G Rail Tunnel Evaluation

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ROCKY MOUNTAIN HIGH SPEED RAIL FEASIBILITY STUDY

TECHNICAL MEMORANDUM:

RAIL TUNNEL EVALUATION

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Figure 1 . Eurostar high speed trainset in Eurotunnel mock up

Introduction:

Railroads have been building tunnels for over a hundred in an effort to cross barriers imposed by mountains, rivers, seas, or other existing infrastructure. The tunnels often serve to ease the operations by providing short cuts, and easing of the grades, and avoiding persistent alignment problems. As the high speed rail networks are built out worldwide, tunnels provide opportunities to eliminate curves, and keeping grades as flat as possible to maintain service levels that attract riders.

France, England, Germany, Italy and Spain advanced their high speed rail industry complex at the same time and began their build out within in their borders with their own rolling stock, power supply and track configurations prior to the establishment of the European Union. Since the EU intercity high speed rail has expanded from intra-country schemes into cross-border, trans-Europe networks that allow the use of French, German, Italian or other rolling stock to provide international city connections. Tunnels have been used to shorten the routes and cross intervening seas or mountain ranges. The most famous tunnel is the English Channel Tunnel, or Chunnel, that connects England with France, and carries high speed rail between London and Paris and beyond with the continuing build out of the rail network. German and Italian intercity rail networks contain numerous tunnels and viaducts. With the exception of the English Channel Tunnel, all of these tunnels are designed as twin parallel tunnels carrying a single track and measuring approximately 24-33 (7.4-10 m) in diameter. The parallel tunnels are connected by cross passages at regular intervals to provide movement of air with the passage of the train into and through the tunnel, and to allow for safe evacuation of passengers into parallel tunnel in the case of fire. The cross passages are typically 11 ft (3.5m) in diameter are typically at least one tunnel diameter or more.

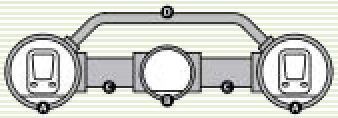

Figure 2 Three parallel tunnel configuration of the English Channel Tunnel, showing two running tunnels, center service tunnel, and pressure relief ducts.

The English Channel Tunnel consists of three parallel tunnels, two that carry opposing rail traffic, and a smaller center "service" tunnel. The service tunnel functions are a carriage way for service vehicles for operations and maintenance, emergency egress, and air pressure relief. The service tunnel also served as the "exploratory pilot tunnel", permitting an assessment of the geologic and hydrologic conditions along the entire route prior to the construction of the two larger tunnels to either side.   Despite, the additional cost and longer period of construction, this three tunnel configurations provides many useful functions before and during operations. Based on evidence from the Channel Tunnel an analysis of air pressures, pressure relief ducts and the lateral forces imposed on the train is required during the next level of design.

Figure 3._ ICE 3 train exiting the Oberhaider-Wald tunnel in Germany

The higher speeds of the modern passenger trains passing into and through tunnels require slightly larger tunnels to provide space for catenary, safety walkways, ventilation equipments and structures, and to provide a larger clearance envelope. Portals also are taking on more flared designs to reduce some of the air pressure impacts at the portal interface and reduced cross section within the tunnel. Passenger cars often are pressurized to eliminate passenger discomfort as trains pass in and out of tunnels.

Worldwide high speed rail networks include large percentages of tunnels and viaducts such as in Germany, where as much as 34% of the ICE line between Frankfurt to Cologne route is built in tunnel. Similarly, tunnels are common on the Eurostar high speed rail lines between England and France, on TGV routes in France and into Spain, Taiwan, Korea, Japan, Italy, France and Spain and Sweden, Norway. Throughout Europe, former national railway operations are upgrading power supplies, systems, and track gauge to allow for cross border operations of their equipment which until recently had been precluded by national network configurations.

In the US, proposed high speed rail corridors in most of the major physiographic and economically defined regions---including Northeast, Southeast, Midwest, Northwest, California, as well as other local service areas as the Rocky Mountain High Speed Rail Network.   As elsewhere, mountains, rivers, and cities impose the need for tunnels along their routes.

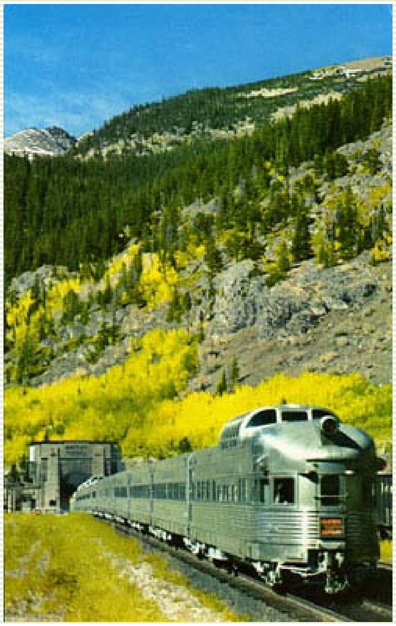

Figure 4. East Portal of the Moffat Tunnel passing under James Peak in the Rocky Mountains (West of Denver, pass at about elevation 9000 ft.)

Completed in 1927

Measures 16 ft w x 24 ft hight

Constructed using Drill and Blast

Concrete lined tunnel horseshoe

Figure 5. West Portal of the Roger's Pass Mt. MacDonald Rail Tunnel, longest tunnel in North America

Rail alignment alternatives through the Rocky Mountains will require a significant amount of tunneling to maintain operable and safe grades, avoid areas prone to rock falls and avalanches, and to provide the shortest routes There are a number of historic tunnels through the Rocky Mountains and a few of these are dedicated to freight and passenger rail services. The Moffat Tunnel, completed in 1927, is a single track tunnel that was built to cut off 27 miles to reduce the elevation of the older tunnel. The Moffat Tunnel passes under James Peak, has a cross section of 16 ft wide by 24 ft high. The longest tunnel (14.7 km) in North America is the Mount MacDonald Rail Tunnel at Roger's Pass through the Rocky Mountains in British Columbia, Canada. The Mt. MacDonald Tunnel provided additional capacity and safer, separate, bi-direction traffic. The most recent US tunnels have been built for highway services including the older Eisenhower tunnel, and the environmentally sensitive and aesthetic Glenwood Canyon Tunnels along Route 70. These tunnels are not long when compared to recent rail and highway tunnel in Europe and compared to those planned as part of this feasibility study.

RMRA HSR Tunnel Configurations:

There are a couple of tunnel configurations to consider, depending on a number of parameters and conditions, including tunnel length, geology, groundwater conditions, as well as fire-life safety and ventilation requirements.

The three basic configurations included in this feasibility evaluation include:

- Two tunnels, connected with cross passages
- Three tunnels (incl. Service tunnel and cross passages (e.g., English Channel Tunnel)
- Single large "bore" tunnels carrying two rail tracks in a single tunnel

The Cross passages function as access and egress to and from running tunnels for operations and maintenances services as well as emergency evacuation, ventilation. Cross passages are 11 ft diameter and are spaced every 1230 (375m). Piston relief ducts measured 7 ft (2 m) and were located every 820 ft or (250 m), relieved the air pressure build up ahead of the train.

Modern Tunnel Construction

Tunnel size and designs of rail tunnel are constrained by the clearance envelopes of the train, and catenary, allowable grades, the speeds through the tunnel, ventilation, and more recently, the criteria for safe egress of passengers in the event of a fire within the tunnel. With regard to size, smaller tunnels were always considered to be the most stable and safest to construct. As a consequence, historically, most tunnels, unless unusually short and in sound rock, were built as two parallel tunnels. Until the mid-1980's most rail tunnels were constructed using drill and blast methods through rock, as expected in the Rocky Mountain HSR Tunnels. Moffat Tunnel, Eisenhower Tunnel, the Glenwood Canyon Tunnels, and most of Mt. MacDonald tunnel were built this way. In the 1980's Robbins Company developed the first tunnel boring machine, and the tunneling business continues to evolve with tunnel boring machines taking on the arduous task of tunneling through all types of rock, soil, faults zone and under high water pressures, not possible until recently.

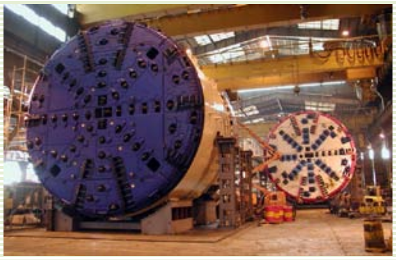

Figure 6. Double Shielded Robbins TBMs measuring 30 ft diameter ready for the Spanish high speed rail tunnels.

Tunnel with a diameter of 25-30 feet are now common, with demand for tunnels with diameters over 30 ft growing with recent demonstrated success in Europe and throughout Asia. At the present time, tunnel boring machine with higher thrust capacity and torque can bore tunnels over 50 ft (15.4 m) in diameter, which are capable of carrying multiple rail tracks or lanes of highway. As the geologic conditions deteriorate, the machine designs become more sophisticated with single and double shields to support the ground at the face and allow for immediate installation of the permanent ground support.

Robbins rock TBMS have been used on many of the high speed rail tunnels, including five machine used on the English Channel tunnel or Eurotunnel, and double shield rock TBMs, shown in Figure 7, recently commissioned for the tunnels for the TGV trains to connect into Spain.

Table 1. Typical Rail Tunnel Configuration

Configuration	No. Tunnels/tracks	Cross Passages	Example - Rail
Twin parallel	2 tunnels; single track; std gauge;	Spacing about 1200 ft; similar to metro tunnels	ICE-Simplon Tunnels; TGV tunnels in Spain
Three parallel	Smaller third tunnel provides service, egress, & ventilation and opportunity to be pilot exploratory tunnels	Cross Passages About 11 ft diam.	Chunnel; 25 ft diameter; 16 ft service tunnel; 11 ft cross passages
Single large bore	1 tunnel/ double track	Possible refuge chambers or shaft egress	Trans Hudson Express (out for bid); typ 40-55 ft diameter (14-15 m) China Rail Tunnel

A number of tunnels measuring 46-51ft (14-15.4 m) have been successfully completed and open to operations including the 4th Elbe Tunnel in Germany, the SMART dual use tunnel in Malaysia, Madrid and Barcelona, and Sir Adam Beck –Niagara Tunnel –most of the large bores are highway tunnels, but there is nothing to preclude a single large bore tunnel for rail operations, unless local operational and safety concerns would dictate other design considerations. A large double stack single bore is envisioned for the new rail tunnel that will connect New Jersey and New York under the Hudson River. (the ARC tunnel or Access to the Region's Core). The ARC tunnel will carry two Rail tracks on two levels.

Rocky Mountain HSR Tunnels:
Five principal tunnels, listed below, are proposed in the alignment study. These are proposed as 25 ft diameter. Twin bore, tri-bore and single bore configurations are considered.

Table 2. Principal Rocky Mountain High Speed Rail Tunnels

RMR Tunnel	Length of Tunnel
Aspen	51,000 ft
Georgetown	14,000 ft
North Fork	30,000 ft
Breckenridge	22000 ft
Black Hawk	6,000 ft

At the feasibility and concept level design, the recommended configuration for long term operations of high speed system would dictate twin parallel tunnels, connected with cross passages and large enough to provide safe egress and supply proper ventilation and ventilation controls in the event of a fire or mishap in the tunnels.

In the last 20 years, the demand for more and higher speed intercity passenger rail in various regions of the US and a couple of rail fires has raised the issue of passenger safety. Recent tunnel fires in the Baltimore Rail tunnel, the Mont Blanc highway tunnel, and English Channel Tunnel have reinforced the concern about passenger evacuation and egress in tunnels. In the case of the two fires in the Chunnel, the safe evacuation and transport of the passengers to and from the parallel tunnel has been proven safe and effective. Repairs have been made to the tunnel lining and the tunnels returned to service. The Mont Blanc Tunnel highway tunnel with large quantities of combustible fuels, resulted in loss of life. The lessons learned from this tunnel fire, many having to do with human behavior and response, are still being evaluated. Unlike urban metro systems, there are no guidelines at the present time for the safe egress and safe operations of rail tunnels and bridges. Proliferation of high speed rail systems and the increase of passenger rails systems, in general, will put pressure on the state departments of transportation to consider similar guidelines.

Currently, in the United States, the design of railroad tunnels does not specifically require nor specify fire life safety and ventilation requirements in rail tunnels. However, recent fires in the English Channel tunnel and safe evacuation and rescue of the passengers, has demonstrated the merits of regularly spaced cross passages between parallel tunnels. In the design phase, we recommend a sensitivity analysis be conducted to evaluate the trade-offs among the diameter of the tunnels and number, size and spacing of pressure relief ducts or shafts, as well as operating speeds within the tunnels.

Based on the conceptual level of information about the tunnel alignments and lengths, we feel these tunnels are constructible with modern tunneling methods, but will require careful preliminary site investigation and mapping to identify and locate major fault zones, rock types and ground conditions along each tunnel alignment. A potential cost savings could be realized with advanced mapping to determine if a liner is necessary for the entire length of tunnel, and if so what type of lining would suffice.

Tunnel Costs:

There are many factors that go into the costs of tunnels, the most important of which is the location, geography, and hydro-geological conditions encountered. At this level of study a range of costs per linear ft or mile of tunnel is best. Review of a number of rail projects constructed in the past ten years, in the US and Europe provided the ranges of costs. These costs are based on published projects costs and included only those tunnel projects that have been constructed. It is assumed that each of these projects include some portions of cut and cover or open cut portal transition to the tunnel.

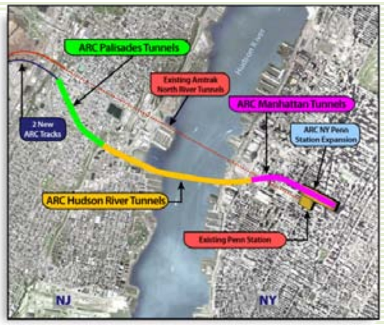

Figure 7. New large bore tunnel for rail into NYC:

Access to the Region's Core-Trans-Hudson Tunnel that will carry intercity rail between New Jersey and Manhattan will measure approximately 50 ft diameter.

Based on a review of the English Channel Tunnel, ICE tunnels, and recent TGV tunnels, we recommend a range of tunnel costs for this conceptual level evaluation between $20,000 and $73,000 per linear foot, reflecting a twin 25 ft diameter tunnel at the low end and the complex, long, three tunnel and cross passages of the English Channel tunnel in challenging submarine cross-border at the upper end . The English Channel tunnel total project costs was 12 Billion English Pounds, and ran 80% over original costs, some of which is attributed to redesign of the vehicles and systems required late in the program. The English Channel tunnel is the marker for the highest range as it includes three parallel submarine tunnels and landside underground cavern works. Other simpler ICE and TGV rail tunnels have been built in a more convention twin tunnel configuration. Their completed costs are trending between $25,000 and $30,000 per linear foot for tunnel with a diameter of 24-27 feet. These values are based on recent rail tunnel costs from ICE Simplon Tunnel, the East Side Access tunnels in Manhattan, Lyon to Turin TGV tunnels. The costs are given as total project costs, which we assume to include the systems.

Figure 8. Robbins Tunnel Boring Machine single shield used in unstable ground

Review of the recent large bore tunnels with a diameter of 45-51 ft (14-15 m) cost from $27,000 to $50,000 per linear ft. Most of these tunnels have been constructed to accommodate double stack roadways but the cost of the tunneling would dominate the cost compared to the relative cost differences in the road pavement, or rail and systems. To date, none of these large bores have been used for high speed rail systems, no doubt due to operational and safety concerns. The large bore tunnels built to date are mostly accommodate stacked 2 to 3 lane highways (e.g. Malaysia or Madrid) or stack metro lines and station platforms (e.g. Barcelona)

Tunnel Design and Construction:

Determination of the methods of excavation and support and final lining depends on the geotechnical site investigation and the testing of samples retrieved from the exploratory borings. Because of the rough terrain and depth of cover over many tunnels in mountainous terrain, the engineers rely on fewer borings and on small scale geologic maps and outcrop maps to project and interpolate the types of rock, the degree of fracturing and the amount and pressure of inflow

Figure 9. English Channel Tunnel showing concrete segmental lining, utilities and systems strung on sides and single track with walkway

of groundwater. Fault zones and the ground conditions within and approaching the faults often present the greatest challenges to tunneling because of the presence of high water pressures and highly fractured to soft "gouge" materials that can be unstable and require special support and approaches.

Understanding both overburden pressures and groundwater pressures are significant to the advance rate and ultimate completion of the tunnels. Until recently, small diameter pilot tunnels were recommended where exploratory borings are too deep or terrain to rugged. Pilot tunnels continue to be used today, and are often converted to use as a service or ventilation tunnel built in parallel to the existing tunnel. Alternatively, the pilot tunnels were excavated in the crown of the larger tunnel and enlarged to full size with the design to account for the conditions revealed in the pilot tunnel excavation. Exploratory tunnels were used in Cumberland Gap Tunnels, H3 Tunnels in Hawaii and the Mt. MacDonald Rail Tunnel.

With continued sophisticated developments of technology and mechanical designs, tunnel boring machines (TBMs) have extended the realm of tunneling to provide safer, faster, and more continuous mining compared to the drill and blast, muck and support, and final lining installation cycles used since the earliest tunneling. For long tunnels, as envisioned here, one or more tunnel boring machines would provide a faster, safer operation. These machines are designed based on the size, permanent liner design, and most importantly based on an assessment of the types and properties of rock anticipated along the alignment. Similarly, newer shielded pressure face machines provide control the inflow of the groundwater and the ability to change into and out of pressure mode.

Temporary and/or permanent liner systems can be erected immediately behind the cutterhead of the tunnel boring machine in a "continuous" mining, mucking and lining operation. As the cutterhead bores one stroke (about 3-5 feet), then either rock bolts or precast concrete liner segments are erected to form a ring of final lining and support. A final shotcrete lining or cast in place liner can be installed at some distance behind the tunnel boring machine if ground conditions warrant. Many rail tunnels across the US have been operating decades without concrete lining when stable rock conditions allowed. This would be a

Figure 10. Drill jumbo drilling holes in face for drill and blast excavation. Temporary shotcrete is visible on the sidewalls.

significant cost savings on the project. Estimates of ground support would result from the geologic mapping and site investigation and tunnel design efforts.

Tunnel construction methods:

Tunneling for the high speed rail tunnels could be done by one or a combination of the following common methods:

Drill and Blast: Drill and blast techniques are used to loosen and excavate rock. Advances are accomplished in 3-5 ft long “rounds” or length, with a number of drill holes-loaded with dynamite are detonated with a short delay sequence. After the bad air is ventilated, the fractured rock is loaded onto a muck truck or train and hauled out of the tunnel. Rock bolts or steel sets or shotcrete are applied to support the ground and allow for the drilling of the next round. The rockbolts are often used in combination with shotcrete as either temporary or permanent lining, depending on the final use of the tunnel, need to water proof and consider aesthetics.

For large diameter tunnels, the heading may be divided into smaller openings to excavate and support smaller more stable openings.

© Mechanical Excavation: Tunnel boring machines have evolved in the last 20 years to provide tunnels of various sizes, and to allow continuous excavation and installation of the final liner in one continuous operation, and to also allow long tunnels of various sizes to be excavated and lined in one continuous operation. Machines are designed to excavate soils or rock or a mixture in the extreme cases. Immediately behind the advancing face, temporary and permanent support systems are installed to protect the workers and to allow for final fitting out of the liner behind the machine or after the machine has been extracted. Average advance rates of these continuous tunneling range from 30 to 50 feet per day with days completing 100 feet or more per day common.

For short tunnels, portal and TBM launch tunnels, shaft, and difficult ground, we recommend the Sequential Tunneling Method (SEM): As the name implies, the SEM allows for partial excavation of portions of the tunnel to provide a safe and secure opening in soils, or fractured rock, and for large caverns, and tunnel openings of irregular shape. The ground is temporarily supported by sprayed shotcrete as soon as achievable following excavation. A final liner may be installed or additional shot crete depending on the functional, aesthetic, and maintenance requirements. The method has been used in a number of metro tunnels in the Washington Area to control settlement, and for short tunnel segments. This method has also been used throughout Europe.

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