California High-Speed Train Project

TECHNICAL MEMORANDUM

Basic High-Speed Train Tunnel Configuration
TM 2.4.2

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Prepared by PB

for the California High-Speed Rail Authority

System Level Technical and Integration Reviews

The purpose of the review is to ensure:
Technical consistency and appropriateness
Check for interface issues and conflicts

System level reviews are required for all technical memorandums. Technical Leads for each subsystem are responsible for completing the reviews in a timely manner and identifying appropriate senior staff to perform the review. Exemption to the System Level technical and integration review by any Subsystem must be approved by the Engineering Manager.

System Level Technical Reviews by Subsystem:

Systems: *Signed document on file*______________ ___ 23 July 2009
Rick Schmedes Date

Infrastructure: *Signed document on file*_________________ 9 July 2009
John Chirco Date

Operations: *Signed document on file*______________ ___ 17 July 2009
Paul Mosier Date

Maintenance: *Signed document on file*______________ ___ 17 July 2009
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TABLE OF CONTENTS

ABSTRACT

This Technical Memorandum establishes approximate finished dimensions for bored and cut-and-cover tunnels in which high-speed passenger trains run exclusively, for use during 15% Design level in determining alignment corridors and right-of-way requirements, and in the development of cost estimates. The basic tunnel configuration is assumed to be twin, single-track tunnels and the rolling stock is assumed to be sealed. Tunnel shapes are circular (TBM driven) for bored tunnels and rectangular for cut-and-cover tunnels. All tunnels are assumed watertight.

The basic tunnel configurations incorporate train profiles, static gauge, kinematic envelope, fixed equipment envelope, tangent and superelevated track, construction tolerances, escape walkways, pantograph catenary and support structure, ballasted or fixed (slab) track, and drainage. These items are at an early stage of design and are subject to refinements which may affect finished tunnel dimensions. Wherever possible, allowances have been made to accommodate future changes for those items that have not yet been defined such as fixed equipment including cables and pipes.

The basic tunnel dimensions are established to comply with the European Technical Specifications for Interoperability (TSI) requirements for a 10 kPa (1.45 psi) maximum pressure variation in tunnels and underground structures for trains complying with high-speed rolling stock criteria at a maximum operating speed of 220 mph. The purpose of limiting the pressure changes is to mitigate adverse health effects or discomfort to passengers and workers; these criteria are known as medical health criteria.

A preliminary assessment of the required free tunnel cross sectional areas for different train speeds and tunnel lengths are established from data provided in UIC 779-11R "Determination of railway tunnel cross sectional areas on the basis of aerodynamic considerations." The UIC code is concerned only with the aerodynamic effects on passengers and workers hence represent the medical health criteria. Finished tunnel dimensions are established based on the required free tunnel cross sectional areas. The medical health criteria represent the critical case (largest tunnel size) for short tunnels.

As tunnel length increases, medical health criteria become less critical and the effects of aerodynamic drag on the trains in the tunnels increases significantly compared with open track operation. Heat generated from the aerodynamic drag, air conditioning of the trains, and systems, builds up in the tunnels. These effects can be mitigated by increasing the tunnel size, cooling the tunnels, reducing the aerodynamic drag of the trains, and increasing the power available to the trains. A qualitative discussion of these complex issues is included in this TM. Quantitative analysis will be carried out during subsequent design phases.

The following factors may influence the finished tunnel dimensions and will be studied further during detailed design:

- Emergency ventilation requirements
- Portals, junctions, interfaces and transitions between bored tunnels, cut-and-cover tunnels and other structures

Various measures can be used to mitigate these effects, including pressure relief ducts between tunnels and airshafts between the tunnels and ground surface. These mitigation measures will be addressed along with a quantitative analysis of aerodynamic effects in future studies.

1.0 INTRODUCTION

1.1 PURPOSE OF TECHNICAL MEMORANDUM

This technical memorandum establishes approximate finished dimensions for new construction of bored and cut-and-cover tunnels in which high-speed passenger trains run exclusively, for use in determining alignment corridors, right-of-way requirements, and in the development of cost estimates for the 15% design level.

1.2 STATEMENT OF TECHNICAL ISSUE

The basic dimensions are established to comply with the European Technical Specifications for Interoperability (TSI) requirements for a 10 kPa (1.45 psi) maximum pressure variation in tunnels and underground structures along any train complying with the High-Speed Rolling Stock, at the maximum permitted speed of 220 mph. The purpose of limiting the pressure changes is to mitigate adverse health effects or discomfort to passengers and workers, and these criteria are known as the medical health criteria.

The basic tunnel configurations incorporate train profiles, static gauge, kinematic envelope, tangent and superelevated track, construction tolerances, escape walkways, pantograph catenary and support structure, ballasted or fixed (slab) track, and drainage. These items are at an early stage of design and are subject to changes which may affect finished tunnel dimensions. Wherever possible, allowances have been made to accommodate future changes or those items which have not yet been defined such as fixed equipment including cables and pipes. No allowance has been made for catenary tensioning devices such as weights, and ventilation fans, as it is assumed that they will be accommodated in niches outside of the running tunnels unless jet fans are used. This document does not include assessment of the aerodynamic drag on the rolling stock traveling through the tunnels, specifically increased energy requirements or required slower operating speeds as a result of friction, displacement (pushing) of the air within the tunnels, or the resulting heat build-up in the tunnels.

Assessment and development of basic design guidelines for the single, twin-track tunnels, portals, shafts and other tunnel structures and the interfaces between tunnels and portals have not been considered in this technical memorandum and will be the subject of separate technical memoranda.

1.2.1 Definition of Terms

The following technical terms and acronyms used in this document have specific connotations with regard to California High-Speed Train system.

<u>Blockage Ratio</u> Ratio of train cross section area to tunnel cross section area

<u>Free Cross Section Area</u> The standard tunnel cross section area excluding clearance for tunnel design details and fixed equipment

<u>Medical Health Criterion</u> Maximum pressure variation (peak-to-peak value) in the tunnel (outside of the train) independent of time.

<u>Passenger Aural Comfort Criteria</u> Maximum pressure change inside the train within a specified period of time to limits the discomfort on passenger ears when passing through a tunnel.

<u>Pressure Comfort</u> Conditions where there is no passenger ear discomfort due to pressure change.

<u>Pressure Tightness Coefficient</u> Time in which the difference between internal and external pressures upon a stepwise pressure change decrease from 100% to approximately 38% of the initial pressure difference.

<u>Sealing Quality</u> The capacity of the train to limit inside pressure change within given limits.

Acronyms

Authority	California High-Speed Rail Authority
CHST	California High-Speed Train
CHSTP	California High-Speed Train Project
HST	High-Speed Train
KPH/kph	Kilometers per Hour
MPH/mph	Miles per Hour
NFPA	National Fire Protection Association
THSR	Taiwan High-Speed Rail
TM	Technical Memorandum
TSI	European Technical Specifications for Interoperability
UIC	Union Internationales des Chemins de fer (International Union of Railways)

1.2.2 Units

The California High-Speed Train Project is based on U.S. Customary Units consistent with guidelines prepared by the California Department of Transportation and defined by the National Institute of Standards and Technology (NIST). U.S. Customary Units are officially used in the United States, and are also known in the U.S. as “English” or “Imperial” units. In order to avoid confusion, all formal references to units of measure should be made in terms of U.S. Customary Units. In the case where source documents use metric units, the metric units have been retained and a conversion to U.S. Customary Units follows.

Guidance for units of measure terminology, values, and conversions can be found in the Caltrans Metric Program Transitional Plan, Appendice B U.S. Customary General Primer (http://www.dot.ca.gov/hq/oppd/metric/TransitionPlan/Appendice-B-US-Customary-General-Primer.pdf). Caltrans Metric Program Transitional Plan, Appendice B can also be found as an attachment to the CHSTP Mapping and Survey Technical Memorandum.

2.0 DEFINITION OF TECHNICAL TOPIC

2.1 GENERAL

This Technical Memorandum establishes approximate finished dimensions for bored and cut-and-cover tunnels in which high-speed passenger trains run, based on the European Technical Specifications for Interoperability (TSI) requirements for maximum pressure variation in tunnels and underground structures for trains complying with high-speed rolling stock at the maximum operating speed of 220 mph. The purpose of limiting the pressure changes is to mitigate adverse health effects or discomfort to passengers and workers, and these criteria are known as the medical health criteria.

2.2 LAWS AND CODES

Assessment, compliance and/or demonstration of equivalency for applicable laws and codes will follow.

2.3 BASIC TUNNEL CONFIGURATION

Several basic tunnel configurations are used for railway tunnels. Common configurations for high-speed passenger, conventional passenger, and freight railway tunnels are:

Bored Tunnels

- Twin single-track tunnels, each with a single-track, and having cross passages between tunnels.
- Single tunnel with twin-tracks with separation wall and escape walkways between tracks and access doors in separation wall.
- Single tunnel with twin-tracks without separation wall, escape walkways adjacent to tunnel walls. Refuge areas and/or access shafts to surface are usually required for long tunnels.

Cut-and-Cover Tunnels

- Single-track twin boxes with escape shafts or cross-passages.
- Twin-track, single box with separation wall and escape walkways between tracks, doors in separation wall.
- Twin-track, single box without separation wall, escape walkway by walls of tunnel, refuges and escape shafts to surface usually required for longer tunnels.

Several factors must be considered in the selection of the tunnel configuration including the following:

- Train speed
- Alignment
- Tunnel length
- Aerodynamics
- Ventilation
- Fire and life-safety
- Depth of tunnel
- Access and egress
- Geologic conditions and ground stability
- Groundwater conditions
- Right-of-way
- Method of construction
- Environmental considerations
- Operations and maintenance
- Capital, operating, and maintenance costs
- Construction schedule

It is beyond the scope of this technical memorandum to address all these factors in detail. Assumptions have been made in order to determine basic finished tunnel dimensions.

A fire, life-safety and passenger evacuation strategy for each tunnel configuration must be developed in coordination with the authority having jurisdictions for operational safety as this is critical to establishing the appropriate tunnel configuration at tunnel locations.

Assessment and development of basic design guidelines for the single, twin-track tunnels, portals, shafts and other tunnel structures will be the subject of separate technical memoranda.

2.3.1 Bored Tunnels

This technical memorandum considers only a twin, single-track tunnel configuration for bored tunnels. This arrangement requires a wider right-of-way than a single, twin-track tunnel configuration and has been established as the basic tunnel configuration to be used by designers in advancing the 15% Design level of the high-speed rail corridor.

The twin, single-track tunnel arrangement is a common configuration in construction of new transit systems and for tunnels carrying shared high-speed passenger and freight trains. It has also been used for passenger only high-speed rail. A recent example of passenger only high-speed rail is the HS1 line in London (formerly known as Channel Tunnel Rail Link / CTRL Phase 2 project). The configuration is most common with shared use (passenger and freight train) tunnels, as the risk of fire and fire loading for freight trains is much higher than from passenger trains. A primary consideration for this configuration is to include each track in a separate tunnel and provide a refuge area or escape route from one tunnel to the other tunnel in the event of a fire or emergency condition. For twin bore tunnels, it is desirable to maintain a center pillar roughly equal to the tunnel diameter in order to limit stresses between tunnel bore and allow for excavation of the second bore.

The alternative is a single, twin-track tunnel configuration that may or may not have a separation wall with doors between tunnels. An example with a separation wall is the KCRC West Rail tunnels in Hong Kong between Tseung Wan and Kam Tin. These rock tunnels were driven by the drill and blast construction method and carry medium-speed train lines. Examples of single tunnels carrying twin-tracks without a separation wall are numerous and include the majority of the tunnels constructed for the Taiwan High Speed Rail Project.

2.3.2 Cut-and-Cover Tunnels

This technical memorandum considers both twin, single-track and single, twin-track box configurations for the cut-and-cover tunnels. The latter is assumed to have a separation wall between tracks.

2.3.3 Interfaces

Interfaces and transitions between bored and cut-and-cover tunnels and portals have not been considered in this technical memorandum.

2.3.4 Finished Shape and Method of Construction

Assumptions for shape and method of construction have been made for both bored and cut-and-cover tunnels. It is beyond the scope of this study to discuss alternate tunnel shapes and the various methods of tunnel excavation and support that are closely related to the tunnel shape.

2.3.4.1 Bored Tunnel

The majority of the bored tunneling on the high-speed rail alignment is through the Pacheco Pass, Tehachapi and the San Bernardino mountains. Some of the tunneling is likely to encounter unstable and faulted ground, high water inflow quantities, and high ground water pressures. For environmental reasons, it may be undesirable to lower the water table during construction. Some of the tunnels will be several miles in length and access will be limited. TBM bored tunnels are well suited to these conditions and will result in a circular shaped tunnel. For the purposes of this document, the finished shape of the bored tunnels is therefore assumed to be circular and the method of construction to be TBM-driven. There are alternative methods of excavation able to achieve similarly shaped tunnels (arched or elliptical), such as drill and blast or sequential excavation method, though these methods may require pre-treatment of the ground to prevent water inflows. The methodology and conclusions of this study may also be applicable to these tunnels.

Tunnels will have a watertight, smooth concrete lining for safety, durability, low maintenance and reduced aerodynamic drag.

2.3.4.2 Cut-and-Cover Tunnel

For the purposes of this study, the finished shape of cut-and-cover tunnels is assumed to be rectangular. The method of construction and excavation support will vary according to environmental and access constraints, depth of excavation, utilities, sensitive structures, ground settlement considerations, presence of water, maintenance of traffic during construction, and availability of easements and staging areas adjacent to the permanent structures.

2.4 ROLLING STOCK, STATIC GAUGE, DYNAMIC ENVELOPE AND EQUIPMENT

2.4.1 Rolling Stock

Train profiles for candidate high-speed rail rolling stock were prepared to enable calculation of the train cross sectional areas. These drawings are included in Appendix A. Key dimensions and cross sectional areas are summarized in Appendix B. The information was derived from a variety of sources and requires verification following selection of the high-speed rolling stock. The cross sectional areas of rolling stock shall only be relied on for the purpose of calculating the free tunnel cross sectional area required to comply with the TSI medical health criteria and aerodynamic drag calculations.

2.4.1.1 Duplex / Bi-level

Shinkansen Bi-level and TGV Duplex train profiles are included in Appendix A. A prototype of an AGV Duplex has as not yet been manufactured.

2.4.1.2 Single Level

Shinkansen N700 and AGV (prototype) Single Level train profiles are included in Appendix A.

2.4.2 Static Gauge

A composite high-speed vehicle static gauge has been developed that is similar to UIC GC gauge. Refer to Technical Memorandum TM 1.1.10 - Structure Gauges. Correspondence with Alstom refers to the TGV duplex and a future AGV duplex vehicle as fitting within a G3 gauge. It is noted that the top of the G3 outline is different to the AGV single-level.

2.4.3 Dynamic Envelope

2.4.3.1 Tangent and Superelevated Track

A maximum superelevation of 7 inches has been established as a CHSTP system requirement. Maximum superelevation, if used in any of the tunnel alignments, is critical to the minimum width calculation for cut-and cover tunnels. Refer to Technical Memorandum TM 1.1.10 - Structure Gauges.

2.4.4 Pantograph and Catenary Electrical and Mechanical Envelopes

The pantograph and catenary detail is based on a single, twin-track tunnel arrangement and is therefore larger than would be expected for a single, twin-track tunnel arrangement. Non-standard (exceptional) OCS configurations, such as may be used on the low-speed approach to the Transbay terminal, are more compact and have not yet been assessed. Refer to Technical Memorandum TM 3.2.3 - Pantograph Clearances.

2.4.5 Fixed Equipment Envelope

A provisional list and size of continuous fixed equipment which may be located within the free cross sectional area of the tunnel was developed in order to make a preliminary estimate of the cross sectional area which is occupied by the equipment and the clearances required for the equipment in the fixed equipment envelope. The list has been prepared only to establish a preliminary estimate of the cross sectional area occupied by this equipment and the clearances required in the fixed equipment envelope. It is not intended that for this to be a definitive list nor does it represent final size of equipment. A list of intermittent fixed equipment that does not need to be included in the estimate of cross sectional area is included for completeness.

2.4.6 Continuous Equipment

The following continuous equipment may be located in the free tunnel cross sectional area:

- 6 x 6" OD High Voltage Electric cables
- 10 x 3" OD Low Voltage Electric cables
- 8" OD Wet Standpipe (fire line)
- 2" OD Emergency air pipe
- 13" OD Sump pump discharge pipe
- 1" OD Leaky feeder cable
- 1" OD Earthing tape and corrosion protection
- 2" OD handrail
- Communications and Signaling equipment
- Sliding cross passage doors (only required in double track tunnels with separation wall between tracks)

It is estimated that a cross sectional area of 20 square feet is required to allow for the continuous fixed equipment and for pantograph and catenary wire equipment in the free tunnel cross sectional area. It is recognized that this is a conservative estimate as some of the equipment may be accommodated in cableways and duct banks cast into the escape walkway and tunnel invert concrete and will not be in the free tunnel cross sectional area.

2.4.7 Intermittent Equipment

The following intermittent equipment may be located in the free tunnel cross sectional area and a space allowance will be necessary within the fixed equipment envelope. No cross sectional area allowance is necessary as the equipment is not continuous.

- Signage
- Tunnel walkway lighting
- Emergency radio antennae
- Fire telephone box
- Blue light station (at cross passages)
- Rail lubricator tank
- Train control / signal case
- Fire extinguishers

2.4.8 Excluded Equipment

2.4.8.1 Ventilation Fans

No allowance has been made for ventilation fans in the basic tunnel configuration. Ventilation fans are assumed to be located in niches adjacent to tunnels unless jet fans are used which will be located in the tunnel. Jet fans will not be continuous and so do not need to be taken into account in the free tunnel cross section calculations. Niches and enlargements present no difficulties in cut–and-cover tunnels but may present a significant construction challenge in bored tunnels.

2.4.8.2 Catenary Tensioning Devices

No details of the tensioning system (if required) were available at time of writing and no allowance has been made in the basic tunnel configuration. Tensioning devices such as weights, if required, are assumed to be located in niches adjacent to tunnels.

2.4.8.3 Chiller Units and Cooling Pipes

The requirement for chiller units and cooling pipes will be the subject of a separate study and no specific allowance has been made in the basic tunnel configuration. Chiller units would be located in niches. Cooling pipes would be located in the tunnel. The requirement for cooling of the tunnels to minimize heat buildup from aerodynamic drag will be the subject of study during detailed design.

2.4.8.4 Pump Sumps

No allowance for pump sumps has been made in the basic tunnel configuration. Pump sumps are assumed to be located in cross passages adjacent to tunnels or, if operation and maintenance requirements allow, the sumps could be located in or below the invert of the running tunnels.

2.5 OTHER TUNNEL SIZE PARAMETERS

2.5.1 Invert

2.5.1.1 Drainage

Concrete Trackform

Trackwash and Firemain - It is assumed that water from trackwash and fire main testing will be directed along the invert of bored and cut-and-cover tunnels in a formed open channel. This will only occur during maintenance and not during revenue operation. The channel has not been sized.

Designed Hydrostatic Pressure Relief of Lining/ Drained Tunnels - It is assumed that all tunnels will be lined and undrained for environmental reasons. No allowance has been made for deliberate drainage of water from behind the lining to reduce water pressure.

Leakage - There may be relatively small quantities of water continuously leaking through the lining after construction is complete. This water will need to be directed to drains below the invert. Water flowing on the invert may not be acceptable during high-speed revenue operation as it can be sucked up during passage of trains.

Ballasted Track - This will require a more complex drainage system below or within the ballast and has not been studied in detail.

2.5.2 Trackform

2.5.2.1 Bored Tunnels

An allowance of approximately 3-feet depth from top of invert concrete to lining at tunnel center point has been made in the bored tunnels. This will allow use of a direct fixation (slab) or ballasted trackform and maintain sufficient clearance for either superelevated or tangent track. A direct fixation (slab) trackform is preferred in tunnels and is standard practice in new construction for rail tunnels due to its low maintenance requirements. Maintenance is a key consideration in tunnels due to restricted access, limited space for tamping activities, and short possession times.

2.5.2.2 Cut-and-Cover Tunnels

An average allowance of approximately 3'-2" depth from top of invert concrete to lining at tunnel center point has been made in the cut-and-cover tunnels. This will allow use of a direct fixation (slab) or ballasted trackform and maintain sufficient clearance for both superelevated and tangent tracks. As a guideline, ballasted track on viaducts typically requires a minimum depth of ballast of approximately 12 -14 inches below cross ties. If slurry walls are constructed as permanent tunnel walls, a connection between the slurry wall reinforcement cages and invert concrete slab reinforcement will be required and this may require a flat slab invert arrangement with steps to adjust for changes in level. Hence a generous allowance for trackform concrete has been made to accommodate all possible methods of construction.

2.5.3 Escape Walkway

The horizontal and vertical location of the escape walkway cannot be confirmed until a passenger evacuation strategy has been adopted and approved for the CHSTP. Assumptions for walkway size and placement were made based on TSI requirements and European practice. Established high-speed rail practice is to locate the escape walkway at or near the level of the rail rather than at the level of the vehicle door sill to avoid air turbulence during high-speed train operation. The assumed envelope of the escape walkway are shown on the drawings achieve the requirements of NFPA 130.

2.5.4 Construction Tolerances

2.5.4.1 Bored Tunnel

A construction tolerance allowance of 6 inches in diameter has been allowed.

2.5.4.2 Cut-and-Cover Tunnel

A vertical construction tolerance of 1 in 100 for construction of excavation support walls (if required) has been assumed. Typical depth to invert is assumed to be 50 feet which results in a 6 inch vertical tolerance on each of the two vertical walls. A horizontal construction tolerance allowance of 4 inches is assumed for the soffit slab.

2.6 POLICY CONSIDERATIONS

The following policy issues are assumed in the development and presentation of the information contained in this design guidance.

The assumptions for the basic tunnel configuration are detailed in the following subsections. The tunnel configuration incorporates train profiles, static gauge, kinematic envelope, tangent and superelevated track, construction tolerances, escape walkways, pantograph catenary and support structure, ballasted or fixed (slab) track, and drainage. Many of these items are at an early stage of design and are subject to changes which may affect finished tunnel dimensions. Where possible, allowances have been made to accommodate future changes or those items which have not yet been defined.

- Bi-level high-speed rolling stock may be used.
- The AGV single-level train, a prototype not yet in production, does not comply with the CHSTP policy requiring the trainset to be a proven technology.
- Rolling stock will have excellent sealing characteristics similar to or better than ICE-3 and Shinkansen trains.
- The crosspassages and or doors connecting the single-track running tunnels will be completely sealed to allow trains to travel in opposite directions at the same time within the single-track tunnels, or if connections are not sealed, trains will not be allowed to pass in opposite directions within tunnels at the same time.
- It will not be possible to run trains at speeds in excess of 250 mph in the tunnels and meet the medical health criteria.

3.0 ANALYSIS AND ASSESSMENT

3.1 VENTILATION, TRANSIENT AIR PRESSURES, AERODYNAMICS AND TEMPERATURE

The following key issues are related to the free cross sectional area of the tunnel:

- Transient Air Pressures
- Aerodynamic Drag
- Temperature

These factors are closely related to the tunnel length and are discussed in the following sections.

Emergency ventilation is not considered to be critical to sizing the tunnels. The purpose of emergency ventilation is to provide smoke control and purging in the event of a fire in the tunnel so that passengers can escape from the stationary train to the adjacent tunnel via the nearest cross passage. It is assumed that sufficient emergency ventilation can be provided for a given free tunnel cross sectional area in the form of vent shafts to surface and vent fans located at intervals in the shafts and niches in the tunnel in a similar way to typical mass transit railway tunnel emergency ventilation system, or jet fans in the running tunnels. The speed of the train is not relevant as it is stationary during the exiting procedure and short tunnels will be unlikely to need as much emergency ventilation as long tunnels.

3.1.1 Transient Air Pressures

A train passing through a tunnel causes a very complex, unsteady flow field. The pressure transients are mainly produced by the entrance and exit of the nose and tail of the train. The compression and expansion waves propagate along the tunnel with the speed of sound relative to the local airflow. These sonic waves are reflected at the ends of the tunnel and partly reflected if passing a nose or a tail of a train. A compression wave is reflected at a tunnel portal as an expansion wave, a rarefaction wave as a compression wave. This results in a complex superposition of waves. For waves of the same sign the interference is additive and may cause severe pressure gradients in a short time interval. The train therefore travels through a combination of waves which mainly depend on, but are not limited to, the train speed, the train aerodynamic characteristics, the tunnel cross-section (dimensions) and the tunnel geometry (shape).

A representation of the waves generated by two trains passing each other while travelling in opposite directions is shown in Figure 3-1.

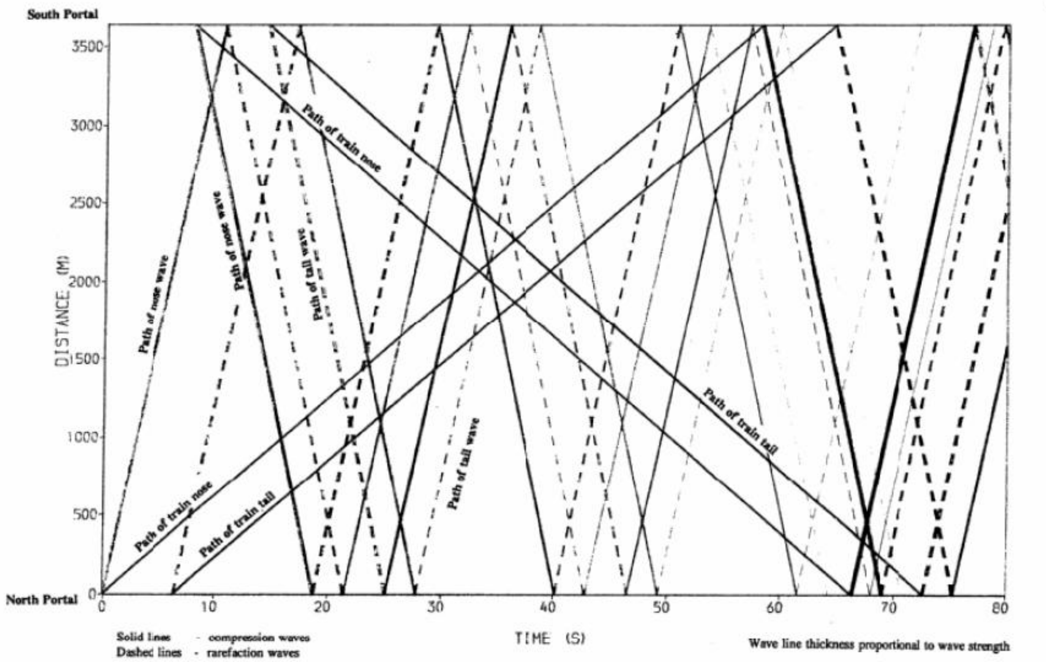


Figure 3-1 **Impact of the Combinations of Pressure Waves on Train Noses and Train Tails for Two Trains Travelling in Opposite Directions**

This figure shows that each train is traveling through multiple combinations of pressure waves. The train noses and train tails are not affected by the same combinations. As a result, static pressure experienced by train and passenger vary along the tunnel length as shown in Figure 3-2.

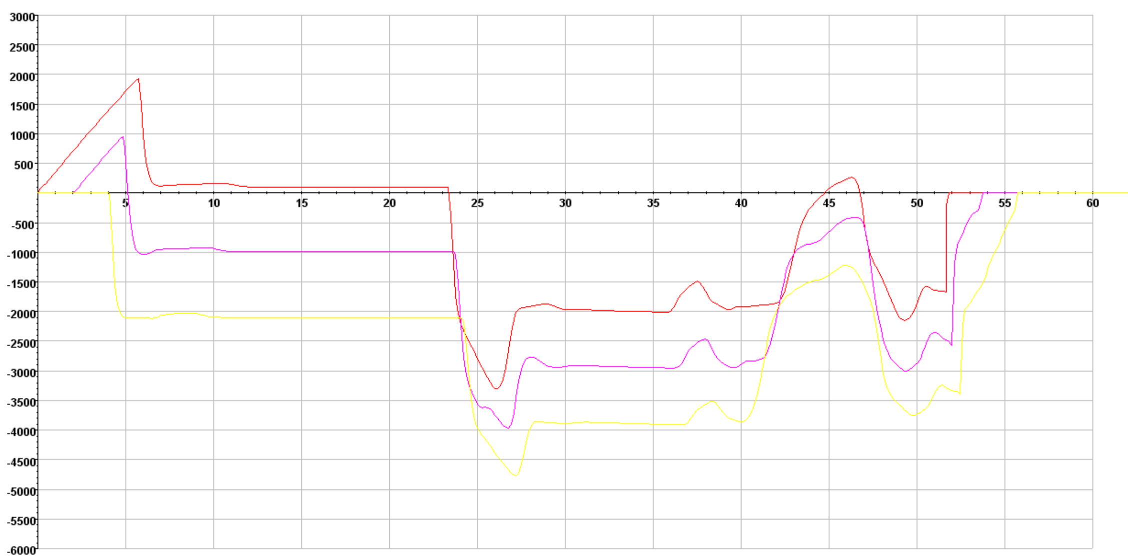


Figure 3-2 **Static Pressure Variation (Pa) Versus Time (s)**

This figure illustrates static pressure variation (Pa) versus time (s) at three locations on the train while the train is running along the tunnel. Data used in this example is as follows:

- Train length – 400 m (1312 ft);
- Tunnel length – 5000 m (3.1 miles);
- Train speed – 350 kph (220 mph);
- Blockage Ratio (train to tunnel cross section ratio) - 0.15

Transient air pressures are highest in short tunnels and are reduced in long tunnels. The transient pressures also increase with train speed.

3.1.2 Effect of Transient Air Pressures on People

There are two concerns that result from these transient pressure waves and both are related to the effects on people; comfort criteria that relates to changes in pressure over time and affects people in unsealed trains, and medical health criteria that are related to instantaneous changes in pressure and may also affect people in sealed trains if there is a sudden loss of sealing. If unsealed trains are specified, a preliminary assessment of tunnel size is obtained using the comfort criteria. If sealed trains are specified, the comfort criteria do not apply, and medical health criteria can be used to provide a preliminary assessment of required tunnel size. Note that unsealed trains (comfort criteria) require larger tunnels and/or reduced allowable speeds compared with sealed trains (medical health criteria).

Comfort Criteria

Comfort criteria relate to rapid and significant changes of pressure across the ear drum and affect people travelling in unsealed trains. The pressure changes on an unsealed train are typically less than 4 kPa (0.58 psi) which is small compared with the 25 kPa (3.6 psi) routinely experienced on a civil aircraft. However the rate of change of pressure experienced on an unsealed train are 20 kPa to 50 kPa per second (2.9 psi to 7.25 psi per second) which is much greater than the 0.02 kPa (0.003 psi) for aircraft descent and 0.04 kPa (0.006 psi) for aircraft ascent. Even people with normal unblocked eusachian tubes have no time to adjust by active means such as swallowing or passive means such as the automatic venting of the middle ear. Each country has different comfort criteria requirements and there are no TSI requirements for comfort criteria.

It is assumed that CHST rolling stock will be specified to have excellent sealing characteristics similar to Shinkansen and the ICE-3 rolling stock, and comfort criteria will not apply. Supply and maintenance of extremely well-sealed trains is a high cost item and will require careful specification and design of rolling stock.

Medical Health Criteria

Medical health criteria relate to pressure differences across the ear drum which can give rise in extreme cases to ear damage. The extreme case that gives cause for concern is rapid decompression or compression, which could occur if the sealing system of a sealed passenger train compartment suddenly failed due to a window breaking, for example. Note that these pressure differences also affect people outside the train who may be stationary. TSI requirements were developed from advice received by UIC from a group of medical experts who recommended limiting allowable peak to peak pressure variations to 10 kPa (3 feet head of water).

The medical health criteria are specified in TSI, Infrastructure Section, Clause 4.2.16.1 which states:

“General requirements

> *The maximum pressure variation in tunnels and underground structures along any train complying with the High-Speed Rolling Stock TSI intended to run in the specific tunnel shall not exceed 10 kPa during the time taken for the train to pass through the tunnel, at the maximum permitted speed.*

Lines of category I

> *The free cross-sectional area of the tunnel shall be determined so as to comply with the maximum pressure variation indicated above, taking into account all the types of traffic planned to run in the tunnel at the maximum speed at which the respective vehicles are authorized to run through the tunnel.*

Lines of categories II and III

> *On these lines, the maximum pressure variation indicated above shall be met.*
>
> *If the tunnel is not modified to meet the pressure limit the speed shall be reduced until the pressure limit is met.”*

3.1.3 Aerodynamics

One of the characteristics unique to high-speed train operation is the significance of aerodynamic effects occurring along the track. The aerodynamic resistance acting against the train movement is of quadratic nature so that a high-speed train moving in free air is subject to similar aerodynamic limitations as a low flying aircraft. Further restrictions exist in tunnels. The faster the train moves, more progressively energy expenditure increases to overcome aerodynamic resistance until an economic feasibility limit is reached. The relations between the influence of speed on ridership volume, the magnitude of energy consumed, expenditures associated with sealed rolling stock and their worth in relation to the total length of tunnels, as well as energy needed to cool tunnels of subcritical cross sectional areas determine the actual operational speed on high-speed rail lines worldwide.

3.1.3.1 Free Air Train Resistance on Level Track

Any aerodynamic consideration starts with a free air train resistance equation that constitutes a basic performance parameter and aerodynamic signature of a particular train. This equation consists of a constant representing train resistance independent of speed, a linear member representing train resistance proportional to speed such as the effect of rolling friction, and a quadratic member representing aerodynamic resistance. This member is expressed as a drag coefficient in free air reflecting the dynamic properties of the shape and size of the train multiplied by the square of speed.

The train resistance may be expressed in deca-Newtons [daN] per train, as a unit train resistance in [daN] per ton, or in kN if the mass of the train is known. It can be further expressed as power in mega watts [MW].

3.1.3.2 Steady State Aerodynamics in High-Speed Rail Tunnels

The steady state aerodynamics represents air as an uncompressible fluid which is a permissible assumption at high-speeds (Lancien, Caille, Jutard, Parent de Cruzon, 1987). It is descriptive of a state that eventually develops after a train travels through a tunnel for a time period that is sufficient to establish a permanent fluid flow regimen. It is characteristic of long tunnels; however indications of steady state forming exist in tunnels of any lengths. The steady state aerodynamic analyses provide primarily basic information on energy demand and its thermal conversion.

The free air train resistance equation of a high-speed train is modified by substituting the drag coefficient in tunnel for its drag coefficient in free air to arrive at an equation for train resistance in tunnels. The drag coefficient in tunnel consists of the free air drag coefficient enlarged by an increment, a mathematical function that includes the effect of Blockage Ratio, tunnel length and frictional conditions in the tunnel expressed by separate coefficients.

The air in long tunnels is pushed in the direction opposite to the movement of the train increasing the friction between the virtual layers of air. Also, the pressure differential between the train's front and rear further increases the friction and associated aerodynamic resistance. This differential often controls the train design and comfort criteria.

The energy necessary to overcome the aerodynamic resistance in long tunnels eventually converts to kinetic energy of air, turbulence and heat. When an undersized cross section of a tunnel is used, the air in a tunnel has to be cooled to avoid problems associated with elevated temperatures and to ensure survivable tunnel environment in a case of emergency evacuation. The total power expenditure can reach the double of the traction demand of the train. The power is supplied to the train to overcome aerodynamic resistance while moving through the tunnel, and additionally, the power is supplied to cooling system to remove a major part of the aerodynamic traction contingent converted to heat.

The critical cross section of a long tunnel is thus defined as the smallest cross section that can be used without a cooling system to comply with applicable tunnel safety codes.

The described basic train resistance equation for tunnels constitutes only a part of steady state aerodynamic analyses. These include also prediction of pressure conditions in tunnels at various locations along the train and at various locations within the tunnel, as well as associated individual air flow speeds that are constant in the steady state regimen, and various secondary aerodynamic effects including turbulences.

3.1.4 Temperature

Electrical power used by trains in overcoming aerodynamic and rolling resistances degrades into heat. Within a tunnel environment, this is supplemented by heat from power losses, train air conditioning systems and tunnel services. On the Channel Tunnel, studies showed that in ultimate traffic conditions, the average level of heat generated would be 80 MW with only 10 MW conducted away through rock strata and tunnel ventilation. A cooling system was developed which removed heat from the tunnel to keep air temperatures below 25°C (77°F). Without cooling, temperatures inside tunnels could reach 50°C (122°F) after several months of operation. Water chilled to 3°C (37°F) was circulated through 2 x 400 m (1315 ft) pipes mounted to the marine running tunnel walls. Maintaining temperatures below 20°C (68°F) in the Channel Tunnel, at which no train air conditioning would be required, was considered to be impractical.

Once the aerodynamic drag and power requirements on design gradients have been calculated, the optimum operating air temperature must be established and the measures to reduce the air temperature from its heated state due to operation of the trains to the optimum temperature established. These measures can be adopted within the established free cross sectional area as space is available to include chiller pipes in the running tunnels. Associated cooling equipment will be located in niches or shafts.

There may be alternative means to cool the tunnels such as continuous ventilation and a cost benefit analysis will be carried out during the subsequent design phases.

3.2 TUNNEL DIMENSIONS BASED ON MEDICAL HEALTH CRITERIA

A preliminary assessment of required free tunnel cross sectional area and tunnel dimensions to comply with medical health criteria has been carried out in this section. The effects of aerodynamic drag and heat buildup on tunnel dimensions are complex issues and will be addressed during a detailed assessment of tunnel dimensions.

The strength of the pressure transients depends on a large number of parameters, but is chiefly proportional to train speed, and the ratio of train cross sectional area to tunnel cross sectional area (known as the Blockage Ratio).

Procedures have been developed from extensive research and development (including wind tunnel tests and large scale experimental studies) carried out by British Rail and Deutsche Bahn AG which resulted in theoretical predictions of the pressure characteristics for a given tunnel size. These procedures were formalized in UIC Guideline 779-11R “Determination of railway tunnel cross sectional areas on the basis of aerodynamic considerations.” The UIC guideline contains data curves which give Blockage Ratios based on train cross sectional areas, train speeds and tunnel lengths. The free tunnel cross sectional area can be calculated from the Blockage Ratio and the train cross sectional area.

Neither TSI nor UIC define the shape of the tunnel, only that tunnel must be of uniform cross section. It is assumed that the guidelines apply to cut-and-cover box structures as well as bored tunnels. It is recommended that this assumption is verified using the UIC software Sealtun version 2 in a later design phase.

3.2.1 Calculation of Free Tunnel Cross Sectional Area

The formula for calculating the free tunnel cross sectional area for one train operation and a train length of 400m (1312 ft) is as follows:

Tunnel free cross sectional area = Train cross sectional area / Blockage Ratio

Where:

Train cross sectional area is calculated as the projected frontal area above mid axle of the leading vehicle (see UIC 779-11 R Appendix E), and

The Blockage Ratio is obtained from the limit curves in UIC 779-11 R Appendix F, Figure 4.

3.2.1.1 Determination of Train Cross Sectional Area

TSI Infrastructure Section, clause 6.2.6.5 states

"Assessment of maximum pressure variation in the tunnel (10 kPa criterion) is to be made using the results of calculations made by the Infrastructure Manager or the contracting entity on the basis of all operational conditions with all the trains complying with the High Speed Rolling Stock TSI and intended to run in the specific tunnel to be assessed.

The input parameters to be used are to be such that the reference characteristic pressure signature of the trains (defined in High Speed Rolling Stock TSI) is fulfilled.

The reference cross section areas of the interoperable trains to be considered is to be, independently to each motor or trailer vehicle:

— 12 m^2 for vehicles designed for GC reference kinematic profile,

— 11 m^2 for vehicles designed for GB reference kinematic profile,

— 10 m^2 for vehicles designed for smaller kinematic profiles.

The assessment will take into account the construction features which reduce the pressure variation (tunnel entrance shape, shafts, etc.) if any, as well as the tunnel length."

This clause considers only TSI gauge compliant rolling stock.

Train cross-sectional areas measured from CAD drawings of the various types of high-speed rolling stock are summarized in Appendix B. Shinkansen single-level and bi-level rolling stock have the largest train cross sectional areas of the high-speed trains currently contemplated with 118 sf and 150 sf, respectively. As the Shinkansen bi-level train has the largest cross sectional area, this train was used to size the tunnels to give a conservative result. The calculations are highly sensitive to the train cross sectional area. Accordingly, calculations that are related to the cross section area of the vehicle should be verified following selection of the high-speed rolling stock.

3.2.1.2 Calculation of Blockage Ratio

The Blockage Ratio, B_{tu}, is determined from UIC 779-11R, Appendix F. The curves in these figures have been generated using computer software program Sealtun Version 2.

For one train operation, and a train length of 400m (1312 ft), Figure 4 of UIC 779-11 R Appendix F is used. This is reproduced in Appendix C.

From the curves in Appendix C the Blockage Ratio can be calculated for a given tunnel length (L_{tu}) ranging between 1 km (0.6 miles) and 10 km (6.2 miles), and train speeds (V_{tr}) of 330 kph (205 mph), 350kph (220 mph) and 400 kph (250 mph).

The critical case i.e., largest required free tunnel cross sectional area is when the Blockage Ratio is smallest for a given train speed. On the curves, this critical case is between tunnel lengths of 1 km (0.6 miles) and 3.5 km (2.2 miles) for train speeds of 400 kph (250 mph), 350 kph (220 mph), and 330 kph (205 mph) respectively. Below and above these tunnel lengths, the Blockage Ratio increases i.e., free tunnel cross-sectional area decreases.

By comparison the critical case for 100 m (328 feet) trains traveling at any speed is at a tunnel length of 480 meters (0.3 miles).

For a train length of 400m (1312ft), there are no data points for tunnels of less than 1 km (0.6 miles) and more than 10 km (6.2 miles) and there are no data points on the curve for speeds of less than 330 kph (205 mph). Lower speeds should be studied during a detailed assessment. However it is likely that there is a small reduction in tunnel diameter (less than 1 foot) for reduction in speed below 330 kph (205 mph).

It is recommended that a detailed assessment is carried out using UIC software program Sealtun Version 2 to get more data points for various speeds and tunnel lengths.

3.2.1.3 Calculation of Free Tunnel Cross Section Area

The free tunnel cross sectional areas have been calculated for the following tunnel lengths for train speeds of 400 kph (250 mph), 350 kph (220 mph) and 330 kph (205 mph) and are summarized in Appendix B:

- Less than 0.6 miles (1 km)
- 0.6 miles to 2.2 miles (1 km to 3.5 km) – This represents the critical case i.e., largest required free tunnel cross sectional area.
- Greater than 2.2 miles to 3.1 miles (3.5 km to 5 km)
- Greater than 3.1 miles to 4.7 miles (5 km to 7.5 km)
- Greater than 4.7 miles to 6.2 miles (7.5 km to 10 km)
- Greater than 6.2 miles (10 km)

An allowance of 20 sf has been added to each of these free cross sectional areas to account for fixed equipment.

3.2.2 Tunnel Geometry

3.2.2.1 Bored Tunnel

The finished bored tunnel cross sectional area is the sum of the following areas and allowances:

- Free tunnel cross sectional area as calculated above and required by the medical health criteria
- 20 sf for fixed equipment
- 6-inch allowance on diameter for construction tolerance (tunnel built too low or too small)
- 3-foot depth of invert concrete
- An escape walkway at track level (slightly raised above invert level)

These allowances have been previously described in detail in Section 2.

A drawing showing variation in tunnel diameter with speed is included in Appendix D.

Approximate finished tunnel cross sectional areas and finished tunnel diameters were calculated for the single-track circular tunnel (TBM driven) using these allowances (see spreadsheet in Appendix B).

The free tunnel cross section area was measured on CAD drawings and adjusted to correspond with the calculated free cross sectional area from the spreadsheet. The adjusted finished tunnel diameter was rounded up to the nearest six inches.

Note that the finished diameter is measured to the intrados of the tunnel permanent/final liner.

Shinkansen trains are larger (wider and taller) than the AGV and TGV trains and represent the critical case. The single-level train with the largest cross sectional area is the Shinkansen 700 at 118 sf. At a speed of 220 mph, this train requires a nominal 26'-6" finished tunnel diameter to comply with medical health criteria.

The bi-level train with the largest cross sectional area is the Shinkansen bi-level at 150 sf. The Shinkansen bi-level train requires an increase of 3 feet in finished tunnel diameter from 26'-6" to 29'-6" over the Shinkansen 700 single-level train at a train speed of 220 mph for the critical case (tunnel lengths of 0.6 miles to 2.2 miles). This is approximately the same as the difference in height between the two trains.

<u>Conclusion:</u>

The choice of single-level or bi-level (duplex) trains has a significant influence on free tunnel cross sectional area.

Recommendation:

Progress 15% design level definition of high-speed train corridors, right-of way, and environmental permitting based on largest rolling stock under consideration, i.e., the Shinkansen bi-level train.

Develop cost estimates for both single-level and bi-level trains and infrastructure unless policy direction favors one or the other.

Results

Using the largest train (the Shinkansen bi-level) for the critical case of tunnel lengths of 0.6 miles to 2.2 miles gives the following results:

1. An increase in speed from 205 mph to 220 mph requires an increase of 1' 6" in tunnel diameter, from 28'-0" to 29'-6".
2. An increase in speed from 220 mph to 250 mph requires an increase of 3'-6" feet in tunnel diameter, from 29'-6" to 33'-0" feet.

Conclusion

For tunnel lengths of 0.6 miles to 2.2 miles, it is not cost effective to design for trains speeds of 250 mph to comply with medical health criteria.

For tunnels shorter than 0.6 miles and tunnels longer than 2.2 miles, tunnel diameters can be reduced for a train speed of 220 mph while still complying with medical health criteria.

Aerodynamic performance of the train, power consumption and heat generated must be considered and may represent the critical case for longer tunnels.

3.2.2.2 Cut-and-Cover Tunnel

The finished cut-and-cover cross sectional area is the sum of the following areas and additional allowances:

- Free tunnel cross sectional area as calculated and required by medical health criteria.
- 20 sf for fixed equipment.
- 12 inch vertical construction tolerance (assuming slurry wall construction).
- 4 inch horizontal tolerance for soffit slab.
- Average 3'-2" feet depth of invert concrete.
- An escape walkway at track level (slightly raised above invert level).

These allowances are described in Section 2.

The structure gauge has a minimum fixed width of 21'-9". A width of 23'-9" has been assumed for the purposes of calculating tunnel heights at different design speeds. These heights have been shown on the directive drawings for the critical case for tunnels of 0.6 miles to 2.2 miles.

The required free tunnel cross sectional areas and design speeds are tabulated on the directive drawings. Designers then determine an appropriate width and height to suit alignment corridor and right-of-way constraints and establish efficient structural spans for the depth of construction required.

The actual free tunnel cross-sectional area was measured and adjusted to correspond with the calculated free cross sectional area from the spreadsheet. The adjusted finished tunnel height was rounded up to the nearest 6 inches.

A drawing illustrating the variation in tunnel height with speed is included in Appendix D.

3.3 MITIGATION MEASURES

Various measures that can be used to mitigate these effects, including pressure relief ducts between tunnels and airshafts between the tunnels and ground surface. These mitigation measures will be studied further as required to ensure an efficient and optimum tunnel configuration during advanced design. The effect of these mitigation measures can be modeled with UIC software.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Basic tunnel configurations for tunnels where high-speed trains are operating exclusively are included in Section 6. Train profiles drawings prepared to enable calculation of the train cross sectional areas are included in Appendix A. Key dimensions and cross sectional areas are summarized in Appendix B. Appendix C presents the UIC Medical Health Limits Blockage Ratio curves used in the preparation free space requirements. Appendix D presents cross sections for the basic bored and cut-and-cover tunnel configurations.

<u>Key findings are summarized as follows:</u>

The choice of single-level or bi-level / duplex trains has a big influence on free tunnel cross sectional area. Using the largest train (the Shinkansen Bi-level) for the critical case of tunnel lengths of 0.6 miles to 2.2 miles gives the following results:

- An increase in speed from 205 mph to 220 mph requires an increase of 1'-6" in tunnel diameter, from 28'-0" to 29'-6".
- An increase in speed from 220 mph to 250 mph requires an increase of 3' 6" feet in tunnel diameter, from 29'-6" to 33-0" feet.

For tunnel lengths of 0.6 miles to 2.2 miles, it is not cost effective to design for trains speeds of 250 mph to comply with medical health criteria.

For tunnels shorter than 0.6 miles and tunnels longer than 2.2 miles, tunnel diameters may be reduced for a train speed of 220 mph while still complying with medical health criteria.

Aerodynamic performance of the train, power consumption and heat generated must be considered and may represent the critical case for longer tunnels.

The following are recommended steps during subsequent phases of tunnel design

- The effect of aerodynamic drag and heat buildup on tunnel dimensions are more complex issues to resolve than medical health criteria and will be addressed during a detailed assessment of tunnel dimensions.
- As the information was derived from a variety of sources, it is recommended that the calculations related to train length and cross sectional are verified following selection of the high-speed rolling stock.
- Perform a detailed assessment of blockage rate calculation using UIC software program Sealtun Version 2 to obtain additional data points for different speeds and tunnel lengths.
- Rolling stock shall be sealed to levels equal to or exceeding those used on Shinkansen and ICE-3 trains.
- Develop case histories of comparable high-speed rail tunnels around the world including tunnel diameters, actual operating speeds, rolling stock sealing characteristics for single-track twin tunnel, passenger only high-speed operations.
- Study potential mitigation measures, including pressure relief ducts between tunnels and airshafts between the tunnels and ground surface to optimize tunnel dimensions. The effect of these mitigation measures can be modeled with UIC software.

5.0 SOURCE INFORMATION AND REFERENCES

1. TSI (Technical Specifications for Interoperability) for safety in Railway Tunnels in European High-Speed lines, version 20 December 2007
2. UIC Code 779-11 R, 2nd Edition, February 2005, Determination of Railway Tunnel Cross Sectional Areas on the Basis of Aerodynamic Considerations
3. GAWTHORPE R.G., Pressure Effects in Tunnels, 2000
4. THSRC Taiwan High Speed Rail Project, 2002
5. MACDONALD MOTT, The Channel Tunnel - A Designer's Perspective, 1994
6. SYSTRA, Draft TM 2.4.2 Basic Tunnel Configuration, June 2008
7. BS EN 14067:2006 Railway Applications - Aerodynamics

6.0 DESIGN MANUAL CRITERIA

6.1 BASIC TUNNEL CONFIGURATION

6.1.1 General

This document establishes approximate finished dimensions for bored and cut-and-cover tunnels in which high-speed passenger trains run exclusively, for use during 15% Design level in determining alignment corridors and right-of-way requirements, and in the development of cost estimates. The basic tunnel configuration is assumed to be twin, single-track tunnels and the rolling stock is assumed to be sealed. Tunnel shapes are circular (assumed TBM driven) for bored tunnels and rectangular for cut-and-cover tunnels. All tunnels are assumed watertight.

The basic tunnel dimensions are established to comply with the European Technical Specifications for Interoperability (TSI) requirements for a 10 kPa maximum pressure variation in tunnels and underground structures for any train complying with high-speed rolling stock criteria at the maximum permitted operating speed of 220 mph. The purpose of limiting the pressure changes is to ensure no adverse health effects or discomfort to passengers and workers; these criteria are known as medical health criteria.

A preliminary assessment of the required free tunnel cross sectional areas for different train speeds and tunnel lengths were established from data provided in UIC 779-11R "Determination of railway tunnel cross sectional areas on the basis of aerodynamic considerations." Finished tunnel dimensions are established based on the required free tunnel cross sectional areas. Detailed numerical modeling is required during advanced design and recommendations for numerical modeling are provided in the UIC code. It should be clarified that the UIC code is concerned only with the aerodynamic effects on passengers and workers hence the medical health criterion.

Various measures can be used to mitigate these effects, including pressure relief ducts between tunnels and airshafts between the tunnels and ground surface. These mitigation measures will be studied further as required to ensure an efficient and optimum tunnel configuration during advanced design.

6.1.2 Tunnel Cross Section

6.1.2.1 Determination of Train Cross Sectional Area

The Shinkansen bi-level rolling stock has the largest train cross sectional area of the high-speed trains currently contemplated and was used to determine Blockage Ratios from the UIC guideline. It is noted that the calculation is sensitive to the train cross sectional area. Accordingly, calculations that are related to the cross section area of the vehicle should be verified following selection of the high-speed rolling stock.

6.1.2.2 Calculation of Blockage Ratio

The Blockage Ratio, B_{tu}, is determined from UIC 779-11R, Appendix F.

Tunnel free cross sectional area = Train cross sectional area / Blockage Ratio

Where:

Train cross sectional area is calculated as the projected frontal area above mid axle of the leading vehicle (see UIC 779-11 R Appendix E), and

The Blockage Ratio is obtained from the limit curves in UIC 779-11 R Appendix F, Figure 4.

The curves in these figures were generated using computer software program Sealtun Version 2.

For single train operation and a train length of 1312 ft (400 m), Figure 4 of UIC 779-11 R Appendix F is used.

The Blockage Ratio can be calculated for a given tunnel length (L_{tu}) ranging between 0.6 miles (1 km) and 2.2 miles (10 km), and train speeds (V_{tr}) of 200 mph (330 kph), 220 mph (350 kph) and 250 mph (400 kph).

The critical case i.e., largest free tunnel cross sectional area is when the Blockage Ratio is smallest for a given train speed. From the UIC curves, this critical case is between tunnel lengths of 0.6 miles (1km) and 2.2 miles (10 km) for train speeds of 250 mph (400 kph) 220 mph (350 kph) and 200 mph (330 kph) respectively. Below and above this tunnel length, the Blockage Ratio increases i.e., free tunnel cross-sectional area decreases.

For comparison, the critical case for 325 ft (100 m) trains traveling at any speed is at a tunnel length of 0.3 miles. i.e., if shorter trains are used, the critical case will be at a shorter tunnel length.

6.1.2.3 Calculation of Free Tunnel Cross Section Area

The free tunnel cross sectional area have been calculated for the following tunnel lengths for train speeds of 250 mph (400 kph), 220 mph (350 kph) and 200 mph (330 kph).

- Less than 0.6 miles (1 km)
- 0.6 miles to 2.2 miles (1 km to 3.5 km)
- Greater than 2.2 miles to 3.1 miles (3.5 km to 5 km)
- Greater than 3.1 miles to 4.7 miles (5 km to 7.5 km)
- Greater than 4.7 miles to 6.2 miles (7.5 km to 10 km)
- Greater than 6.2 miles (10 km)

An allowance of 20 sf has been added to each of these free cross sectional areas to account for fixed equipment.

6.1.3 Tunnel Geometry

6.1.3.1 Bored Tunnel

The finished bored tunnel cross sectional area is the sum of the following areas and additional allowances:

- Free tunnel cross sectional area as calculated and required by the medical health criteria
- 20 sf for fixed equipment
- 6-inch allowance on diameter for construction tolerance (tunnel built too low or too small)
- 3-foot depth of invert concrete
- An escape walkway at track level (slightly raised above invert level).

The critical case is at tunnel lengths of 0.6 miles to 2.2 miles and requires a finished tunnel diameter of 29'-6".

For tunnels shorter than 0.6 miles and tunnels longer than 2.2 miles, tunnel diameters can be reduced for a train speed of 220 mph while still complying with medical health criteria.

Aerodynamic performance of the train, power consumption and heat generated must be considered and may represent the critical case for longer tunnels.

6.1.3.2 Cut-and-Cover Tunnel

The finished cut-and-cover cross sectional area is the sum of the following areas and additional allowances:

- Free tunnel cross sectional area as calculated above and required by the medical health criteria.
- 20 sf for fixed equipment.
- 12-inch vertical construction tolerance (assuming slurry wall construction).
- 4-inch horizontal tolerance for stepped invert concrete for adjustments to track grade
- Average 3'-2" depth of invert concrete.
- An escape walkway at track level (slightly raised above invert level).

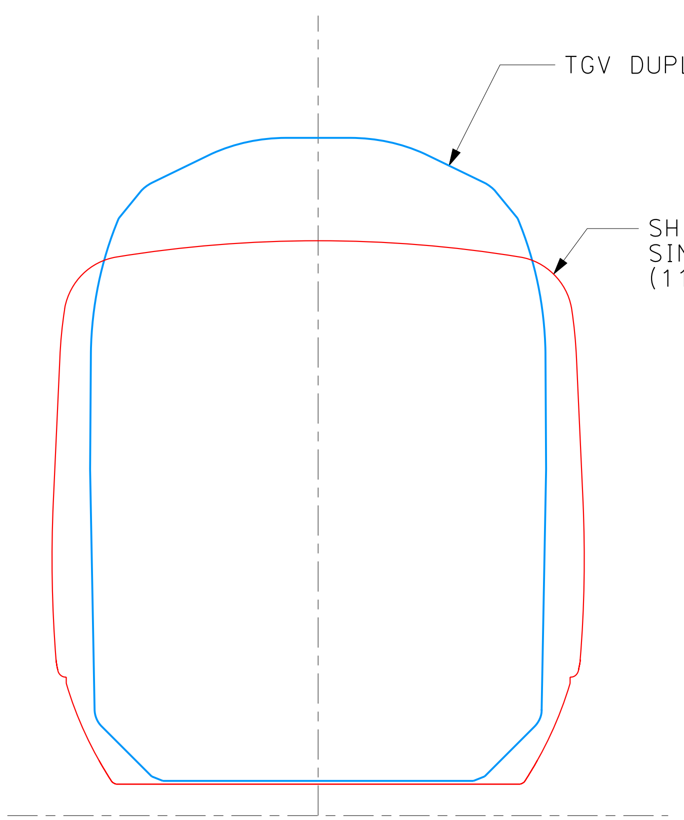
The structure gauge has a minimum fixed width of 21'-9". A width of 23'-9" has been assumed for the purposes of calculating tunnel heights at different design speeds. These heights have been shown on the directive drawings for the critical case for tunnel lengths of 0.6 miles to 2.2 miles.

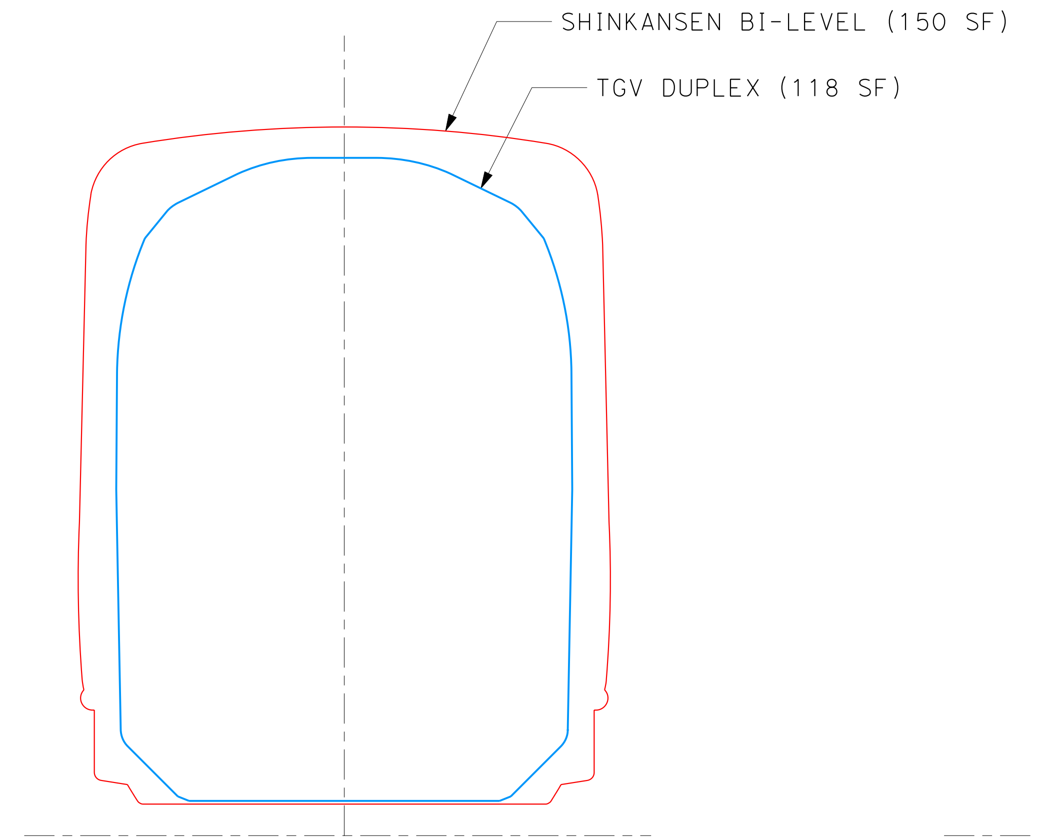
The required free tunnel cross sectional areas and design speeds are tabulated on the directive drawings. Designers determine an appropriate width and height to suit alignment corridor and right-of-way constraints and determine efficient structural spans for the depth of construction required.

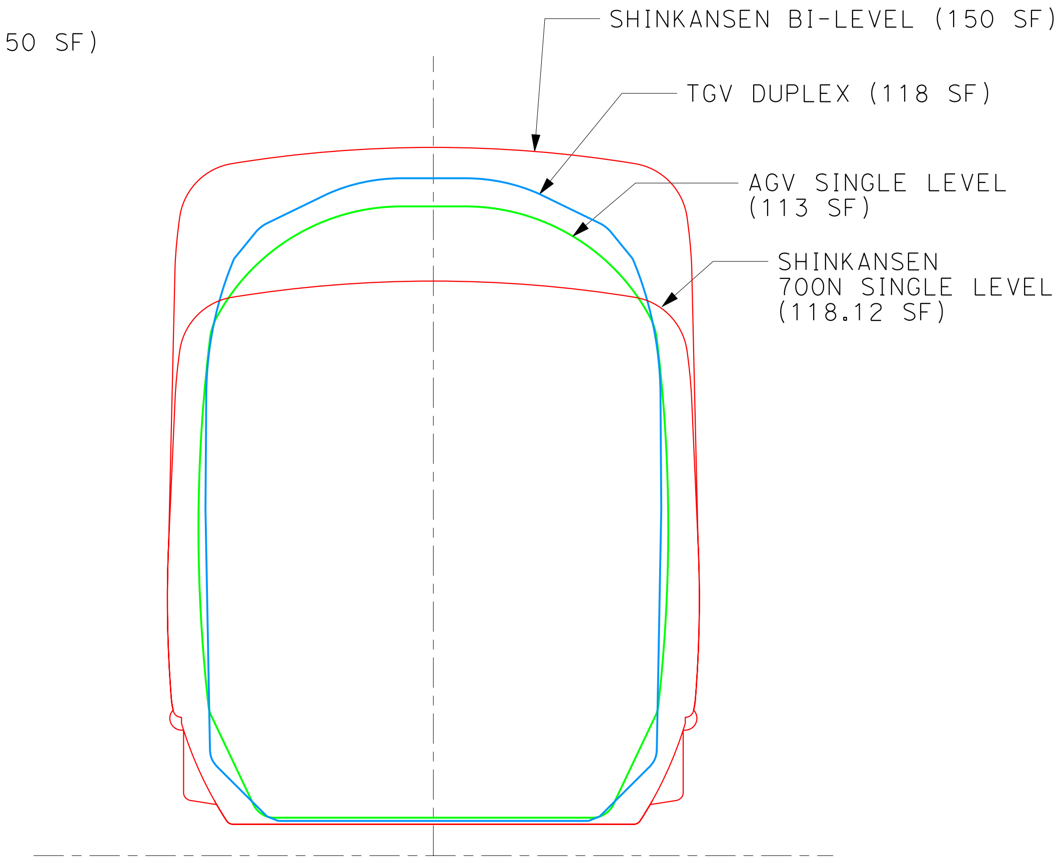
The actual free tunnel cross-sectional area was measured and adjusted to correspond with the calculated free cross sectional area from the spreadsheet. The adjusted finished tunnel height was rounded up to the nearest six inches.

Basic tunnel cross sections are presented in Appendix D.

APPENDIX A – REPRESENTATIVE TRAIN PROFILES







NOTES:

DETAILS ARE NOT DRAWN TO BE EXACT.

THE DRAWING IS ONLY USED FOR THE TUNNEL CROSS SECTIONAL AREA CALCULATIONS.

2 0 2 4

1/2"=1'-0"

REV	DATE	BY	CHK	APP	DESCRIPTION

DESIGNED BY J. THOMPSON
DRAWN BY P. DO
CHECKED BY J. CHIRCO
IN CHARGE J. CHIRCO
DATE 06-12-09

CALIFORNIA HIGH-SPEED RAIL AUTHORITY
FLYCALIFORNIA
Without ever leaving the ground.

CALIFORNIA HIGH-SPEED TRAIN PROJECT

TM 2.4.2 BASIC TUNNEL CONFIGURATION
COMPARISON OF HIGH SPEED ROLLING STOCK
CROSS-SECTIONAL AREAS

CONTRACT NO. 13259
DRAWING NO. -
SCALE AS SHOWN
SHEET NO.

APPENDIX B – MEDICAL HEALTH LIMITS CALCULATIONS

Appendix B - Table 1

Calculations for Bored Tunnel Free Cross Sectional Areas
based on Medical Health Criteria for Design Speed of 250 mph (400 kph)

Tunnel Length miles	Km	Train Type	Train profile Height	width	Approx C/S Area	Approx. C/S Area	CAD Calculation	from CAD Cal	Blockage Ratio	Tunnel Free C/S Area	Invert Concrete Estimated C/S Area	Walkway Concrete estimated C/S Area	Fixed Equipment Allowance	Total Free Area Required	Approx Total Tunnel C/S Area	Approx Theoretic Tunnel Radius	Approx Theoretical Tunnel Diameter	6" Construct Tolerance Allowance	Adjusted Tunnel Diameter	Adjusted Tunnel C/S Area	Equivalent Constructio Tolerance C/S Area	Constructio Tolerance equivalent Free CS Are	Suggeste Free C/S Tunnel C/S Area	Approx Required Finished Tunnel Diameter	CAD Adjusted Finished Tunnel Diameter
			m	m	m2	ft2	ft2	m2		ft2	ft2	ft2	ft2	ft2	ft2	ft	ft	ft	ft	ft2	ft2	ft2	ft2	ft2	ft2
<0.6 Miles	**<1 km**																								
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**0.215**	698	36	15	20	718	769	15.65	31.29	0.50	31.79	793.44	24.76	19.76	737.44	31.79	32.00
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**0.215**	549	36	15	20	569	620	14.06	28.11	0.50	28.61	642.68	22.26	17.26	586.68	28.61	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**0.215**	549	36	15	20	569	620	14.05	28.10	0.50	28.60	642.09	22.25	17.25	586.09	28.60	
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**0.215**	526	36	15	20	546	597	13.78	27.57	0.50	28.07	618.42	21.84	16.84	562.42	28.07	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**0.215**	506	36	15	20	526	577	13.56	27.12	0.50	27.62	598.72	21.48	16.48	542.72	27.62	
0.6m to 2.2m	**1 km to 3.5 km**																								
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**0.200**	750	36	15	20	770	821	16.17	32.34	0.50	32.84	846.58	25.58	20.58	790.58	32.84	33.00
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**0.200**	591	36	15	20	611	662	14.52	29.03	0.50	29.53	684.60	22.99	17.99	628.60	29.53	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**0.200**	590	36	15	20	610	661	14.51	29.02	0.50	29.52	683.98	22.98	17.98	627.98	29.52	
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**0.200**	565	36	15	20	585	636	14.23	28.46	0.50	28.96	658.54	22.54	17.54	602.54	28.96	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**0.200**	544	36	15	20	564	615	14.00	27.99	0.50	28.49	637.38	22.17	17.17	581.38	28.49	
>2.2m to 3.1m	**>3.5 km to 5 km**																								
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**0.215**	698	36	15	20	718	769	15.65	31.29	0.50	31.79	793.44	24.76	19.76	737.44	31.79	31.50
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**0.215**	549	36	15	20	569	620	14.06	28.11	0.50	28.61	642.68	22.26	17.26	586.68	28.61	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**0.215**	549	36	15	20	569	620	14.05	28.10	0.50	28.60	642.09	22.25	17.25	586.09	28.60	
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**0.215**	526	36	15	20	546	597	13.78	27.57	0.50	28.07	618.42	21.84	16.84	562.42	28.07	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**0.215**	506	36	15	20	526	577	13.56	27.12	0.50	27.62	598.72	21.48	16.48	542.72	27.62	
>3.1m to 4.7m	**>5 km to 7.5 km**																								
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**0.228**	659	36	15	20	679	730	15.25	30.50	0.50	31.00	754.48	24.14	19.14	698.48	31.00	31.00
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**0.228**	519	36	15	20	539	590	13.71	27.42	0.50	27.92	611.94	21.72	16.72	555.94	27.92	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**0.228**	519	36	15	20	539	590	13.70	27.41	0.50	27.91	611.39	21.71	16.71	555.39	27.91	
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**0.228**	497	36	15	20	517	568	13.45	26.89	0.50	27.39	589.01	21.31	16.31	533.01	27.39	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**0.228**	478	36	15	20	498	549	13.23	26.46	0.50	26.96	570.38	20.96	15.96	514.38	26.96	
>4.7m to 6.2m	**>7.5 km to 10 km**																								
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**0.250**	600	36	15	20	620	671	14.62	29.24	0.50	29.74	694.15	23.15	18.15	638.15	29.74	30.00
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**0.250**	472	36	15	20	492	543	13.16	26.31	0.50	26.81	564.35	20.85	15.85	508.35	26.81	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**0.250**	472	36	15	20	492	543	13.15	26.30	0.50	26.80	563.84	20.84	15.84	507.84	26.80	
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**0.250**	452	36	15	20	472	523	12.91	25.81	0.50	26.31	543.46	20.46	15.46	487.46	26.31	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**0.250**	435	36	15	20	455	506	12.70	25.40	0.50	25.90	526.50	20.13	15.13	470.50	25.90	
>6.2m	**>10 km**																								
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**0.270**	556	36	15	20	576	627	14.13	28.25	0.50	28.75	648.93	22.37	17.37	592.93	28.75	28.50
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**0.270**	437	36	15	20	457	508	12.73	25.45	0.50	25.95	528.67	20.18	15.18	472.67	25.95	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**0.270**	437	36	15	20	457	508	12.72	25.44	0.50	25.94	528.20	20.17	15.17	472.20	25.94	
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**0.270**	419	36	15	20	439	490	12.49	24.97	0.50	25.47	509.32	19.80	14.80	453.32	25.47	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**0.270**	403	36	15	20	423	474	12.29	24.58	0.50	25.08	493.60	19.49	14.49	437.60	25.08	

Appendix B - Table 2

Calculations for Bored Tunnel Free Cross Sectional Areas
based on Medical Health Criteria for Design Speed of 220 mph (350 kph)

Tunnel Length miles	Km	Train Type	Train profile Height	width	Approx C/S Area	Approx. C/S Area	CAD Calculation	from CAD Cal	Blockage Ratio	Tunnel Free C/S Area	Invert Concrete Estimated C/S Area	Walkway Concrete estimated C/S Area	Fixed Equipment Allowance	Minimum Total Free Area Required	Approx Total Tunnel C/S Area	Approx Theoreti Tunnel Radius	Approx Theoretical Tunnel Diameter	6" Construct Tolerance Allowance	Adjusted Tunnel Diameter	Adjusted Tunnel C/S Area	Equivalent Construct Tolerance C/S Area	Construct Tolerance equivalen Free CS A	Suggested Free C/S Tunnel C/S Area	Approx Required Finished Tunnel Diameter	CAD Adjusted Finished Tunnel Diameter
			m	m	m2	ft2	ft2	m2		ft2	ft2	ft2	ft2	ft2	ft2	ft	ft	ft	ft	ft2	ft2	ft2	ft2	ft2	ft2
<0.6 Miles	**<1 km**																								
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**0.270**	556	36	15	20	576	627	14.13	28.25	0.50	28.75	648.93	22.37	17.37	592.93	28.75	28.50
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**0.270**	437	36	15	20	457	508	12.73	25.45	0.50	25.95	528.67	20.18	15.18	472.67	25.95	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**0.270**	437	36	15	20	457	508	12.72	25.44	0.50	25.94	528.20	20.17	15.17	472.20	25.94	
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**0.270**	419	36	15	20	439	490	12.49	24.97	0.50	25.47	509.32	19.80	14.80	453.32	25.47	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**0.270**	403	36	15	20	423	474	12.29	24.58	0.50	25.08	493.60	19.49	14.49	437.60	25.08	
0.6m to 2.2m	**1 km to 3.5 km**																								
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**0.260**	577	36	15	20	597	648	14.36	28.73	0.50	29.23	670.67	22.75	17.75	614.67	29.23	29.50
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**0.260**	454	36	15	20	474	525	12.93	25.87	0.50	26.37	545.82	20.50	15.50	489.82	26.37	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**0.260**	454	36	15	20	474	525	12.93	25.86	0.50	26.36	545.34	20.49	15.49	489.34	26.36	
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**0.260**	435	36	15	20	455	506	12.69	25.38	0.50	25.88	525.73	20.12	15.12	469.73	25.88	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**0.260**	419	36	15	20	439	490	12.49	24.97	0.50	25.47	509.42	19.80	14.80	453.42	25.47	
>2.2m to 3.1m	**>3.5 km to 5 km**																								
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**0.275**	545	36	15	20	565	616	14.01	28.02	0.50	28.52	638.65	22.19	17.19	582.65	28.52	28.50
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**0.275**	430	36	15	20	450	501	12.63	25.25	0.50	25.75	520.56	20.02	15.02	464.56	25.75	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**0.275**	429	36	15	20	449	500	12.62	25.24	0.50	25.74	520.10	20.01	15.01	464.10	25.74	
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**0.275**	411	36	15	20	431	482	12.39	24.78	0.50	25.28	501.56	19.65	14.65	445.56	25.28	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**0.275**	396	36	15	20	416	467	12.19	24.39	0.50	24.89	486.12	19.34	14.34	430.12	24.89	
>3.1m to 4.7m	**>5 km to 7.5 km**																								
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**0.290**	517	36	15	20	537	588	13.69	27.37	0.50	27.87	609.93	21.69	16.69	553.93	27.87	28.00
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**0.290**	407	36	15	20	427	478	12.34	24.68	0.50	25.18	497.90	19.57	14.57	441.90	25.18	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**0.290**	407	36	15	20	427	478	12.34	24.67	0.50	25.17	497.46	19.57	14.57	441.46	25.17	
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**0.290**	390	36	15	20	410	461	12.11	24.22	0.50	24.72	479.87	19.21	14.21	423.87	24.72	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**0.290**	375	36	15	20	395	446	11.92	23.84	0.50	24.34	465.23	18.91	13.91	409.23	24.34	
>4.7m to 6.2m	**>7.5 km to 10 km**																								
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**no data**																28.00
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**no data**																
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**no data**																
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**no data**																
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**no data**																
>6.2m	**>10 km**																								
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**no data**																28.00
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**no data**																
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**no data**																
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**no data**																
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**no data**																

Appendix B - Table 3

Calculations for Bored Tunnel Free Cross Sectional Areas)
based on Medical Health Criteria for Design Speed of 205 mph (330 kph)

Tunnel Length miles	Km	Train Type	Train profile Height	width	Approx C/S Area	Approx. C/S Area	CAD Calculation	from CAD Cal	Blockage Ratio	Tunnel Free C/S Area	Invert Concrete Estimated C/S Area	Walkway Concrete estimated C/S Area	Fixed Equipment Allowance	Total Free Area Required	Approx Total Tunnel C/S Area	Approx Theoreti Tunnel Radius	Approx Theoretical Tunnel Diameter	6" Construct Tolerance Allowance	Adjusted Tunnel Diameter	Adjusted Tunnel C/S Area	Equivalent Construct Tolerance C/S Area	Construct Tolerance equivalen Free CS A	Suggested Free C/S Tunnel C/S Area	Approx Required Finished Tunnel Diameter	CAD Adjusted Finished Tunnel Diameter
			m	m	m2	ft2	ft2	m2		ft2	ft2	ft2	ft2	ft2	ft2	ft	ft	ft	ft	ft2	ft2	ft2	ft2	ft2	ft2
<0.6 Miles	**<1 km**																								
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**0.294**	510	36	15	20	530	581	13.61	27.21	0.50	27.71	602.76	21.56	16.56	546.76	27.71	28.00
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**0.294**	402	36	15	20	422	473	12.27	24.54	0.50	25.04	492.24	19.46	14.46	436.24	25.04	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**0.294**	401	36	15	20	421	472	12.27	24.53	0.50	25.03	491.81	19.45	14.45	435.81	25.03	
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**0.294**	384	36	15	20	404	455	12.04	24.08	0.50	24.58	474.46	19.10	14.10	418.46	24.58	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**0.294**	370	36	15	20	390	441	11.85	23.71	0.50	24.21	460.01	18.81	13.81	404.01	24.21	
0.6m to 2.2m	**1 km to 3.5 km**																								
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**0.294**	510	36	15	20	530	581	13.61	27.21	0.50	27.71	602.76	21.56	16.56	546.76	27.71	28.00
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**0.294**	402	36	15	20	422	473	12.27	24.54	0.50	25.04	492.24	19.46	14.46	436.24	25.04	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**0.294**	401	36	15	20	421	472	12.27	24.53	0.50	25.03	491.81	19.45	14.45	435.81	25.03	
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**0.294**	384	36	15	20	404	455	12.04	24.08	0.50	24.58	474.46	19.10	14.10	418.46	24.58	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**0.294**	370	36	15	20	390	441	11.85	23.71	0.50	24.21	460.01	18.81	13.81	404.01	24.21	

Appendix B - Table 4

Matrix of Minimum Free Tunnel Cross-sectional Areas for Bored Tunnels

Bored Tunnel Minimum Free Tunnel C/S Area (ft^2)		Tunnel Length (miles)					
		< 0.6	**0.6 to 2.2**	**> 2.2 to 3.1**	**> 3.1 to 4.7**	**> 4.7 to 6.2**	**> 6.2**
Design Speed (mph)	**250**	737	**791**	737	698	638	593
	220	593	**615**	583	554	554	554
	205	547	**547**	547	547	547	547

Appendix B - Table 5

Calculations for Cut and Cover Tunnel Free Cross Sectional Areas based on Medical Health Criteria for Design Speed of 250 mph (400 kph)

Tunnel Length miles	Km	Train Type	Train profile Height	width	Approx C/S Area	Approx. C/S Area	CAD Calculation	from CAD Cal	Blockage Ratio	Tunnel Free C/S Area	Fixed Equipment Allowance	Total Free Area Required	Structure gauge width	Horizonta Construc Tolerance 12"	Minimum width	Free Height	Soffit Construc Tolerance 4"	free Adjusted soffit height	free area incl tolerance	Invert Concrete Estimated C/S Area	Walkway Concrete estimated C/S Area	Corner concrete	Concrete total	total box C/S area	total box height	Equivalent Construction Tolerance C/S Area	CAD Adjusted Finished Tunnel Height
			m	m	m2	ft2	ft2	m2		ft2	ft2	ft2	ft	ft	ft	ft	ft	ft	ft2	ft2	ft2	ft2	ft2	ft2	ft	ft2	ft
<0.6 Miles	<1 km																										
		Shinkansen Bi Level	4.50	3.40	15.30		150.00	13.93	0.215	698	20	718	22.75	1.00	23.75	31.55	0.25	31.80	755.16	72.8	12.5	9	94.3	849.46	35.77	41.70	36.00
		Shinkansen 700T (Single level)	3.60	3.36	12.10		118.12	10.97	0.215	549	20	569	22.75	1.00	23.75	25.03	0.25	25.28	600.38	72.8	12.5	9	94.3	694.68	29.25	35.19	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		118.00	10.96	0.215	549	20	569	22.75	1.00	23.75	25.00	0.25	25.25	599.78	72.8	12.5	9	94.3	694.08	29.22	35.16	
		AGV Prototype (Single Level)	4.13	3.00	12.38		113.00	10.49	0.215	526	20	546	22.75	1.00	23.75	23.98	0.25	24.23	575.50	72.8	12.5	9	94.3	669.80	28.20	34.14	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	no profile available		0.215	506	20	526	22.75	1.00	23.75	23.13	0.25	23.38	555.30	72.8	12.5	9	94.3	649.60	27.35	33.29	
0.6m to 2.2m	1 km to 3.5 km																										
		Shinkansen Bi Level	4.50	3.40	15.30		150.00	13.93	0.200	750	20	770	22.75	1.00	23.75	33.85	0.25	34.10	809.78	72.8	12.5	9	94.3	904.08	38.07	44.00	38.50
		Shinkansen 700T (Single level)	3.60	3.36	12.10		118.12	10.97	0.200	591	20	611	22.75	1.00	23.75	26.84	0.25	27.09	643.39	72.8	12.5	9	94.3	737.69	31.06	37.00	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		118.00	10.96	0.200	590	20	610	22.75	1.00	23.75	26.81	0.25	27.06	642.75	72.8	12.5	9	94.3	737.05	31.03	36.97	
		AGV Prototype (Single Level)	4.13	3.00	12.38		113.00	10.49	0.200	565	20	585	22.75	1.00	23.75	25.71	0.25	25.96	616.65	72.8	12.5	9	94.3	710.95	29.93	35.87	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	no profile available		0.200	544	20	564	22.75	1.00	23.75	24.80	0.25	25.05	594.94	72.8	12.5	9	94.3	689.24	29.02	34.96	
>2.2m to 3.1m	>3.5 km to 5 km																										
		Shinkansen Bi Level	4.50	3.40	15.30		150.00	13.93	0.215	698	20	718	22.75	1.00	23.75	31.55	0.25	31.80	755.16	72.8	12.5	9	94.3	849.46	35.77	41.70	36.00
		Shinkansen 700T (Single level)	3.60	3.36	12.10		118.12	10.97	0.215	549	20	569	22.75	1.00	23.75	25.03	0.25	25.28	600.38	72.8	12.5	9	94.3	694.68	29.25	35.19	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		118.00	10.96	0.215	549	20	569	22.75	1.00	23.75	25.00	0.25	25.25	599.78	72.8	12.5	9	94.3	694.08	29.22	35.16	
		AGV Prototype (Single Level)	4.13	3.00	12.38		113.00	10.49	0.215	526	20	546	22.75	1.00	23.75	23.98	0.25	24.23	575.50	72.8	12.5	9	94.3	669.80	28.20	34.14	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	no profile available		0.215	506	20	526	22.75	1.00	23.75	23.13	0.25	23.38	555.30	72.8	12.5	9	94.3	649.60	27.35	33.29	
>3.1m to 4.7m	>5 km to 7.5 km																										
		Shinkansen Bi Level	4.50	3.40	15.30		150.00	13.93	0.228	659	20	679	22.75	1.00	23.75	29.86	0.25	30.11	715.14	72.8	12.5	9	94.3	809.44	34.08	40.02	34.50
		Shinkansen 700T (Single level)	3.60	3.36	12.10		118.12	10.97	0.228	519	20	539	22.75	1.00	23.75	23.70	0.25	23.95	568.86	72.8	12.5	9	94.3	663.16	27.92	33.86	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		118.00	10.96	0.228	519	20	539	22.75	1.00	23.75	23.68	0.25	23.93	568.30	72.8	12.5	9	94.3	662.60	27.90	33.84	
		AGV Prototype (Single Level)	4.13	3.00	12.38		113.00	10.49	0.228	497	20	517	22.75	1.00	23.75	22.71	0.25	22.96	545.35	72.8	12.5	9	94.3	639.65	26.93	32.87	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	no profile available		0.228	478	20	498	22.75	1.00	23.75	21.91	0.25	22.16	526.27	72.8	12.5	9	94.3	620.57	26.13	32.07	
>4.7m to 6.2m	>7.5 km to 10 km																										
		Shinkansen Bi Level	4.50	3.40	15.30		150.00	13.93	0.250	600	20	620	22.75	1.00	23.75	27.25	0.25	27.50	653.19	72.8	12.5	9	94.3	747.49	31.47	37.41	32.00
		Shinkansen 700T (Single level)	3.60	3.36	12.10		118.12	10.97	0.250	472	20	492	22.75	1.00	23.75	21.65	0.25	21.90	520.08	72.8	12.5	9	94.3	614.38	25.87	31.81	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		118.00	10.96	0.250	472	20	492	22.75	1.00	23.75	21.63	0.25	21.88	519.56	72.8	12.5	9	94.3	613.86	25.85	31.78	
		AGV Prototype (Single Level)	4.13	3.00	12.38		113.00	10.49	0.250	452	20	472	22.75	1.00	23.75	20.75	0.25	21.00	498.68	72.8	12.5	9	94.3	592.98	24.97	30.91	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	no profile available		0.250	435	20	455	22.75	1.00	23.75	20.02	0.25	20.27	481.32	72.8	12.5	9	94.3	575.62	24.24	30.17	
>6.2m	>10 km																										
		Shinkansen Bi Level	4.50	3.40	15.30		150.00	13.93	0.270	556	20	576	22.75	1.00	23.75	25.30	0.25	25.55	606.79	72.8	12.5	9	94.3	701.09	29.52	35.46	31.00
		Shinkansen 700T (Single level)	3.60	3.36	12.10		118.12	10.97	0.270	437	20	457	22.75	1.00	23.75	20.11	0.25	20.36	483.54	72.8	12.5	9	94.3	577.84	24.33	30.27	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		118.00	10.96	0.270	437	20	457	22.75	1.00	23.75	20.09	0.25	20.34	483.06	72.8	12.5	9	94.3	577.36	24.31	30.25	
		AGV Prototype (Single Level)	4.13	3.00	12.38		113.00	10.49	0.270	419	20	439	22.75	1.00	23.75	19.28	0.25	19.53	463.73	72.8	12.5	9	94.3	558.03	23.50	29.43	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	no profile available		0.270	403	20	423	22.75	1.00	23.75	18.60	0.25	18.85	447.65	72.8	12.5	9	94.3	541.95	22.82	28.76	

Appendix B - Table 6

Calculations for Cut and Cover Tunnel Free Cross Sectional Areas
based on Medical Health Criteria for Design Speed of 220 mph (350 kph)

Tunnel Length miles	Km	Train Type	Train profile Height	width	Approx C/S Area	Approx. C/S Area	CAD Calculation	from CAD Cal	Blockage Ratio	Tunnel Free C/S Area	Fixed Equipment Allowance	Total Free Area Required	Structure gauge width	Horizonta Construc Tolerance 12"	Minimum width	Free Height	Soffit Construc Tolerance 4"	free Adjusted soffit height	free area incl tolerance	Invert Concrete Estimated C/S Area	Walkway Concrete estimated C/S Area	Corner concrete	Concrete total	total box C/S area	total box height	Equivalent Constructior Tolerance C/S Area	CAD Adjusted Finished Tunnel Height
			m	m	m2	ft2	ft2	m2		ft2	ft2	ft2	ft	ft	ft	ft	ft	ft	ft2	ft2	ft2	ft2	ft2	ft2	ft	ft2	ft2
<0.6 Miles	**<1 km**																										
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**0.270**	556	20	576	22.75	1.00	23.75	25.30	0.25	25.55	606.79	72.8	12.5	9	94.3	701.09	29.52	35.46	29.50
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**0.270**	437	20	457	22.75	1.00	23.75	20.11	0.25	20.36	483.54	72.8	12.5	9	94.3	577.84	24.33	30.27	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**0.270**	437	20	457	22.75	1.00	23.75	20.09	0.25	20.34	483.06	72.8	12.5	9	94.3	577.36	24.31	30.25	
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**0.270**	419	20	439	22.75	1.00	23.75	19.28	0.25	19.53	463.73	72.8	12.5	9	94.3	558.03	23.50	29.43	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**0.270**	403	20	423	22.75	1.00	23.75	18.60	0.25	18.85	447.65	72.8	12.5	9	94.3	541.95	22.82	28.76	
0.6m to 2.2m	**1 km to 3.5 km**																										
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**0.260**	577	20	597	22.75	1.00	23.75	26.24	0.25	26.49	629.10	72.8	12.5	9	94.3	723.40	30.46	36.40	30.50
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**0.260**	454	20	474	22.75	1.00	23.75	20.85	0.25	21.10	501.11	72.8	12.5	9	94.3	595.41	25.07	31.01	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**0.260**	454	20	474	22.75	1.00	23.75	20.83	0.25	21.08	500.61	72.8	12.5	9	94.3	594.91	25.05	30.99	
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**0.260**	435	20	455	22.75	1.00	23.75	19.98	0.25	20.23	480.54	72.8	12.5	9	94.3	574.84	24.20	30.14	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**0.260**	419	20	439	22.75	1.00	23.75	19.28	0.25	19.53	463.84	72.8	12.5	9	94.3	558.14	23.50	29.44	
>2.2m to 3.1m	**>3.5 km to 5 km**																										
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**0.275**	545	20	565	22.75	1.00	23.75	24.86	0.25	25.11	596.25	72.8	12.5	9	94.3	690.55	29.08	35.01	29.50
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**0.275**	430	20	450	22.75	1.00	23.75	19.76	0.25	20.01	475.24	72.8	12.5	9	94.3	569.54	23.98	29.92	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**0.275**	429	20	449	22.75	1.00	23.75	19.74	0.25	19.99	474.77	72.8	12.5	9	94.3	569.07	23.96	29.90	
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**0.275**	411	20	431	22.75	1.00	23.75	18.94	0.25	19.19	455.79	72.8	12.5	9	94.3	550.09	23.16	29.10	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**0.275**	396	20	416	22.75	1.00	23.75	18.28	0.25	18.53	440.00	72.8	12.5	9	94.3	534.30	22.50	28.43	
>3.1m to 4.7m	**>5 km to 7.5 km**																										
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**0.290**	517	20	537	22.75	1.00	23.75	23.62	0.25	23.87	566.79	72.8	12.5	9	94.3	661.09	27.84	33.77	28.50
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**0.290**	407	20	427	22.75	1.00	23.75	18.78	0.25	19.03	452.04	72.8	12.5	9	94.3	546.34	23.00	28.94	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**0.290**	407	20	427	22.75	1.00	23.75	18.76	0.25	19.01	451.60	72.8	12.5	9	94.3	545.90	22.99	28.92	
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**0.290**	390	20	410	22.75	1.00	23.75	18.01	0.25	18.26	433.60	72.8	12.5	9	94.3	527.90	22.23	28.16	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**0.290**	375	20	395	22.75	1.00	23.75	17.38	0.25	17.63	418.63	72.8	12.5	9	94.3	512.93	21.60	27.53	
>4.7m to 6.2m	**>7.5 km to 10 km**																										
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**no data**																		28.50
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**no data**																		
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**no data**																		
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**no data**																		
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**no data**																		
>6.2m	**>10 km**																										
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**no data**																		28.50
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**no data**																		
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**no data**																		
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**no data**																		
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**no data**																		

Appendix B - Table 7

Calculations for Cut and Cover Tunnel Free Cross Sectional Areas
based on Medical Health Criteria for Design Speed of 205 mph (330 kph)

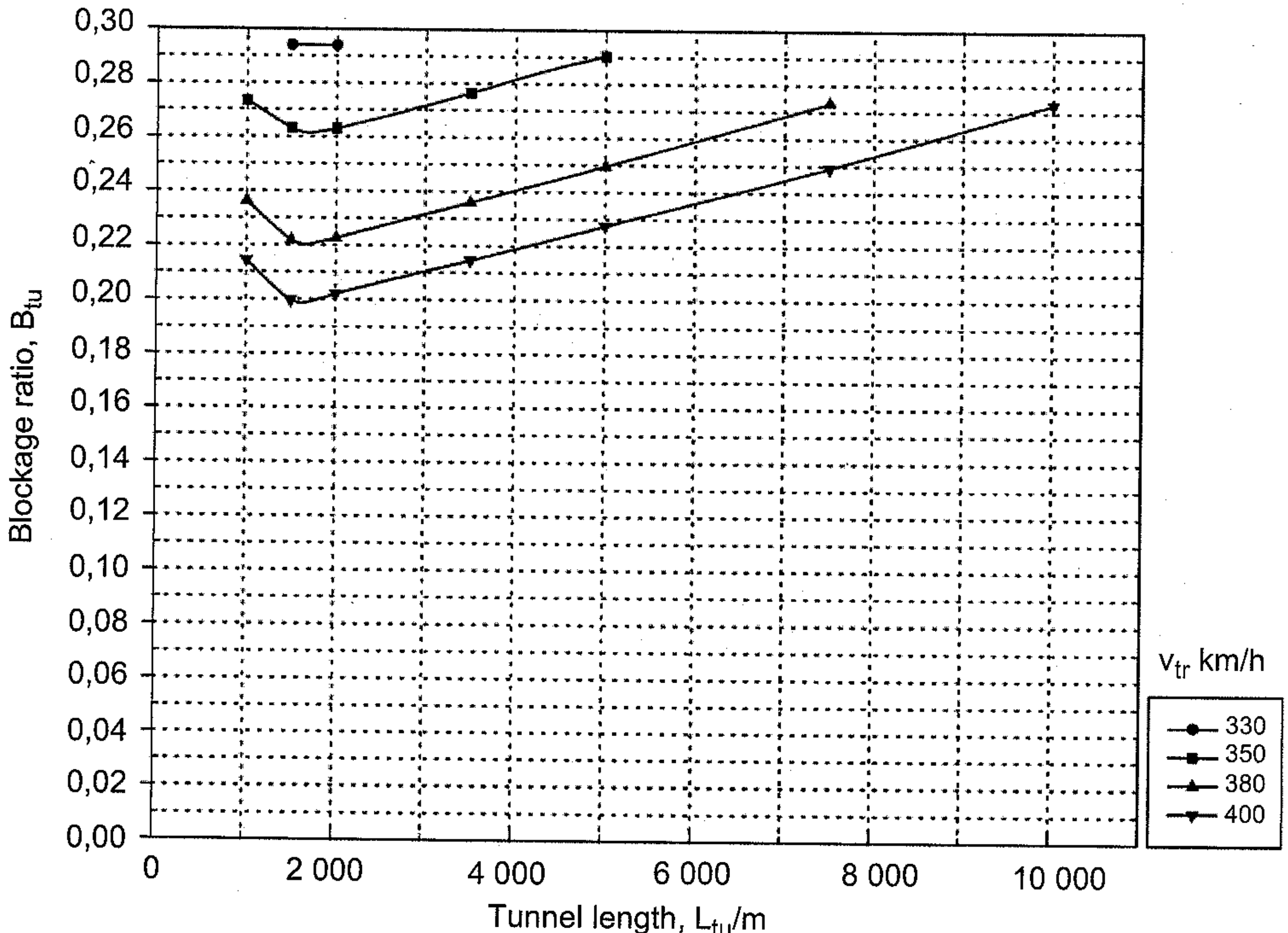
Tunnel Length miles	Km	Train Type	Train profile Height	width	Approx C/S Area	Approx. C/S Area	CAD Calculation	from CAD Cal	Blockage Ratio	Tunnel Free C/S Area	Fixed Equipment Allowance	Total Free Area Required	Structure gauge width	Horizontal Construc Tolerance 12"	Minimum width	Free Height	Soffit Construc Tolerance 4"	free Adjusted soffit height	free area incl tolerance	Invert Concrete Estimated C/S Area	Walkway Concrete estimated C/S Area	Corner concrete	Concrete total	total box C/S area	total box height	Equivalent Construction Tolerance C/S Area	CAD Adjusted Finished Tunnel Height
			m	m	m2	ft2	ft2	m2		ft2	ft2	ft2	ft	ft	ft	ft	ft	ft	ft2	ft2	ft2	ft2	ft2	ft2	ft	ft2	ft2
<0.6 Miles	**<1 km**																										
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**0.294**	510	20	530	22.75	1.00	23.75	23.31	0.25	23.56	559.45	72.8	12.5	9	94.3	653.75	27.53	33.46	28.00
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**0.294**	402	20	422	22.75	1.00	23.75	18.54	0.25	18.79	446.26	72.8	12.5	9	94.3	540.56	22.76	28.70	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**0.294**	401	20	421	22.75	1.00	23.75	18.52	0.25	18.77	445.82	72.8	12.5	9	94.3	540.12	22.74	28.68	
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**0.294**	384	20	404	22.75	1.00	23.75	17.77	0.25	18.02	428.07	72.8	12.5	9	94.3	522.37	21.99	27.93	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**0.294**	370	20	390	22.75	1.00	23.75	17.15	0.25	17.40	413.30	72.8	12.5	9	94.3	507.60	21.37	27.31	
0.6m to 2.2m	**1 km to 3.5 km**																										
		Shinkansen Bi Level	4.50	3.40	15.30		**150.00**	**13.93**	**0.294**	510	20	530	22.75	1.00	23.75	23.31	0.25	23.56	559.45	72.8	12.5	9	94.3	653.75	27.53	33.46	28.00
		Shinkansen 700T (Single level)	3.60	3.36	12.10		**118.12**	**10.97**	**0.294**	402	20	422	22.75	1.00	23.75	18.54	0.25	18.79	446.26	72.8	12.5	9	94.3	540.56	22.76	28.70	
		TGV Duplex (RGV2N2)	4.30	2.91	12.52		**118.00**	**10.96**	**0.294**	401	20	421	22.75	1.00	23.75	18.52	0.25	18.77	445.82	72.8	12.5	9	94.3	540.12	22.74	28.68	
		AGV Prototype (Single Level)	4.13	3.00	12.38		**113.00**	**10.49**	**0.294**	384	20	404	22.75	1.00	23.75	17.77	0.25	18.02	428.07	72.8	12.5	9	94.3	522.37	21.99	27.93	
		TGV Atlantic (Single Level)	3.48	2.90	10.11	108.84	**no profile available**		**0.294**	370	20	390	22.75	1.00	23.75	17.15	0.25	17.40	413.30	72.8	12.5	9	94.3	507.60	21.37	27.31	

Appendix B - Table 8

Matrix of Minimum Free Tunnel Cross-sectional Areas for Cut and Cover Tunnels

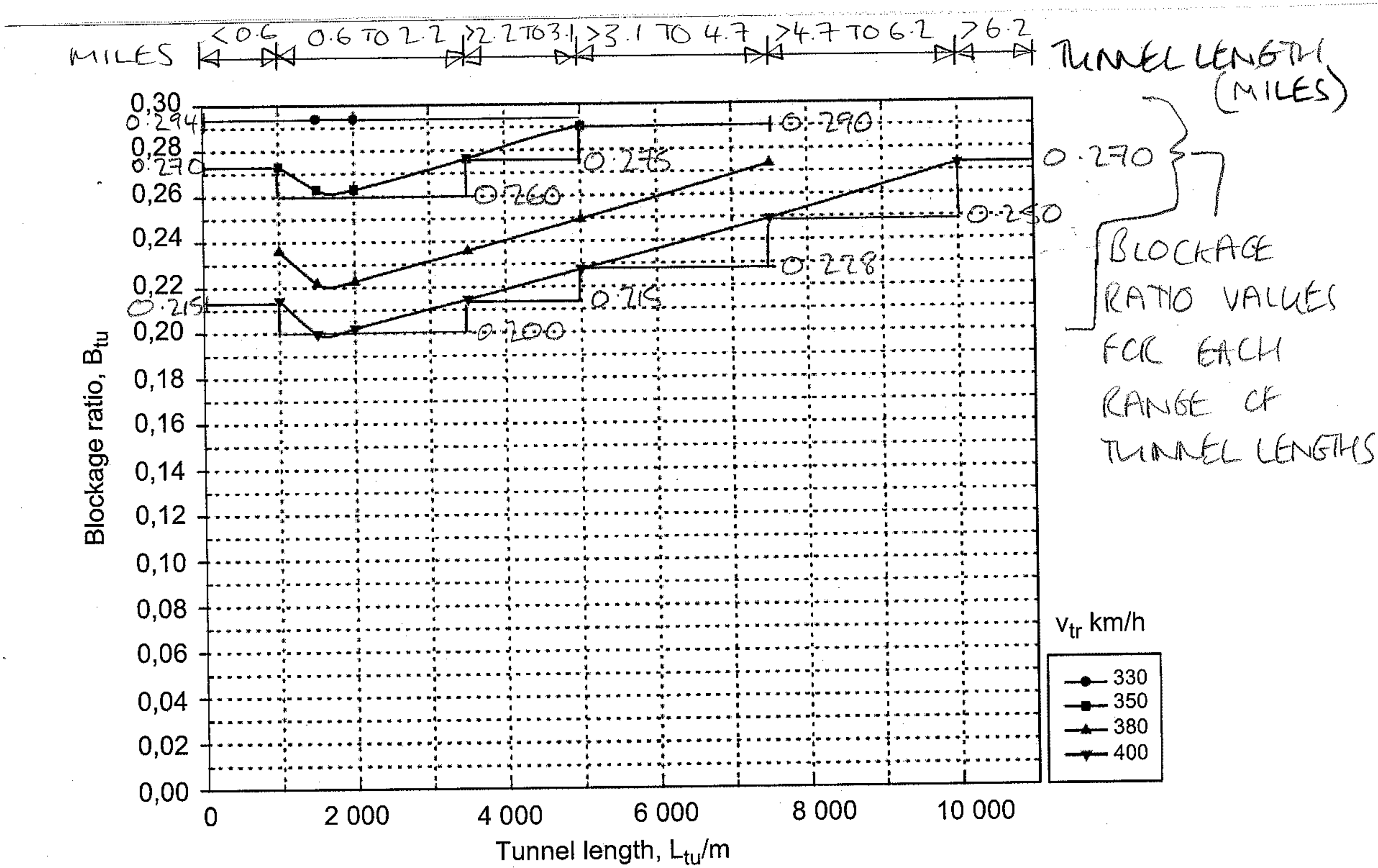
Cut and Cover Tunnel Minimum Free Tunnel C/S Area (ft^2)		Tunnel Length (miles)					
		< 0.6	**0.6 to 2.2**	**> 2.2 to 3.1**	**> 3.1 to 4.7**	**> 4.7 to 6.2**	**> 6.2**
Design Speed (mph)	**250**	755	**810**	755	715	653	607
	220	607	**629**	596	567	567	567
	205	559	**559**	559	559	559	559

APPENDIX C – MEDICAL HEALTH LIMITS BLOCKAGE RATIO CURVES



UIC 779-11 R APPENDIX F

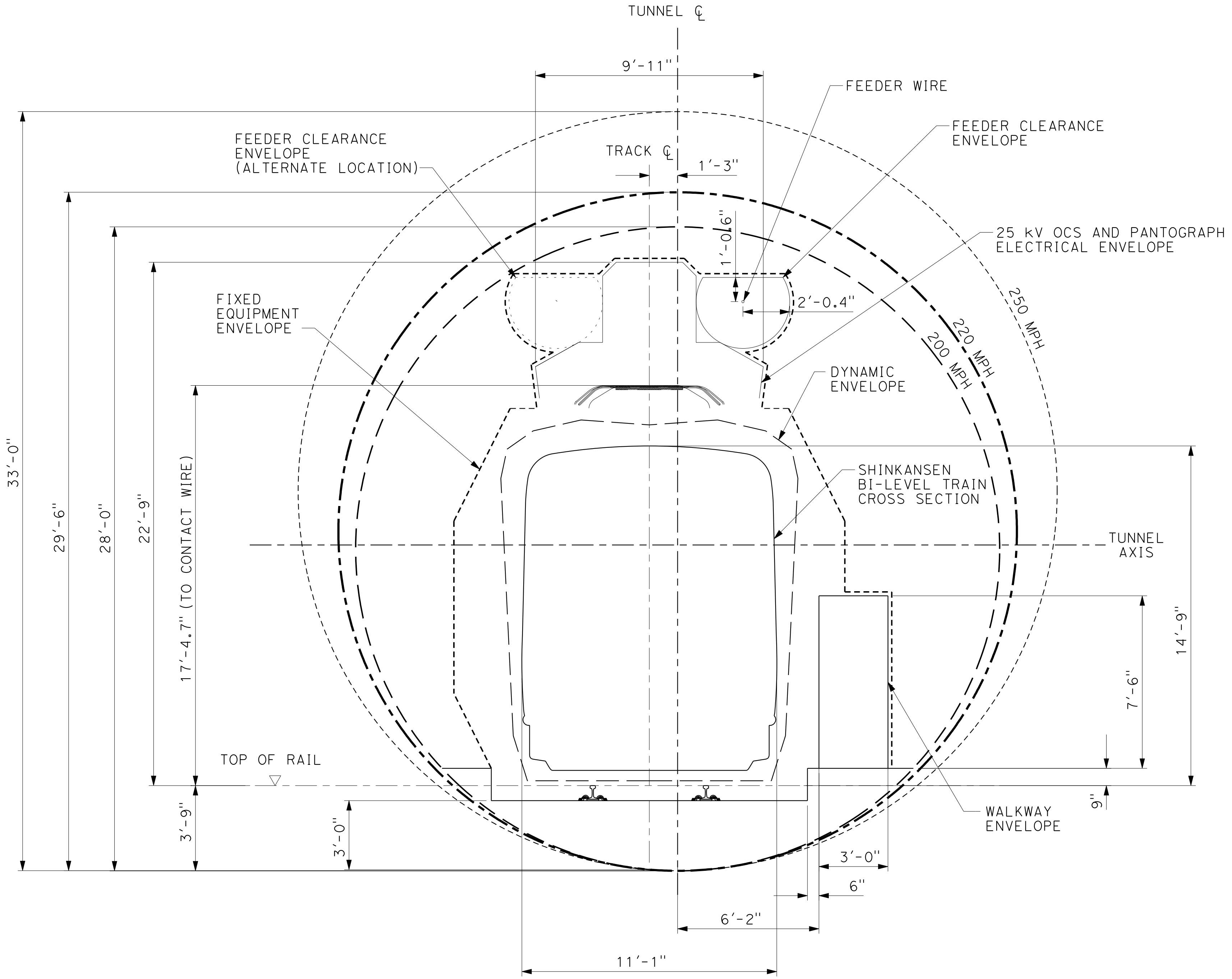
Fig. 4 - Checks on medical health limits, one train operation, train length = 400 m



UIC 779-11 R APPENDIX F

Fig. 4 - Checks on medical health limits, one train operation, train length = 400 m

APPENDIX D – BASIC TUNNEL CROSS SECTIONS



CROSS-SECTIONS FOR TUNNEL LENGTH
OF 0.6 MILES TO 2.2 MILES

NOTES:

1. FREE TUNNEL CROSS-SECTIONAL AREAS COMPLY WITH REQUIREMENTS OF EUROPEAN TECHNICAL SPECIFICATIONS FOR INTEROPERBABILITY FOR HIGH SPEED TRAINS, 2008 INFRASTRUCTURE SECTION, CLAUSE 4.2.16.1.
2. FREE TUNNEL CROSS-SECTIONAL AREAS HAVE BEEN CALCULATED IN ACCORDANCE WITH MEDICAL HEALTH CRITERIA CURVES UIC GUIDELINE 779-11 R "DETERMINATION OF RAILWAY TUNNEL CROSS SECTIONAL AREAS ON THE BASIS OF AERODYNAMIC CONSIDERATIONS", APPENDIX F, FIGURE 4.
3. FREE TUNNEL CROSS-SECTIONAL AREAS HAVE NOT BEEN CALCULATED TO MINIMIZE AERODYNAMIC RESISTANCE OR MINIMIZE HEAT BUILD UP IN TUNNELS.
4. FOR PANTOGRAPH DETAILS, REFER TO TM 3.2.3 PANTOGRAPH CLEARANCE ENVELOPE.
5. FOR DYNAMIC ENVELOPE DETAILS, REFER TO TM 1.1.10 STRUCTURE GAUGES.

TABLE 1

MINIMUM FREE TUNNEL CROSS-SECTIONAL AREAS
TO COMPLY WITH MEDICAL HEALTH CRITERIA

MINIMUM FREE TUNNEL C/S AREA (SF)		TUNNEL LENGTH (MILES)					
		< 0.6	0.6 TO 2.2	>2.2 TO 3.1	>3.1 TO 4.7	>4.7 TO 6.2	> 6.2
DESIGN SPEED (MPH)	250	740	**795**	740	700	640	595
	220	595	**615**	585	555	<555	<555
	200 OR LESS	550	**550**	550	<550	<550	<550

ASSUMPTIONS FOR TABLE 1:

1. TRAIN LENGTH OF 1312 FEET
2. SINGLE TRAIN OPERATION
3. EXCELLENTLY SEALED TRAIN (SHINKANSEN OR ICE 3)
4. FIXED EQUIPMENT ALLOWANCE OF 20 SF
5. 6" ALLOWANCE ON DIAMETER FOR CONSTRUCTION TOLERANCE
6. AREAS ROUNDED UP TO NEAREST 5 SF

TABLE 2

BORED TUNNEL INTERNAL DIAMETERS EQUIVALENT
TO MINIMUM FREE TUNNEL CROSS-SECTIONAL AREAS

BORED TUNNEL INTERNAL DIAMETER (FT)		TUNNEL LENGTH (MILES)					
		< 0.6	06 TO 2.2	>2.2 TO 3.1	>3.1 TO 4.7	>4.7 TO 6.2	> 6.2
DESIGN SPEED (MPH)	250	32	**33**	31.5	31	30	28.5
	220	28.5	**29.5**	28.5	28	<28	<28
	200 OR LESS	28	**28**	28	<28	<28	<28

ASSUMPTIONS FOR TABLE 2:

1. DIAMETERS ROUNDED UP TO NEAREST 6 INCHES

LEGENDS:

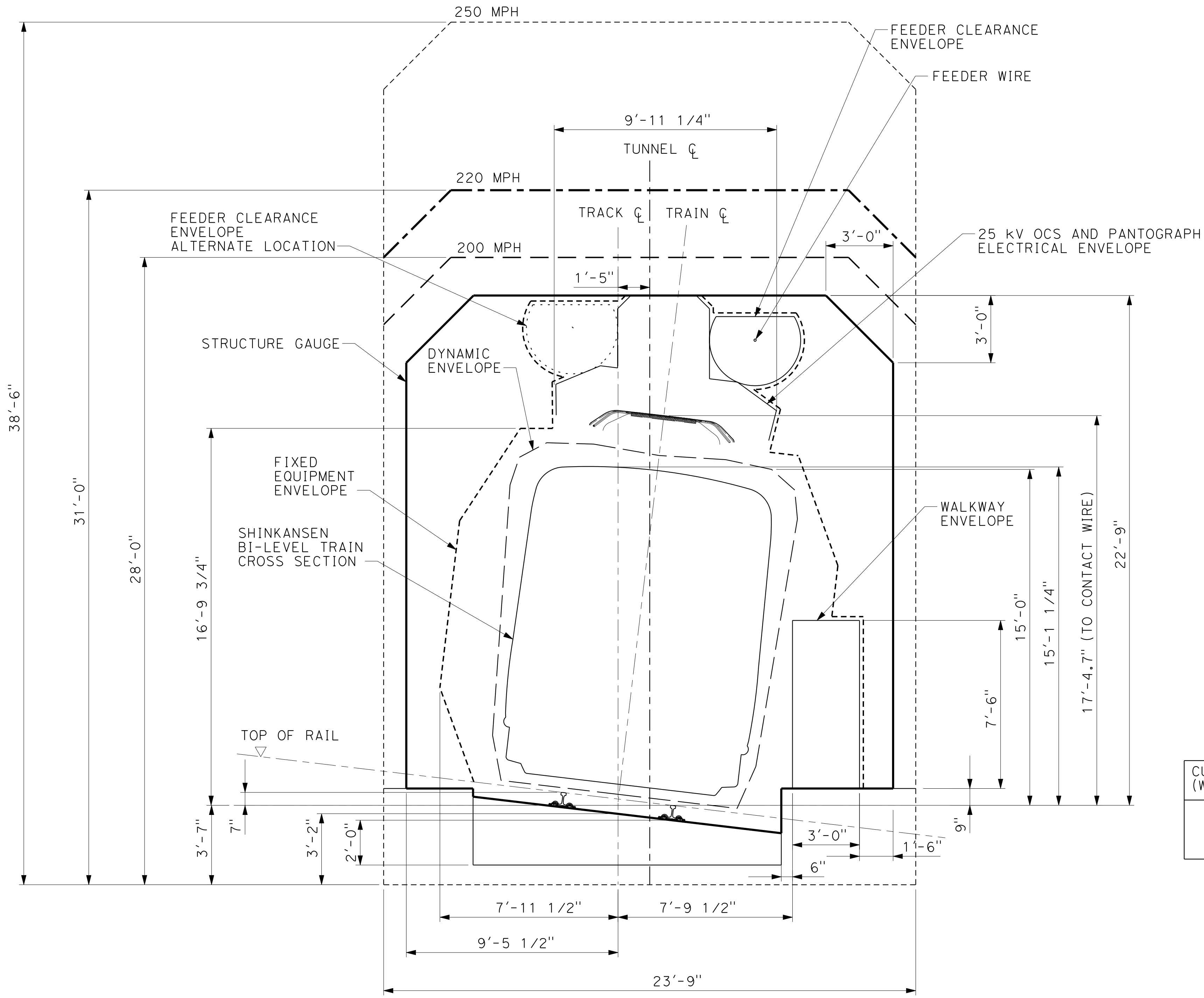
MINIMUM FREE TUNNEL CROSS-SECTIONAL AREA REQUIRED (250 MPH): 795 SF

MINIMUM FREE TUNNEL CROSS-SECTIONAL AREA REQUIRED (220 MPH): 615 SF

MINIMUM FREE TUNNEL CROSS-SECTIONAL AREA REQUIRED (200 MPH): 550 SF

TRAIN CROSS-SECTIONAL AREA: 150 SF

3 0 3 6
1/3"=3'-0"



CROSS-SECTIONS FOR TUNNEL LENGTH OF 0.6 MILES TO 2.2 MILES

NOTES:

1. FREE TUNNEL CROSS-SECTIONAL AREAS COMPLY WITH REQUIREMENTS OF EUROPEAN TECHNICAL SPECIFICATIONS FOR INTEROPERABILITY FOR HIGH SPEED TRAINS, 2008 INFRASTRUCTURE SECTION, CLAUSE 4.2.16.1.
2. FREE TUNNEL CROSS-SECTIONAL AREAS HAVE BEEN CALCULATED IN ACCORDANCE WITH MEDICAL HEALTH CRITERIA CURVES UIC GUIDELINE 779-11 R "DETERMINATION OF RAILWAY TUNNEL CROSS SECTIONAL AREAS ON THE BASIS OF AERODYNAMIC CONSIDERATIONS", APPENDIX F, FIGURE 4.
3. FREE TUNNEL CROSS-SECTIONAL AREAS HAVE NOT BEEN CALCULATED TO MINIMIZE AERODYNAMIC RESISTANCE OR MINIMIZE HEAT BUILD UP IN TUNNELS.
4. FOR PANTOGRAPH DETAILS, REFER TO TM 3.2.3 PANTOGRAPH CLEARANCE ENVELOPE.
5. FOR DYNAMIC ENVELOPE DETAILS, REFER TO TM 1.1.10 STRUCTURE GAUGES.

TABLE 1

MINIMUM FREE TUNNEL CROSS-SECTIONAL AREAS TO COMPLY WITH MEDICAL HEALTH CRITERIA

MINIMUM FREE TUNNEL C/S AREA (SF)		TUNNEL LENGTH (MILES)					
		< 0.6	0.6 TO 2.2	>2.2 TO 3.1	>3.1 TO 4.7	>4.7 TO 6.2	> 6.2
DESIGN SPEED (MPH)	250	755	**810**	755	715	655	610
	220	610	**630**	600	570	<570	<570
	200 OR LESS	560	**560**	560	<560	<560	<560

ASSUMPTIONS FOR TABLE 1:

1. TRAIN LENGTH OF 1312 FEET
2. SINGLE TRAIN OPERATION
3. EXCELLENTLY SEALED TRAIN (SHINKANSEN OR ICE 3)
4. FIXED EQUIPMENT ALLOWANCE OF 20 SF
5. 6" ALLOWANCE ON EACH VERTICAL WALL AND 4" ALLOWANCE ON SOFFIT FOR CONSTRUCTION TOLERANCE
6. AREAS ROUNDED UP TO NEAREST 5 SF

TABLE 2

CUT AND COVER TUNNEL INTERNAL HEIGHTS EQUIVALENT TO MINIMUM FREE TUNNEL CROSS-SECTIONAL AREAS

CUT-AND-COVER TUNNEL INTERNAL HEIGHT (FT) (WIDTH FIXED AT 23.75 FT)		TUNNEL LENGTH (MILES)					
		< 0.6	06 TO 2.2	>2.2 TO 3.1	>3.1 TO 4.7	>4.7 TO 6.2	> 6.2
DESIGN SPEED (MPH)	250	36	**38.5**	36	34.5	32	30
	220	30	**31**	29.5	28.5	<28.5	<28.5
	200 OR LESS	28	**28**	28	<28	<28	<28

ASSUMPTIONS FOR TABLE 2:

1. HEIGHTS ROUNDED UP TO NEAREST 6 INCHES

LEGENDS:

MINIMUM FREE TUNNEL CROSS-SECTIONAL AREA (250 MPH): 810 SF

MINIMUM FREE TUNNEL CROSS-SECTIONAL AREA (220 MPH): 630 SF

MINIMUM FREE TUNNEL CROSS-SECTIONAL AREA (200 MPH): 560 SF

3 0 3 6
1/3"=3'-0"