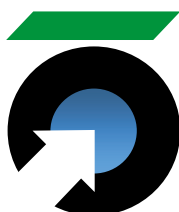


CURRENT PRACTICE ON CROSS-PASSAGE DESIGN TO SUPPORT SAFETY IN RAIL AND METRO TUNNELS

ITA-COSUF
Regulations, Guidelines and Best Practice

N° ISBN: 978-2-9701242-4-5

ITA COSUF N° 03 / MAY 2019



ITA COSUF

ITA Committee on
Operational Safety of
Underground Facilities

ITA COSUF n° 03 - **Current practice on cross-passage design to support safety in rail and metro tunnels**
N°ISBN: 978-2-9701242-4-5 / May 2019

The International Tunnelling and Underground Space Association/Association Internationale des Tunnels et de l'Espace Souterrain (ITA/AITES) publishes this report to, in accordance with its statutes, facilitate the exchange of information, in order: to encourage planning of the subsurface for the benefit of the public, environment and sustainable development to promote advances in planning, design, construction, maintenance and safety of tunnels and underground space, by bringing together information thereon and by studying questions related thereto. This report has been prepared by professionals with expertise within the actual subjects. The opinions and statements are based on sources believed to be reliable and in good faith. However, ITA/AITES accepts no responsibility or liability whatsoever with regard to the material published in this report. This material is: information of a general nature only which is not intended to address the specific circumstances of any particular individual or entity; not necessarily comprehensive, complete, accurate or up to date; This material is not professional or legal advice (if you need specific advice, you should always consult a suitably qualified professional).

CURRENT PRACTICE ON CROSS-PASSAGE DESIGN TO SUPPORT SAFETY IN RAIL AND METRO TUNNELS

ITA-COSUF

Regulations, Guidelines and Best Practice

Cross-passages are important elements of twin-tube rail or metro tunnels. During construction and operation, the cross-passages serve different functions. For the operation phase of a tunnel, major requirements result from the different needs of normal, maintenance and emergency mode of tunnel operation.

During an emergency, cross-passages contribute significantly to the safety of tunnels by providing an escape route for the tunnel users from the incident to the non-incident tube, i.e. to a safe area, and by providing an access route for emergency forces from the safe area to the incident tube. Cross-passages need to be designed such that smoke or hazardous gases may not propagate into or through the cross-passages in order to protect the safe area in the non-incident tube. During normal operation, the cross-passages shall house and protect technical equipment of various technical systems (e.g. low voltage power supply, data / communication installations, etc.). During maintenance, the cross-passages shall support a safe working environment for staff.

Different layouts of cross-passages for rail and metro tunnels are implemented to support the predefined protection goals within the overall safety concept and to meet the other functional requirements. This document aims at supporting the design of appropriate safety aspects of cross-passages in rail and metro tunnels by providing an overview of safety relevant aspects and common practice. Designers should consider them and analyse to which extent the given layouts and requirements apply to their project of interest.

The document at hand was established by “Activity Group 2 – Regulations, Guidelines and Best Practice” of the Committee on Operational Safety of Underground Facilities (COSUF) of the International Tunnelling and Underground Space Association (ITA). Major contributions to the document were given by Marco Bettelini, Marc Boitel, Les Fielding, Helmut Kern, Reto Linder, Samuel Rigert and Severin Waelchli under the lead of Stig Ravn and Peter Reinke of Activity Group 2. The authors would like to express their gratitude to the reviewers Eric Premat, Haukur Ingasson, John Day and members of the ITA-COSUF Steering Board who have enriched this work.

For the future, any comments and suggestions to further update or expand this overview are very welcome.

>> TABLE OF CONTENTS

1 INTRODUCTION	5
2 OBJECTIVES	5
3 SCOPE	6
4 DEFINITIONS AND REFERENCED DOCUMENTS	6
4.1 DEFINITIONS	6
4.2 RELATED STANDARDS AND GUIDELINES	7
4.3. REFERENCED PUBLICATIONS	8
5 BOUNDARY CONDITIONS FOR CROSS-PASSAGE	8
6 PURPOSE AND FUNCTIONAL REQUIREMENTS OF CROSS-PASSAGES.....	9
6.1 OVERVIEW	9
6.2 PURPOSE DURING CONSTRUCTION	9
6.3 PURPOSE DURING NORMAL OPERATION	9
6.4 PURPOSE DURING MAINTENANCE	10
6.5 PURPOSE DURING INCIDENTS	10
7 TYPICAL DESIGN SOLUTIONS AND NORMATIVE REQUIREMENTS FOR CROSS-PASSAGES	10
7.1 NORMATIVE REQUIREMENTS	10
7.2 LAYOUT OF CROSS-PASSAGE	13
7.3 APPEARANCE AND VISIBILITY	16
7.4 EQUIPMENT	18
7.5 SAFETY COMPONENTS IN THE TUNNEL TUBES	23
8 ILLUSTRATIVE EXAMPLES OF CROSS-PASSAGES (STATE-OF-THE-ART)	24
8.1 RAIL TUNNELS	24
8.1.1 GOTTHARD-BASE TUNNEL	24
8.1.2 LOETSCHBERG BASE TUNNEL	28
8.1.3 NEW GUANJIAO TUNNEL	31
8.1.4 STUTTGART 21	33
8.2 METRO TUNNELS	34
8.2.1 DELHI METRO LINE 8	35
8.2.2 METRO MILAN LINE M5	36
8.2.3 METRO DOHA PHASE 1 GOLD LINE	37
9 CONCLUSIONS ON CURRENT PRACTICE AND TRENDS	38

1 >> INTRODUCTION / 2 >> OBJECTIVES

1 INTRODUCTION

An increasing share of traffic tunnels are designed as twin-tube systems. The tubes are inter-connected by galleries. During the construction, operation and refurbishment phases of the tunnel's lifecycle, these cross-passages may serve different purposes:

- To connect an incident tube with a safe area by providing an egress path for evacuees or an access path for rescue services during an emergency
- To offer a temporary shelter or waiting area for evacuees or rescue services during an emergency
- To provide an aerodynamic, fire- and smoke-safe separation between different tubes during all operation modes
- To house technical equipment in a controlled environment during all operation modes
- To provide an access path for staff to technical equipment inside the cross-passage or in the opposite tube(s) during maintenance mode of operation

- To support ventilation purposes and the environmental control of the tunnels during all operation modes
- To provide a passage for tunnel works and transportation (conveyor belts, pipes, cables, drainage, vehicles, etc.) during construction and refurbishment phases.

Because of these various requirements and boundary conditions, the layout of cross-passages in tunnels may vary considerably. In addition, the construction of cross-passages in twin-tube tunnels may be a risk-prone activity and become a costly task depending on the ground conditions. Therefore, the design of cross-passages requires particular attention in order to meet the numerous technical, legal, safety and economic requirements.

Specific aspects of the aforementioned requirements of cross-passages are the tasks to provide operational safety and the consideration of the specific requirements of rail and metro tunnels.

Safety guidelines for road tunnels have reached a high level of detail and exhibit a substantial degree of international harmonization. In contrast, safety requirements for rail tunnels and underground systems are limited to more basic requirements and are less uniform (e.g. TSI-SRT [1], NFPA 130 [15], UIC [5]). This applies as well to cross-passage design of rail and metro tunnels. Therefore, a comprehensive overview of state-of-the-art, safety-oriented cross-passage design for rail and metro tunnels is desirable.

The layout and key parameters characterizing cross-passages, including maximum distance, minimum dimensions, technical equipment and level of protection, depend on a number of regulations and vary significantly from country to country. Such differences are only partly due to the specific characteristics of a tunnel but are related to a large extent to the lack of explicit regulations or references on such issues. An overview appears helpful to present similarities and differences and facilitate the proper inclusion of operational safety requirements in tunnel design.

2 OBJECTIVES

This document aims at supporting the design of safety aspects of cross-passages in rail and metro tunnels. Objectives of the current practice overview at hand are as follows:

- To provide expert guidance for general design issues and optimum design
- To avoid suboptimal design and prevent mistakes, which could require costly refurbishments
- To provide practical examples of current practice
- To support international harmonization and foster technical advance
- To compensate existing normative gaps.

The following aspects shall be addressed herein:

- Basic concepts of cross-passages and relevant reference documents
- Functions of cross-passages and functional requirements
- Overview of normative requirements
- Typical design solutions with respect to layout, appearance, main dimensions, equipment and protection
- Illustrative examples from tunnels in operation or at an advanced design stage.

3 >> SCOPE / 4 >> DEFINITIONS AND REFERENCED DOCUMENTS

3 SCOPE

This guideline focuses on the safety requirements and solutions for cross-passages of twin-tube rail and metro tunnels (see Figure 1). The objective of this document is to provide a better understanding of the importance and implications of the relevant issues. It should be understood that the focus on the safety aspects of cross-passage design in this document is only one of many other closely linked aspects. It is by no means intended as a replacement of national and international regulations or recommendations. Amongst others, this guideline does not cover the following aspects:

- Road tunnels
- Structural issues and construction of cross-passages
- Technical details of equipment and components
- Emergency galleries parallel to a single-tube traffic tunnel



Figure 1: Cross-passage between tunnel tubes

- Emergency exits with vertical stairwells
- Emergency exits with horizontal adits
- Shelter rooms
- Emergency exits and galleries in emergency stops
- Emergency exits with single door assemblies in tunnel tubes separated by a single wall only (e.g. submersed tunnels with parallel tubes)
- Emergency exits in double-deck tunnels.

In addition, this guideline does not attempt to present universally applicable solutions for the design and construction of cross-connections. Every tunnel has its own characteristics and peculiarities, related to a wide spectrum of requirements and boundary conditions, ranging from geology, construction method, type of traffic, national or regional safety approaches and rolling stock to maintenance and retrofit.

4 DEFINITIONS AND REFERENCED DOCUMENTS

4.1 DEFINITIONS

Definitions for selected terms used in this document are given below. A more comprehensive list of definitions relevant to the subject addressed is given, for example, by TSI-SRT [1], NFPA 130 [15], UIC [5] or ISO [6].

Double-bore, single-track tunnels: Double-bore, single-track tunnels (in contrast to single-bore, double-track tunnels) are being built, amongst others, to provide a safe area in the non-incident tube, to avoid accidents caused by a derailed train obstructing the adjacent track, to allow safer maintenance by stopping train operation in one tube and to assure better rescue conditions in the event of an accident, especially in the event of fire ([5]).

Escape travel distance: The maximum distance from a certain location in an incident tube to a safe place (non-incident tube, portal, emergency exit) in order to enable self-rescue ([5]).

Cross-passage: Connection between tunnel tubes, generally equipped as egress and intervention route. A cross-passage provides a safe separation of the incident tube (danger zone) from the non-incident tube (safe area). The cross-passage itself is not necessarily a safe area but mostly an egress/access path only. Connections between two tunnel tubes with a single door in a dividing wall are not considered as cross-passages within this document.

Egress: Exiting from a zone exposed to harmful effects of a fire to a safe area or point of safety.

Escape route/path: Provision of walkways in tunnels to facilitate escape (normally along tunnel walls lateral to trackway; also in or between tracks if there is front/back-end disembarkment from vehicle and/or not enough lateral space); further escape route/path through cross-passages, adits, shafts, stations ([5]).

Emergency scenario: Scenarios shall consider the location, start-time and temporal

evolution of the size of the fire and the related sequence of emergency actions (e.g. time of detection, alarm, train stop, ventilation activation, etc.).

Safe area / Point of safety: A place inside or outside a tunnel or station where all of the following criteria apply:

- a) Conditions are survivable
- b) Access for people is possible aided or unaided
- c) People may accomplish self-rescue, if possible, or may wait to be rescued by the rescue services using procedures detailed in the emergency plan
- d) Communication shall be possible (mobile phone, fixed connection).

Tenable environment / conditions: A tunnel environment or conditions that allows the self-rescue or survival of occupants. The level of tenability may be different for the self-rescue phase and for the intervention phase, where protected emergency services are present in the tunnel system.

4.2 >> RELATED STANDARDS AND GUIDELINES

Design fire: Definition of the fire properties used, for example, for design of ventilation, fire-resistance of civil structures, risk assessment, particularly in terms of maximum value and temporal development of the fire heat-release rate, smoke plume temperature and release rate of harmful gases.

Human behaviour: Mood, emotions and physical reactions of individuals, as well as the interactions of a group of persons confronted with an emergency situation. Typically, the range of human behavior covers everything from staying calm to panic. However, the occurrence of panic during fire incidents is rare and the people concerned usually show rational behavior.

Person with disabilities and person with reduced mobility (PRM): Any person who has a permanent or temporary physical, mental, intellectual or sensory impairment which, in interaction with various barriers, may hinder their full and effective use of transport on an equal basis with other passengers or whose mobility when using transport is reduced due to age [TSI-SRT, [1]].

4.2 RELATED STANDARDS AND GUIDELINES

Standards and guidelines frequently referred to in tunnelling projects are given in the following listing. Their focus is characterised as follows:

- International focus: [1] [2] [3] [4] [5] [6] [7]
- National focus: [8] [9] [10] [11] [12] [13] [14] [15] [16] [17] [18]
- Long-distance / Heavy rail focus: [1] [2] [3] [6] [7] [10] [11] [14] [15] [16] [17] [18]
- Metro / Light rail focus: [4] [5] [6] [7] [8] [9] [12] [13] [15]
- Tunnel focus: [1] [5] [10] [12] [14] [15] [16] [17] [18]
- General infrastructure / technical systems focus: [2] [3] [4] [6] [7] [8] [9] [11] [13]

- [1] European Commission, "Commission Regulation (EU) No 1303/2014 of 18 November 2014 concerning the technical specification for interoperability relating to 'safety in railway tunnels' of the rail system of the European Union", TSI-SRT, 2014
- [2] European Commission, "Commission Regulation (EU) No 1300/2014 of 18 November 2014 concerning the technical specification for interoperability to accessibility of the Union's rail system for persons with disabilities and persons with reduced mobility", TSI-PRM, 2014
- [3] European Commission, "Commission Regulation (EU) No 1302/2014

- of 18 November 2014 concerning the technical specification for interoperability relating to the 'rolling stock – locomotives and passenger rolling stock' subsystem of the rail system in the European Union", TSI-LOC-PAS, 2014
- [4] European Committee for Standardization (CEN), "Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS) - Part 1: Basic requirements and generic process", European Norm EN 50126-1:1999, 1999
- [5] Union International des Chemin Fer (UIC), "UIC-Codex 779-9 - Safety in Railway Tunnels", August 2003
- [6] International Standards Organization ISO, "Fire safety engineering - Part 1: Application of fire performance concepts to design objectives", ISO/TR 13387-1, 1999
- [7] International Standards Organization ISO, "Life-threatening components of fire – Guidelines for the estimation of time available for escape using fire data", ISO 13571, 2012
- [8] German Ministry of Transportation, "Verordnung über den Bau und Betrieb der Strassenbahnen (BoStrab) - Regulation on construction and operation of underground fixed guideway transit and passenger rail systems", in German, 1987 with last modification in 2007
- [9] German Ministry of Transportation, "Technische Regeln Strassenbahnen – Brandschutz (TR Strab BS) - Technical standard for tramways – fire protection (TR Strab BS)", Edition: 21.08.2013

- [10] EBA – Eisenbahn-Bundesamt, "Anforderungen des Brand- und Katastrophenschutzes an den Bau und den Betrieb von Eisenbahntunneln – Requirements of fire and emergency management in rail tunnels", in German, 01.07.2008
- [11] EBA – Eisenbahn-Bundesamt, "Leitfaden für den Brandschutz in Personenverkehrsanlagen der Eisenbahnen des Bundes – Guideline for fire safety in infrastructure for passenger transportation of federal railways", in German, 01.03.2011
- [12] Ministère des transports, de l'équipement, du tourisme et de la mer; "Arrêté du 22 novembre 2005 relatif à la sécurité dans les tunnels des systèmes de transport public guidés urbains de personnes" (in French); Journal officiel du 9 décembre 2005
- [13] Le ministre d'Etat, ministre de l'écologie, du développement et de l'aménagement durables, et la ministre de l'intérieur, de l'outre-mer et des collectivités territoriales, "Arrêté du 24 décembre 2007 portant approbation des règles de sécurité contre les risques d'incendie et de panique dans les gares" (in French), Journal officiel du 16 avril 2008
- [14] Ministère de l'Intérieur, Ministère de l'Équipement, des Transports et du logement, "Instruction technique interministérielle relative à la sécurité dans les tunnels ferroviaires", N°98 300 du 8 juillet 1998
- [15] NFPA 130, "Standard for fixed guideway transit and passenger rail systems", National Fire Protection Agency, 2017

5 >> BOUNDARY CONDITIONS FOR CROSS-PASSAGE

- [16] Swiss Tunnel Code, "SN 505 197/1, SIA 197/1:2003. Design of Tunnels - Railway Tunnels", 2003
- [17] SBB/CFF/FFS (Switzerland), Selbstrettungsmassnahmen in Tunnel - Infrastrukturmassnahmen zur Erleichterung der Selbstrettung in Tunnel», I-20036, 2015
- [18] TB10020-2012, "Railway Tunnel Design Code on Disaster Prevention, Rescue and Evacuation", China, 2012

4.3 REFERENCED PUBLICATIONS

- [19] H. Ehrbar, L. Gruber & A. Sala (Editors), "Tunneling the Gotthard – The success story of the Gotthard Base Tunnel", STS Swiss Tunneling Society, ISBN 978-3-033-05803-3, 2016
- [20] ITA COSUF, "An Engineering Methodology for Performance-Based Fire Safety Design of Underground Rail Systems", ITA COSUF No. 01, ISBN 978-2-9700858-2-9, 2014

5 BOUNDARY CONDITIONS FOR CROSS-PASSAGE

The characteristics and features of tunnels may vary considerably leading to different cross-passage requirements. Different boundary conditions affecting , more or less directly, the layout of cross-pass-ages in rail and metro tunnels are given in Table 1.

It is critically important to understand that numerous aspects affect the cross-passage layout as shown by the examples of Table 1.

These need to be reviewed for each individual project. The safety aspects and solutions cannot be considered in isolation from the various other functional requirements of cross-passage and the tunnel features. It is a major difference, for instance, whether the cross-passage is part of a metro tunnel with typically short access distances in a tropical climate setting or part of a long-distance high-speed Alpine rail tunnel with mixed traffic.

As a consequence of the multitude of boundary conditions affecting the cross-passage design (see Table 1), universally valid recommendations are difficult to specify. The best concept and solution of safe cross-passage design depend on the specific requirements and boundary conditions of a tunnel.

Table 1: Boundary conditions affecting cross-passage requirements

Aspect	Variations
Purpose	<ul style="list-style-type: none"> Rail, metro, utilities, combinations thereof
Types of trains	<ul style="list-style-type: none"> Passenger trains (urban, long-distance), freight trains, shuttle trains High-speed, "moderate", low speed traffic Heavy rail, light rail
Rules and standards	<ul style="list-style-type: none"> National or international laws (for cross-border projects), standards, guidelines, regulations, recommendations, common-practice, requirements of local fire-safety authorities
Location	<ul style="list-style-type: none"> Urban, sub-urban, inter-urban, remote, mountainous, under-water
Global layout	<ul style="list-style-type: none"> Single tube, twin tube, multi tube, with/without service tunnel Single track, twin track, multiple track
Civil design	<ul style="list-style-type: none"> Construction method: Drilled, drill-and-blast, cut-and-cover, submersed Length Free cross-sectional dimensions of traffic tunnels Horizontal and vertical alignment Access distance from outside to tunnel Station design Mutual distance / number of cross-passages Length of cross-passages
Train or rolling stock features	<ul style="list-style-type: none"> Velocity Geometry: Length, width, height Power supply: Diesel, electric (catenary, third-rail, battery) Emissions Heat release Quantity and type of goods No. of passengers Principal egress path from train (lateral, front & back ends) On-board fire suppression systems Fixed-block or moving-block (cab-based or communication-based) signalling With train driver, unattended train operation
Operational aspects	<ul style="list-style-type: none"> Vehicle frequency / headway Minimal allowed stopping distance Uni- / bi-directional traffic Allowed type of vehicles Operation rules

6 >> PURPOSE AND FUNCTIONAL REQUIREMENTS OF CROSS-PASSAGES

Aspect	Variations
Environmental conditions	<ul style="list-style-type: none"> • Tunnel aerodynamics (train induced pressure changes and airflow) • Outside meteorology (weather, thermal draft, etc.) • Environmental conditions in tunnel (Temperature, humidity, air flow, pressure variations) • Air quality: Pollution, dust
Ventilation of tunnel	<ul style="list-style-type: none"> • Natural / mechanical • Longitudinal / transverse / semi-transverse / push-pull • Ventilation zones or not • Shafts for ventilation
E&M aspects of tunnel	<ul style="list-style-type: none"> • Power supply • Communication • Lighting • Water supply and pressurization • Fixed fire suppression systems: All along tunnel, local fire-fighting sections
Safety / Incident protection	<ul style="list-style-type: none"> • Design fire and incident scenarios • Egress concept from trains (via lateral doors or front/rear-end disembarkment) • Egress concept in tunnel, i.e. on lateral sidewalks, on trackway • Intervention access of emergency services: by walking from portals, stations, emergency shafts and galleries; by rescue trains in non-incident or incident tube; by road vehicles moving on trackway accessible for road vehicles in non-incident or incident tube • Station design to cope with evacuees from tunnels
Security	<ul style="list-style-type: none"> • Access control and surveillance limited to portals only or at every cross-passage • Separation of critical E/M equipment from egress path
PRM	<ul style="list-style-type: none"> • Geometry and quality of egress path
Occupational health requirements / accident prevention	<ul style="list-style-type: none"> • Accident prevention (risks from slamming of cross-passage doors at high air velocity) • Locking of doors during high-speed train operation or always unlocked
Incident management	<ul style="list-style-type: none"> • Organisation of emergency forces • Means of communication

6 PURPOSE AND FUNCTIONAL REQUIREMENTS OF CROSS-PASSAGES

6.1 OVERVIEW

Cross-passages connect two tunnel tubes. The functionality and use of cross-passages is different during construction and operation, resulting in different requirements related to the different operating conditions.

The following sections list possible functions of cross-passages during construction, normal operation and emergency operation. Functions and requirements have to be considered carefully during the design phase, in order to find the best solution for the specific project.

6.2 PURPOSE DURING CONSTRUCTION

During construction with the parallel construction of the 2 tubes, cross-passages are used mainly for logistic purposes.

Examples include:

- Housing of technical equipment/logistic for construction purposes
- Material storage
- Support of ventilation and cooling of construction-sites in tunnel
- Self-rescue and protection in the event of fire incidents during construction

They also represent singular points of the regular tunnel excavation process and can significantly influence aero-thermal conditions and air quality in tunnel. They need therefore a proper planning and require a complex logistic concept.

6.3 PURPOSE DURING NORMAL OPERATION

During normal operation, cross-connections are generally not accessible. Their role is mainly as follows:

- Housing of technical equipment (electrical installations for power supply, data/communication, signalling, fire detection, drainage, light, water supply, water storage)
- Protection of technical equipment requiring a well-controlled environment in terms of temperature, air quality (in particular dust concentration) and pressure fluctuations
- Cable transit
- Support of tunnel ventilation

During normal operation, cross-connection can influence aero-thermal conditions in tunnels.

7 >> TYPICAL DESIGN SOLUTIONS

6.4 PURPOSE DURING MAINTENANCE

Maintenance can be carried out while one or both tunnel tubes are closed to traffic or, in particular cases, with trains circulating in both tunnel tubes. The requirements are as follows:

- Appropriate working-place conditions
- Protection of the staff during train transit
- Appropriate rest area during breaks
- Protection in case of relevant incidents

The requirements on the quality of the working environment concern primarily temperature, humidity, pollutants concentration, air velocity and pressure fluctuation.

In case of maintenance works within cross-connections, specific requirements on occupational safety apply. In case of incident in the tunnel, the requirements on cross-connections are similar as in case of relevant incidents in normal operating conditions.

6.5 PURPOSE DURING INCIDENTS

The main requirements are related to self-rescue, protection of escaping persons and support to emergency services:

- Means of escape providing an egress passage for escaping persons during self-rescue
- Shelter / waiting area for escaping persons
- Access provision, logistic support and protection for emergency services
- Protection for the persons in the safe tunnel tube until full evacuation to the exterior is completed
- Protection of safety-relevant equipment, which must operate during the whole emergency

It should be noted that cross-passages are generally used for transit rather than as shelters:

- “The function of cross-passages is to connect the main tunnel to safe places; they themselves are not a safe place because generally they are not a spacious enough for a large number of people.” [5]

It is generally accepted that full protection and functionality of all cross-connections is required at least during the time required for full evacuation to the exterior. Requirements arising from intervention are related to the safety concept adopted for the specific tunnel (intervention strategy, equipment of rescue services etc.).

7 TYPICAL DESIGN SOLUTIONS AND NORMATIVE REQUIREMENTS FOR CROSS-PASSAGES

7.1. NORMATIVE REQUIREMENTS

Commonly referenced international norms and recommendations for the cross-passage design and their scope are as follows:

- TSI-SRT [1]: Specifications regarding safety in rail tunnels
- TSI-LOC-PAS [3]: Specifications regarding locomotives and passenger rolling stock' subsystem
- NFPA 130 [15]: Specifications regarding passenger rail systems
- UIC [5]: Specifications regarding safety in railway tunnels

In rules and standards minimum requirements of cross-passage are defined by features such as:

- Dimensions of egress routes in the tunnel tubes (walkways)
- Location and distance between egress routes
- Dimensions of cross-passage
- Doors in egress routes (cross-passage doors)
- Lighting
- Signing
- Fixed communication means
- Accessibility for disabled people and, more generally, persons with reduced mobility

Other important aspects are generally not covered by regulations. Typical examples are:

- Layout
- Ventilation
- Space provisions for further systems (e.g. space for cabinets of rail communication, signalling, etc.)
- Door type and characteristics

A systematic overview and comparison of selected norms and recommendations can be found in Table 2 (cross-passage doors) and Table 3 (cross-passages and egress route).

7.1 >> NORMATIVE REQUIREMENTS

Table 2: Relevant standards and norms for cross-passage door design

Standard / norm	Min. door width	Min. door height	Door type	Opening direction	Self-closing	Max. opening-force	Fire resistance	Smoke-tightness	Pressure-variations resistance	Over-pressure
TSI-SRT 2014 [EU]	1.40 m	2.00 m	-	-	-	-	-			-
SIA 197/1 2004 [CH]	1.00 m	2.00 m	swing or sliding	direction of escape	-	-	until finish of self-rescue serviceable	by appropriate means	consider dynamic pressure	-
Revision SIA 197/1 (201X)	1.40 m*	2.00 m	swing or sliding	direction of escape	-	-	until finish of self-rescue serviceable	by appropriate means	consider dynamic pressure	-
Eisenbahn Bundesamt 2008 [D]	1.20 m	2.25 m	swing	right door-wing in direction of escape	yes	-	F30 30 min	yes	-	-
Ministere De l'interieur / Direction De La Defense Et De La Securite Civiles 2011 [F]	1.40 m	2.20 m	-	-	-	-	"horse ligne urbaine" 120 min "ligne urbaine" 30 min	yes	-	yes
Bau und Betrieb von neuen Eisenbahntunneln bei Haupt- und Nebenbahnen 2000 [Ö]	min. 1 m		swing	direction of escape	-	-	T90	-	-	yes
NFPA 130 2014 [USA]	0.81 m	2.1	swing or sliding	-	yes	220 N	min. 90 min*	yes	to consider	yes
UIC-Code 779-9 2003	-	-	-	-	-	-	-	-	-	yes
UNECE 2003 [EU]				-	-	-	30 min	yes	consider dynamic pressure	yes
Regelwerk SBB; I-20036; Selbstrettungs-massnahmen in Tunnel; 05/2015 [17]	1.40 m	2.00 m	sliding	sideward	yes	100 N	E90 gem. VKF	max. 0.05 m³/s at p >50 Pa	to consider	can be installed
LA Sécurité des Tunnels ferroviaires en France; SNCF, Direction de L'ingenierie; 2006	1.40 m	2.20 m	-	-	-	-	"horse ligne urbaine" 120 min "ligne urbaine" 30 min	yes	-	yes

7.1 >> NORMATIVE REQUIREMENTS

Table 3: Relevant standards and norms for cross-passage design

Standard / norm	Min. width of escape walkway	Min. height of escape walkway	Min. width behind escape door	Min. height behind escape door
TSI-SRT 2014 [EU]	0.80 m (4.2.1.6)	2.25 m (4.2.1.6)	1.50 m (4.2.1.5.2)	2.25 m (4.2.1.5.2)
SIA 197/1 2004 [CH]	1.00 m (8.8.3.4)	2.20 m (8.8.3.4)	2.00 m (8.8.4.4)	2.20 m (8.8.4.4)
Revision SIA 197/1 (201X)	1.00 m (8.8.3.5)	2.25 m (8.8.3.5)	2.00 m (8.8.5.4)	2.25 m (8.8.5.4)
Eisenbahn Bundesamt 2008 [D]	1.20 m (2.2)	2.25 m (2.2)	min. as wide as escape way; min. area of 25 m ² stowage	
Ministere De l'interieur / Direction De La Defense Et De La Securite Civiles 2011 [F]	0.70 m (3.1.2)	2.00 m (3.1.2)	2.40 m min. 25 m ² (4.1.2 + 4.1.3)	2.20 m min. 25 m ² (4.1.2 + 4.1.3)
Bau und Betrieb von neuen Eisenbahntunneln bei Haupt- und Nebenbahnen 2000 [Ö]	1.20 m (2.2)	2.20 m (2.2)	min. area of 25 m ² stowage	
NFPA 130 2014 [USA]	H: 2.00 m (B: 0.43 m) H: 1.575 m (B: 0.76 m) H: 0 m (B: 0.61 m) (6.3.2.1)		1.12 m (6.3.2.2)	2.10 m (6.3.2.2)
UIC-Code 779-9 2003	> 0.7 m (I40)		2.25 m (benchmark) (I46)	2.25 m (benchmark) (I46)
UNECE 2003 [EU]	> 0.7 m (C 3.01)	depending on the tunnel (C 3.01)		
Regelwerk SBB; I-20036; Selbstrettungsmassnahmen in Tunnel; 05/2015 [17]	1.2 m (2.1)	2.25 m (2.1)	2.00 m (2.2.1)	2.25 m (2.2.1)
LA Sécurité des Tunnels ferroviaires en France; SNCF, Direction de L'ingenierie; 2006	> 0.7 m	2.00 m (3.1.2)	2.4 m min. 25 m ²	2.20 m min. 25 m ²
Dokumentation der Deutschen Bahn Brand- und Katastrophenschutz	1.2 m (3.2.2.2)		min. area of 25 m ² stowage (3.2.3.5)	

7.2 >> LAYOUT OF CROSS-PASSAGE

For the design of cross-passages, normative requirements on the egress and evacuation process are necessary. Input data for the

egress analysis can be found in Table 4. Some important normative requirements on cross-passage design are described in

more detail in the following chapters of this document.

Table 4: Input data for egress analysis

Standard / norm	Door capacity (persons per minute through door)	Walking speed during escape
Capacity of doors during evacuation conditions	135 pers. (1 m door) = 0.135 [p / mm*min] 90 pers (1 m door) = 0.09 [p / mm*min]	
NFPA 130	Ramp/stage: 0.0819 [p / mm*min] [5.3.4.3] Escape door: 0.0894 [p / mm*min]	Escape way: 0.63 m/s = 37.7 m/min [5.3.4.4] Railway station: 1.02 m/s = 61.0 m/min [5.3.4.5]
Bettelini Rigert		0.8 – 1.5 m/s = 48 – 99 m/min
Schéma directeur des securités	100 pers./min * m = 0.1 [p / mm*min]	

7.2 LAYOUT OF CROSS-PASSAGE

7.2.1 PURPOSE

The layout (arrangement, size and cross section) of cross-passages has a major influence on its characteristics and functionality.

7.2.2 NORMATIVE REQUIREMENTS

Normative requirements with respect to the layout of cross-passages are dealing mainly with minimum dimensions. A few general, more qualitative requirements are defined in normative documents as well but are not treated in a systematic manner.

Cross-passages shall be protected (sealed) against the traffic space (e.g. [16]). Doors are installed on both sides. Swing doors shall open in the direction of egress. Doors shall be operational at least until self-rescue has been completed (e.g. [16]). The egress path shall be unobstructed and flat (no steps), with a uniform, slip-resistant surface design (e.g. [15]).

Table 5: Selection of international normative requirements for cross-passage distance and dimensions

Standard / norm	Minimum width of cross-passage	Minimum height of cross-passage	Mutual distance between cross-passages
NFPA 130 [13]	1.12 m (6.3.2.2)	2.10 m (6.3.2.2)	244 m (6.3.1.6)
UIC-Code 779-9 [4]	2.25 m benchmark; (I46)	2.25 m benchmark; (I46)	500 m (I43)
TSI –SRT [1]	1.50 m (4.2.1.5.2)	2.25 m (4.2.1.5.2)	500 m (4.2.1.5.2)

7.2 >> LAYOUT OF CROSS-PASSAGE

7.2.3 DESIGN ASPECT

Escape distances: Short distances ensure rapid escape in the event of fire and smoke and short access distances for emergency services [5].

Size of escape route in the cross-passage: The size (width and height) of the egress route in the cross-passage and of the cross-passage doors are of crucial importance for the egress capacity (Figure 2). Size and capacity of the cross-passage should be adapted and harmonized with the size and the egress capacity of the tunnel. For the design of cross-passages, normative requirements on the egress and evacuation process are necessary. Input data for the egress analysis can be found in Table 4.

Dimensions: The dimensions of cross-passages depend on several factors, including the expected number of escaping persons in case of an incident, the sequence of evacuation (including the required area for the rescue team) and the technical components installed in the cross-passage. Limiting factors include geological conditions and coverage.

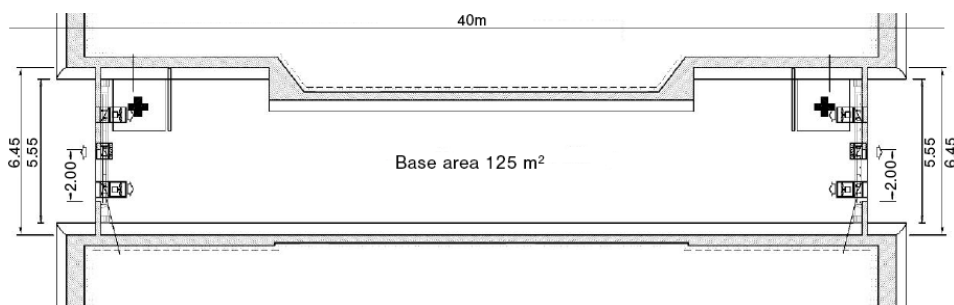
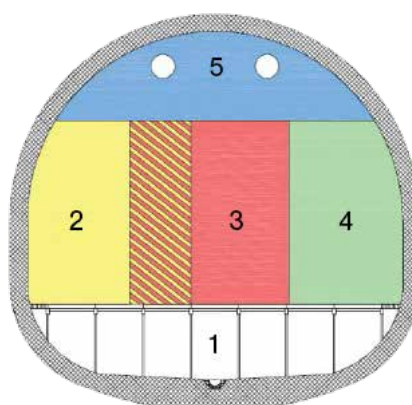


Figure 2: Footprint of cross-passage of base tunnel of Lyon Turin rail link



Components

1. Cable- and installation compartment
2. Technical compartment
3. Escape area
4. Rescue area (for fire and medical support)
5. Field of ventilation

Figure 3: Arrangement of functions in cross-passage (example only; different combinations of functions possible)

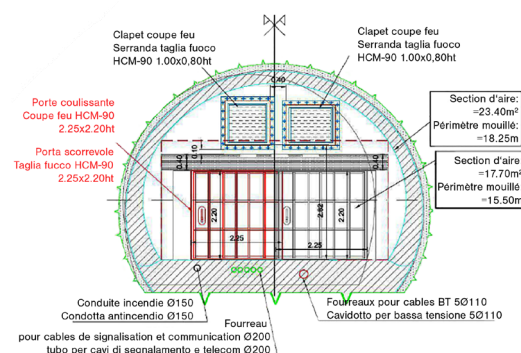
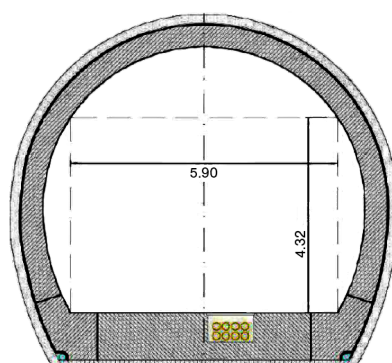


Figure 4: LTF cross-section

7.2 >> LAYOUT OF CROSS-PASSAGE

Area for technical equipment in the cross-passage: The technical equipment installed in tunnel cross-passages is typically supporting rail traffic during normal operation (e.g. communication, power supply, false floor, drainage, data transfer etc.). Technical equipment required for handling emergency situations (e.g. emergency lighting, door control, fire detection system and safety- and radio installation) is often installed in cross-passages, because it requires a certain level of redundancy. Cross-passages, placed at regular distances are thus perfectly suited, as they allow connection and supply to tunnel safety equipment from two sides (see example from Gotthard Base Tunnel in Figure 5).



Figure 5: Equipment in cross-passage of Gotthard Base Tunnel

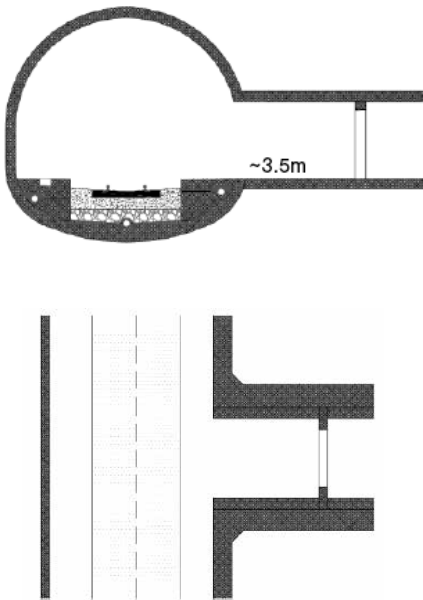


Figure 6: Area in front of the cross-passage door (Example: 3.5 m between sidewalk and door)

Area in front of the cross-passage door:

Waiting persons tend to collect in front of the emergency doors of the cross-passages, if the capacity and the throughput rate of the cross-passages is smaller than required. This can lead to stress and panic for the escaping persons and should be avoided. Also, on the other (assumed safer) side of the cross-passage, there is the risk for escaping people to fall down on the track if there is no additional space for orientation after their exit from the cross-passage.

Appropriate areas in front of the cross-passages should be provided (Figure 6). They must be carefully defined. The door must not be placed too far away from the tunnel, as this may hinder orientation and recognition of the door under difficult visibility conditions (smoke).

7.3 >> APPEARANCE AND VISIBILITY

False floor in cross-passage: False floors in cross-connections are required in case of substantial equipment installed in these spaces as well as significant cable transit requirements.

As an example, the entire area of the cross-passage in the GBT has a raised floor with a 0.60 m × 0.60 m grid (Figure 7). This consists of a substructure of stainless steel with fiber-glass concrete covers, which are not bolted down. In order to ventilate the space under the raised floor, GRP ventilation grilles are set between the cross-passage walls and the raised floor, so that any humidity can evaporate through normal air circulation. Since the pressure is compensated through the grilles, significant pressure difference below and above the floor is prevented and therefore time and labour-intensive fixings for the raised floor panels are not required [19].



Figure 7: GBT false floor [source: ABAG Doppelboden]

7.3 APPEARANCE AND VISIBILITY

7.3.1 PURPOSE

The appearance and visibility of cross-passages largely the result of the colour of the cross-passage door and walls, lights and lighting, signals and possibly sound messages. These elements shall ensure rapid self-rescue in case of emergency. The escaping persons have to be supported by means of clearly understandable emergency messages, colours and guidance system. They shall be able to get to a safe area (cross-passage or portal) even under difficult self-rescue conditions.

7.3.3 DESIGN ASPECTS

Appearance of the cross-passage / fire protection door: In case of fire, a cross-passages becomes a protected area with usually a door at each end. The fire-protection doors should be clearly labelled as such, allow for easy opening in escape direction, be self-closing and prevent the passage of smoke and heat.

7.3.2 NORMATIVE REQUIREMENTS

There are only limited and rather generic international regulations concerning the appearance of cross-passage, e.g. in NPFA 130. Appearance of cross-passages and

emergency exits is often defined by the tunnel designers and operators. However, harmonization on an international level is highly desirable. Table 6 gives an overview on the few existing regulations in normative documents with international applicability.

Table 6: Appearance, normative requirements

Standard / norm	Colour of the fire-protection door
NPFA 130; [15]	Green >92/58/EWG>(3.4) (4.2.1.5.5) (only signalization)

Signals and signs: The signals/signs should be simple and readily comprehensible. To avoid providing misleading or confusing information signals/signs in the tunnel should be limited to those that are strictly necessary to provide clear and concise information to persons evacuating in an emergency.

(Emergency) lighting: The main task of the lighting lies in leading of escaping people to a safe area. The brightness of the tunnel lighting has a large impact to the sense of space and the orientation. The emergency lighting is usually part of the lighting system but coupled to the emergency power system and continue to function in the event of main power failure to the tunnel lighting system.

7.3 >> APPEARANCE AND VISIBILITY

Visual guidance: The advantage of a visual guidance lies in the ability to lead the escaping people in the safe direction, even if the visibility conditions are limited due e.g. to smoke.

Another advantage lies in the capability of remote control of the system. Thereby the system is much more adaptable than the normal static emergency light. The dynamic visual guidance can be installed in addition to the usual lighting or emergency lighting of the tunnel.

Visibility: The visibility in the tunnel/cross-passage should be ensured during the whole emergency scenario. Good visibility contributes to a feeling of safety and is indispensable for the orientation.

Acoustic system: In cross-passages, messages from acoustic systems can inform persons about correct behaviour and instruct them about the next steps (e.g. “wait in this area”, or “go to location xy”). Cross-passages are separated from the tunnel, have a different ambience than the tunnel. Persons get an impression of safety and

need to be informed about what to do next. Acoustic systems can help in informing the persons in the cross-passage.

Acoustic systems are more and more used also in tunnel tubes, to give information to persons and to support orientation in cases of bad visibility (function as sort of “acoustic lighthouse”).

Considering the challenging acoustic conditions in tunnels and cross-passages, specific acoustic systems are generally required.

7.3.4 TYPICAL SOLUTIONS / FURTHER DESCRIPTION

Signs: Emergency exit sign (minimum size of 600 x 300 mm) are installed in the middle of the door / beside of the passage (No. 6 in Figure 8). The symbolized escaping person on the sign should walk in the right direction, depending on the opening directions (shifting direction) of the emergency door. Additional indication of door-operation direction beside of the door handle or directional arrow in tension direction.

The cross-passage door has to be equipped on the inside of the door with a sign to alert the escaping persons that they are entering a tunnel still in operation.

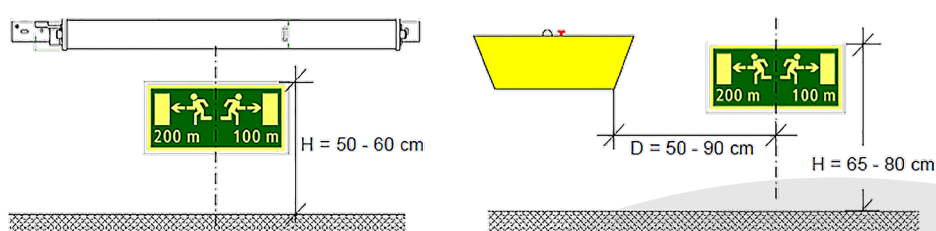


Figure 8: Place of installation of emergency sign in a tunnel [17]

Remark: The exact location of the sign has to be adapted to the given circumstances in the tunnel (underground conditions/ location of the illumination)

Appearance / Visibility:



Components

1. Green paint of tunnel wall and cross-passage door
2. Permanent lighting (horizontal / 24 h)
3. Permanent escape lighting (vertical / 24 h)
4. Prism escape lighting (above door / 24 h)
5. Fluorescent marking of emergency exit
6. Escape sign on door

Figure 9: Identification and equipment emergency door [17]

7.4 >> EQUIPMENT

7.4 EQUIPMENT

7.4.1 FIRE-PROTECTION DOORS

Purpose: The fire-protection doors of cross-passages have two important functions: During an incident, the door system shall provide an escape path into a safe area (cross-passage or non-incident tube) and a protective barrier against smoke and heat. During normal operation mode, the door shields the cross-passage, and mainly the contained electrical

equipment, from impairment by heat, humidity, dust, pressure changes, etc. Operational reliability and durability of the door is, in every case, indispensable.

In order to maintain an operable non-incident tube, the cross-passage must provide sufficient protection to its equipment. Fire-rated doors may not sufficiently suppress heat ingress into the cross-passage (for example in case of fire in front of the cross-passage, even fire rated doors may lead to heat ingress

and temperatures not being acceptable by technical equipment inside the cross-passage). Supportive ventilation might be required to carry away heat and maintain the technical functionality at least of equipment in the cross-passage serving the non-incident tube.

Normative requirements: The normative door requirements are mostly defined according to the following attributes: geometry, layout, opening direction (swing door), self-closing mechanism, opening-strength, fire resistance. For a detailed listing of the norms see Section 7.2.

- **Dimensions:** The dimension of the door depends on the passing rate of persons. The maximum number of people passing the door depends on the number of cross-passages in the tunnel, the length and capacity of the transportation system and the effective number of passengers (usual assumption: peak time). The door dimensions shall be chosen considering these boundary conditions.
- **Opening direction:** Swing doors shall open in egress direction. The opening angle can influence the egress capacity of the door (see Section 7.2). Sliding doors are used in many countries. While not opening in escape direction, they allow coping with a significant pressure difference between the cross-passage and the tube.
- **Self-closing (automatic closure):** A self-closing mechanism minimizes the amount of smoke entering into the cross-passage and restores the overpressure conditions.

- **Opening mechanism:** The defined mechanism force guarantees the ability to open the door under all circumstances of the predefined scenarios. In case of an incident, the door has to function at least until the end of the self-rescue phase, without any problems or deadlocks. If the mechanical opening system is out of order, it must be possible to open the door with an adequate physical force (typically 100 to 220 N).
- **Fire resistance:** The fire resistance guarantees the reliability and integrity of the door as a shutoff device over a certain defined time. Requirements on fire resistance of cross-passage doors are specified mostly at national level and range commonly between 30 and 90 min.

- **Door-tightness (air, smoke and dust):** The tightness of the door contributes an optimal lifetime for the equipment and thereby minimizes the maintenance work and protects the escaping people in case of emergency.
- **Pressure variations resistance:** The resistance of the door against pressure variations guarantees the protection of the different components of the door (e.g. drive motor, guide rail, brackets, etc.)

Table 7: Normative requirements, fire-protection door

Standard / norm	Minimum door width	Minimum door height
NFPA 130; [15]	0.81 m (6.4.2.2)	
UIC-Code 779-9; [5]		
TSI – SRT; [1]	1.40 m (4.2.1.5.2)	2.00 m (4.2.1.5.2)

7.4 >> EQUIPMENT

Typical solutions / further description:

Swing door

- Easier to install
- Lower initial cost
- Less maintenance works
- In case of maintenance with train operation in one tube, risk of accidents by uncontrolled slamming
- Difficult to open in case of large overpressure in the CP in the absence of mechanical support
- During emergency, first door of cross-passage opens in egress direction, however, second door opens against egress direction



Figure 10: Double-leaf segment swing door of Wienerwald Tunnel (view from inside the CP)

Sliding door

- Higher initial costs
- Door not opening against egress direction
- No risk of accidents by slamming doors
- Opening force for door independent of pressure difference across door
- Self-closure assured for different pressure differences
- Clear indication for opening direction required as escaping persons need to understand sideways open direction



Figure 11: Single segment sliding door of Loetschberg Base Tunnel (view from inside the CP)

7.4.2 VENTILATION SYSTEM FOR NORMAL/ MAINTENANCE/EMERGENCY OPERATION

Purpose: In case of incident, it is important to have a fully functional ventilation system for ensuring safe conditions for the escaping people in the tunnel and the cross-passage. The ventilation system has to satisfy certain requirements for all operating conditions (normal, maintenance and emergency operation):

- Normal operation: The climate in the cross-passage (i.e. the environmental conditions in terms of air temperature, humidity, dust concentration, pressure

fluctuations) is an important factor for the lifetime of electrical equipment installed inside cross-passages. During normal operation, the ventilation system is used to create an acceptable climate for all the installations. Depending on the ventilation system, this may involve fresh air supply, overpressure ventilation of cross-passages (prevention of dust infiltration), cooling and/or filtering of supplied air.

- Maintenance operation: During maintenance works in the tunnel, the environmental conditions inside the cross-passages need to meet the occupational work requirements for maintenance staff. In addition,

the ventilation needs to satisfy the requirements of the technical equipment inside the cross-passage.

- Emergency operation: The ventilation system controls the pressure difference between the cross-passage and the tunnel tube. Especially in case of an incident, an overpressure inside the cross-passage relative to the incident tube has to be guaranteed to prevent the infiltration of smoke and possible toxic gases into the cross-passage. In addition, an air exchange to remove heat might be needed because even fire-resistant doors may lead to a significant ingress of heat into the cross-passage.

7.4 >> EQUIPMENT

Normative requirements: Normative requirements are usually limited to functional prescriptions of the ventilation goals during emergency operation. This involves the definition of minimum and maximum overpressure and the definition of minimum and maximum airflow through open doors.

The limitation of opening forces of emergency doors for occupants is another normative requirement for the ventilation system.

However, there are typically no normative prescriptions about the layout and design of the ventilation system.

Design aspects: The goals of cross-passage ventilation presented in the previous section can be achieved in different ways. Typical technical solutions are discussed in the following section.

The key parameter for ventilation design are:

- Air flow rates in case of open doors and leakages in case of closed doors
- Pressure difference between the cross-passage and the tunnel tubes if the doors are closed
- Noise

The requirements are in most cases dictated by safety in case of fire emergency. The minimum airflow required for preventing smoke penetration in case of open doors is typically 0.75 to 1 m/s. Design is usually carried out based on significantly larger values, taking into account leakages etc. Airflows in excess of 4 to 5 m/s can disturb self-rescue and intervention and should be avoided if possible.

The usual range of pressure differences ranges from 30 to 80 Pa. Significantly larger values could become critical in terms of

door opening forces. Sliding doors are significantly less sensitive than swing doors.

Noise in cross-passages can hinder communication and sometimes represent a significant disturbance. Sufficient attention should be devoted to proper noise mitigation in case of long stays in the cross-passages.

Typical solutions / further description:

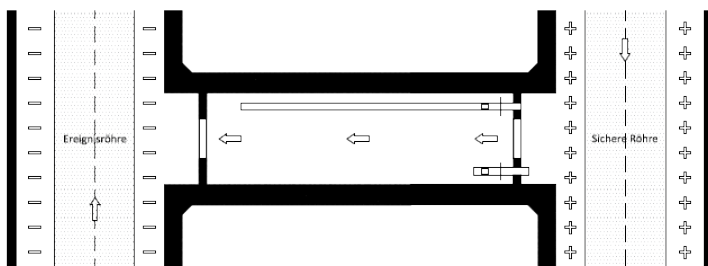


Figure 12: Ventilation by overpressure in the healthy tunnel tube

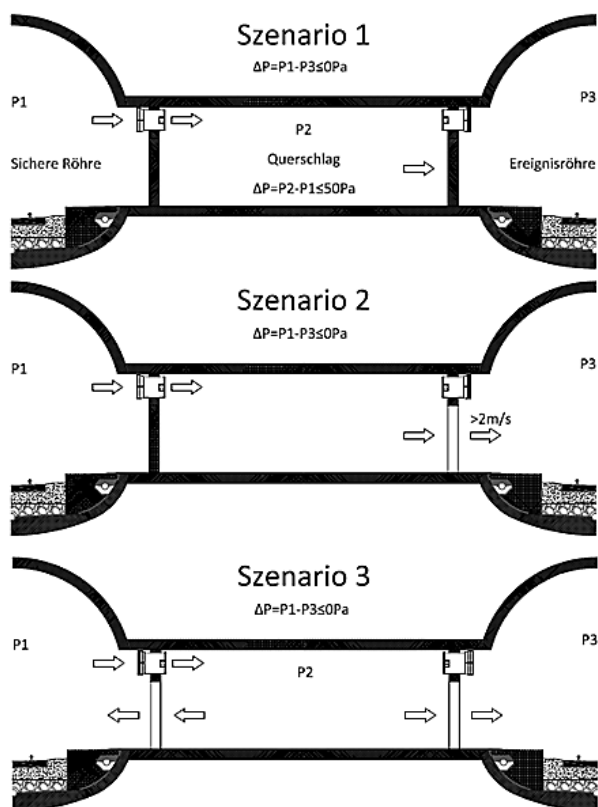
Ventilation of the cross-passage by an independent ventilation system in the CP

- The benefit of this option is an autonomous and controllable system that guarantees a constant wind draft and pressure control.

However, due to the high number of components and their distributed installation locations, the initial and maintenance costs are comparatively high.

- During normal operation and maintenance: In normal- or maintenance operation, the ventilation system of the cross-passage is working autonomously and the air exchange of the CP works with the cooler of the two tunnels only.
- During incidents: At the beginning, both doors of the cross-passage are closed and the ventilation of the safe tunnel-tube is pumping fresh air into the cross-section. This results in an over-pressure situation in the cross-section. When the door to the incident tube is opened, the pressure balances and an air velocity prevents the infiltration of smoke and gas. When the door to the safe tunnel tube is opened, it is necessary to pump a higher amount of air in the cross-section to uphold the overpressure situation. Note that this ventilation system will not work properly, if both doors are open at the same time. Infiltration of smoke into the cross-passage can only be prevented if at least one door is closed.

7.4 >> EQUIPMENT



Ventilation by independent ventilation system in the CP

- If a cross-passage is very long (more than approx. 50 m), it can be advantageous to divide the passage into three sections. The main section is the cross-passage, the other two parts serve as an insulation lock at the two sides of the cross-passage (see Figure 14).
- During incidents: In case of incidents, the safeguard function is similar to the system without intermediate doors. The overpressure situation is generated through an independent ventilation system and controlled with pressure relief dampers.
- The two additional doors create air locks, which make this solution less vulnerable in case of open doors. Only in cases where all four doors are open at the same time, rapid smoke propagation into the cross-passage could be expected.

Figure 13: Ventilation by independent ventilation system in the CP

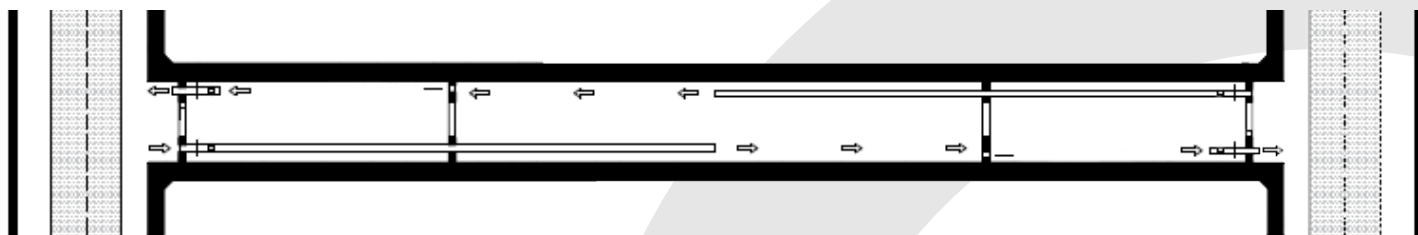


Figure 14: Ventilation system of a long cross-passage

Independent ventilation system of a long cross-passage

- If a cross-passage is very long (more than approx. 50 m), it can be advantageous to divide the passage into three sections. The main section is the cross-passage, the other two parts serve as an insulation lock at the two sides of the cross-passage (see Figure 14).
- During incidents: In case of incidents, the safeguard function is similar to the system without intermediate doors. The overpressure situation is generated through an independent ventilation system and controlled with pressure relief dampers.
- The two additional doors create air locks, which make this solution less vulnerable in case of open doors. Only in cases where all four doors are open at the same time, rapid smoke propagation into the cross-passage could be expected.

7.4 >> EQUIPMENT

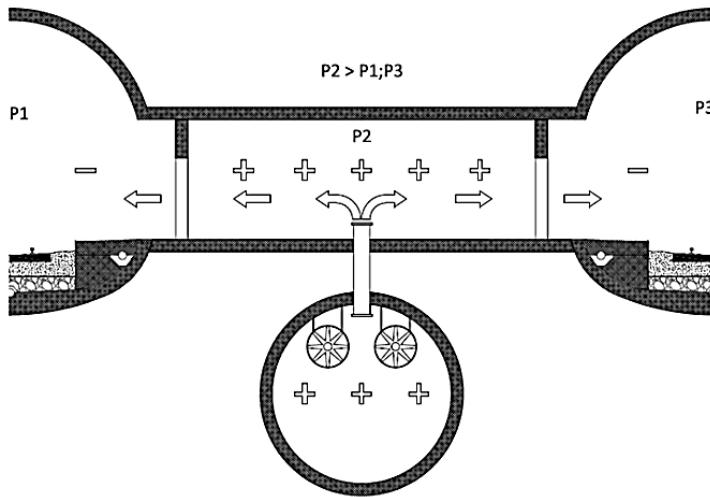


Figure 15: Ventilation of the cross-passage by an exploratory tunnel

Ventilation of the cross-passage through an exploratory or service tunnel

- The ventilation system is arranged in the exploratory gallery and the gallery is connected with the cross-passages by small ventilation duct.
- During normal operation and maintenance: In case of normal operation, the ventilation system of the gallery is providing fresh air to the cross-passage. This sets the cross-passage on overpressure and prevents inflow of dust from the tunnel tubes. A certain amount of heat generation by equipment in the cross-passage can also be managed with this ventilation system.
- During incidents: In case of an incident, the ventilation system generates an overpressure situation in the CP to prevent the entry of smoke and gas into the cross-passage.

Advantages of this design solution are that cross-passages can be supplied with fresh air and thus is set on overpressure during normal operation. This allows for perfect protection of electrical equipment. Additionally, the ventilation equipment is easily accessible for maintenance also during normal operation.

7.4.3 FURTHER EQUIPMENT / INFRASTRUCTURE IN CROSS-PASSAGE

Further systems, which could be installed in cross-passages:

- Communication/information board
- Monitoring/Video system
- Power supply
- Safety- and radio equipment (emergency telephone)
- Fixed or mobile fire extinguisher
- Fire, smoke and gas detection system
- Rescue equipment
- First aid kits
- Maintenance /emergency lighting
- Door access control
- Data transfer infrastructure
- Loudspeaker

Regular control and maintenance are required for reliable operation. The equipment has to be shielded from any external negative impacts (e.g. dust, temperature, variation, great heat impact, fire, human impact, etc.). Therefore, the space requirements for further systems must be considered as well while dimensioning cross-passages.

Safety- and radio installation (emergency telephone): Emergency telephones or similar means of communication so that passengers, too, can use them in case of emergency, connected with the operation centre (independent of train radio or mobile phone). Emergency telephones shall permit adequate and reliable communication during any emergency. The telephone system is the redun-

dancy level for communication. The system should be combined with telephones for other operating purposes (maintenance, operational disturbance, etc.). [5]

Video monitoring: Video monitoring allows controlling the situation in the cross-passage during maintenance and emergency.

Door access control: Measures to prevent unauthorized access to the cross-passage: signs, fencing, secure locks, remote or local surveillance. Protect against sabotage or vandalism in the cross-passage and reduce accidents with people entering/walking through the cross-passage [5].

The control system releases an alarm (with location) in the control central control.

7.5 >> SAFETY COMPONENTS IN THE TUNNEL TUBES

7.5 SAFETY COMPONENTS IN THE TUNNEL TUBES

7.5.1 PURPOSE

The layout of a cross-passage is influenced by certain characteristics of the tunnel. During normal operation, a cross-passage may be the location for electrical supply and control devices of tunnel equipment (lighting, signals, traffic control, ventilation, etc.). During emergency situations, the egress path starts in the incident tube and goes on through the cross-passage. Design of the egress path in the tunnel does influence

the egress path in the cross-passage. For example, the width of the cross-passage has to be adapted to the width of the egress path in the tunnel, in order to avoid bottlenecks.

Safety elements of tunnels do influence the cross-passage design. The following sections provide an overview of the most important tunnel safety element in terms of cross-passage design. This involves normative requirements and description of typical design solutions.

7.5.2 NORMATIVE REQUIREMENTS

There are various international and national normative requirements for the layout of egress paths. Generally, the requirements for metro tunnels are less stringent than for rail tunnels. The following minimum safety equipment is required in rail tunnels:

- Signs showing direction to next cross-passage
- Loudspeakers in the tunnel
- Handrail
- Illumination of egress path
- Facilities for communication

7.5.3 DESIGN ASPECTS

Escape Route: The different walkway dimensions do not have a major influence on the evacuation process. Considering that a single person typically needs a path width of about 0.6 – 0.65 m, overtaking is not possible without leaving the walkway, especially with limited sight, as it is the case in tunnels.

Table 8: Representative international normative requirements escape route

Standard / norm	Minimum width of escape route	Minimum height of escape route
NFPA 130; [15]	H: 2.00 m (W: 0.43 m) H: 1.575 m (W: 0.76 m) H: 0 m (W: 0.61 m) (6.3.2.1 [11])	
UIC-Code 779-9; [54]	> 0.7 m (140 [4])	
TSI – SRT; [1]	0.80 m (4.2.1.6) [1]	2.25 m (4.2.1.6 [1])

Escape Distances: Representative recommendations on the maximum allowable escape distances are presented in Table 9.

Table 9: Representative international normative requirements for escape distances

Standard / norm	Maximum escape distances
NFPA 130; [15]	244 m (6.3.1.6 [13])
UIC-Code 779-9; [5]	500 m (143 [4])
TSI-SRT; [1]	500 m (4.2.1.5.2 [1])

Acoustic System: The complexity of the installing acoustic systems in a tunnel, related to reflection and rapid spreading of waves on the smooth concrete, has to be considered carefully. The reflection and spreading of the waves engender an undesired distortion and are even worse in combination with the ventilation noise and loud discussions during an emergency. The requirement of the acoustic system is to gain a high efficacy is the comprehensibility.

The most common method of the acoustic system in the rail-tunnels is the so-called “collective alarming message”. Information is released through all speakers spread over the whole tunnel at one time. Unfortunately, messages are often distorted and unintelligible.

A more modern technology is the “SLASS-concept” (synchronized longitudinal announcement speaker system), that balances the delay of the sound and eliminates the disturbing echo.

Emergency tunnel lighting: Lights along one or both tunnel walls for illuminating the escape routes in the event of a train evacuation. The design and layout of the lighting system shall ensure uniform illumination of the escape route in order to enable evacuees to walk safely [5].

Fire, smoke and gas detection system: Installation of fire, smoke and gas detectors in tunnels, enabling rapid location of a fire in ignition phase. Fire, smoke and gas detectors are maintenance-intensive [4] and are rarely used.

Persons with disabilities and reduced mobility (PRM): According to the 1975 United Nations Declaration on the Rights of Disabled Persons, “Disabled persons are entitled to the measures designed to enable them to become as self-reliant as possible”. This directly impacts several aspects of infrastructural design and operation.

The TSI-PRM [2] specifically addresses issues related to the accessibility to the rail infrastructure for persons with disabilities

8 >> ILLUSTRATIVE EXAMPLES OF CROSS-PASSAGES (STATE-OF-THE-ART)

and with reduced mobility, characterized as follows: "Person with disabilities and person with reduced mobility" means any person who has a permanent or temporary physical, mental, intellectual or sensory impairment which, in interaction with various barriers, may hinder their full and effective use of transport on an equal basis with other passengers or whose mobility when using transport is reduced due to age."

However, TSI-PRM is relevant for stations and rolling stock only. Regarding tunnels, TSI-SRT [1] refers to TSI-LOC-PAS ([3], Chap. 4.2.10.5.1) which states: "... It is permitted to consider that passengers with reduced mobility are to be assisted by other passengers or staff, and that wheelchair users are evacuated without their wheelchair. ...". Regarding the cross-passage layout, this is the only specific requirement for PRM.

8 ILLUSTRATIVE EXAMPLES OF CROSS-PASSAGES (STATE-OF-THE-ART)

In this chapter, examples of cross-passages of recently realized tunnel projects are presented. The examples shall illustrate state-of-the-art design solutions. A limited number of tunnel projects is shown only (four examples of cross-passages in rail tunnels, four examples of cross-passages in metro tunnels) and therefore cannot be considered as being complete.

8.1 RAIL TUNNELS

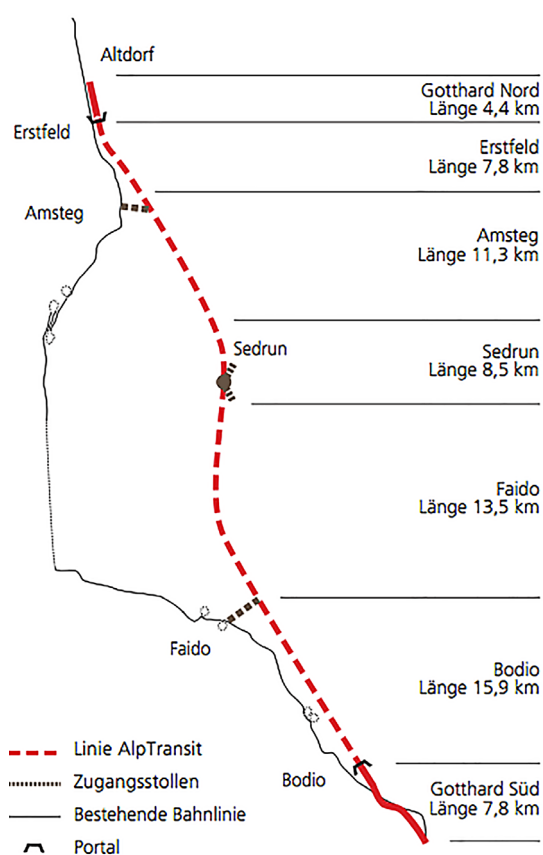
8.1.1 GOTTHARD-BASE TUNNEL (GBT)

The Gotthard base tunnel is the main part of the new railway link through the Alps and was opened in 2016. It is currently the world's longest railway tunnel with a length of 57 km. The tunnel consists of two single-track tubes with emergency-stop stations in distances of about 20 km.

The tunnel is used by both, passenger and goods trains. Safety considerations have played an important role from the beginning of the design. The safety concept is based on the following principles [19]:

- fair chance on self-rescue for every person
- rescue and evacuation of all persons in the tunnel must be finished within 2 hours

8.1.1.1 KEY TUNNEL DATA

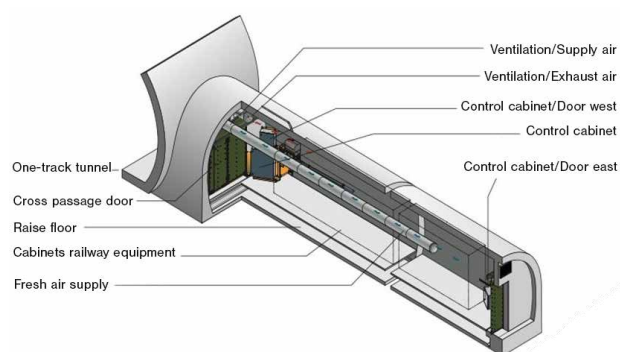


Project	Gotthard Base Tunnel
Construction period	1996 to 2014
Start of operations	2016
Tunnel construction costs	CHF 9.9 billion
Total length	57 km
Number of tubes	2
Gap between CP's	312 m
Number of CP's	175
Maximum rock overburden	2300 m
Maximum design speed	250 km/h
Type	Mixed traffic (goods and passengers)

Figure 16: Alignment Gotthard Base Tunnel
[source: Alptransit Gotthard]

8.1.1 >> GOTTHARD-BASE TUNNEL

8.1.1.2 KEY CROSS-PASSAGE DATA



Length of CP	10.4 - 73.4 m
Clear width of cross-passageways (without cabinets)	3.5 m
Height of CP	3.5 m
Door type	Sliding door
Clear width of door	1.60 m
Height of door	2.30 m
Ventilation System	over-pressure in the healthy tunnel-tube

Figure 17: Schematic cross-passage [source: Alptransit Gotthard]

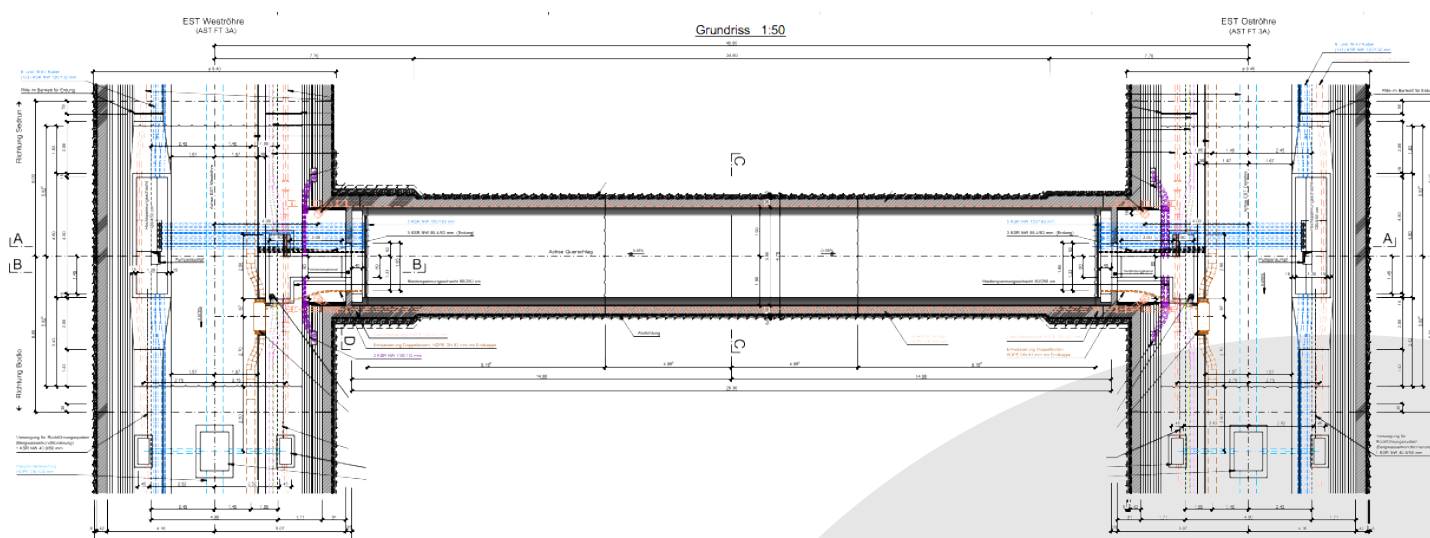


Figure 18: GBT ground plot

Cross-passage door: The cross-passage door was specifically designed for the GBT with the following technical requirements [19]:

- The restricted installation space in the cross-passage;
- Maximum transporting weight of 2'000 kg
- Simplest possible, manually operated, with, at most, an auxiliary actuator;
- Dynamic differential pressure of +/- 20 kPa for more than one million load cycles;
- Maximum operating effort of 100 N to open the door;
- Opening of the door must also be possible at an emergency pressure of 1 kPa;

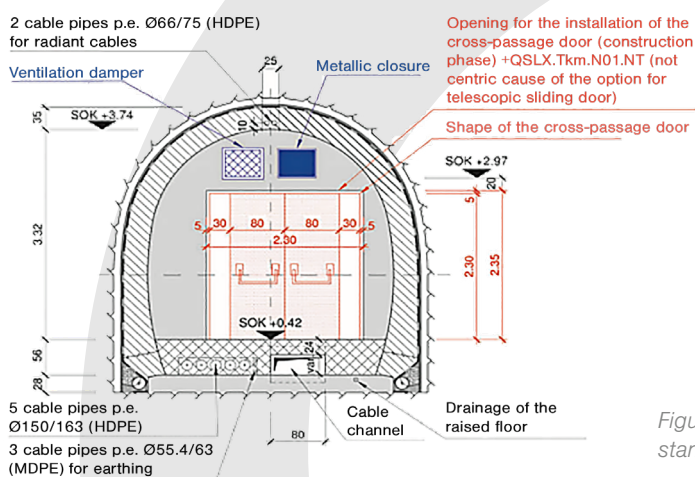


Figure 19: Cross section of a standard cross-passage [179]

8.1.1 >> GOTTHARD-BASE TUNNEL

- Maximum door opening time of 5 s across the full 1.6 m width of the door;
- Intuitively correct actuation of the door by escaping persons in case of an incident;
- Automatic closure, with a maximum closing time of 10 s and with continued functionality even after complete failure of the energy supply;
- Door-tightness requirements of maximum 50 m³/h leakage at a pressure of 100 Pa;
- Fire-resistance requirements of 90 minutes at 1'000°C;
- The temperature of the entire door surface area cannot exceed an average value of 200°C, with a maximum value when measured at a point of 240°C;
- Sealing against smoke is achieved with a special fire retardant gasket in the joints, which foams up as the temperature rises and hermetically seals the door around its perimeter, and the middle joint.

The segment sliding door features a main leaf, which opens in a straight line, and a hinged secondary leaf. An electric auxiliary actuator was selected in order to make it possible to meet the specified maximum operating force and opening time.



Figure 20: Double-leaf segment sliding door [19]

Cross-passage ventilation: The maximum permissible temperature in the cross-passage is 35°C. The air supply and exhaust fans of the cross-passage ventilation can each be operated in two stages and can provide 1-2 m³/s of air. Both fans are thus capable of exchanging the air in the cross-passage within at least one hour and divert 7 kW of waste heat from the technical installations. In order to ensure the operational reliability of the tunnel and the technical installations, the ventilation plant is designed with redundancy, so if one fan fails, the second one can take on its entire capacity. [19]

- Standard and maintenance operation: Cooling of the cross-passages is implemented by the cross-passage ventilation with air from the cooler tube. In a normal case, the exhaust fan is active and creates negative pressure in the cross-passage. The cool tunnel air is forced through the long air supply duct to the opposite cross-passage end wall. From there, the air moves through the cross-passage, is warmed and is then blown back into the "cold" tunnel. [19]
- Incident operation: In case of an incident, about 50% of the cross-passage ventilation systems would always suck air out of the affected tunnel. That is why, all dampers in the air supply ducts to the incident tunnel are closed in incident operation. In order to maintain ventilation and cooling the cross-passages, a ventilation damper to the opposite tunnel is opened at the same time. The exhaust fans remain practically in continuous operation in these cross-passages. [19]

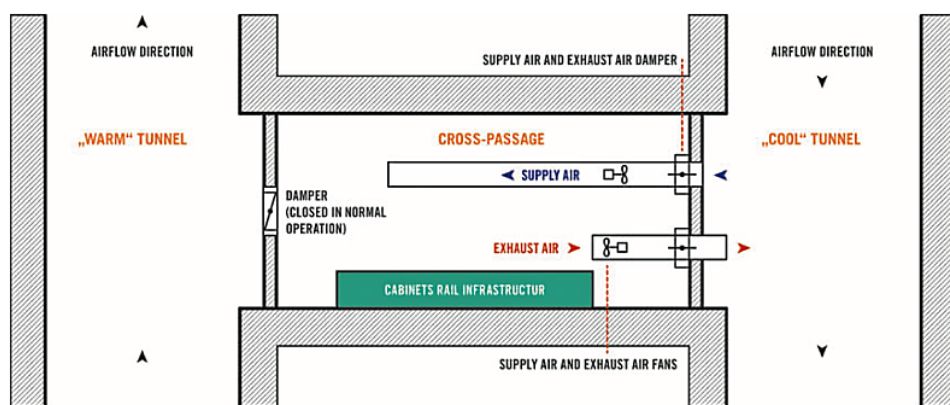


Figure 21: Ventilation system for the cross-passage [17]

8.1.1 >> GOTTHARD-BASE TUNNEL

Further installation in the cross-passages:

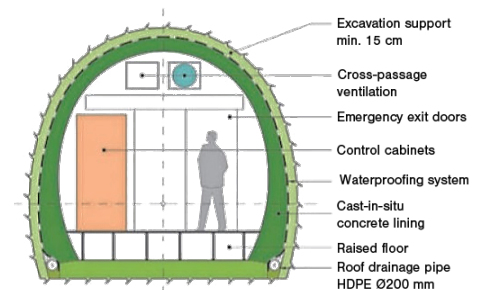
- **Raised floor:** In order to simplify maintenance work or to connect the equipment in the cross-passage, the entire area of the cross-passage has a raised floor with a 0.60 m x 0.60 m grid. This consists of a substructure of stainless steel with fiberglass concrete covers, which are not bolted down. In order to ventilate the space under the raised floor, GRP ventilation grilles are set between the cross-passage walls and the raised floor, so that any moisture can evaporate by means of normal air circulation. Since the pressure is compensated through the grilles, no pressure differences above and below the raised floor are prevented and therefore time and labour-intensive fixings for the raised floor panels can be omitted [19].

- **Technical equipment:** All the equipment and control cabinets installed in the cross-passages are dust-tight and comply with IP65, and their data and electricity supply are redundantly connected from both tubes. The control cabinets are of modular construction so that they can be easily installed or removed. Simple maintenance tasks to the equipment are carried out directly at the location, but if larger and more time-consuming works are necessary, the component or cabinets is replaced and is repaired outside the tunnel [19].

The information is continuously structured and efficiently transmitted to the control centre. In addition to the complex cabinets, the cross-passages are equipped with:

- Emergency phone
- Public address system Access control
- Video System
- Extinguishing water system / fire extinguisher

Figure 22: Cross section of a cross-passage in the Gotthard Base Tunnel [19]



8.1.1.3. ADDITIONAL DETAILED DESCRIPTION AND BACKGROUND INFORMATION

General Information: The centreline spacing of the two single-track tunnels is generally 40 m, but was extended for rock-mechanical reasons to 70 m in the Sedrun section; the tunnels are closer together at the portals, however. The top-of-rail level in the two tunnels is at the same elevation, while drainage of the cross-passage is accomplished via a downward gradients towards both the single-track tunnels [19].

Safety concept: According to the operational concept, passenger trains will stop at the emergency stations in the MFS Sedrun or Faido in case of an incident. From there, the passengers and the train crew can reach Type 1 protected areas (inner safe area of MFS) via short escape routes. If in the course of an event a train cannot reach the nearest emergency station or the portal of the tunnel and stops at any place inside the tunnel,

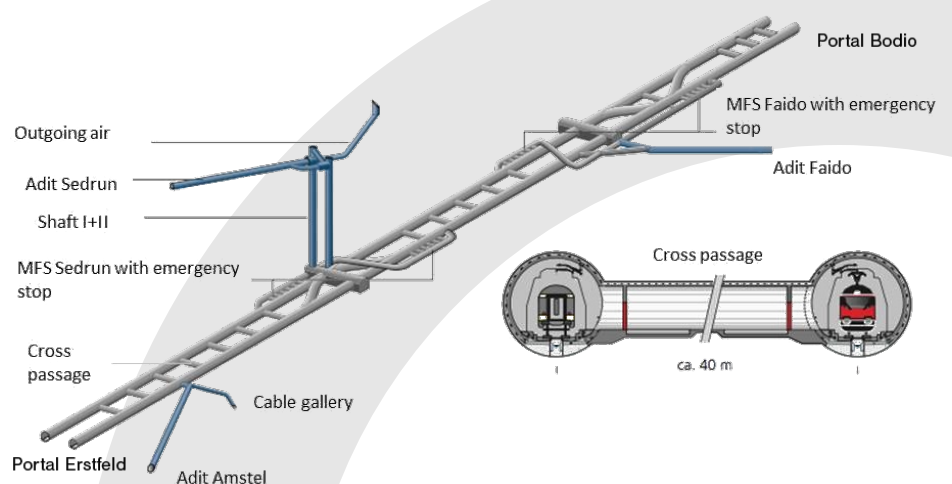


Figure 23: Scheme of the Gotthard Basel Tunnel system [source: Alptransit Gotthard]

the passengers have to flee through the cross-passage from the affected tube to the unaffected tube (Type 2 protected area). From there, they are evacuated out of the tunnel on

trains within 90 minutes. During these critical 90 minutes of evacuation, the closures (doors and dampers) and ventilation system of the cross-passages have a decisive task [19].

8.1.2 >> LOETSCHBERG BASE TUNNEL

Ventilation concept: The ventilation system in the multifunctional station is an important safety element in the GBT. The system is responsible for the overpressure in the “safe” tunnel tube, which prevents the infiltration of smoke into the

cross-passage and additionally ensures fresh air in the emergency exits. At each of the portals of the tunnel, six jet fans together with the MFS regulate the conditions and the overpressure (in case of an incident) in the tubes.

The ventilation system of the GBT is unique because the operation- and incident system does not work complementary but are independent of each other.

8.1.2 LOETSCHBERG BASE TUNNEL

8.1.2.1 KEY TUNNEL DATA

The Loetschberg Base Tunnel forms part of the Loetschberg Base Line (LBL), which is a principal element of the cross-alpine rail links in Switzerland and the European high-speed rail network. The Loetschberg Base Tunnel (LBT; drill and blast and TBM excavation) with

a length of approximately 35 km is being built in different stages. The first stage was taken in operation in 2007. During this first stage, only the southern part of LBT is a single-track, double-tube system. The northern section is operated using one tube in bi-directional mode (see Figure 1). At the final stage, the tunnels consist of 2 single track tunnels which are connected with accessible cross-passages approximately every 330 m.

In addition, the base tunnel system includes multifunctional stations (MFS) with crossovers and emergency train stations. During normal operation, passenger trains run at velocities of up to 250 km/h and freight trains at max. 160 km/h.

8.1.2.2 KEY CROSS-PASSAGE DATA

The typical cross-passage is shown Figure 24. The cross-passage is closed by remotely controlled, motorized sliding doors. The cross-passage houses electrical cabinets with different functions. They leave enough space for an at least 2 m wide walkway.

Key data of the cross-passage is given in Table 10.

Table 10: Key data of cross-passages in Loetschberg Base Tunnel

Key element	Dimension / Type / Description
Length of cross-passage	approx. 30 m
Clear width of cross-passage	3.5 m
Height of cross-passage	3.5 m
Door type	sliding door, single element
Clear width of door	2.00 m
Height of door	2.20 m
Ventilation System	over-pressure in the non-incident tunnel-tube



Figure 24: Cross-passage in Loetschberg Base Tunnel from rail tunnel (left) and inside (right)

Page currently under revision

8.1.2 >> LOETSCHBERG BASE TUNNEL

Page currently under revision

8.1.3 >> New GUANJIAO TUNNEL

8.1.3 NEW GUANJIAO TUNNEL

The New Guanjiao Tunnel, or Guanjiao Base Tunnel, is part of the Qinghai-Tibet railway line between Tianpeng and Cha Hannuo stations. The entrance and exit portals are at just above 3'300 m.a.s.l. The double tube tunnel is 32.69 km long and China's second longest railway tunnel. Each tunnel tube is single track. The two tubes are linked by 77 cross-passages with an average spacing of 420 m. In the middle of the tunnel, a rescue station with further 12 cross-passages is found. A more than 3 km long adit connecting the rescue station with the outside is used for ventilation and service purposes. No cross-overs for the rail lines are present, thus rendering the two tubes aerodynamically separated.



Figure 29: Alignment Guanjiao tunnel [source: China Railway First Survey and Design Institute]

8.1.3.1 KEY TUNNEL DATA

Project	Guanjiao Base Tunnel
Construction period	2007 to 2014
Start of operations	2014
Tunnel construction costs	RMB 4.96 billion
Total length	32.69 km
Number of tubes	2
Gap between CP's	420 m
Number of CP's	77 (plus 12 in rescue station)
Maximum design speed	160 km/h
Type	Mixed traffic (goods and passengers)

8.1.3.2 KEY CROSS-PASSAGE DATA

The technical requirements for cross-passages and doors according to the Chinese guidelines on disaster prevention [18] are as follows:

- The cross-passage minimum free cross-section area shall be 4.0 m x 3.5 m (width x height). For rescue stations, the minimum section size shall be 4.5 m x 4.0 m (width x height).
- The protection door shall be easy to open
- The protection door shall be minimum 1.5 m x 2.0 m (clear width x clear height). Within rescue stations, a minimum size of 3.4 m x 2.0 m (overall clear width x clear height) shall be set up at both ends of cross-passage.
- A longitudinal slope of cross-passage shall be maximum 1%. Protection door shall be located at gentle slope area.
- The distance between cross-passage shall be maximum 500 m. For rescue stations, the gap shall be maximum 60 m.

These requirements lead to the key cross-passage data in Table 11.

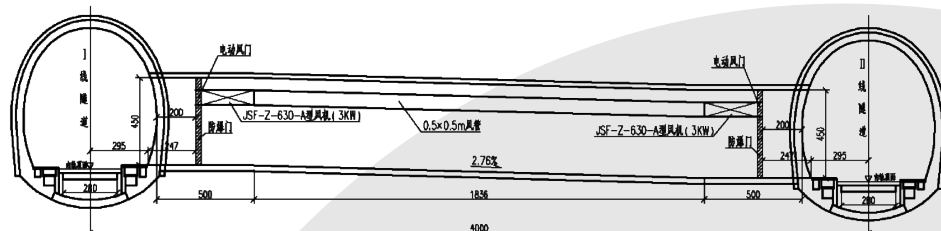


Figure 30: Ground plot of Guanjiao cross-passage

Table 11: Key data of cross-passages in Guanjiao Tunnel

Key element	Dimension / Type / Description
Length of cross-passage	40 m
Clear width of cross-passage	4.8 m
Height of cross-passage	5.0 m
Door type	Swing door
Clear width of door	1.7 m (2 x 1.7 m in rescue station)
Height of door	2.0 m
Ventilation system	Overpressure in non-incident tunnel tube

8.1.3 >> NEW GUANJIAO TUNNEL

Cross-passage door: The cross-passages in the New Guanjiao Tunnel are 40 m long. In all the 77 cross-passages along the whole length of the tunnel, a 1.7 m wide and 2.0 m high swing door is installed. The door is opened in escape direction from the rail tunnel into the cross-passage.

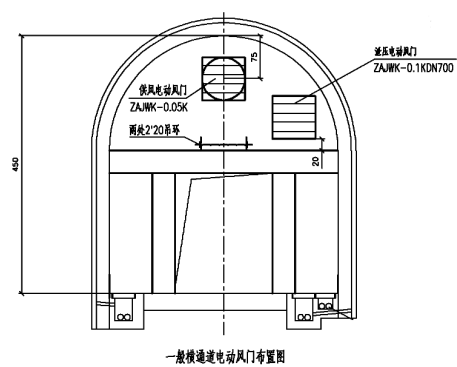


Figure 31: Cross-section of typical cross-passage of Guanjiao tunnel with one escape door

Within the rescue station, additional 12 cross-passages serve as escape route to the non-incident tunnel tube. The rescue station's passages are equipped with two swing doors at each end, one opening in each direction of travel (total of 4 doors per cross-passage). The doors are 1.7 m wide and 2.0 m high each.

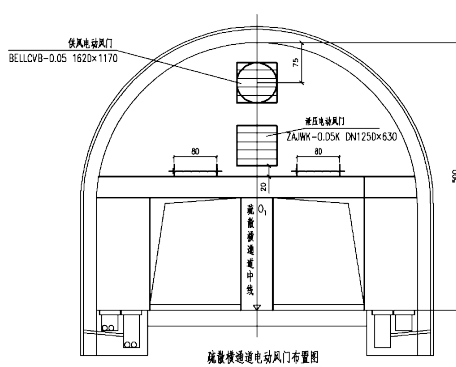


Figure 32: Cross-section of cross-passage in rescue station of Guanjiao tunnel with two escape doors

The doors installed in the tunnel are metal sheet doors with concrete filling. The doors can be opened using a wheel and they are not self-closing. The latter implies strict requirements on the ventilation system to prevent smoke entry into the cross-passage over longer time periods.



Figure 33: Cross-passage doors at Guanjiao rescue station

Cross-passage ventilation: During normal or maintenance operation, the cross-passages of Guanjiao tunnel are passively ventilated by opening the dampers at both ends. The piston effect of the driving trains provides a pressure difference between the two tunnel tubes and ensures a minimum air exchange within the cross-passage. In case of maintenance, a specific pressure difference between the two tunnel tubes can be created by the use of the jet fans at the portal areas and/or the smoke extraction system at the rescue station.

In the case of an emergency, the cross-passages are pressurized using the overpressure generated by the jet fans in the non-incident tunnel tube. No additional fans are installed within the cross-passages. The system consists of motorized dampers at each end of the cross-passage. Depending on the fire location, the dampers towards the non-incident tunnel tube are opened automatically. Hence the cross-passage is set to overpressure.

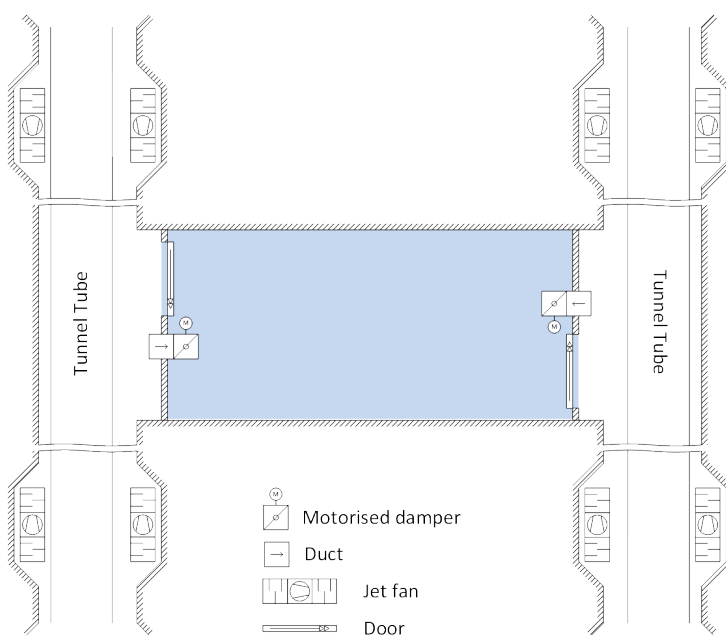


Figure 34: Ventilation schematic for typical cross-passage

8.1.4 >> STUTTGART 21

8.1.3.3 ADDITCROSS-PAONAL DETAILED DESCRIPTION AND BACKGROUND INFORMATION

The New Guanjiao Tunnel is equipped with a smoke extraction system at the rescue station. The smoke is extracted above the rail track and exhausted by 2 fully redundant axial fans through the adit to the ambient. There is no fresh air supply to the incident tunnel tube except through the non-incident tube and the cross-passages. The passengers are required to escape into the rescue station's cross-passages and to the non-incident tunnel tube, where they are evacuated using a rescue train.

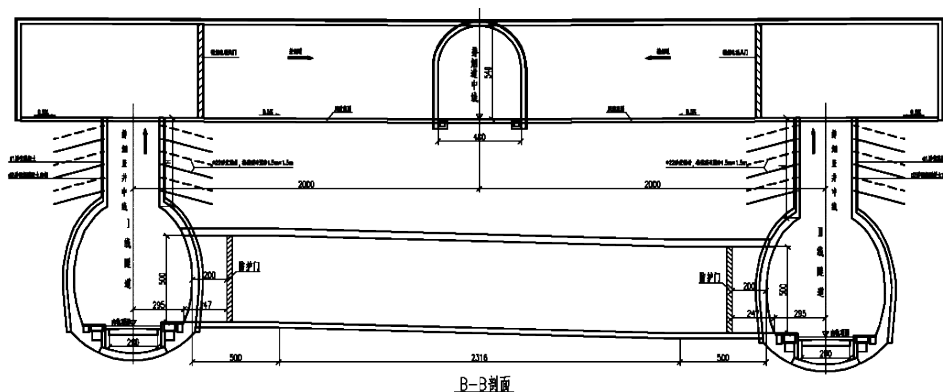


Figure 35: Smoke extraction system in rescue station

8.1.4 STUTTGART 21

8.1.4.1 KEY TUNNEL DATA

The tunnel layout of the Stuttgart 21 project is representative for the approach taken for cross-passage design of German rail tunnels which is guided by the German guideline on fire safety of rail tunnels ([11]) and the European TSI-SRT on safety in railway tunnels ([1]). The Stuttgart 21 project in the city of Stuttgart is the transformation of the existing train station from an above-ground terminal stop with 16 tracks to an underground through-station with 8 tracks. The new Central Station is connected by 30 km of mostly twin-tube tunnels to existing or new rail infrastructure. Tunnels leading to the south (Filder, 9.9 km; Unter- und Obertürkheim, 5.5 km / 7.2 km) and to the north (Bad Cannstatt, 4.1 km; Feuerbach, 3.7 km) are arranged to connect to the regional, national and international rail network. The maximum train speed of 250 km/h is reached in the Filder Tunnel.

8.1.4.2 KEY CROSS-PASSAGE DATA

Following [10] and [1], key requirements regarding cross-passages of twin-tube systems are as follows:

- Maximum distance between cross-passages 500 m
- Minimum free height of 2.25 m and free width of 1.2 m of egress path
- Separation of the rail tunnels by two door sets
- Door set distance inside cross-passage, i.e. length of cross-passage, at least 12 m leading to a quasi air-lock

- Doors to be smoke-tight and self-closing
- Door wings to open in the escape direction, i.e. two opening directions required
- Single door wing to be at least 1 m wide

The typical layout of a cross-passage is shown in Figure 36 (with the particular case of housing a firefighting water reservoir). Further electromechanical equipment (e.g. cabinets for power supply, control systems, communication, etc.) is arranged in separate technical rooms, branching off from the cross-passages.

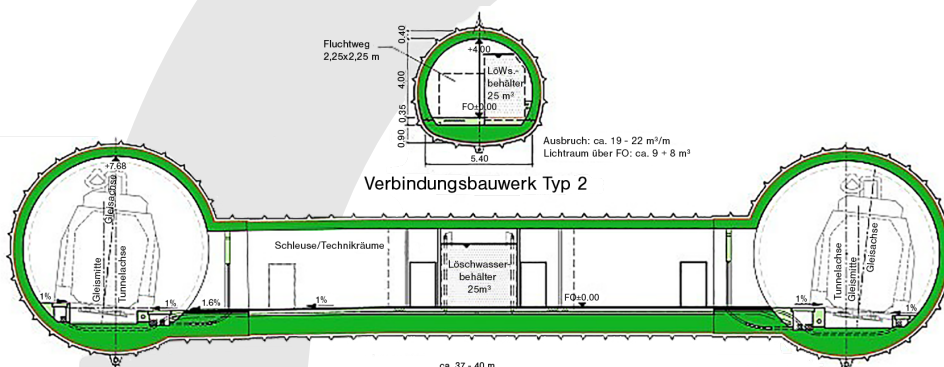


Figure 36: Cross-passage of Stuttgart 21 tunnel

8.2 >> METRO TUNNELS

8.1.4.3 ADDITIONAL DESCRIPTION AND BACKGROUND INFORMATION

Figure 37 shows further installation for fire safety in the area of the cross-passage.

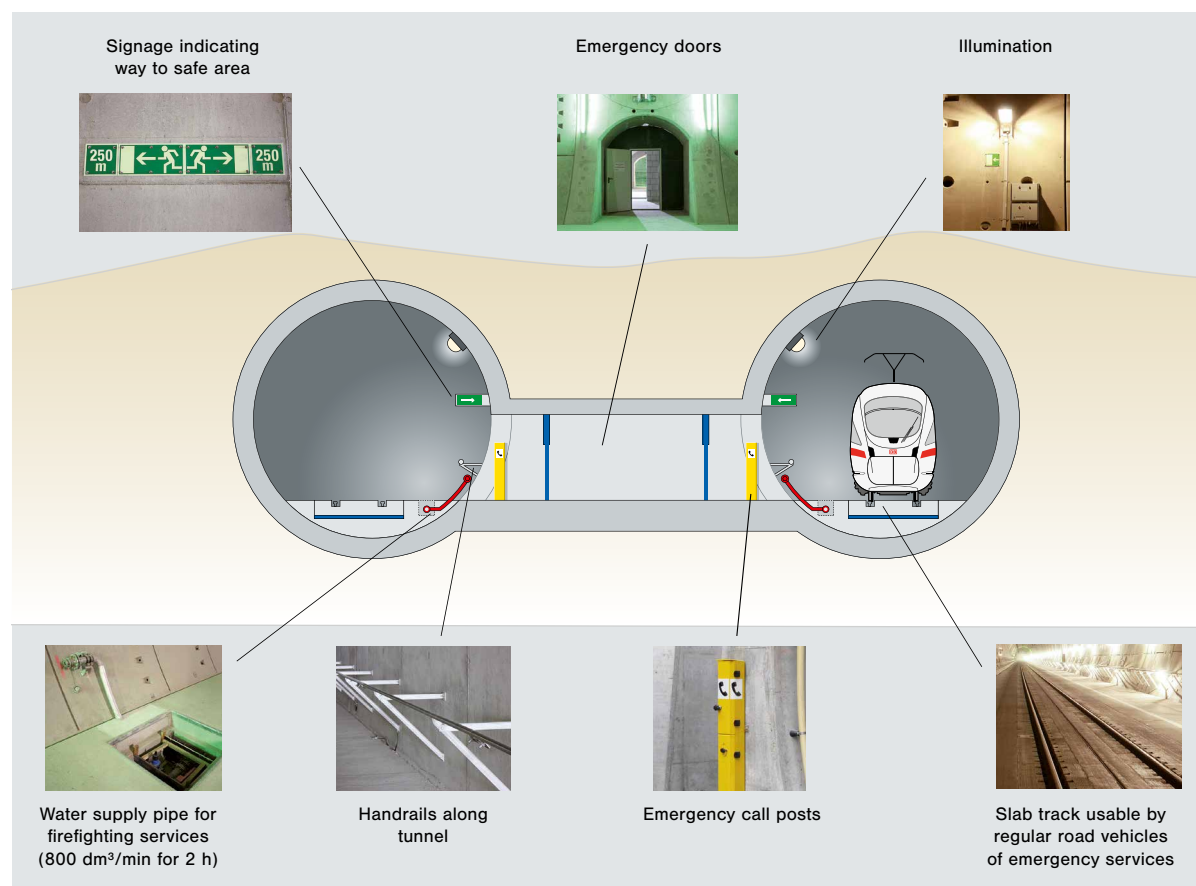


Figure 37: Cross passages of Stuttgart 21 tunnels and further measures to support fire safety in tunnels

8.2 METRO TUNNELS

The aforementioned examples of cross-passage design refer to long-distance, high-speed, heavy-rail tunnels. In comparison to these, metro tunnels in the sense of this document are typically characterized by the following features:

- shorter trains (e.g. 50 to 200 m long metro train instead of 400 m long long-distance train)
- slower trains (e.g. 60 to 100 km/h instead of 200 to 300 km/h)
- shorter headway (e.g. 90 s instead of 3 min at peak time)

- higher passenger density (e.g. 8 passenger per metre of metro train at peak time instead of 2 passengers per metre in long distance train)
- shorter distance to next underground station or portal
- passenger transportation only, i.e. no freight trains

Because of these differences, cross-passages of metro tunnels are characterized by the following:

- The cross-passage spacing in metro tunnels is often shorter than in long-distance rail tunnels mainly because of the shorter trains and higher passenger density.
- The cross-passages of metro tunnels are less equipped with electro-mechanical equipment because the distance to technical rooms at the portals and/or stations is typically shorter than in long-distance rail tunnels.

8.2.2 >> METRO MILAN LINE M5

8.2.1.3 ADDITIONAL INFORMATION

The length of the cross-passages varies between 6 to 10 m. The cross-passages are protected with fire door assemblies, which have a fire protection rating of 1.5 h. The door itself is designed as a self-closing swinging door, with a minimum of 1.12 m clear width and 2.1 m height to enable the occupants to escape easily in case of

an incident. Inside the cross-passage, no temperature sensitive equipment is installed except telephones for direct connection to the operation control centre. The cross-passages are essentially airtight, i.e. there is no local mechanical ventilation system to create an air flow inside the cross-passage.

Vehicles of Line 8 are equipped with front-end evacuation ramps. In case of incident,

the passengers are advised to detrain from one front end and to walk to the next station or portal. The accessibility of the sidewalks and the adjacent cross-passages is severely limited by the difference in height between trackway and sidewalk. Therefore, the cross-passages are not intended as main evacuation path.

8.2.2 METRO MILAN LINE M5

8.2.2.1 GENERAL INFORMATION

Metropolitana di Milano, the metro system of the city of Milan, Italy, went into operation in 1964 being Italy's second metro system. The system includes 4 lines, some with overhead catenary system, some with third rail.

The line M5 runs between Bignami in the north east of the city to the San Siro stadium and started operation in 2015. It is the first line of the Milan metro running completely driverless (fully automatic). The total length of M5 metro line is 12.9 km serving 19 stations.

8.2.2.2 KEY CROSS-PASSAGE DATA

The metro line M5 is running with two parallel tunnel tubes with interconnecting cross-passages. The cross-passages are connected to exit shafts, either directly accessible from the cross-passage or located next to one of the tunnel tubes.

The cross-passages are equipped with two swing doors at each end, opening into escape direction.

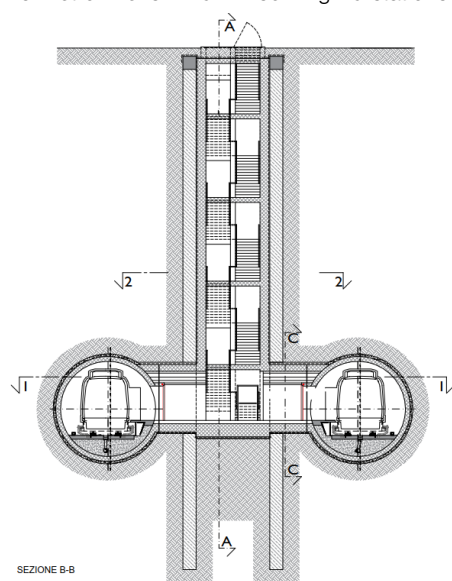


Figure 39: Cross-passage of Line M5 with escape shaft between the tunnel tubes

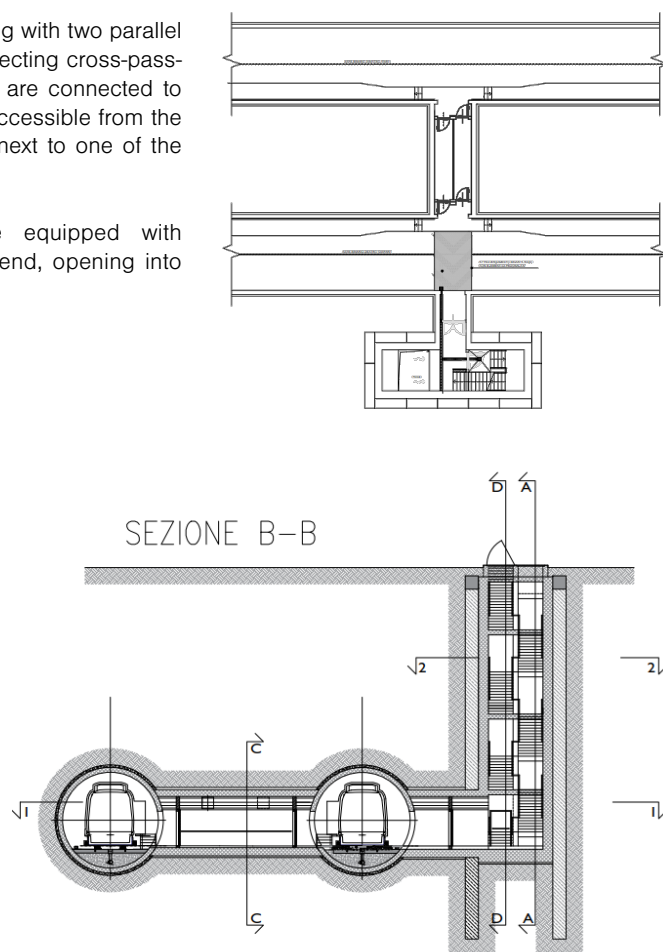


Figure 40: Cross-passage of Line M5 with escape shaft next to one tunnel tube

8.2.3 >> METRO DOHA PHASE 1 GOLD LINE

8.2.3 METRO DOHA PHASE 1 GOLD LINE

The Doha Metro of Phase 1 will comprise a network of 4 lines extending from the centre of Doha to the north, west and south of the city. As of 2018, civil works are mostly finished and the tunnels and about 30 underground stations are being equipped with rail and further technical equipment and interiors. The network of Phase 1 shall be operational in 2021.

The Gold Line is part of the Metro Doha network. As most other underground parts,

the twin-tube, single-track tunnels were excavated by TBM's. Cross-passages form important elements of the tunnel network. Following NFPA 130 ([15]), the cross-passages are placed at mutual distances of not more than 244 m.

Cross-passageways are separated from the running tunnels by self-closing fire door assemblies having a fire protection rating of 1.5 h. Door openings are 1.1 m wide and 2.1 m high exceeding the requirements of NFPA 130 ([15]). In the case of Doha Metro, many cross-passages are equipped with niches

housing sensible parts of the mechanical, electrical and plumbing (MEP) equipment.

Figure 41 is a top view of a cross-passage footprint of Doha Metro. The interior of the cross-passage is about 8 m long, 2.3 m high and 2.2 m wide. The free footprint of the 2 niches is 2 m x 1 m.

Figure 42 shows an architectural view.

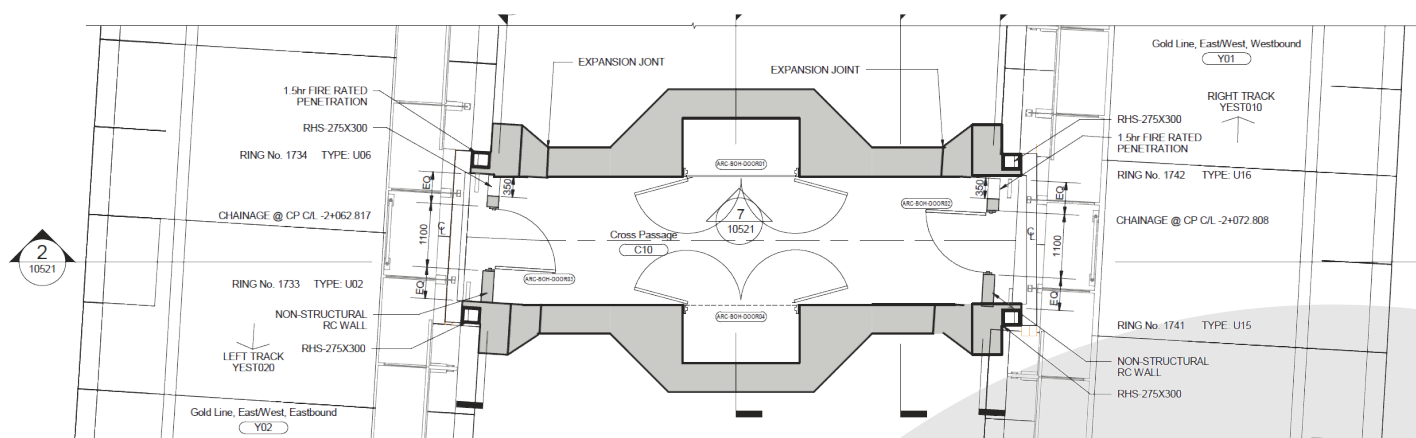


Figure 41: Top view of cross-passage foot-print of Gold Line of Doha Metro

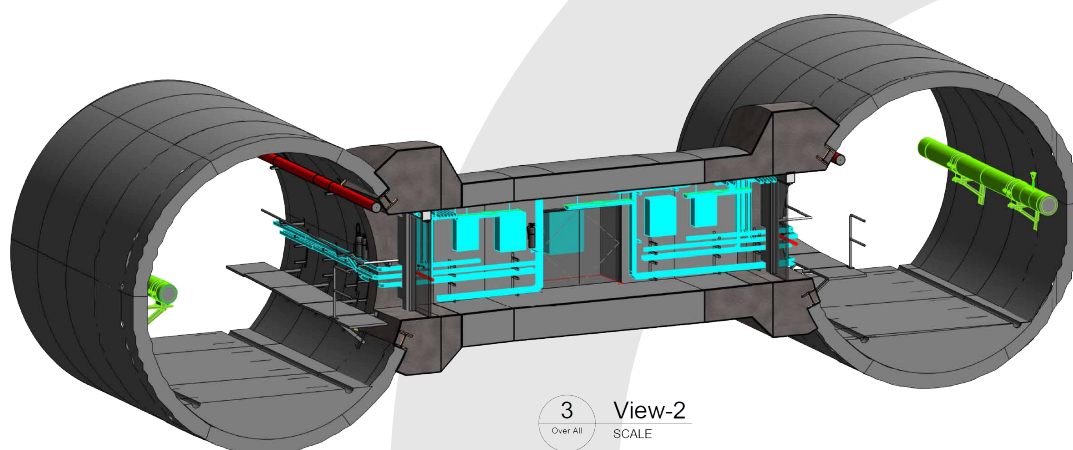


Figure 42: Architectural view of cross-passage of Gold Line of Doha Metro with MEP installations

9 >> CONCLUSIONS ON CURRENT PRACTICE AND TRENDS

9 CONCLUSIONS ON CURRENT PRACTICE AND TRENDS

Rail and metro tunnels are characterized by a number of features and peculiarities. Similarly, cross-passages are found in a variety of designs and features as well. As a result of the different requirements and boundary conditions, it is not advisable to try providing specific and universally valid specifications. This chapter focuses on particularly relevant aspects to be accounted for and well-established solutions based on good practice and

on the considerations expressed in the previous chapters.

It should be noted that most regulation focus on minimum requirements, such as the maximum allowable distance between cross-connections and of the minimum width of doors and walkways. Requirements are project dependent and are particularly dependent on density of passengers, train length, train type, smoke-management system etc. A general procedure for identifying the best-suited distance basis is outlined in the ITA-COSUF guideline [20].

9.1 SPACING BETWEEN CROSS-PASSAGES

Minimum requirements are defined by national standards and norms. Typical values for the maximum allowable distance between cross-connections range from 244 m to 500 m. The typical values used for the long Alpine tunnels for long-distance traffic are around 300 to 350 m. Many recent metro tunnels for urban, short-distance traffic have cross-passages at distances of about 250 m.

9.2 DIMENSION OF THE ESCAPE WALKWAY AND WAITING ZONE

Minimum requirements are defined by national standards and norms. Typical dimensions of door width range from 0.8 to 1.2 m with a minimum height of 2.0 m. They should be fitted to the capacity of the emergency exits.

It should be noted that a width of 0.8 m is critical for wheelchairs and does not allow for overpassing slower persons on the walkway. Thus, escape velocity is dictated by the slowest persons. NFPA 130 recommends to assume an escape velocity of 37.7 m/min or 0.6 m/s along corridors and ramps for design purposes.

The dimensions of the escape walkways shall be adapted to the dimensions of the doors and to the requirements resulting from train traffic and emergency management.

9.3 DIMENSION AND ARRANGEMENT OF THE CP

There are generally few normative specifications and standards for the dimensions of cross-connections. Key aspects to be considered are self-rescue and intervention concepts as well as possible other uses, e.g. for hosting technical equipment. In some cases, cross-connections are used as temporary safe area for escaping persons, requiring a comparatively large footprint. Otherwise, transit capacity should be compatible with walkway and door capacity.

Some countries require a fire-resistant physical barrier between technical equipment and escape space.

9.4 FIRE-PROTECTING DOORS

Fire-protecting doors are characterized by a large variability related, in particular, to the main dimensions, opening characteristics, thermal and mechanical resistance. The main parameters can be summarized as follows:

- Swing or sliding door, variable from country to country
- Main dimensions typically 1.4 x 2 m
- Thermal resistance typically 30 to 90 min, more in case of long intervention and evacuation times
- Allowable opening force typically less than 100 and 220 N and self-closing mechanism

The required mechanical stability depends on the aerodynamic interaction between trains and tunnel, resulting in pressure fluctuations. The dynamic load can reach up to 20 kPa in case of high-speed traffic.

9.5 AERODYNAMICS, TUNNEL ENVIRONMENT AND VENTILATION

Aerodynamic effects arising from train motion shall be considered because of the resulting dynamic loads. These affect directly the doors and indirectly all equipment installed in the cross-connections, especially with trains speed exceeding 150 km/h.

Dedicated ventilation systems are frequently used for cross-passages for maintaining suitable environmental conditions in normal operating conditions and for protecting them against smoke penetration in case of fire. If available, the tunnel ventilation system has a significant effect on the ventilation of cross-connections and can be used for preventing smoke penetration in case of fire.

Environmental conditions in the tunnel tubes (temperature, humidity, dust concentration etc.) impact cross-connection ventilation.

The variety of proven technical solutions is large and a dedicated analysis of requirements, boundary conditions and viable technical solutions is recommended.

9 >> CONCLUSIONS ON CURRENT PRACTICE AND TRENDS

9.6 APPEARANCE AND VISIBILITY

The appearance and visibility of emergency exits in general and cross-connections in particular should be uniform and familiar to all tunnel users. This is an important long-

term goal, which could be partly achieved in road tunnels. The recommended minimum requirements for ongoing projects are good visibility also in case of unfavourable lighting conditions and uniformity at least for a given line or metro system.

9.7 EQUIPMENT

Required equipment for cross-connections include at least:

- Doors and ventilation
- Appropriate signing, instructions and warnings
- Emergency lighting
- Facilities for communications (at least emergency phones)
- Emergency medical kit
- Protection against smoke penetration and thermal load.

The following equipment are not yet standard but are increasingly used and contribute improving tunnel safety:

- Full video coverage
- Loudspeakers

If further technical equipment required for tunnel operation is installed inside cross-passages, the escape pathway should be clearly marked, identifiable and free of obstacles. Technical equipment not meant for public use shall be properly protected.

9.9 DISABILITY

Person with disabilities and person with reduced mobility shall be accounted for at different levels. The core objective is providing a fair chance of self-rescue also to disabled persons in case of incident with train stop in a tunnel.

9.8 DEFINITION OF POINT OF SAFETY

Points of safety offer protection until the escaping persons can be evacuated to the outside. The required interval depends on the rescue concept adopted and can reach up to 4 hours. The following requirements result immediately from the basic specifications and must be maintained for the whole interval specified in the safety concept:

- Protection against smoke and heat penetration through separating walls and doors
- Ventilation system with fresh-air supply granting appropriate environmental conditions
- Full accessibility from the fire tube and from the outside, with vehicles appropriate for the evacuation of all occupants
- Appropriate means of communication allowing for appropriate assistance for a prolonged time.

The aspects, which are particularly relevant for cross-connections, can be summarized as follows: obstacle-free routes, suitable doors and entrances, suitable width of walkways, doors and transit corridors, lighting, visual information (signposting, pictograms, printed or dynamic information), spoken information.

