Appendix A11

Technical Memorandum:

Raised Safety Walks and Egress

TECHNICAL MEMORANDUM: RAISED SAFETY WALKS AND EGRESS

KENSINGTON EXPRESSWAY PROJECT, PIN 5512.52

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KENSINGTON EXPRESSWAY PROJECT, PIN 5512.52

TECHNICAL MEMORANDUM: RAISED SAFETY WALKS AND EGRESS

1. Introduction

1.1. Project Location and Description

The Kensington Expressway Project is seeking to reconnect communities surrounding a stretch of the currently depressed NYS Rte. 33, Kensington Expressway corridor, Figure 1. The project includes the reconstruction of the Kensington Expressway with a tunnel extending approximately 4,100 feet from the southern portal at Dodge Street to the northern portal at Sidney Street, Figure 2.

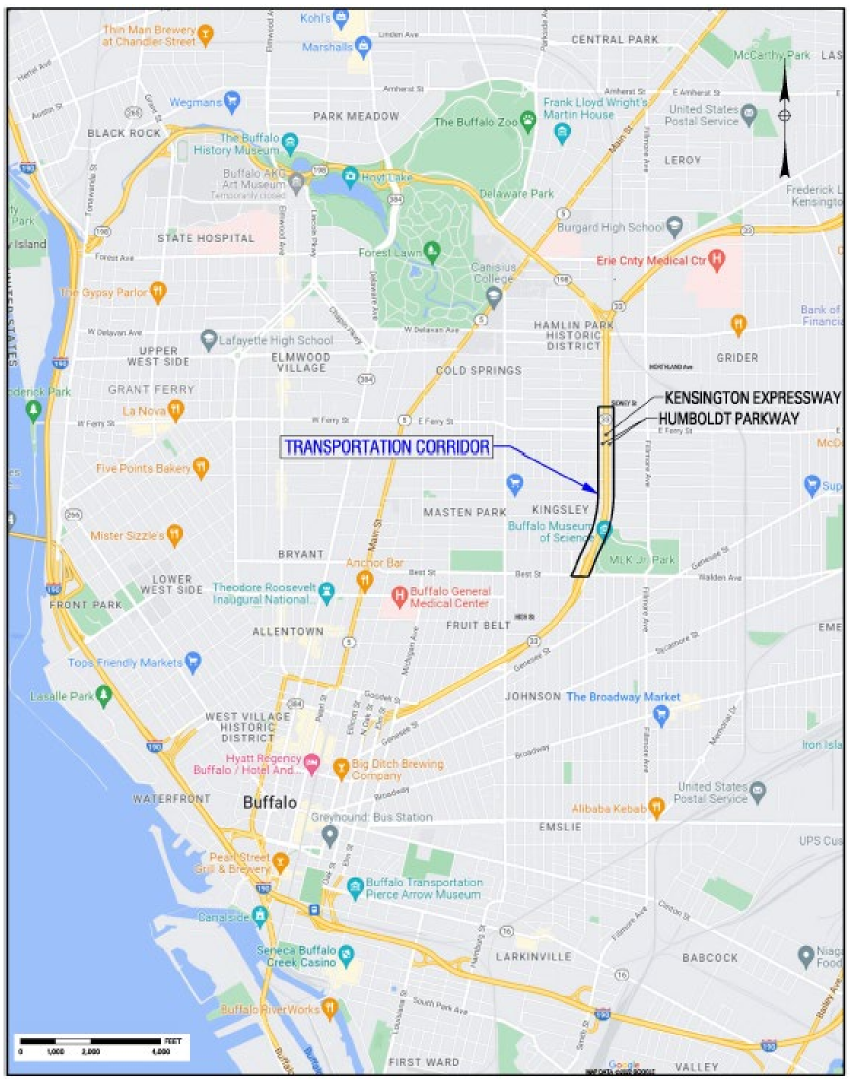

Figure 1 Project Location Map

Figure 2 Kensington Expressway Capping Plan

1.2. Objectives

This Technical Memorandum serves to document existing guidelines and code requirements for raised safety walks and egress within tunnels and provide recommendations regarding their use within the tunnel of the Kensington Expressway Project.

2. Federal and State Codes, Guidelines, and Standards

2.1. Raised Safety Walk

2.1.1. NYSDOT *Highway Design Manual*

The NYSDOT *Highway Design Manual*, Chapter 2, Article 2.7.5.9 requires the use of a 3.5 ft minimum raised safety walk on one side of a tunnel for freeway tunnels greater than or equal to 800 ft in length, Figure 3 and Table 2. The purpose of this safety walk is undefined.

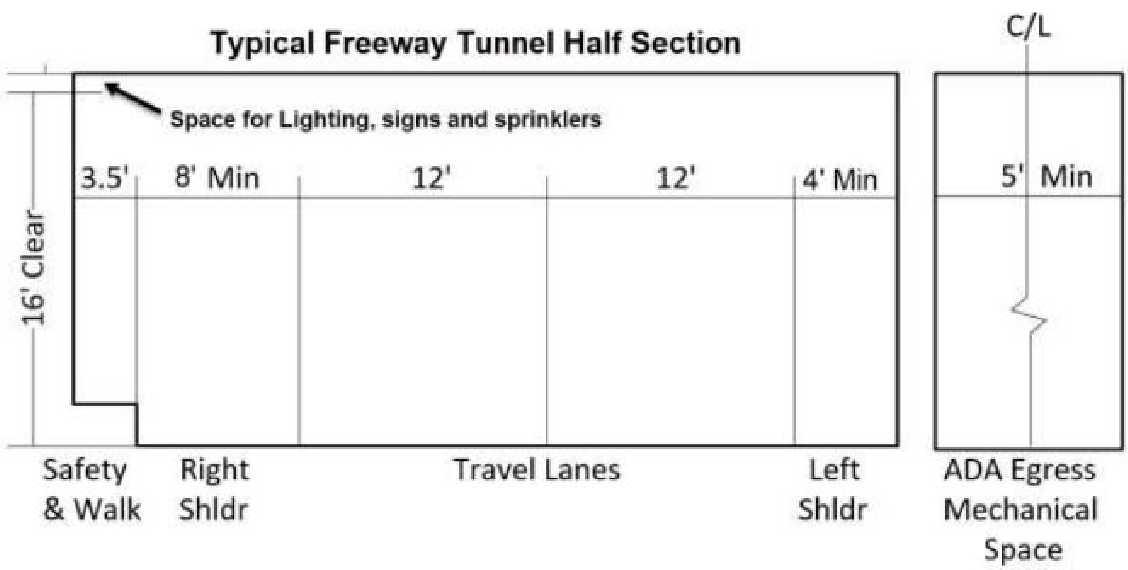

Figure 3 NYSDOT Highway Design Manual Typical Tunnel Section

2.1.2. FHWA

Tunnel Operations, Maintenance, Inspection, and Evaluation (TOMIE) Manual, 2015:

The TOMIE Manual identifies potential safety concerns of raised safety walks. Article 4.6.3.1: "It is also not uncommon for vehicles to crash against railings, curbs, and walkways."

2.1.3. AASHTO

AASHTO LRFD *Road Tunnel Design and Construction Guide Specifications*, First Edition, 2017:

- Article 2.7.3: "A minimum walkway width of 3′-6″ shall be provided outside the shoulders or, when no shoulders are present, outside the roadway. The walkway shall be raised above the roadway by a minimum of six inches."

AASHTO *Technical Manual for Design and Construction of Road Tunnels – Civil Elements*, June 2010:

- Article 1.3.3: Tunnel geometry must account for "shoulders or safety walks," implying that both are not required.
- Article 1.3.6.1: "Emergency egress walkways should be a minimum of 3.6 ft wide and should be protected from oncoming traffic."
- Article 2.4.3: "Sidewalks are required in road tunnels to provide emergency egress and access by maintenance personnel. The 5th Edition of Green Book (2004) recommends that raised sidewalks or curbs with a width of 2.5 ft or wider beyond the shoulder area be used as emergency egress…."

AASHTO *A Policy on Geometric Design of Highway and Streets*, 7th Edition, 2018:

- Article 4.7.2: "Vertical curbs and walkways may be desirable along the faces of long walls and tunnels, particularly if full shoulders are not provided. These curbs tend to discourage vehicles from driving close to the wall, and thus the walkway, reducing the risk to persons walking from disabled vehicles."
- Article 4.16.4: "Where sidewalks are provided for emergency egress by pedestrians, they must be designed to be accessible to and usable by pedestrians with disabilities… In long tunnels, 200 ft [60m] or more in length, the sidewalk width must be at least 4 ft [1.2 m] with passing sections at least 5-ft [1.5-m] wide every 200 ft [60 m]. Since varying the tunnel cross section to provide passing sections may be impractical, sidewalk with a continuous width of 5 ft [1.5 m] must generally be provided."
- Article 4.16.4: "Raised sidewalks are provided for through pedestrian movements in some nonfreeway tunnels. Normally, pedestrians are not permitted in freeway tunnels; however, raised sidewalks should be provided for emergency walking and for access by maintenance personnel."

2.1.4. International Recommendations and Best Practices

World Road Association (PIARC), *Prevention and Mitigation of Tunnel-Related Collisions*, D.5 Road Tunnel Operations, 2019R03EN:

This document compiles best practice experiences and advises on safe tunnel design. Some of the relevant considerations on safety, maintenance, and operation regarding elevated walkways are compiled in the table below (Table 1):

P8-T3	Avoid curb stones
General description and goal Traditional tunnel cross sections often include elevated lateral walkways, which are separated from the road surface by curb stones (height difference typically about 15 cm, but there are also other solutions with a much bigger height difference); practical experience shows, that this design on the one hand does not protect people being present on the walkways but on the other hand increases the collision risk, because it is located very close to the driving lane and if a vehicle hits the curb stone at high speed the likelihood of getting out of control is very high.	
Relevant aspects / context The main function of lateral walkways in general - whether elevated or not – is the function as escape route for emergencies (in particular tunnel fires). Moreover, lateral walkways may be used for maintenance purposes. In case of congestion an elevated walkway may impede car drivers from parking their cars on the walkway (thus blocking it). But the height difference is also a hindrance for people with reduced mobility. Lastly, elevated lateral walkways have some relevance for the general configuration of a tunnel cross section, because installations like cables or the surface drainage system can be placed underneath.	
Specifications Standard cross sections are typically defined in national guidelines (for example the RABT in Germany and the RVS 09.01.22 in Austria); many traditional standard cross sections (in particular in Europe) include lateral walkways with curb stones; in some guidelines the curb stones were eliminated – like in the Italian tunnel design guidelines "Caratteristiche Geometriche e funzionali delle Gallerie" from ANAS; in other guidelines a significant reduction of the height of the curbstone (to 3 cm) was introduced - like in the recent update of the German RABT.	
Effects on collision risk • Effect(s): Positive; distance to infrastructure elements next to driving lane is increased considerably, hence, drivers have a better chance to notice that they left the driving lane and correct their mistake (in particular if supported by measure P8-T5 rumble strips); more space available for safe evasion manoeuvres; both effects reduce the frequency of the affected collision types. Effect can be further improved if combined with measure M1-T3 Safety barrier against tunnel wall; • Relevant collision types: Collisions with tunnel infrastructure, collisions with other obstacles, side or side-swipe collisions, head-on collisions. • Effectiveness measure: Proven. • Supported by relevant cases: Yes (for example AT-01, AT-07, AT-10). • Supported by relevant literature: No (not found). • Supported by expert judgement WG2: Yes.	
Effects on other aspects of tunnel safety • Possibilities for self-rescue / evacuation: Positive, because an obstacle for people with reduced mobility is eliminated – also relevant for people evacuating in an atmosphere of reduced visibility (for example presence of smoke); however, increased likeliness that the walkway might be blocked by stopping vehicles. • Possibilities for emergency response services: Positive - an obstacle in the road surface is eliminated. • Other aspects: Neutral (if the walkway is kept and only the curb stones are eliminated) - the elevated walkway does not protect people standing there (for instance in case of vehicle breakdown); this statement is supported by expert opinion and practical experience (real incidents and videos of near- collisions).	
Implementation • Technical complication: Difficult to implement in existing tunnels, in particular if installations are placed underneath an elevated lateral walkway. • Hindrance for traffic (in case of existing tunnels): High – if implemented in an existing tunnel, major structural changes are required. • Investment / lifecycle cost: Low (for new tunnels) – High (for existing tunnels).	

Table 1 PIARC – Best Practice Experience and Recommendations

2.2. Egress Corridor

2.2.1. NYSDOT *Highway Design Manual*

The NYSDOT *Highway Design Manual*, Chapter 2, Article 2.7.5.9 requires a 4 ft minimum egress corridor on one side of a tunnel, and further expands that "the shoulder may serve as the Emergency Egress if it is 4 ft min" (Table 2).

Tunnel Critical Design Elements				
Elements	Freeway<800'	Freeway≥800'	Non-Freeway<200'	Non-Freeway≥200'
Design Speed	Use speed range for Mountainous (Note 5)		See Note 1	
Lane Width	12 ft min	12 ft min	11 ft min	11 ft min
Right Shoulder Width	8 ft min	8 ft min	4 ft min	4 ft min
Left Shoulder Width	4 ft min	4 ft min	2 ft min	2 ft min
Raised Safety Walk	3.5 ft min on one side	3.5 ft min on one side	Not required IF sidewalk provided	Not required IF sidewalk provided
Emergency Egress	4 ft min one side (Note 2)	4 ft min one side (Note 2)	4 ft min one side (Note 2)	4 ft min one side (Note 2)
5 ft Separated/Firerated Corridor	Not required	Required	Not required	Required for tunnels ≥ 800 ft
Sidewalk	NA	NA	4.0 ft min	5 ft min
Minimum Vertical Clearance	16 ft min	16 ft min	16 ft min	16 ft min
Notes				
1. For non-freeways, use Mountainous criteria for Design Speed range if available and apply Mountainous criteria for grades (where applicable)				
2. The shoulder may serve as the Emergency Egress if it is 4 ft min				
3. For all tunnels, the minimum clearance between the walls should be 33 ft (for tunnels<200ft) and 34.5 ft (for tunnels ≥ 200 ft).				
4. Note that for bored tunnels, the minimum radius of curves in the tunnel will depend on the boring equipment.				
5. In Urban Core Areas, continue to use values in 2.7.1.1A				

Table 2 NYSDOT Design Criteria

2.2.2. FHWA

Technical Manual for Design and Construction of Road Tunnels – Civil elements, 2009:

Article 1.3.6.1: "Where tunnels are provided in twin tubes, cross passages to the adjacent tube can be considered safe haven."

2.2.3. AASHTO

AASHTO LRFD *Road Tunnel Design and Construction Guide Specifications*, First Edition, 2017:

- Article 2.8.7.2: "An overall evacuation plan shall be developed that includes a system of tunnel egress which... creates a tunnel evacuation system with a logical and clearly marked path of egress within all portions of the tunnel to safe refuges within fire-protected areas of a tunnel, adjacent tunnel, or safe refuge outside the tunnel."

- Article C7.7.1.3: Cross passages are required by NFPA 502 when the tunnel length exceeds limits specified. Cross passages are used in conjunction with side-by-side tunnels."

AASHTO *Technical Manual for Design and Construction of Road Tunnels – Civil Elements*, June 2010:

- Article 1.3.6.1: "Where tunnels are tunnels constructed as twin tubes, cross passages to the adjacent tube can be considered safe haven. Cross passages should be of at least 2-hour fire rating construction, equipped with self-closing fire-rated doors that open in both direction or sliding doors, and located not more than 656 ft apart. An emergency walkway at least 3.6 ft wide should be provided on each side of the cross passageways."

- Article 1.3.6.1: "Emergency egress walkways should be a minimum of 3.6 ft wide and should be protected from oncoming traffic."

- Article 2.2.4: "For cut and cover, jacked, and immersed tunnels, it is preferable for the traffic tubes for the two directions to be constructed within a single structure, so that emergency egress by vehicle occupants into a neighboring traffic tube can be provided easily. Note that NFPA 50-2008 requires that the two tubes be divided by a minimum of 2-hour fire-rated construction in order to consider cross passageways between the tunnels to be utilized in lieu of emergency egress."

- Article 2.4.3: "NFPA 502 requires an emergency egress walkway within cross passageways to be of a minimum clear width of 3.6 ft." (note: contradictory to NFPA, see below)

2.2.4. National Fire Protection Association (NFPA)

NFPA 502, *Standard for Road Tunnels, Bridges, and Other Limited Access Highways*, 2023:

- Article 7.6.1: "All road tunnels… shall be provided with a means to stop approaching traffic."

- Article 7.16.6.3.1: "The tunnel roadway surface, when supported by a traffic management system, shall be considered as a part of the egress pathway."

- Article 7.16.6.3.2: "The egress pathway shall have a minimum clear width of 1.12 m (3.7 ft)."

- Article 7.16.6.7: "Where cross-passageways are used as an emergency exit, provisions shall be included that stop all traffic operation in the adjacent tunnel."

2.2.5. Recent Technical Literature

The most recent version of the comprehensive *Road Tunnel Ventilation Compendium and Practical Guideline* (see Pospisil, P., 2nd Edition, 2020, ISBN 978-3-9524178-4-3) outlines the impact of traffic management on the evacuation and ventilation strategies as follows: "*In all twin-tube tunnels, also the non-incident tube must be immediately closed in case of a fire alarm, since otherwise, in case of moving traffic, the goals of fire ventilation, especially the prevention of smoke spread at the portals, cannot be fulfilled. Enforcement of driver's compliance to signals is crucial* (see Figure 4)."

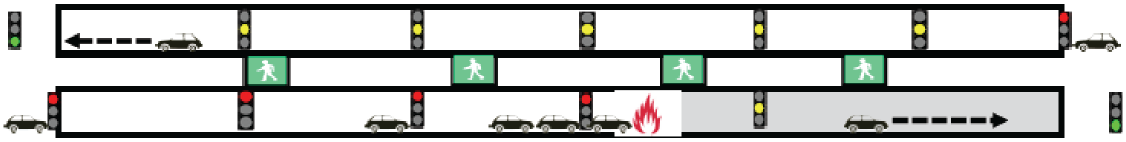

Figure 4 Fire alarm traffic signaling in both tubes of a highway tunnel

3. Lateral Walkways and Their Safety Appraisal

3.1. Raised Walkways

The use of raised walkways in tunnels can be traced back to the design of the Holland Tunnel, which was built between New York and New Jersey and opened in 1927. This iconic tunnel was one of the first to incorporate elevated walkways in its design, Figure 5. Over the following decades, this concept was adopted by other tunnel designers in the United States and has since become a common feature in tunnels, Figure 6, and requirements for a similar raised safety walk are included in the Department's *Highway Design Manual*, Figure 3 and Table 2.

Figure 5 Entrance to Holland tunnel, Jersey City NJ

The elevated walkways in the Holland Tunnel were created to not only improve accessibility for police officers to conduct efficient traffic surveillance, but also to facilitate maintenance operations. The walkways' policing function has been largely replaced by CCTV surveillance. Currently, the primary function of the walkways is to provide maintenance access to equipment rooms and niches that are located along the walkway for which no other access exists.

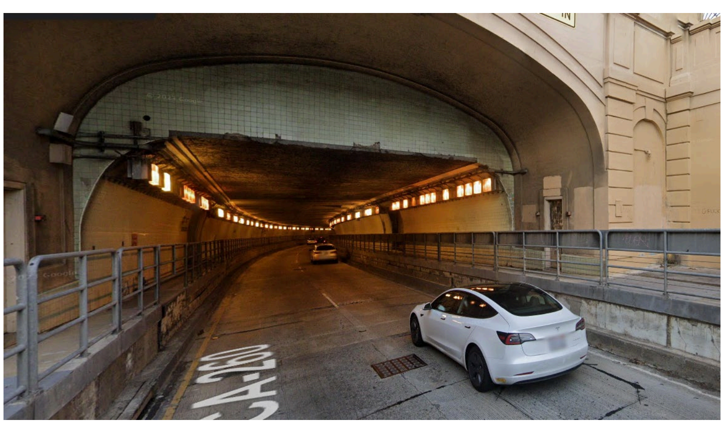

Figure 6 Raised walkways for pedestrians, Posey tunnel, Oakland CA

Often, raised safety walks are found in tunnels that do not have shoulders. These safety walks allow for minimal maintenance activities to occur without the need for lane closures. Access to structure and equipment from a raised safety walk is limited to elements within the horizontal limits of the safety walk, and maintenance operations from the safety walk are limited to what an individual can safely lift and carry. Maintenance and inspection of elements over travel lanes or maintenance of equipment over the safety walk that requires the use of heavy tools or replacement parts (including replacement of lights) require lane closures. A raised safety walk impedes maneuverability of a bucket truck to access equipment in the corner of the tunnel or the upper corner of the structure itself for hands-on inspection requirements.

Elevated walkways also increase maintenance and inspection requirements. Tunnel washing is typically performed once a year, and the elevated walkway can be an obstacle for this cleaning process. Raised walkways can also prevent effective cleaning and maintenance of the tunnel, as they can collect dust and debris over time. This can impair visibility and air quality in the tunnel, which can in turn increase the risk of accidents and other safety incidents.

Railings and raised safety walks are prone to vehicular impact and could cause accidents with deflection of errant vehicles. Intermediate access points, if provided, from the roadway or shoulder introduce additional safety risks of blunt surfaces to oncoming traffic and vaulting hazards in the case of access stairs and / or interruptions in the railing.

Note: Raised walkways were not intended to be used as an egress route during an emergency (fire or collision). These raised walkways do not allow for frequently spaced ADA compliant access points. Elderly, mobility-impaired persons, and children may not be able to use elevated walkways for egress due to the challenges of accessing the walkway via stairs or other means. Providing ADA compliant access to the walkway without causing additional safety concerns (vaulting, blunt surfaces to oncoming traffic, etc.) is challenging. In addition, egress and ingress by responders at the same time can lead to difficulties due to limited space on the elevated walkway. This can make it more challenging for responders to access the incident location and assist those in need of assistance, as well as create potential safety risks for all involved. In the event of an emergency, occupants of a tunnel typically evacuate through the main tunnel or designated emergency exits/cross-passage doors.

Elevated walkways in tunnels can increase the overall width of the tunnel, which can add to the cost and complexity of the construction process. This added cost can be difficult to justify given the absence of measurable benefits that elevated walkways provide for maintenance personnel or tunnel users in emergency situations. Additionally, railings increase future maintenance and inspection costs, require periodic rust protection application, and may require replacement to ensure the safety.

While elevated walkways have historically been recognized as a technical solution in road tunnel design standards, their initial justification and need may no longer exist.

3.2. Curb walkways

Curb walkways, also known as raised walkways or elevated walkways, are often used in tunnels to provide access for maintenance workers and other personnel. They are typically raised by approximately 6 inches from the roadway, allowing personnel to walk on a visually separated surface in the tunnel while traffic continues to move, Figure 7. Curb height walkways are considered mountable and would require lane/shoulder closures with attenuator trucks to protect maintenance personnel.

In some cases, the curb walkways can also be used for emergency egress before the incident has been detected and vehicles have exited the tunnel. In tunnels with low design speeds, curb walkways can be used in lieu of shoulders to serve as guidance for vehicles and help to improve safety in the tunnel. They are designed to be low-profile and not obstruct vehicles, but still provide a visual cue for drivers.

While curb walkways have been standard in many European tunnels for many years, they have also been associated with accidents in many cases. In cases of higher speeds, such as freeways similar to the Kensington Expressway, a curb height walkway would pose a vaulting hazard and would be considered a safety risk prone to such accidents.

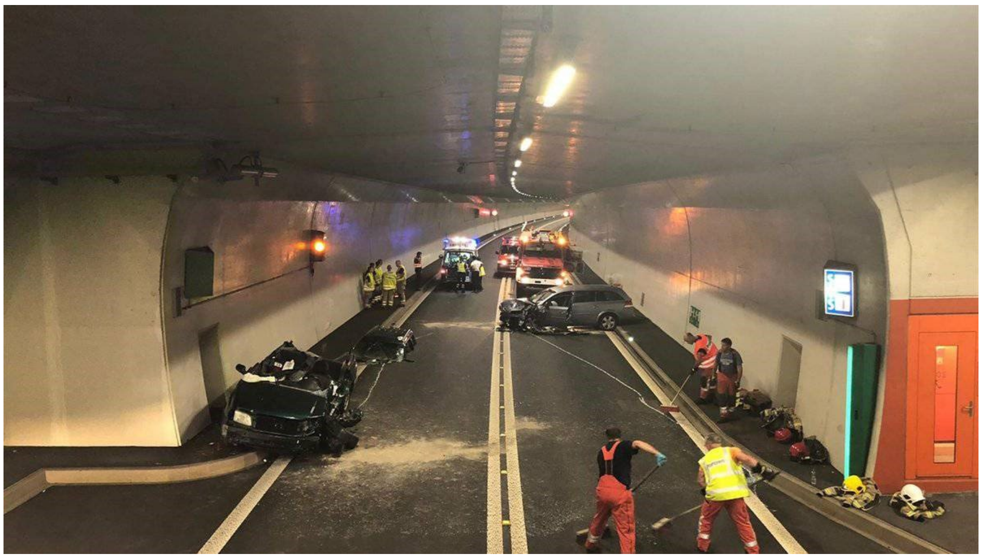

Figure 7 Accident in a tunnel with curb walkways, Roveredo, Switzerland

The use of curb walkways in tunnels is a complex issue, and it's important to consider the specific conditions of each tunnel, including its cross section, design and posted speeds, traffic volume, and emergency evacuation procedures, when deciding whether to include them in the design.

3.3. No walkways

In many tunnels, there are no walkways at all. As permitted by the Department's *Highway Design Manual* (Table 2), where there are shoulders, those may be used for egress, Figure 8.

Figure 8 Tunnel with shoulders, no walkways, I-90 Mercer Island, WA

NCHRP Project 20-68A canvassed various tunnel owners and published Scan 09-05, *Best Practices for Roadway Tunnel Design, Construction, Maintenance, Inspection, and Operations*, in 2011. In this document, the Alaska Department of Transportation and Public Facilities provided feedback that "the [Anton Anderson Memorial] Whittier Tunnel design is easy to maintain because it has no catwalks, substantial railings, or joints of concern…." The agency uses bucket trucks in lane/shoulder closures for light maintenance needs of this 13,300-foot-long combined highway and railroad tunnel.

4. Egress and Ingress Strategies

4.1. Evacuation Times, Course of Action

In case of a fire incident in a tunnel, evacuation behavior does not necessarily commence at the start of a fire. The available evacuation time is divided into several stages: detection and alarm, preparation for evacuation, and the actual movement towards the emergency exits, as illustrated in Figure 9. It is important to note that the time spent on foot inside the tunnel is brief compared to the period when conditions remain safe prior to air quality or structural degradation.

Therefore, it is crucial to ensure that the time for analysis and decision making is utilized effectively, and that information and education are provided to facilitate quick and efficient self-evacuation. This can be achieved by providing clear and effective information and training, as well as ensuring that the evacuation process is well-planned and executed.

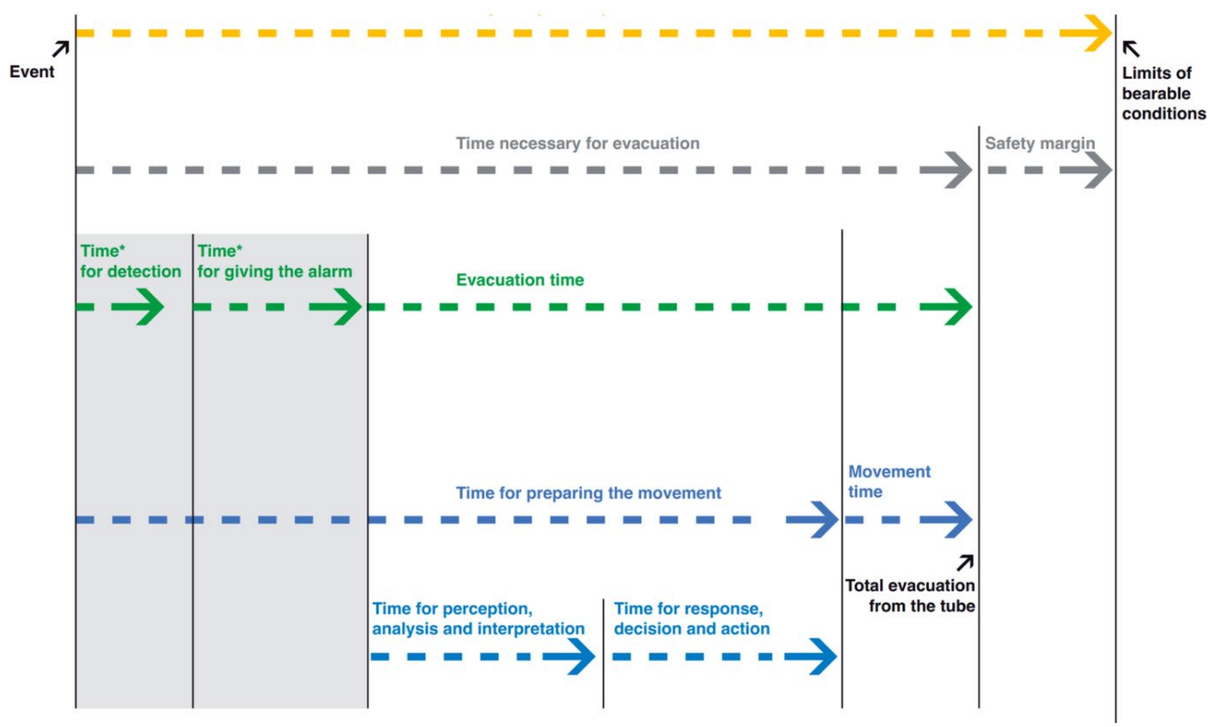

Figure 9 Elements Comparing the Time Necessary for Evacuation with the Time Available for Evacuation

Emergency egress in tunnels is a crucial safety element for tunnel users and responders and will be fully assessed and outlined in the tunnel safety documentation, which will include discussion of equipment such as auditory signals and beacons and visual chevrons and lights to support safe and effective emergency egress.

4.2. Evacuation in the Incident Tunnel

Evacuation in the incident tunnel is the default strategy for egress in the event of an emergency. Tunnel users are typically directed to evacuate the tunnel in the direction opposite to smoke movement, against the direction of normal traffic flow, to where there is clean air.

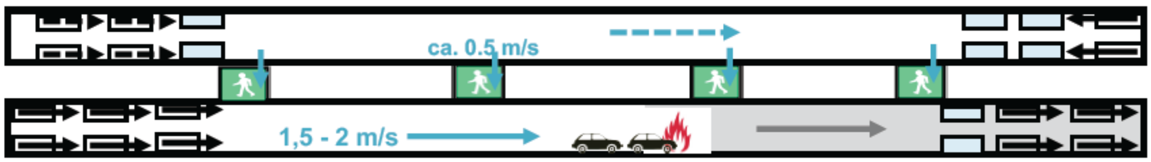

Figure 10 Fire ventilation and safe areas with clean air in both tubes of a highway tunnel

As long as traffic is moving, evacuees use the shoulders to walk along the roadway. As soon as the traffic stops, the whole width of the tunnel can be used.

It is important to note that elevated walkways do not typically play a role in evacuation, ingress, rescue, or firefighting activities in tunnels. While these walkways may provide additional access points or pathways in the event of an emergency, they are not typically designed or equipped to support large-scale evacuation or other emergency response activities.

4.3. Evacuation from the Incident Tunnel

It is important to note that evacuation from the incident tunnel is useful only for tunnel users that are situated in the smoke downstream of a fire, since upstream of the fire they are expected to be in clean air. This situation may occur in case of traffic congestion and a fire at the end of the queue.

The controlled ventilation ensures that in the immediate vicinity of the fire, there is smoke stratification, and smoke spread downstream is slowed down. However, further downstream, the tunnel cross section might fill with smoke, and there it is essential to provide means to evacuate from the incident tunnel.

Such evacuation might be to a safety shelter, where users should be reassured of the location's security upon entering. Such a room would be ventilated and fire protected and might provide phone line to communicate with the tunnel control center.

4.4. Evacuation into the Non-Incident Tunnel and Emergency Service Access

In twin tube road tunnels, the standard solution is to evacuate through cross-passages to the non-incident tunnel as a safe area, as documented in the code review in Chapter 2. The following are some safety strategies typically implemented in conjunction with cross passages to the non-incident tunnel for egress:

- Mechanical ventilation is used to control smoke propagation in the incident tunnel by controlling the air speed. Moderate air flow speed of the approaching air allows for stratification of the hot smoke layers and thus provides safe conditions for evacuation (egress) and approaching responders (ingress) as required by NFPA 502 standard (see Figure 11). The direction of the ventilation in the incident tunnel is in the direction of travel.

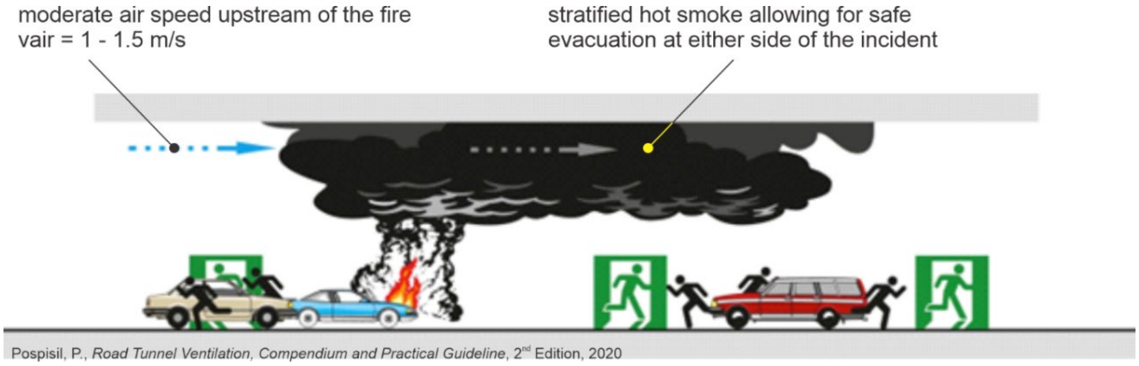

Figure 11 Longitudinal smoke control with low flow velocity (c.f., Pospisil 2020)

- Entry of smoke into the non-incident tunnel is prevented by appropriate ventilation measures, particularly with Jet Fans in the non-incident tube. The non-incident tunnel is ventilated in the same direction as the incident tunnel to prevent smoke from entering the non-incident tunnel at the exit portal (right-hand side of Figure 12). Jet-fans are also used to pressurize the non-incident tunnel and prevent smoke from entering through open cross-passage doors during egress or ingress.

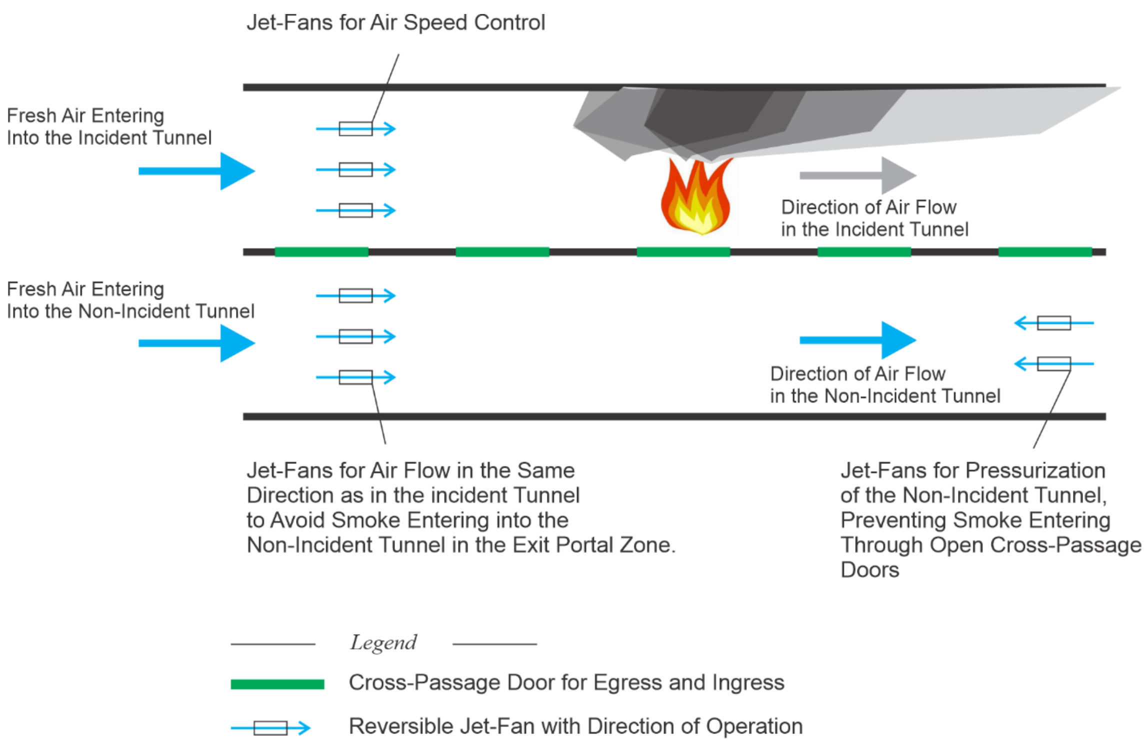

Figure 12 Use of the Mechanical Ventilation System in Both Tunnels (Schematic Illustration)

- In case of a fire, the traffic in both tunnel tubes must be stopped. Stopping measures might include ITS messaging deviating traffic to alternate routes in advance of the tunnel and signals/barriers at the entrance portals indicating closure of both the incident and non-incident tunnels. Stopping of traffic allows for ingress of emergency personnel into the non-incident tunnel and safe egress of individuals evacuating from the incident tunnel. By prohibiting additional vehicles from entering the non-incident tunnel, evacuees reach safe harbor in the non-incident tunnel which becomes otherwise vacant from traveling public.

- Traffic already within both tunnels after the onset of the incident must be warned and slowed down by variable signals (e.g., orange flashing). In first order, moving traffic in the incident tube is hindering evacuation. In comparison to that, moving traffic in the non-incident tube is of secondary importance. Slowing of vehicles exiting the non-incident tunnel mitigates some risk of those evacuating the incident tunnel being struck by a vehicle exiting the tunnel. It can be assumed that within a few minutes, vehicles in both tunnel tubes will have left, except the vehicles blocked by the incident location or during traffic congestion.

- Users should be made aware from clear signage that there may still be moving vehicles in the healthy tube.

- Sliding doors are the preferred means of egress between adjacent tunnels, as they do not reach into the traffic space and allow for opening forces independent of the ventilation scheme. This ensures that the doors can be opened quickly and easily.

- Approaching emergency services must be aware of the presence of people in both tunnel tubes. For emergency services, the empty non-incident tunnel is the fastest and safest means of access to approach close to the fire location and then by cross passages into the incident tunnel to the fire site, since the incident tunnel may be impaired by standing vehicles upstream and smoke downstream.

Even in tunnels with a service / utility corridor between tunnel tubes, the typical emergency exit is to the other tube. In this case, users should be directed to continue into the other tube without stopping in the area connecting the two tubes. The inter-tube area is only for crossing between tubes and should not be treated as an area to wait for help. Users must be prevented by appropriate signage to stay in the inter-tube.

4.5. Evacuation into a Corridor Between Both Tunnels

Emergency/evacuation and service tunnels are often provided in single tube tunnels with bidirectional traffic. In twin tube unidirectional tunnels, an evacuation corridor between tunnels is not considered a generally acknowledged rule of technology or best practice solution for tunnel safety. While these corridors can provide an additional means of escape and help to ensure the safety and well-being of tunnel users in emergency situations, they also present a number of challenges and require careful planning and coordination.

Most importantly, they cannot be effectively used for emergency access, particularly fire trucks.

To keep the corridor free of smoke in case of open egress doors, the corridor needs to be pressurized. This helps to prevent smoke and other hazardous materials from entering the corridor and provides a safe and healthy environment for tunnel users and emergency response personnel.

The corridor also requires adequate lighting, space for people with reduced mobility or wheelchairs, and exits with doors in air locks. These features help to ensure that the corridor is accessible to all users and can support safe and efficient evacuation in the event of an emergency, while maintaining pressurization.

The separate and additional equipment required for an evacuation corridor increases initial project costs and future maintenance requirements. In addition, the width of the egress corridor required for safe and efficient evacuation adds to the capital, operating, and maintenance costs of the overall structure due to the additional width.

Corridors between tunnels are not mandated by generally accepted technology standards, nor are they required by fire and life safety regulations (e.g., NFPA 502). While providing benefits for utility installation and service access, corridors in urban road tunnel projects may create challenges for responders and evacuees due to limited space. Responders may encounter difficulty entering the corridor to assist people in both the incident tunnel and the corridor, while evacuees may find it challenging to escape the corridor.

The function of emergency exit doors from the corridor to the surface must not be impeded by snow or ice during winter conditions. This can be a significant challenge in regions with harsh winter weather and may require additional maintenance efforts to ensure that the doors remain accessible and functional in all conditions.

Therefore, in most projects with utility corridors between two tunnel tubes, the emergency egress is typically still through the corridor to the adjacent non-incident tunnel.

4.6. Evacuation to the Surface

Emergency exits stairs or access tunnels to the surface are applied in many projects, particularly in single-bore tunnels without an adjacent second tunnel bore. However, the installation and maintenance of these exits can present a number of challenges and expenses.

Emergency exits require additional means of ventilation, emergency lighting, means of communication, and other features to ensure their effectiveness in emergency situations. This can add to the cost and complexity of the tunnel construction and maintenance process, requiring additional resources and expertise.

Emergency exits located at the surface can also be vulnerable to vandalism, which can compromise their effectiveness and create additional safety risks. This may require additional security measures, such as cameras or other surveillance systems, to prevent or mitigate damage.

The function of emergency exit doors to the surface must not be impeded by snow or ice during winter conditions. This can be a significant challenge in regions with harsh winter weather and may require additional maintenance efforts to ensure that the doors remain accessible and functional in all conditions.

Emergency exits located in the middle of the tunnel can also present additional challenges for firefighters and other responders, as they require additional resources and coordination to approach and access. This can make the rescue and firefighting process more complex and time-consuming, adding to the overall cost and complexity of the tunnel emergency response system.

Emergency exits to the surface can also require additional capital costs and maintenance efforts.

4.7. Maintenance Access

Maintenance access points to locations of interest, such as mechanical and electrical rooms can be provided both from within the tunnel or from the surface. Access points from the surface are preferred and will usually be by stairway and might be suitable for routine maintenance needs. In the event of repairs that require large or heavy tools or replacement parts, a door at tunnel level, accessible from the shoulder may provide more suitable entry.

Maintenance access at the surface can also be vulnerable to vandalism, which can compromise their effectiveness and create additional safety risks. This may require additional security measures, such as cameras or other surveillance systems, to prevent or mitigate damage.

Maintenance access to the surface must not be impeded by snow or ice during winter conditions. This can be a significant challenge in regions with harsh winter weather and may require additional maintenance efforts to ensure that the doors remain accessible and functional in all conditions.

5. Recommendations and Conclusions

The present report examined the advantages and disadvantages of elevated walkways in tunnels and discussed various evacuation strategies to facilitate safe evacuation in case of emergency.

We recommend the following for the design and operation of the Kensington Expressway tunnel:

1. Provide 8′ right shoulder and 6′ left shoulder to provide safety offset to tunnel walls, minimize accident risks, and allow for adequate shoulder width to serve as egress in case of an incident.

2. Provide cross-passages between adjacent tunnels at regular distances, equipped with fire-resistant sliding doors. This provides multiple means of egress, especially when fires occur during traffic congestion. Cross-passages between tunnels are especially important for fast and safe emergency service access.

3. Implement ITS safety measures, such as advanced warning signs, stop signals, and barriers at the portals, to prevent cars from entering both incident and non-incident tunnels in case of an incident. Additionally, implement measures to reduce the speeds of vehicles exiting the tunnels for additional safety of evacuees.

4. Design and specify tunnel equipment to reduce maintenance intervals to a maximum of once per year.

5. Provide maintenance access to mechanical and electrical rooms (3 anticipated: one near each portal and one near the middle of the tunnel) both from surface and tunnel levels.

Further, we recommend the following be omitted from the design and operation of the Kensington Expressway tunnel:

1. A separate egress and utility corridor between adjacent tunnels is not recommended due to the increased width and cost of the tunnel, without substantial benefit. They are not mandated by generally acknowledged rules of technology or by adequate fire and life safety regulations and may create challenges for responders and evacuees.

2. Elevated walkways are not considered to be a viable means of egress and ingress and are therefore not recommended. This is due to the increased width and cost of the tunnel without tangible benefit, as well as the potential safety risks that they can create.

Overall, the recommendations made in this report comply with the most relevant US standard on tunnel safety (NFPA 502) and represent the generally acknowledged rules of technology on tunnel safety.

In summary, it can be concluded that elevated walkways in tunnels do not contribute significantly to safety and operation. They increase the overall width of the tunnel and lead to additional costs and safety risks. In addition, they can make effective cleaning and maintenance difficult, which can impair visibility and air quality and increase the risk of accidents. Instead, tunnels should be equipped with multiple escape and access routes to the non-incident tunnel and other measures to ensure the safety and well-being of users and emergency responders in the tunnel. By providing clear and concise guidelines for the design, maintenance, and use of these measures, tunnel operators can help ensure the safety and well-being of everyone who uses the tunnel, both in normal and emergency situations.