a hydrant along North Street to the tunnel portals is most likely well in excess of maximum available hose length, provision to bring water to the tunnel portals as well as the need for dry standpipes within the tunnel can be explored. It is anticipated that bringing a water source to the tunnel portals may be satisfactory for this relatively short length of tunnel.

Chapter 4 Emergency Ventilation System

4-1 General

4-1.1 This chapter defines the requirements for the environmental conditions and the mechanical ventilation systems used to meet those requirements for a fire emergency in a station or trainway as required by Section 2-3 and Section 3-2.2. Appendix B provides information on types of mechanical systems for normal ventilation of fixed guideway transit systems and information for providing a tenable environment.

4-1.2 The requirements for a mechanical system intended for the purpose of emergency ventilation shall be determined in accordance with 4-1.2.1 through 4-1.2.4

4-1.2.1 A mechanical emergency ventilation system shall be provided in the following locations:
(1) In an enclosed fixed guideway transit station
(2) In a fixed guideway transit underground or enclosed trainway that is greater in length than 1000 feet.

4-1.2.2 A mechanical emergency ventilation system shall not be required in the following locations:
(1) In an open fixed guideway transit station
(2) Where the length of an underground trainway is less than or equal to 200 feet.

4-1.2.3 An engineering analysis to determine the need for a mechanical emergency ventilation system shall be conducted where the length of the underground or enclosed trainway is less than or equal to 1000 feet and greater than 200 feet.

4-1.2.4 In the event that an engineering analysis is not conducted for the configuration described in 4-1.2.3, a mechanical emergency ventilation system shall be provided.

4-1.3 Where required by 4-1.2, the mechanical emergency ventilation system shall make provisions for the protection of passengers, employees and emergency personnel from fire and smoke during a fire emergency and shall be designed to maintain the required airflow rates for a minimum of 1 hour but not less than the anticipated evacuation time.

The tunnel with a length of 340 feet falls into the length parameters covered by article 4-1.2.3 where an engineering analysis needs to be performed to determine the need for an
emergency ventilation system. This will be performed at the next phase of design, and will include a consideration of risk from various scenarios. Given the tight clearance envelope within the existing tunnel, it is anticipated to be difficult to accommodate an emergency ventilation system within the tunnel.

**Chapter 5 Vehicles**

Not applicable to structures

**Chapter 6 Vehicle Storage and Maintenance Areas**

Not applicable to structures

**Chapter 7 Emergency Procedures**

Not applicable to structures

**Chapter 8 Communications**

Not applicable to structures

**B. AREMA Manual for Railroad Engineering**

The other major governing code for railroad tunnels is the American Railroad Engineering and Maintenance of Way Association (AREMA) Manual for Railroad Engineering. A primary difference between the NFPA 130 and the AREMA Manual is that NFPA 130 is a national standard while the AREMA Manual is published as “a recommended practice to railroad and others concerned with the engineering design and construction of railroad fixed properties”.

Relevant sections of the AREMA Manual include:

**Chapter 1 Roadways and Ballast Part 8 Tunnels**

**Section 8.2.2 Interior Dimensions**

a. *The interior dimensions of the clear space provided for single or double track tunnels shall not at any point be less than those recommended in Chapter 28, Clearances, Part 2, Equipment Diagrams (see Figure 8-1 this Chapter). For tunnels located on curves, additional clearances must be provided for overhang and tilting from superelevation.*

AREMA Figure 8-1 for single tangent track railway tunnels shows an inside horizontal clearance between tunnel walls of 18'-0". Vertical clearance is shown as 17'-9 5/8" at the outside edge of the clearance envelope and increases to 23'-0" at 6'-0" off the centerline of track (see Figure 3 of this report). As previously described, actual horizontal clearance for the Burlington rail tunnel is between 13'-6" and 16'-0" while the vertical clearance is 17'-0" at the crown of the tunnel and at 6'-0" off from track centerline, the vertical clearance is approximately 14'-6". Thus, the existing clearances do not satisfy current minimum standards. However, in AREMA Chapter 28, Section 1.1, it is stated that “The clearances shown are for tangent track and new construction. Clearances for reconstruction work or for alteration are dependant on existing physical conditions and, where reasonably possible, should be improved to meet the requirements for new construction”.

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May 2002  Burlington Rail Tunnel Assessment  45
Section 8.6 Ventilation

This section makes reference that mechanical ventilation for train operation in tunnels must be analyzed. It is generally not required in tunnels less than 2500 feet long and it is influenced by conditions as type of locomotive, train size, tunnel grade, speed, time between trains, ambient temperature, prevailing winds and drafts. NFPA 130 requirements are stricter and will govern the design. Of the conditions listed as being influential, only the prevailing wind is anticipated to be an issue for this project.

Section 8.7 Increasing Clearances in Existing Tunnels

This section provides generic recommendation to develop a plan to increase tunnel clearances. Any study for increasing the clearance of a tunnel should include but not be limited to the following:

- Situation in Vicinity of Tunnel – right of way, accessibility, available areas for working space, utility lines, public roads, availability of waste disposal area.
- Existing Conditions at Tunnel – dimensions, drainage, ballast depth, construction and condition of lining, condition of floor, wall and roof, geologic conditions
- Available Work Time – density of traffic, train schedule and movements, net working time available, rescheduling trains
- Possible or Feasible Solutions – lower tunnel floor, trim out roof and or side walls, open cut on existing line, open cut on relocated line, construct new tunnel on relocated line.

Chapter 8 Concrete Structures and Foundations

Section 11 Lining Railway Tunnels

This section provides generic recommendations for thicknesses of tunnel linings under various conditions and includes drainage provisions for the linings. Section 11.2.7, Refuge Niches, has provisions to supply sidewall refuge niches at approximate intervals of 200 feet on center and staggered with the opposite side so that spacing of niches is approximately 100 feet on center. Niches are 18 inches deep by a minimum of 70” high. The need for safety niches can be discussed with railroad operations. As the train volume on the line is considered low, maintenance operations can be performed under controlled conditions that the niches may not be considered necessary. To add niches into the tunnel would be a costly renovation and an acceptable structural solution would need to be developed. To satisfy the spacing requirements of the AREMA Manual, three niches would be required, two along one wall located approximately 70 feet from each portal and the third located at the midpoint length of the opposite wall.
Section 14  Repair and Rehabilitation of Concrete Structures

This section provides generic recommendations for the rehabilitation of concrete or masonry structures, including tuckpointing for masonry, shotcrete application and surface patching and crack repair.

Chapter 28  Clearances

Section 1   Fixed Obstructions

Section 1.1a  The clearances shown are for tangent track and new construction. Clearances for reconstruction work or for alterations are dependant on existing physical conditions and, where reasonably possible, should be improved to meet the requirements for new construction.

Section 1.1b  On curved track, the lateral clearances each side of track centerline shall be increased 1 ½" per degree of curvature.

Section 1.4 presents Figure 1-3, the clearance diagram for a Single Tangent Track Railway Tunnel.

Section 2   Equipment Diagrams

The applicable equipment diagram for the Burlington to Essex line is Figure 2-3 or Plate C, Equipment Diagram for Limited Interchange Service. Plate C is representative of the freight service that currently makes limited usage of the tunnel. The passenger car envelope that has been provided for this phase of the study is based on a Virginia Railway Express Cab Car diagram.

AREMA Figures 1-3 is included herein as Figure 3, presented earlier in this report. AREMA Figure 2-3, Plate C is depicted in Figure 4 along with the passenger vehicle envelope. Figure 5 depicts how the Plate C Equipment Diagram and the passenger vehicle envelope fit within the existing tunnel.