HIGHWAYS DEPARTMENT

GUIDANCE NOTES

ON

DESIGN OF ROAD TUNNEL STRUCTURES AND TUNNEL BUILDINGS TO BE MAINTAINED BY HIGHWAYS DEPARTMENT

Bridges & Structures Division

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CONTENT

1. INTRODUCTION

These Guidance Notes provide general guidance and requirements on structural design considerations and maintenance provisions for road tunnel structures and tunnel buildings to be maintained by HyD.

A road tunnel is a subsurface structure for vehicular traffic constructed through or under an obstacle. This obstacle may be in the form of other infrastructure development, natural terrain, a mountain, a body of water or the combination of the above. For the purpose of these Guidance Notes, road tunnel structures should include all major structures of a road tunnel, including permanent structural lining, structural compartments, portals, adits, ventilation buildings/shafts etc. which are structurally integrated with the road tunnel structures.

Road tunnels can be designed and constructed by different methods, depending on a number of factors, including functional requirements, geological and environmental considerations, construction methodologies and technologies, plant and equipment etc.

For demarcation purpose, an underpass is a highway structure that goes beneath another road(s), railway(s) or other highway structures and is usually forming part of a local grade separated highway system. Reference should be made to Structures Design Manual for Highways and Railways 2013 Edition (SDMHR) [1] for the design of the underpass.

Tunnel buildings to be maintained by HyD are engineering structures such as ventilation buildings, pumping station, kiosks, toll booths, satellite control buildings/points, control kioks etc. Tunnel buildings to be maintained by ArchSD include administration buildings which is basically for office accommodation with human activities in support of tunnel operation, building elements such as internal finishes and architectural features, workshops and garages. A maintenance matrix on various structures, systems and elements for the tunnel operaton should be devised and agreed at the design stage.

The recommendations in these Guidance Notes will take immediate effect, and are applicable to projects which are new or under planning involving road tunnels or tunnel buildings to be maintained by HyD. In addition, designers and project offices should consult maintenance authorities to specify Tunnel Protection Zone for road tunnels to prevent adverse impact due to future developments.

These Guidance Notes should not be considered as exhaustive. Designers and project offices should also observe and comply with relevant up-to-date standards and statutory requirements relating to safety, structural integrity, durability, maintenance and operational need, and ensure that provisions and recommendations given in these Guidance Notes are applicable to their designs.

Designs of road tunnel structures and tunnel buildings to be maintained by HyD should be circulated to B&S Division for comments on structural design aspects and respective Regional Offices on maintenance aspects. Designs on geotechnical aspects, geometry (including road geometry and road safety requirements), traffic control and surveillance, E&M provisions, fire safety provisions, etc. are outside the scope of these Guidance Notes. Designers and project office should refer to relevant design standards, e.g. Transport Planning & Design Manual (TPDM) [14] and seek advice from relevant authorities and departments accordingly.

2. ROAD TUNNEL STRUCTURES

Road tunnels in Hong Kong are commonly constructed by the following methods/ combination of methods: (i) Boring by Tunnel Boring Machine (TBM), (ii) Drill-and-blast, (iii) Cut–and-cover and (iv) Prefabricated tubes immersion. Designers and the project office should decide on the options to be adopted in the design with due regard to functional need, constructability, safety, geological and environmental consideration, economy as well as long-term durability and maintenance requirement, etc.

2.1 GENERAL DESIGN REQUIREMENTS

The structural design of road tunnels should take into consideration the requirements for tunnel operation, inspection and maintenance. The needs for the provision of maintenance access, lighting, communication, utility troughs, electrical and mechanical installations, drainage, provision of fire service installations, ventilation and traffic surveillance equipment etc. should be well addressed in advance of the structural design stage so as to assess their loading effects on road tunnels. Adequate safe maintenance access and opening should be provided for the routine inspections and the delivery of plant and materials for maintenance respectively. Designers should seek comments and advice from relevant authorities and parties.

According to Code of Practice for Minimum Fire Service Installations and Equipment and Inspection, Testing and Maintenance of Installations and Equipment [3] by Fire Services Department (FSD), systems for fire service installations shall be provided. In particular, dynamic smoke extraction system shall be provided when tunnel exceeds 230 m in length.

Water seepage is a common issue for tunnels which may arouse public concern and affect the tunnel operations if not handled properly. There are many different types of design and construction of tunnel structures, for example, tunnels formed by tunnel boring machines with different types of linings, diaphragm walls, drill-and-blast, mined tunnels, immersed tube, in-situ reinforced concrete structures, etc. The tunnels may also be situated in land or undersea with considerable depth. Seepage often occurs at locations of change in structure type, change in pavement permeability, construction joints and movement joints, etc. As such, designers should pay particular attention to the tunnel design on the prevention and mitigation of seepage by means including but not limited to concrete type, crack width control, protection of reinforcement, concrete covers, movement joints and construction joints, waterproofing, etc., with due considerations of the particular tunnel structures. Specifically, if diaphragm walls are proposed as structural external walls of tunnels, designers should provide full substantiation for such proposal in the design submissions for consideration and agreement by B&S Division and maintenance authorities. Sufficient drainage systems should be provided to drain away the seepage. Discharging points should be provided in tunnels and tunnel buildings (e.g. cross fall in overhead ventilation ducts (OHVD), drainage channels for tunnel walls behind VE panels, sub-pavement drains) in case draining the water seepage is required. In no case such seepage should adversely affect the structural performance and durability of the tunnels. The structures should also be well detailed such that future remedial measures for seepage would be possible with minimum disturbance to the tunnel operation, for example, adequate space should be allowed for injection grouting for structural walls that may be vulnerable to seepage. During the detailed design stage of a tunnel project, the designer shall submit detailed proposals with due regard to materials, design, construction method, etc. to effectively mitigate and control possible water seepage problems in the tunnel to B&S Division and maintenance authorities for comments. Suitable design/system/materials of joints shall be adopted to achieve appropriate watertightness, details of joints/waterproofing should be specified in the design submissions. The designer should submit the proposals on addressing seepage issues and seek comments from B&S Division and maintenance authorities.

Besides prudent design considerations, good workmanship also plays a vital role to ensure quality control on construction projects. Particular attention should be paid to factors during construction stage to prevent water seepage, for example, workmanship on concrete casting, adequate concrete mix design, detailing and preparation of construction joints, construction method, etc. In case of casting of massive concrete members, schemes of temperature control and proper curing should be devised to prevent cracks due to high heat of hydration and shrinkage. Sequence of concreting shall be controlled to minimize cracks due to early concrete shrinkage.

2.2 DESIGN WORKING LIFE

Unless otherwise agreed, the design working life of road tunnels and associated structures structurally integrated with tunnels should be taken as 120 years. For the avoidance of doubt, any tunnel buildings which are structurally integrated with a tunnel or essential for tunnel operations, such as ventilation buildings, ventilation shafts, etc., should be designed as tunnel structures with 120 years of design working life.

2.3 TYPICAL COMPONENTS OF A ROAD TUNNEL

A road tunnel should be able to accommodate the designed envelope for traffic movement as well as other functional and maintenance requirements, including ventilation, drainage, lighting, utilities and power, traffic surveillance equipment, maintenance walkway and emergency cross passage etc. A typical road tunnel should contain the following structural elements:

(i) Tunnel lining
(ii) Internal wall
(iii) Suspended ceiling slab for OHVD or other utility installation
(iv) Suspension systems (e.g. hangers) for ceiling slab
(v) Road slab and pavement
(vi) Road plinth and safety walkway
(vii) Cross passage
(viii) Ventilation shaft / adits
(ix) Portal structure
(x) Approach ramp and retaining side walls

Provision of other non-structural components including road drainage, utility trough, non-structural cladding/finishing, ventilation ducts, lighting, fire-fighting and traffic surveillance equipment etc. should also be considered in

the design.

2.4 TYPICAL LOADINGS TO BE CONSIDERED IN ROAD TUNNEL STRUCTURES

Various loadings typical to road tunnel structures are listed below. The list of loadings shown below is not exhaustive. Designers should carefully assess types, magnitudes and directions of loadings that would occur in road tunnel and combine them in such a way with due consideration to produce critical structural effect:

(i) Self-weight of all tunnel elements, supported carriageway, footpath, supported tunnel buildings, supported bridges and landscaped decks;
(ii) Soil loads on tunnel structures;
(iii) Groundwater, seepage forces and earth pressure loads as well as floatation under various water tables;
(iv) Loads arising from differential settlement of structures and structural elements;
(v) Traffic loads;
(vi) Accidental loads due to vehicle collision, vehicle explosion, fire load, impact of vessel anchors etc.;
(vii) Dead loads and maintenance loads of E&M installations and vibration loadings due to E&M equipment's operations;
(viii) Wind loads such as wind loads on tunnel portals and shafts;
(ix) Loads due to temperature effects, creep and shrinkage;
(x) Earthquake loads;
(xi) Loads during construction;
(xii) All other existing loads on the top of the tunnel;
(xiii) Loads due to extreme weather, tidal impact and climate change effects; and
(xiv) Loads due to other planned development on top or in the vicinity of road tunnels, including future roads, buildings and infrastructure development

2.4.1 EARTHQUAKE LOADS

For earthquake loads, road tunnels should be designed to withstand seismic forces and distortions imposed on them by lateral ground movements resulted from the earthquake ground motion as well as dynamic loads arisen from the inertia response of structural elements under seismic actions. The following three types of deformations imposed by the surrounding ground,

namely, (a) compression and extension in the longitudinal direction, (b) bending in the longitudinal direction, and (c) ovalling/ racking in the transverse direction should be considered. Dynamic approaches as stated in Eurocodes should be adopted in the structural analysis. For the purpose of the design of road tunnels, the Importance Factor as stated in SDMHR [1] for earthquake resistance should be 2.3 which corresponds to a return period of 2500 years.

2.4.2 LOADINGS DUE TO EXTREME EVENTS

For other effects arising from extreme weather, including the rise in sea level, abnormal rainfall intensities, temperature changes etc., precautionary measures such as raised road profile at entrances, tunnel sumps, entrance barriers and floodgates etc. should be considered in the design. Comments from relevant authorities including HKO, DSD and CEDD should be sought where appropriate.

2.4.3 COMBINATION OF LOADINGS

As regards the various combination of loadings acting on road tunnels arising from surrounding interfaces, including soil, rock, aqueous bodies and other imposed loads due to other structures and geotechnical features etc., designers should consult and agree with the relevant authorities on geotechnical aspects with regard to the geotechnical design parameters, assumptions and designed loads to be adopted for assessing and designing road tunnels.

2.4.4 EFFECT OF SHRINKAGE

Effect of shrinkage due to different humidity across the depth of the pavement/lining should be duly considered in particular when the back of pavement/lining is close to the source of subsurface run-off or seepage.

2.5 CONDITION OF EXPOSURES

The design condition of exposures, nominal cover to reinforcement and design crack width to be adopted for reinforced concrete elements would have significant influence on the durability of road tunnels. Exposure class XC4 in Table 5.2 of SDMHR [1] with limiting crack width of 0.25mm shall be adopted for assuming the durability of road tunnel elements under the aggressive environment of road tunnel. Exposure class XS2 with limiting

crack width of 0.15mm shall be adopted for parts of structure permanently submerged in sea water. Exposure class XS3 with limiting crack width of 0.15mm shall be adopted for parts of structures directly affected by sea water spray or 0.10mm for exposed to abrasive action by sea water.

Notwithstanding the above, designers should carry out reviews and assessments in order to specify exposure class which commensurate with the tunnel's specific situations and other controlling factors such as humidity, carbon dioxide concentration, design assumptions and concrete protective measures, etc. Designers should provide full substantiations if lower exposure class is adopted to ensure the adequacy of concrete cover in protection against carbonation.

In addition to nominal cover to reinforcement, designers should also adopt protective measures, such as application of protective coating, to protect critical reinforced concrete road tunnel elements against carbonation, chloride attack or sulphate attack. The protective coating should not release hazardous substances in case of tunnel fire. The omission of such protective measures in new tunnel design shall be fully justified, deliberately highlighted, and agreed by the tunnel maintenance team(s) of HyD during the tunnel design stage.

2.6 FIRE RESISTANCE

(1) Road tunnels should be designed to prevent catastrophic collapse and spalling of concrete in the case of a fire incident so as not to endanger tunnel users during evacuation and firefighters in fire-fighting or rescue. Designers should adopt the latest fire design codes and comply with the latest requirements of FSD in the design of tunnel structures.

(2) Designers should assess fire risks of road tunnels and their consequences and adopt risk mitigation measures for various elements of road tunnels according to relevant fire design codes. The fire curves to be used, elements to be protected, forms and extents of protection required should be assessed with due considerations of fire exposure by the designers. Time for repairing and re-opening the tunnel to traffic due to various fire conditions and the associated long-term performance, inspection and maintenance requirements after respective fire conditions should also be addressed in the design.

(3) To reduce the risk of concrete spalling under fire for all structural concrete, monofilament propylene fibres not less than 1.0kg/m^3 shall be included in

the concrete mix regardless of any thermal barrier to be installed. The fibres shall be 6 – 12mm long and 18 – 32μm in diameter, and shall have a melting point less than 180°C. If monofilament propylene fibres of 1.0kg/m^3 is included in the concrete mix, fibres with 32μm in diameter shall be used. Wire mesh should not be adopted in the prevention of concrete spalling under fire.

2.6.1 FIRE RESISTANCE PERIOD

As a general rule, the Fire Resistance Period should be taken as 4 hours unless agreed otherwise. Designers should document all considerations for deriving the adopted Fire Resistance Period in the design of road tunnel structures. Designers should also check with relevant authorities including FSD and TD with regard to any specific fire resistance requirements, prohibition of dangerous goods vehicles from using road tunnels, etc. in determining the Fire Resistance Period.

2.6.2 VENTILATION PROVISION IN FIRE RESISTANCE DESIGN

Reference should be made to the Code of Practice for Minimum Fire Service Installations and Equipment and Inspection, Testing and Maintenance of Installations and Equipment [3] by FSD when carrying out fire resistance design and risk assessment for road tunnels. According to Clause 4.42 of the subject Code of Practice, systems for fire service installations shall be provided. In particular, dynamic smoke extraction system shall be provided when tunnel exceeds 230m in length. Comments from FSD and Electrical and Mechanical Services Department (EMSD) and appropriate maintenance authorities should be sought.

2.6.3 THERMAL BARRIER

Thermal barriers should be installed to protect the tunnel lining in case of fire when the road tunnel is submerged in the sea or located in "unstable ground"("unstable ground" is defined as "ground that will collapse if unsupported" with reference to Guidelines for Structural Fire Resistance for Road Tunnel [15] published by the International Tunneling Association (ITA)) where the consequence of tunnel lining collapse could be considered as catastrophic. The system of thermal barriers should be capable to withstand the Rijkswaterstaat (RWS) time/temperature fire curve for 120 minutes [4].

The system of thermal barriers should be a board type and pass the jet fire test

in accordance with ISO 22899-1:2007 [5]. It should not be made of Magnesium Oxide (MgO) or materials affecting the durability of any tunnel elements/facilities.

The anchor used for fixing the thermal barrier on the tunnel lining should be made of High Corrosion Resistance (HCR) steel capable to withstand the Rijkswaterstaat (RWS) time/temperature fire curve for 120 minutes. The anchor should also be designed to hold the thermal barrier in case of earthquake. Non-destructive test should be carried out on at least 5% of total number of anchors to verify the anchor strength after installation. At least 2% of the thermal barriers should be fixed by anchors which allow removal and reinstatement of barrier panels without replacement of anchors.

2.6.4 LINEAR HEAT DETECTION SYSTEM

Linear heat detection systems are widely adopted for actuating smoke extraction system as well as fire alarm systems in case of fire in road tunnel. For the sake of fire safety, the linear heat detection systems should comply with, inter alia, the system integrity requirements as stipulated in Clause 12.2.2(m) of BS 5839-1:2017 (Incorporating Corrigendum No.1) [16] or similar requirements of other standards acceptable to FSD. To facilitate the linear heat detection system to be designed and installed in full compliance with the system integrity requirements, a system configuration is attached in Appendix A for reference. The above system configuration is an option complying with the system integrity requirements. For other system configurations, designers should seek advice and agree with FSD to ensure the proposed system configuration can comply with the said requirements.

2.7 DRAINAGE DESIGN

(1) Road tunnels should be provided with drainage systems designed to fulfil the standard for road pavement drainage as stipulated in RD/GN/035A [17] and sufficient to cope with water from all sources such as underground seepage, surface runoff, water leakage from broken pipes, tunnel cleansing water, etc. Entrances of approach ramps, all openings into road tunnels and associated elements such as adits, ventilation shafts etc. should be located above the 1 in 200-year return period flood level of the adjacent area with due considerations of climate change projections and adequate provision for storm surge and freeboard wherever possible. Flood protection measures, such as flood barriers / flood gates, should be incorporated into the design of the proposed tunnels, taking into account the future operation and maintenance of the

proposed road tunnels under the effects of climate change and extreme weather conditions. Comments should be obtained on the drainage design of pumping systems as well as the flood protection measures for E&M facilities from EMSD. All the holes of the utility trough covers connecting to tunnels and at outdoor section should be plugged or sealed to avoid flow being carried into the tunnel. Also, all the cable ductings before connecting to tunnels shall be plugged or sealed at drawpits. The impact of burst water mains / fire services installations and blocked surface water drains causing the change of design flood level should be assessed. The design of waterproofing system for road tunnels should follow BS 8102: 2009 – Code of Practice for Protection of below Ground Structures against water from the ground [6].

(2) Drains located underneath the carriageway would be blocked after years of accumulation of debris and mineral precipitation from tunnel seepage in view of high mineral content of groundwater in rock tunnel. Cleansing of these blocked drains is extremely difficult and their in-situ replacement is in general not feasible due to the operation of the road tunnel. As such, the sub-soil/sub-pavement drain should be specifically designed with due consideration on the adequacy of drainage capacity especially due to blockage. Specific drainage product of sufficient strength, adequate size and durability should be adopted to minimize the chance of blockage. Adequate space should be allowed for personnel to carry out inspection and cleansing of the drainage components subject to the requirements of the maintenance authorities. Covered U-channel instead of drains located underneath the carriageway should be adopted along the carriageway to facilitate inspection and maintenance work whenever possible. U-channels should be properly designed and they should be robust, durable and free from rocking. For those components that would need to be replaced during the design working life of the tunnel, design considerations for possible future replacement may be required. Provisions (e.g. safe maintenance accesses for both plant and materials, space for replacement, division of components to minimize traffic disruptions during replacement) shall be allowed in the design for replacement of components of tunnels in the future.

(3) Cross fall and longitudinal fall should be provided on carriageway throughout the tunnel. Pump stations, sumps and separators should be provided at suitable locations in the tunnel where possible impacts on tunnel operation would be minimized. The cut-in/off and control mechanism of the pumps should be designed robustly. The possibility of any unintended stoppage of the pumps must be eliminated as otherwise the accumulated flow will cause serious disruption to the operation and safety of the tunnel.

Drainage system shall be installed with flame trap with reference to requirements stipulated in Section 7 of CD 352 [7] considering accidental spillage of fuel from vehicles.

The use of cut-off drains at the tunnel portals is usually the last defence of preventing entrance of rainstorm to tunnel inside, but cut-off drains were found to have long term maintenance problems under continuous vibration due to heavy traffic load. To avoid stormwater and other surface runoff flowing into the tunnel, road levels in both longitudinal and transverse directions at tunnel entrances should be properly designed with an aim to collect stormwater from gullies and/or channels at the two sides as much as possible first to minimize the number of cut-off drains. Associated drainage system with adequate discharge capacity should be provided. If the use of cut-off drains at the tunnel portals is unavoidable, the design of cut-off drains (including the covers and supporting walls) shall cater for dynamic vehicular loading and vibration. Where the tunnel has a steep approach ramp, due consideration should be given to avoid overflow to the ground when the tunnel gradient changes. Sufficient gullies or roadside covered continuous channels should be provided to intercept and to minimize the overland flow on the approach ramp, especially if it is wide and with small cross fall. Separate drainage system for collection of run-off from the catchment of tunnel approach ramp and cut-off drain(s) should be provided with due consideration of gully grating efficiency and turbulence effect in intermediate manholes.

2.8 VENTILATION AND OTHER E&M SYSTEM

(1) The structural design of road tunnels, including the lining, OHVD slab, suspended ceiling and hanging system for E&M equipment etc., should take into account the loading and vibration effects arising from the operations of the ventilation systems.

(2) The internal dimension and layout of the road tunnel should be designed to accommodate ventilation ducts and other E&M equipment. Either natural ventilation, longitudinal ventilation, transverse ventilation or any variations or combinations of them are commonly adopted to suit the actual operational circumstances. The primary objectives of a tunnel ventilation system are (a) to monitor the air quality inside the tunnel continuously and take necessary action to limit the concentration of air pollutants from vehicles emissions to allowable levels and (b) to control the spread of smoke in case of a tunnel fire.

2.9 MAINTENANCE CONSIDERATIONS

(1) A comprehensive maintenance strategy should be developed for the maintenance of road tunnels in good conditions. Different types of tunnels, locations, ground and surroundings would require different maintenance strategies. In this regard, individual tunnel should have its own maintenance strategy which should be reflected in an inspection and maintenance manual for future inspection and maintenance. The inspection and maintenance manual should be submitted to tunnel maintenance authorities with the items include, but not limited to the following:

(i) Maintenance scope, objectives and strategy
(ii) Maintenance parties, roles and responsibilities
(iii) Service life of various elements of road tunnels.
(iv) Types of defects that may occur
(v) Types and frequency of inspection for various elements of road tunnels as well as their monitoring requirements, if any
(vi) Inspection equipment and monitoring device
(vii) Criteria of maintenance actions
(viii) Maintenance schedule and programme for various types of structural and non-structural elements
(ix) Recommended maintenance works and procedures
(x) Inspection procedure and sequence for special features, such as tunnel lining, hanging system for E&M equipment, drainage system, fire service installation etc.
(xi) Design information relevant to maintenance planning and implementation, e.g. loadings, drawings, schedule of movement joints along the tunnel with information regarding their locations and movement ranges, etc.
(xii) Maintenance records or reports, certification or service reports
(xiii) Details and requirements of cyclic lane closure for inspection and maintenance
(xiv) Any other items as required by the designers and the maintenance authorities (e.g. Emergency Preparedness Plan to handle the flooding impact under Super Typhoon Direct-Hit Event).

Separate design submission for safety and access provision for maintenance and operation shall be provided to tunnel maintenance authorities.

(2) During the design stage, comments from relevant maintenance authories should be sought and reference should be made to HyD Guidelines No.

HQ/GN/26 Guidelines on Maintenance of Road Tunnels [9].

(3) For those components that would need to be replaced during the design working life of the tunnel, design considerations for possible future replacement may be required. Guidelines issued by Labour Department, such as "Guidance Notes on Manual Handling Operations", "A Guide to Part VII of the Occupational Safety and Health Regulation (Manual Handling Operations)", shall be taken into account into the design of the size of replaceable elements. If frequent removal of the elements for inspection is expected, the size of these replaceable elements shall be designed to be handled manually. Furthermore, regular sizes shall be designed for replaceable elements as far as practicable. If the concerned elements could not be replaced by manual handling, maintenance manual advising how the concerned items could be replaced shall be submitted to relevant maintenance authorities for consideration/comments. The maintenance manual shall show the proposed method statement of replacement of the elements (including but not limited to access path, quantity of manpower and plants involved, any lifting appliance/gears required, the type of tools required and the proposed working area etc.).

(4) The defect liability period and warranty for specially designed facilities shall be extended. Proprietary products proposed to be used in the tunnel structures shall be discussed and agreed with the maintenance authorities. Maintenance cost of the proprietary products shall be duly considered in the selection of the proprietary products. Details of the proposed proprietary product, including its expected service life, life cycle cost estimates, as well as any special inspection and maintenance arrangement required by the supplier/manufacturer and the relevant authorities shall be provided to the maintenance authorities for comments and consideration.

2.9.1 MAINTENANCE CONSIDERATIONS IN PAVEMENT DESIGN AND HEADROOM REQUIREMENTS

(1) Both flexible and rigid pavements are commonly adopted in road tunnels. If rigid road pavement is to be adopted, the design should be such that it could facilitate efficient reconstruction of the pavement using precast rigid pavement panel. In that connection, the sizes of the pavement panel should be standardized as far as practicable and precise as-built construction record should be provided.

(2) Structural slabs inside the road tunnels should not be used as the running

surface. Concrete wearing slab or bituminous surfacing should be provided on top of the structural slabs of the tunnel.

(3) When designing the approach carriageway to road tunnel including the toll plaza, the heavy traffic load, due to the vehicles' frequent acceleration and deceleration, changing lane and braking on up/down-ramp, should be properly addressed in the design of the pavement and of any covers and gratings on the carriageway, in particular cut-off drains.

(4) Where concrete pavement is to be adopted in a road tunnel, an additional clearance of 0.1m should be provided on top of the designed minimum vehicular vertical clearance of 5.1m as specified in Transport Planning & Design Manual (TPDM) [14] to cater for future overlaying of bituminous surfacing.

(5) The ceiling of carriageways should be painted in black with inorganic paint. The paint shall be incombustible.

(6) The damage of bituminous road pavement in tunnels due to water seepage should also be avoided.

2.9.2 MAINTENANCE CONSIDERATIONS IN WATERPROOFING DESIGN

(1) Tunnel can be designed to be either undrained or drained, according to the groundwater/seepage control methodology. The lining of undrained tunnels should be designed to withstand full hydrostatic pressures as well as the pressures generated by the ground. In the drained tunnel design, seepage forces should be taken into account in the design of lining.

(2) Undrained tunnel design with complete waterproofing layer is the preferable tunnel design option for drill-and-blast rock tunnels. If drained tunnel design is to be adopted for drill-and-blast rock tunnels, waterproofing layer should be provided at tunnel crown and behind tunnel walls of tunnel lining.

(3) Waterproofing details of the joints between tunnel units and segments should be duly designed in ensuring the water tightness. Provision should be allowed for any monitoring and collection of seepage in the joints in the future.

2.9.3 ACCESS FOR MAINTENANCE AND INSPECTION WORKS

(1) Adequate and safe maintenance access to all locations and components of the tunnel for inspection and maintenance should be provided. Side access (designated shaft or incorporated in cross passage) to overhead ventilation duct should be provided wherever possible, instead of opening at ceiling slab. Similar side access should also be provided to the tunnel chamber and ventilation duct below carriageway wherever possible, instead of a manhole at road slab. Inaccessible chambers and conduits shall not be allowed in tunnels and tunnel buildings. The access should be provided at intervals of not exceeding 200m. Provision of safe and effective inspection and maintenance access should be considered in the design stage with reference to Guidelines on Inspection of Road Tunnels, HyD Guidelines No. HQ/GN/04 [8]. Provisions should be made for future installation of access facilities inside ventilation shafts without affecting their operation so as to allow close inspection of shaft faces.

(2) If access openings to/from compartments below/above carriageway is required for emergency and maintenance purposes, side access away from carriageway (such as at cross passages/side ducts) should be provided. Provision of any kinds of specific, non-standard design of access opening with complicated mechanical components at carriageway is not allowed unless proven long-term track record of being successfully used at carriageway with heavy traffic can be provided.

(3) Bolts and nuts connections on covers on road slab and cross road drains should be avoided and standard types of manhole covers should be adopted as far as possible. If inevitable, the bolts and nuts connections should be located at where the routine inspection and maintenance works for the connections could be carried out under regular tunnel closure arrangement, their maintenance and inspection should be planned within the regular closure periods of the tunnel.

(4) Heat resistant lighting luminance with minimum 6500 lumen output should be installed along the centre of the ceiling of OHVD at 2.5m interval or otherwise agreed with the tunnel maintenance team(s) of HyD, such that no additional lighting would be required during inspection and maintenance works. Lighting should also be provided to all confined spaces, e.g. exhaust ducts, etc. Lighting switches and electricity sockets shall be provided near the access openings and power supply socket-outlets should be provided at ventilation ducts and underground chambers. Sufficient clearance between

tunnel elements and E&M equipment should be provided for maintenance works subject to manufacturer's recommendations and requirements of tunnel maintenance authorities.

(5) Where access is provided for carrying out inspection and maintenance to any tunnel components including but not limited to ventilation ducts, ventilation buildings, ventilation shafts and E&M equipment, minimum headroom of not less than 1.9m and clear width of not less than 1m should be provided for the passage of personnel and equipment. If any maintenance access (whole or part) cannot achieve the required dimensions, the designer should consider using very durable materials, such as stainless steel reinforcement, for those components of the tunnel in lack of proper maintenance access. In case of doubt, advice on adequacy of accessibility from maintenance authorities should be sought.

(6) Inspection and maintenance of tunnel elements will normally be carried out under restricted working hours. Due considerations and sufficient clearance, including the provision of adequate openings and cross passages, should be given during the design stage to facilitate maintenance and repair in the tight schedule. Wall panels should be designed with built-in inspection doors at 30m intervals to facilitate future inspection of the tunnel lining covered by wall panels. Comments from maintenance authorities should be sought

(7) Apart from the provision of chainage markers at carriageway level, the chainage markers should be provided along ventilation ducts and underground chambers for reference of inspection and record of defects.

2.9.4 SPARE PARTS

Spare parts and storage accommodation should be provided for those components which are susceptible to damage or wear during the service life of a road tunnel. Reference should be made to Section 16.1.3 of SDMHR [1]. The maintenance authorities should be consulted at an early stage in the design of the structures, including tunnel buildings, for advice on the requirements for spare parts for maintenance. The designers should prepare and agree with the maintenance authorities on the list of inventory and items which would require routine maintenance, such as wall panels, E&M equipment, drainage cover etc. The list should include details of their location, number, materials and available suppliers.

2.9.5 HANGING SYSTEM, HOLDING DOWN, ANCHORAGE AND OTHER FIXING ARRANGEMENT

In the circumstance that hanging system or hangers, including holding down bolts, dowel bars and anchorage are provided to support E&M equipment, including jet fans, lighting etc., the design of the hanging system should take into account the following requirements:

(1) The hanging system, including holding down bolts, anchorage, connecting dowel bars etc. should be designed to be permanently fixed or cast in the structural elements of the tunnel without inducing crack or opening in the structural element concerned. Subsequent drilling into the permanent concrete lining to create holes for inserting and fixing the anchorage bolts (by expansion bolts or chemical grouting etc.) should be avoided as far as possible.

The proposed hanging, and anchorage system, with all material testing certificates, design calculations, check certificates, maintenance/inspection and repairing manual should be submitted to the responsible maintenance authorities for comment.

(2) If subsequent drilling into any reinforced concrete elements is necessary for the installation of anchor bolts, proprietary hollow drill bit with vacuum cleaning function should be used. Anchor bolts should be made of A4 grade stainless steel or equivalent. All gaps inside a bolt hole should be sealed with proprietary grout or alternatively treated to maintain the original durability of the concrete elements. Designers should substantiate that the anchor bolts are suitable for structural fixing taking into consideration the stress conditions of the concrete elements.

The potential risk of post-drilled anchor bolt fallen off of overhead slabs, especially due to fatigue, vibration and in the case of fire, should also be duly considered and mitigated. In this regards, undercut bolts should be considered.

(3) For tunnels in oval or horseshoes shape, ceiling slabs for overhead ventilation ducts should be in arch form or other form without using hangers. For tunnels in rectangular shape, the use of hanging system or hangers for tunnel suspended ceiling should be avoided.

(4) The hanging system should be designed to be anchored and cast permanently into the structural element with sufficient anchorage length and strength so

that no part of the system will become loosened by mechanical vibration/movement due to the operation of the E&M equipment or cracks that might appear in the concrete element supporting the hanging system during the service life.

(5) Designers should adopt very durable materials to construct metal frames for supporting heavy elements. Tunnel claddings should be supported by Grade 316 stainless steel frames. Other heavy parts including lighting fittings should be supported by galvanized mild steel frames with painting suitable for long-term protection of structural steel works in aggressive environment. Reference should be made to Section 16.4 of SDMHR [1].

All connecting dowel bars, connectors, holding down, anchorages and fixing arrangements, and all other fixtures should be fabricated from austenitic stainless steel. Reference should be made to Section 16.6 of SDMHR [1].

The cable hangers should be galvanized and coated with epoxy powder to improve resistance against abrasion and corrosion.

2.9.6 INCORPORATION OF UTILITY INSTALLATIONS IN TUNNELS

(1) Prior approval should be sought on any proposal to accommodate utility installations in the tunnel. The need for accommodating utility installations should be confirmed at an early stage in the design to allow designers to make adequate and appropriate provision having due regard to the functions of the tunnel.

(2) Regarding utility services installations road tunnels, reference should be made to Section 1.7 of District Administration Handbook [10] and all utilities should be clearly labeled at 200m interval.

(3) As the utility trough covers are vulnerable to damage, the bottom longitudinal edges of the covers and recess receiving the covers shall be protected by GMS angle wherever appropriate.

(4) Proper design should be conducted for the use of the space behind wall panels for utility installation, including the hangers installed behind the wall panels for supporting cables. To facilitate the laying of new cables onto hangers behind tunnel wall panels, “leading wire” should be provided for all unused hooks of the hangers, such that removal of wall panels at close intervals could be avoided.

2.9.7 TUNNEL MOVEMENTS MONITORING

Monitoring and instrumentation plan for tunnel movements should be formulated for comments by maintenance authorities. Strategic long-term monitoring points should be devised and installed before hand-over of the road tunnel to the maintenance authorities. Designers should seek comment from maintenance authorities for the instrumentation plan and adoption of maintenance instruments, such as survey markers etc.

2.9.8 MAINTENANCE REQUIREMENTS FOR SPECIFIC STRUCTURAL FEATURES

Since there are many post-drilling works to be carried out at the OHVD slab, prestressed OHVD slab should not be used unless there are very strong justifications on the durability of tendons being affected by the post-drilling works. In case of using post-tensioning OHVD slab, the tendon should be protected by High Density Polyethylene (HDPE) sheathing ducts with full grouting. In case of using pre-tensioning OHVD slab, justification should be provided to demonstrate that the durability of tendons would not be affected by the post-drilling works. Specific structural features or installations such as rock bolts, ground anchors, etc. may require special maintenance measures. Advice from maintenance authorities should be sought to the adoption of any of these specific structural features in the design stage. All specific maintenance and inspection procedures for these specific structural features should be detailed in the maintenance and inspection manual.

2.9.9 TUNNEL CLADDINGS

Cladding panels should be designed to facilitate removal and subsequent reinstatement of covering for the concerned tunnel lining for inspection and repair. Regular or ad-hoc inspections should be implemented. In case Vitreous Enamel (VE) claddings are adopted in the tunnel design, the fixing and arrangement of VE panels should be designed to allow removal and installation of individual panels without moving any adjacent panels. Such design arrangement would enhance the efficiency during inspection and maintenance works, in particular in the event of emergency repair so as to minimise the impact to the public nuisance due to temporary road closure. Section 2.9(3) of this Notes should also be referenced in detailing the tunnel claddings.

3. TUNNEL BUILDINGS

3.1 GENERAL STRUCTURAL DESIGN REQUIREMENTS

(1) Designers should ensure the compliance of the structural design of the tunnel buildings with the statutory requirements relevant to building construction and associated works in Hong Kong and fulfillment of the corresponding functional purposes and requirements in terms of structural layout, loadings, access, emergency escape requirements, durability, fire resistance, etc.

(2) Designers should ensure that the buildings are designed in accordance with the relevant Codes of Practice for Buildings in Hong Kong. Reference should be made to the Code of Practice for Structural Use of Concrete [11], Code of Practice for Foundations [12], Code of Practice for Structural Use of Steel [13] and Code of Practice for Fire Safety in Buildings 2011 [2] issued by Buildings Department. Reinforced concrete should be designed to meet the minimum concrete cover requirement as stated in the Code of Practice for Fire Safety in Buildings 2011 [2] issued by Buildings Department and the relevant requirements by the FSD.

3.2 DESIGN WORKING LIFE

A design approach based on a design working life of 50 years should be adopted in the design of tunnel buildings. For the avoidance of doubt, any tunnel buildings which are structurally integrated with a tunnel or essential for tunnel operations, such as ventilation buildings, ventilation shafts, etc., should be designed as tunnel structures with 120 years of design working life.

3.3 OTHER DESIGN REQUIREMENTS

For building services, fire services installations and other building facilities, designers should seek comments from ArchSD, EMSD, FSD, etc. accordingly to ascertain the required information for the structural design. For geotechnical information necessary for structural design of tunnel buildings, comments from GEO should be sought.

3.4 DESIGN REQUIREMENTS FOR TUNNEL BUILDINGS DESIGNED FOR SPECIAL USE

Tunnel buildings designed for special use, such as fuel filling station, dangerous goods store, garage etc., comments from relevant authorities

including FSD, EMSD, etc. should be sought with regard to the building design requirements and regulations concerned.

3.5 MAINTENANCE CONSIDERATIONS

An inspection and maintenance manual should be prepared during the design stage to cater for the particular design and functions of the tunnel buildings. The items that should be included in the manual should cover but not limited to those items for the inspection and maintenance manual of road tunnel structures listed in Section 2.9 above. Comments from relevant maintenance authorities, including HyD/Region, should be sought on aspects which require regular maintenance, such as soft landscaping, during the design stage.

4. INDEPENDENT CHECKING

The designers should ensure the compliance of the relevant design requirements as well as the safety and integrity of the road tunnel structures, tunnel buildings.

4.1 ROAD TUNNEL STRUCTURES

Independent checking of the design of the road tunnel structures should be carried out under Structure Category III as shown in Table 2.2 of SDMHR [1].

4.2 TUNNEL BUILDINGS

Tunnel buildings should be designed and checked in accordance with the statutory requirements relevant to building construction and associated works in Hong Kong. Reference should be made to Buildings Department's Practice Notes for Authorized Persons, Registered Structural Engineers and Registered Geotechnical Engineers.

5. ENQUIRIES

For any enquiries on this document, please contact Chief Highway Engineer/Bridges and Structures.

6. REFERENCES

[1] Structures Design Manual for Highways and Railways 2013 Edition, Highways Department

[2] Code of Practice for Fire Safety in Buildings 2011, Buildings Department

[3] Code of Practice for Minimum Fire Service Installations and Equipment and Inspection, Testing and Maintenance of Installations and Equipment (September 2022), Fire Services Department

[4] Technical Standards for the Provisions and Installations RWS curves, Dutch Ministry of Transport and National Regulator

[5] ISO 22899-1:2007: Determination of the resistance to jet fires of passive fire protection materials -- Part 1: General requirements

[6] BS 8102:2009: Code of Practice for protection of below ground structures against water from the ground

[7] CD 352: Design of Road Tunnels

[8] Guidelines on Inspection of Road Tunnels, HyD Guidelines No. HQ/GN/04, Highways Department

[9] Guidelines on Maintenance of Road Tunnels, HyD Guidelines No. HQ/GN/26, Highways Department

[10] District Administration Handbook, Highways Department

[11] Code of Practice for Structural Use of Concrete (2013), Buildings Department

[12] Code of Practice for Foundation 2017, Buildings Department

[13] Code of Practice for Structural Use of Steel (2011), Buildings Department

[14] Transport Planning & Design Manual, Transport Department

[15] Guidelines for Structural Fire Resistance for Road Tunnel, International Tunneling Association

[16] BS 5839-1:2017 (Incorporating Corrigendum No.1): Fire Detection and Fire Alarm Systems for Buildings – Part 1: Code of Practice for Design, Installation, Commissioning and Maintenance of systems in Non-domestic Premises

[17] Guidance Notes on Road Pavement Drainage Design, HyD Guidelines No. RD/GN/035A, Highways Department

7. APPENDIX

Appendix A System Integrity for Linear Heat Detectors

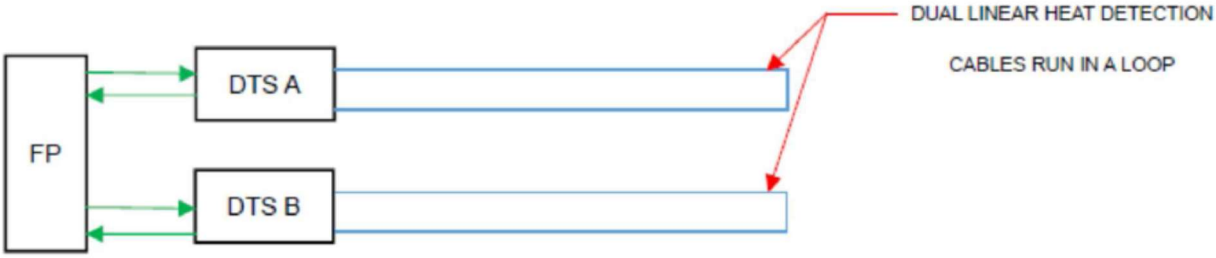
APPENDIX A - SYSTEM INTEGRITY FOR LINEAR HEAT DETECTORS

System Integrity for Linear Heat Detectors

(i) For protection area not exceeding 2,000m^2, a single short circuit or open circuit fault on the linear heat detection cable should not disable protection within the area of 2,000m^2 by providing linear heat detection cable arrangement as shown in figure below.

CASE 1 – Protected Area ≤ 2,000 m^2)

(ii) For protection area exceeding 2,000 m^2, duplicate linear heat detection cables with its associated control panels, should be provided with configuration as recommended by manufacturer, to form a complete redundancy as shown in figure below.



CASE 2 – Protected Area > 2,000 m^2

LEGEND

FP : FIRE PANEL;

DTS : DISTRIBUTED TEMPERATURE SENSING INSTRUMENT;