Bouwdienst Rijkswaterstaat

Directoraat-Generaal Rijkswaterstaat

Ministry of Transport, The Netherlands

Sprinklers in Japanese Road Tunnels

Final Report

December 2001

Chiyoda Engineering Consultants Co.,Ltd.

Project Report BFA-10012

SPRINKLERS IN JAPANESE ROAD TUNNELS

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This report is prepared by Chiyoda on request by RWS and is based on information from existing published literature, interviews with personnel of related organizations and site visits. This report is not an official publication by any Japanese authority.

The text herein is prepared to represent as good as possible the customs and experiences with sprinklers in Japanese tunnels. Its contents and wordings are verified with the interviewed organizations, but the following is noted:

- In case of discrepancy between the original text of Japanese literature and the (translated or interpreted) English text in this report, the original Japanese text applies.
- The interviewed or visited organizations are not to be held responsible for any such discrepancies.

Contents

Acknowledgement

We herewith express our gratitude to the personnel from the Dutch Ministry of Transport, Public Works and Water Management, especially the Civil Engineering Division of the Directorate General Rijkswaterstaat, to invite us to carry out the underlying investigation. Their assistance with advice and comments, as well as their kind cooperation during the technical meetings has been an indispensable part of this investigation.

At the same time we express our gratitude to the personnel from the Japanese organizations that have kindly offered their views and information necessary for this investigation, especially the Metropolitan Expressway Public Corporation, the Japan Highway Public Corporation and Nohmi Bosai Ltd.

Abbreviations

A	Nominal inner diameter of pipes (see further APPENDIX F)
Chiyoda	Chiyoda Engineering Consultants Co.,Ltd.
EHRF	Expressway Highway Research Foundation of Japan (affiliated to JH)
HONSHI	Honshu-Shikoku Bridge Public Corporation
ITA	International Tunneling Association
JH	Japan Highway Public Corporation
JHRI	Japan Highway Research Institute
JRA	Japan Road Association
MEPC	Metropolitan Expressway Public Corporation
MOC	(former) Ministry of Construction
MOLIT	Ministry of Land Infrastructure and Transport
MOT	(former) Ministry of Transport
Nohmi	Nohmi Bosai Ltd.
OECD	Organisation for Economic Co-operation and Development
PIARC	World Road Association
PWRI	Public Works Research Institute (formerly affiliated to MOC, now independent)
RWS	Rijkswaterstaat (Dutch Ministry of Transport and Water Management)

1 Introduction

1 - 1 Background

Since many years, the issue of fire safety in road tunnels is being discussed and investigated in The Netherlands. One of the main reasons for this is the importance of road tunnels in the transportation of goods through The Netherlands in its function as import harbor for Europe through the harbors of Rotterdam and Amsterdam. Focus is placed on the supply of an infrastructure for transportation with as few limitations as possible. Within this context road tunnels require special attention in order to allow a broad range of goods, including dangerous goods, with the highest possible safety level.

The discussion about road tunnel safety in The Netherlands is also based on the type of tunnels it operates. Because of the large number of waterways in the country, a corresponding large number of crossings exist, and whereas the principal crossing consists of bridge structures, the heavy traffic on these waterways have also lead to a well-established custom in the construction of tunnels. The very fact that most Dutch tunnels are underwater tunnels based on a concrete structure (lining) increases the impact in case of structural problems (in the worst case collapse), and underlines the necessity for additional safety measures.

A third reason for the awareness about fire and road tunnel safety is based on experience with tunnel accidents, in The Netherlands and abroad. Since two serious tunnel fire accidents occurred in 1999 in the Mont Blanc Tunnel (France/Italy) and the Tauern Tunnel (Austria) and the most recent fire accidents in the Gleinalm Tunnel (Austria, August 2001) and the Gotthard Tunnel (Switzerland, October 2001), this discussion is increasingly attracting attention.

One of the items in discussion at the moment about fire safety in road tunnels is the use of sprinklers. At present, sprinklers are internationally not recommended for road tunnels. For example, the 1999 PIARC Committee on Road Tunnels states the following recommendations about sprinklers [1]:

> "VI.3.4.3 Recommendations
>
> No European country uses sprinklers on a regular basis. In some tunnels in Europe sprinklers have been used for special purposes. In Japan sprinklers are used in tunnels with important length or traffic to cool down vehicles on fire. In the United States only a few tunnels carrying hazardous cargo have some form of sprinkler. The reason why most countries do not use sprinklers in tunnels is that most fires start in the motor room or in the compartment, and sprinklers are of no use till the fire is open. Sprinklers can be used, however, to cool down vehicles, to stop the fire from spreading to other vehicles (i.e. to

[1] PIARC, Fire and Smoke Control in Road Tunnels, 1999, p.229-231

diminish the fire area and property damage) and to stop secondary fires in lining materials. Experiences from Japan show that sprinklers are effective in cooling down the area round the fire, so that fire fighting can be more effective.

However, the use of sprinklers raises a number of problems, which are summarized in the following points:

- Water can cause explosion in petrol and other chemical substances if not combined with appropriate additives,
- There is a risk that the fire is extinguished but flammable gases are still produced and may cause an explosion,
- Vaporized steam can hurt people,
- The efficiency is low for fires inside vehicles,
- The smoke layer is cooled down and de-stratified, so that it will cover the whole tunnel,
- Maintenance can be costly,
- Sprinklers are difficult to handle manually,
- Visibility is reduced.

As a consequence, sprinklers must not be started before all people have evacuated.

Based on these facts, sprinklers cannot be considered as equipment useful to save lives. They can only be used to protect the tunnel once evacuation is completed. Taking into account this exclusively economic aim (protection of property and not safety), sprinklers are generally not considered as cost-effective and are not recommended in usual road tunnels."

These recommendations are based on a questionnaire to different countries which was also answered by The Netherlands, as follows [2]:

"Sprinkler systems are not applied in tunnels in the Netherlands. The disadvantages are greater than the advantages. In addition the installation and maintenance costs are high.

The most important reason for not using sprinkler systems is that the extinguishing function is not controllable. Since the system is either on or off the amount of water dispended cannot be regulated. In the case of a liquid fire, this can result in undesirable situations regarding potential spread of fire."

These PIARC recommendations are still valid at present. Accordingly, sprinklers are not used in most countries, except for special cases. One of the only countries that have included sprinklers in road tunnel safety standards is Japan.

[2] PIARC, Fire and Smoke Control in Road Tunnels, 1999, p.227

On the other hand, the recent fire accidents in road tunnels and the rapid increase in the number of new road tunnels have lead to renewed discussion in The Netherlands about the use of sprinklers as safety measure in road tunnels. Also in international context, the nuance of recent wordings concerning sprinklers shows slight shifting tendencies:

- The most recent publication concerning road tunnel safety by OECD/PIARC of October 2001 [3] states:

  "…Automatic extinguishing systems (sprinklers) are not recommended as safety equipment in tunnels because of the hazards they may create for people present in the fire and smoke zone. However, they can be used to protect the tunnel once evacuation is completed."

- The most recent publication concerning road tunnel safety by the UN Economic Commission for Europe of December 2001 [4] states:

  "**Measure 3.06 Automatic fire extinguishing system**
  The technology is not yet sufficiently advanced to be able to recommend the use of built-in automatic fire extinguishing systems in tunnels.
  Further industry research is to be conducted on these systems and on other new fire-fighting technologies in order to verify their efficiency and to determine in what conditions they could be used." (p. 37)

  But also:

  "Fixed fire-fight equipment
  Since sprinklers have not been recommended for the time being, it is important that research into alternative technologies should be continued." (p. 46)

[3] OECD, Safety in Tunnels, Transportation if dangerous goods through road tunnels, October 2001, p. 64

[4] UN Economic Commission for Europe, Recommendations of the group of experts on safety in road tunnels, Final Report, December 2001, p. 37, p. 46

1 - 2 Purpose and outline of investigation

As part of the discussion concerning road tunnel sprinklers, the Japanese experience with sprinklers in road tunnels is believed to be of value. For this purpose, the Center for Tunnel Safety of the Dutch Ministry of Transport, Public Works and Water Management (RWS), has requested Chiyoda Engineering Consultants Co.,Ltd. (Chiyoda) to produce a comprehensive report that introduces the developments and present situation about road tunnel sprinklers in Japan.

In order to supply RWS with suitable information, it was decided to collect information on three levels: production, operation and maintenance. Figure 1-1 shows the flow of activities carried out for this investigation.

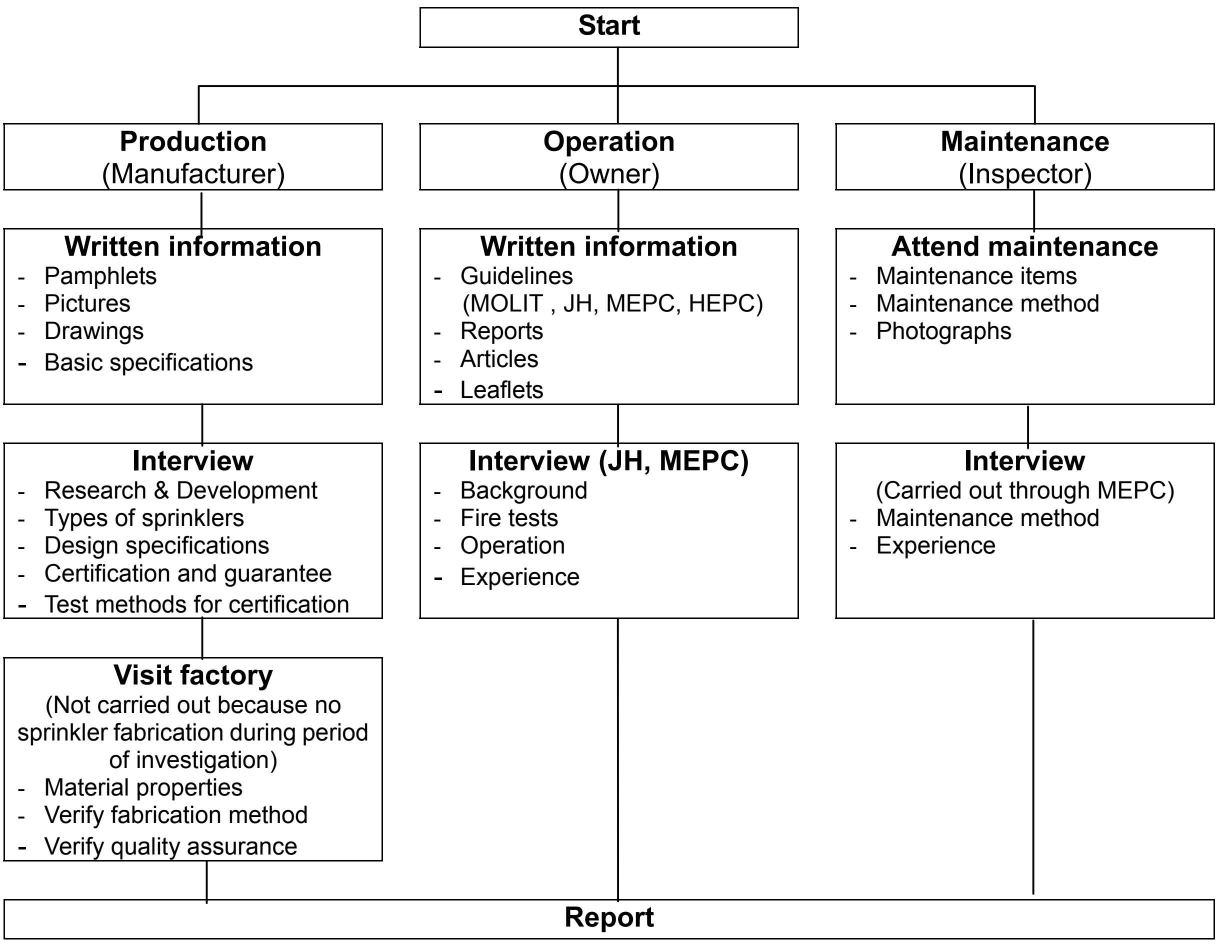

Figure 1-1 Flow chart

2 Japanese Guidelines

2 - 1 Introduction

2 - 1 - 1 General

Japan is a highly mountainous country, and the population mainly concentrates in major urban areas along the coast, the largest six being Tokyo Area, Osaka Area, Nagoya, Hiroshima, Kita-Kyushu and Fukuoka (Figure 2-1). Tokyo Area (Figure 2-2), Osaka Area (Figure 2-3) and Nagoya (Figure 2-4) alone house about 50% of the total population of 120 million. The Tokyo Area (including the prefectures of Tokyo, Yokohama, Kawasaki and Chiba) expanding around the bay of Tokyo, has a total population of almost 30 million people (27% of national population) on an area of around 8,000km^2 (4% of total land area), giving a population density of 3,700 persons/km^2. For comparison, the Randstad in The Netherlands has a population density of almost 1,000 persons/km^2.

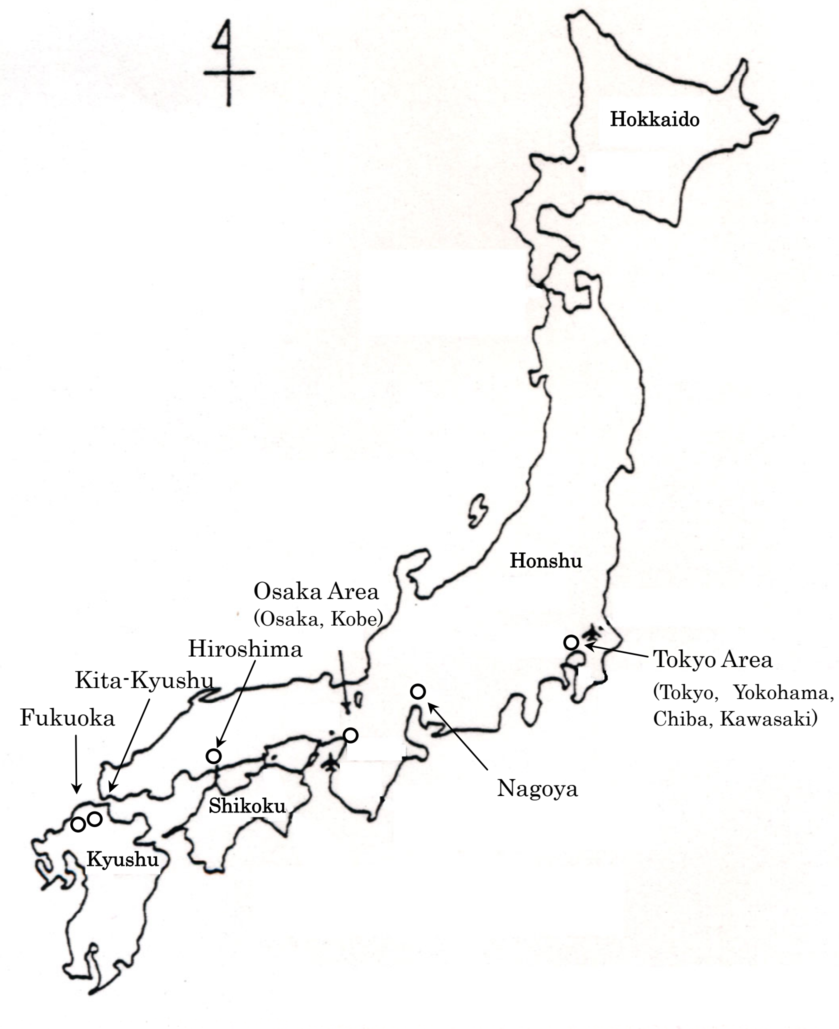

Figure 2-1 Major urban areas in Japan

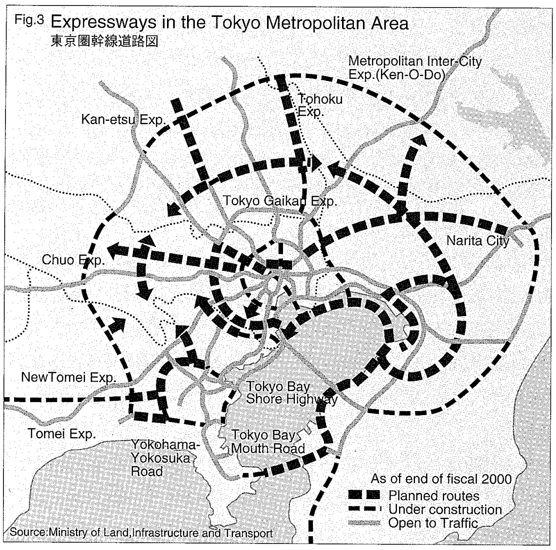

Figure 2-2 Tokyo Area

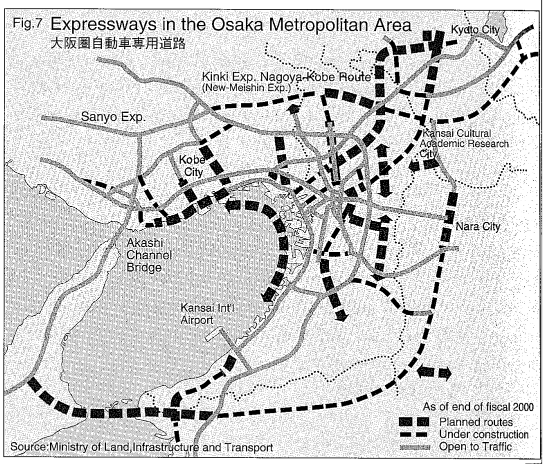

Figure 2-3 Osaka Area

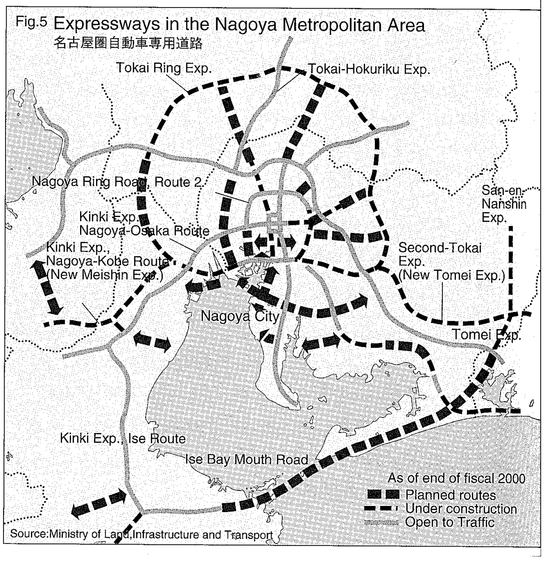

Figure 2-4 Nagoya Area

The Japanese highway network is controlled by a number of public corporations, which are associated to the Ministry of Land Infrastructure and Transport (MOLIT). The MOLIT exists since 2000, and is a merger of the former Ministries of Construction (MOC) and Transport (MOT).

The national highway network is operated by the Japan Highway Public Corporation (JH, established in 1956), and comprises some 6,740km of highways (October 2000). The complexity and the special characteristics of highways in urban areas have called for corresponding treatment, and separate administrations were established: the Metropolitan Expressway Public Corporation (MEPC) for the Tokyo Region in 1959 and the Hanshin Expressway Public Corporation (HEPC) for the Osaka Region in 1962. Since their establishment, the transportation of passengers and freight over these urban roads has increased rapidly, and at present about 1.16 million vehicles per day make use of 264km of urban expressways operated by the MEPC, whereas about 900,000 vehicles per day make use of about 221km expressways operated by the HEPC.

Other authorities that operate tunnels include:

- The Honshu-Shikoku Bridge Authority (HONSHI, in charge of Bridge connections between the Main island (Honshu) and the island Shikoku) operates tunnels in the connection roads between its bridges and the existing road network.
- Before the MOC and MOT were merged into the MOLIT, a number of harbors tunnels were operated by the MOT.
- Some local governments operate road tunnels.

Figure 2-5 gives an overview of the main Japanese governmental bodies that operate road tunnels.

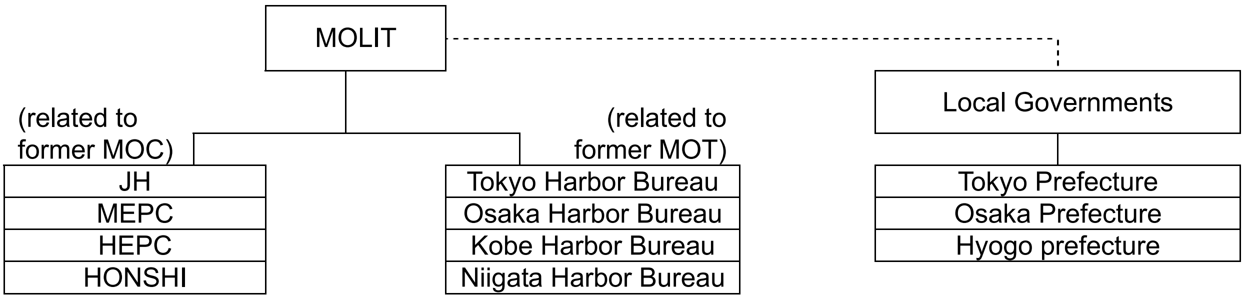

Figure 2-5 Overview of main governmental bodies that operate road tunnels

2 - 1 - 2 Development of guidelines for road tunnel safety facilities [5]

The highway network of postwar Japan was initiated with the first 5-year infrastructure planning decided in 1954, which also paved the way for development of rapid motorization, which was in line with equally rapid economic growth. The first 5-year planning included the construction of a number of long road tunnels, such as the Kanmon Tunnel (L=3,461m) and the Sasako Tunnel (L=2,953m) in 1958.

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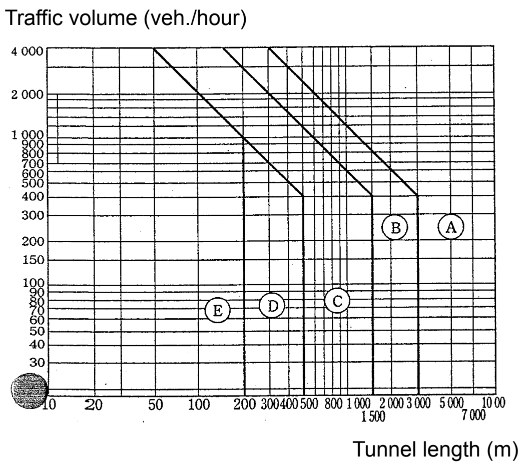
[5] Japan Highway Research Institute (JHRI), “Highway Technology”, No. 15, December 1999 (Japanese)

A fire accident in the Suzuka Tunnel in March 1967 called for urgent introduction of tunnel safety facilities, and based on a Notification stipulated by the Government in April of the same year, the JH published its Guidelines of August 1967, including a classification of tunnels according to tunnel length and traffic volume and safety facilities per category (Figure 2-6), and including the first stipulations concerning sprinklers (stipulation by text and not included in the categorization or table). Figure 2-7 shows the classification and facilities as stipulated in the JH Guideline of June 1979, based on the technical level of the time.

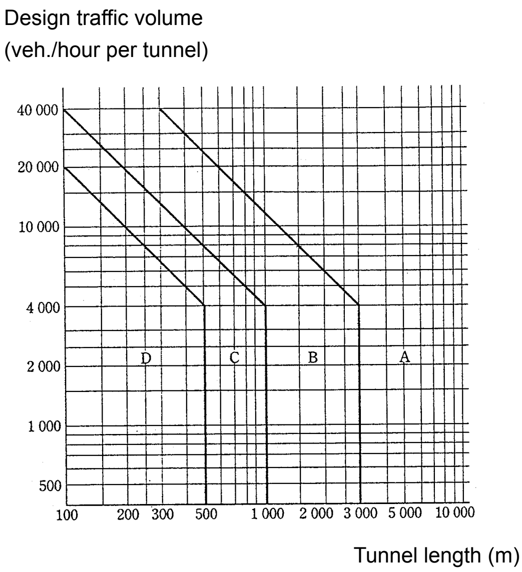
A serious fire accident in the Nihonzaka Tunnel (L=2,045m) in July 1979 (7 fatalities, 173 vehicles burnt out) made additional measures necessary. In the April 1981 version of the JH Guidelines an additional tunnel category was included for long tunnels with large traffic volume (i.e. tunnels similar to the Nihonzaka Tunnel), and the number of safety facilities was increased from 4 to 13. Also after 1981, guidelines have been published and revised in the course of time, but the 1981 stipulations are the base of the present guidelines, as further described in the next sections of this chapter.



Facility / Cat.	Information facilities	Alarm facilities	Fire extinguisher	Fire hydrant
A	Electrically lit message board	Automatic or manual	For ABC fires*	Installed
B	Electrically lit message board	Manual	For ABC fires	Installed
C	Electrically lit message board	Manual	For ABC fires	Installed
D	Electrically lit message board	Manual	For ABC fires	-
E	-	-	For ABC fires	-

* A fire: Wood, paper, cloth, etc.
B fire: Gasoline, oil, etc.
C fire: Electric apparatus, etc.

Figure 2-6 Tunnel categorization and safety facilities, JH Guideline August 1967



Facility / Category		A	B	C	D
Communication	Manual	O	O	O	
	Automatic	O			
	Emergency telephone	O	O	O	O
Message board		O	O	O	O
Fire fight equipment	Fire extinguisher	O	O	O	
	Fire hydrant	O	O		
Other facilities		Water supply, sprinkler, smoke extraction, evacuation, lay-by, evacuation guidance, ITV camera, emergency power supply, emergency lighting			

Figure 2-7 Tunnel categorization and safety facilities, JH Guideline June 1979

Authorities that do not operate large number of tunnels have not stipulated their own guidelines, but follow the MOLIT guidelines (previous MOC guidelines) and specify the needs in accordance with the needs of each tunnel to be built within the requirements of the MOLIT guidelines. Because the outcome is different depending on local conditions, the safety facilities and systems of these tunnels are not described in this report.

In order to introduce the present status of regulations concerning tunnel safety facilities in general and sprinkler facilities in particular, this report focuses on the following guidelines presently in use in Japan (Figure 2-8):

1) MOLIT

- Japan Road Association, Guideline and Explanation for the Installation of Safety Facilities in Road Tunnels, 2001 (Japanese)

2) JH

- JH, Design Principles, Volume 3 (Tunnel), 1998 (Japanese)
- JH, Design Principles, Volume 7 (Electrical and Equipment), 1990 (Japanese)

3) MEPC

- MEPC, Guideline for the Installation of Tunnel Safety Facilities (Concept), 1993 (Japanese)

4) HEPC

- HEPC, Design Guidelines, Volume 1 Part 7 (Tunnel Safety Facilities), 1992 (Japanese)
- HEPC, Design Standard (Tunnel Planning Guideline), 1996 (Japanese)

Figure 2-8 Japanese guidelines concerning tunnel safety facilities (MOLIT, JH, MEPC, HEPC)

2 - 1 - 3 General description of guidelines and position of sprinklers

This section introduces the guidelines of MOLIT, JH, MEPC and HEPC in general, and also gives information about the position of sprinkler systems within each guideline as well as their relation with other safety facilities.

1) MOLIT

The basic guidelines concerning road tunnel safety facilities are prepared by the Japan Road Association (JRA) and officially published by the MOLIT. The MOLIT notifies the other administrations to follow these basic guidelines. The latest version [6] of these basic guidelines (October 2001) includes the following items:

- General stipulation

  The basic rule is stated as: “The installation of safety facilities must be planned based on consideration of their role in the tunnel disaster prevention as a whole, and clarification of their purpose and operation method.”

  Importance is placed on the recognition that safety facilities alone do not construe the total tunnel disaster prevention, but that their specification and operation are the decisive factors of their functionality, especially in order to supply measures to limit the effects of a tunnel fire.

- Types of safety facilities

  The safety facilities are divided into 4 classes as described in Table 2-1.

Table 2-1 Types of safety facilities (MOLIT)

Class		Safety facility
Communication/ alarm facilities	Communication	Emergency telephone
		Push button
		Fire detector
	Alarm	Emergency alarm
Fire-extinguish facilities		Fire extinguisher
		Fire hydrant
Evacuation guidance facilities		Emergency guidance panel
		Smoke extractor, evacuation route
Other facilities		Water supply hydrant
		Leaky feeder system
		Radio (re-) broadcast, loudspeaker system
		Water sprinkler*
		Monitoring equipment

* Water sprinklers are not regarded as fire-extinguish facilities.

[6] Japan Road Association, Guideline and explanation for the installation of safety facilities in road tunnels, 2001 (Japanese)

The communication / alarm facilities are meant to notify tunnel authorities, Fire Brigade and police about a fire or other emergency, and to inform other road users inside and outside the tunnel about the emergency.

Fire extinguishing activities include initial fire fighting by road users and detailed fire fighting by the Fire Brigade. The fire-extinguish facilities in the tunnel are in principle for the purpose of initial fire fighting.

The evacuation guidance facilities are for the purpose to provide guidance for safe evacuation of tunnel users in case of emergency.

The other facilities are for the purpose to support the above facilities.

In addition, tunnels are supplied with uninterruptible power supply, pipes for water supply, and in some cases cooling equipment in ventilation duct (in case the ducts are used for smoke extraction in case of fire, the extractors need to be protected from high temperatures).

– Installation of safety facilities

The safety facilities to be installed in a specific tunnel are based on a categorization of tunnels. The final category of a tunnel is decided case by case, based on investigation and evaluation of a number of factors. The principle factors are the length and the traffic volume (i.e. the expected number of vehicles per day per tube 20 years after opening to traffic) of that tunnel, as given in Figure 2-9.

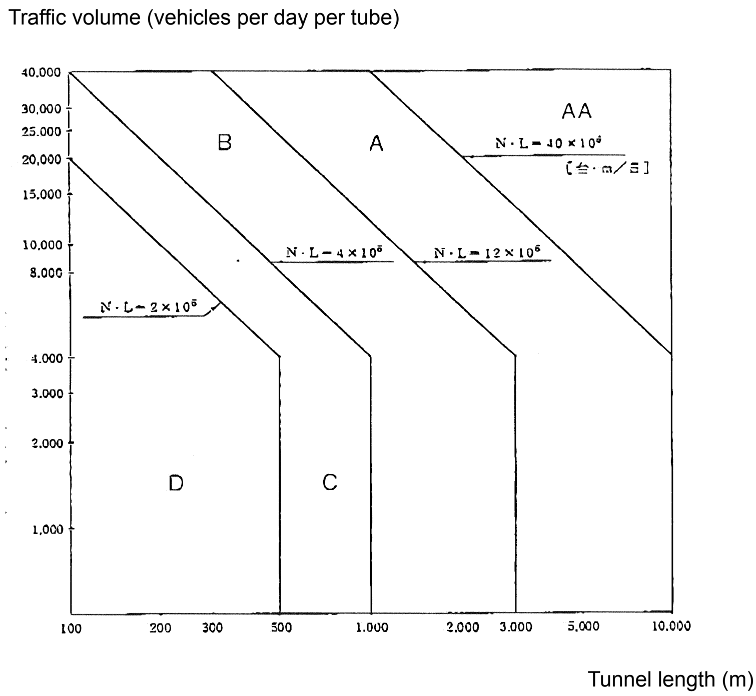


Figure 2-9 Categorization of tunnels (MOLIT)

In case the design velocity of the tunnel is high or in case the tunnel contains a longitudinal curve affecting the visual environment, the category of that tunnel is

mostly increased by one step. Other factors to decide the category of a tunnel include the tunnel width, ventilation method, bi- or uni-directional traffic, control system. It is desirable to take into consideration the expected frequency of tunnel fires (and where possible the magnitude), and to decide the final safety facilities accordingly. In case of two consecutive tunnels shortly after each other, the total length of both tunnels can be used to decide the tunnel category. For tunnels with less than 4,000 vehicles / day (per tube), the tunnel length is the decisive factor because the risk of damage by fire increases. Tunnels shorter than 100m are not subject to categorization. In case of tunnels with a traffic volume higher than 40,000 vehicles / day, the category is based on special investigation, but basically the category of the 40,000 veh./day level is used (100<L<300m: B category, 300<L<1000m: A Category, L>1000m: AA category). Categorization of future tunnels with large dimensions (e.g. 3 or more traffic lanes) will be investigated separately. In case a tunnel is planned as staged construction (e.g. by planning a future construction of an extra tube), the expected traffic volume 10 years after opening to traffic is used to decide the tunnel category. It is also possible to review the tunnel category in case the conditions in reality differ largely from the expectations. In such case, the safety facilities are adjusted as soon as possible within the limits of tunnel construction and operation.
The safety facilities for each tunnel category are as shown in Table 2-2.

Table 2-2 Types of safety facilities (MOLIT)

Class	Safety facility	AA	A	B	C	D
Communication/ alarm facilities	Emergency telephone	O	O	O	O	
	Push button	O	O	O	O	
	Fire detector	O	Δ			
	Emergency alarm	O	O	O	O	
Fire-extinguish facilities	Fire extinguisher	O	O	O		
	Fire hydrant	O	O			
Evacuation guidance facilities	Emergency guidance panel	O	O	O		
	Smoke extractor, evacuation route	O	Δ			
Other facilities	Water supply hydrant	O	Δ			
	Leaky feeder system	O	Δ			
	Radio (re-) broadcast, loudspeaker system	O	Δ			
	Water sprinkler *	O	Δ			
	Monitoring equipment	O	Δ			

O: Must be installed, Δ: Installed if deemed necessary

* Water sprinklers are not regarded as equipment for fire extinguish

For example, fire detectors are to be designed in such a way that a $0.5m^2$ pan fire is detected within 30 seconds.

– Operation of safety facilities

In order to guarantee prompt and accurate operation of the tunnel safety facilities in case of fire or other emergency, it is necessary that the tunnel operator is well aware of their necessity, function and purpose, and that his activities improve the initial fire fight conditions and the evacuation environment.

For this purpose, an operation manual is produced, including the system and method of emergency communication, flow of activities in case of fire or other emergency, operation of safety facilities, contents and method of information to tunnel users, verification method of communication messages.

In addition, emergency practices (training) are carried out regularly (in principle 1 time per year for tunnels longer than 1,000m or tunnels with large traffic volume), including practice of alarm receipt and emergency communication, operation of emergency facilities, dispatch of personnel from tunnel authority, fire extinguish and rescue activities.

Furthermore, information to road users about tunnel safety and safety facilities is important. Dummy safety facilities for practice are placed at parking areas in front of large-scale tunnels, leaflets are distributed with explanation about purpose and use of safety facilities, and information panels and posters are installed.

The guideline also describes the operation of ventilation for smoke extraction, sprinklers, communication facilities and lighting. The sprinkler operation is further described in Chapter 2-4.

– Repair and maintenance of safety facilities

In order to guarantee accurate functionality of safety facilities, it is necessary to carry out regular inspections and maintenance works.

2) JH

Based on the basic requirements concerning tunnel safety facilities stipulated in the MOLIT (at the time still MOC) guidelines, the JH has issued its guidelines (Design Principles), and relevant stipulations concerning sprinklers are given in Volume 3 (Tunnels) and Volume 7 (Electrical and Mechanical Equipment, Part 16-1 Tunnel Emergency Facilities).

Volume 3 (Tunnels) consists of the following items:

– General stipulation [7]

The range of this guideline is defined as "Tunnels with two traffic lanes on highways for motorized vehicles that are constructed and maintained by the JH". In can also be applied for tunnels with three traffic lanes, under the condition that the special characteristics of such tunnels are taken into consideration.

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[7] JH, Design Principles, Volume 3 (Tunnel) Part (4) (Tunnel safety facilities), 1998 (Japanese), p. 1-3

The types of safety facilities described in this guideline are based on the guidelines by MOLIT. Figure 2-10 shows the structure of tunnel disaster prevention, consisting of measures to prevent the occurrence of disaster and measure to prevent damage in case of disaster.

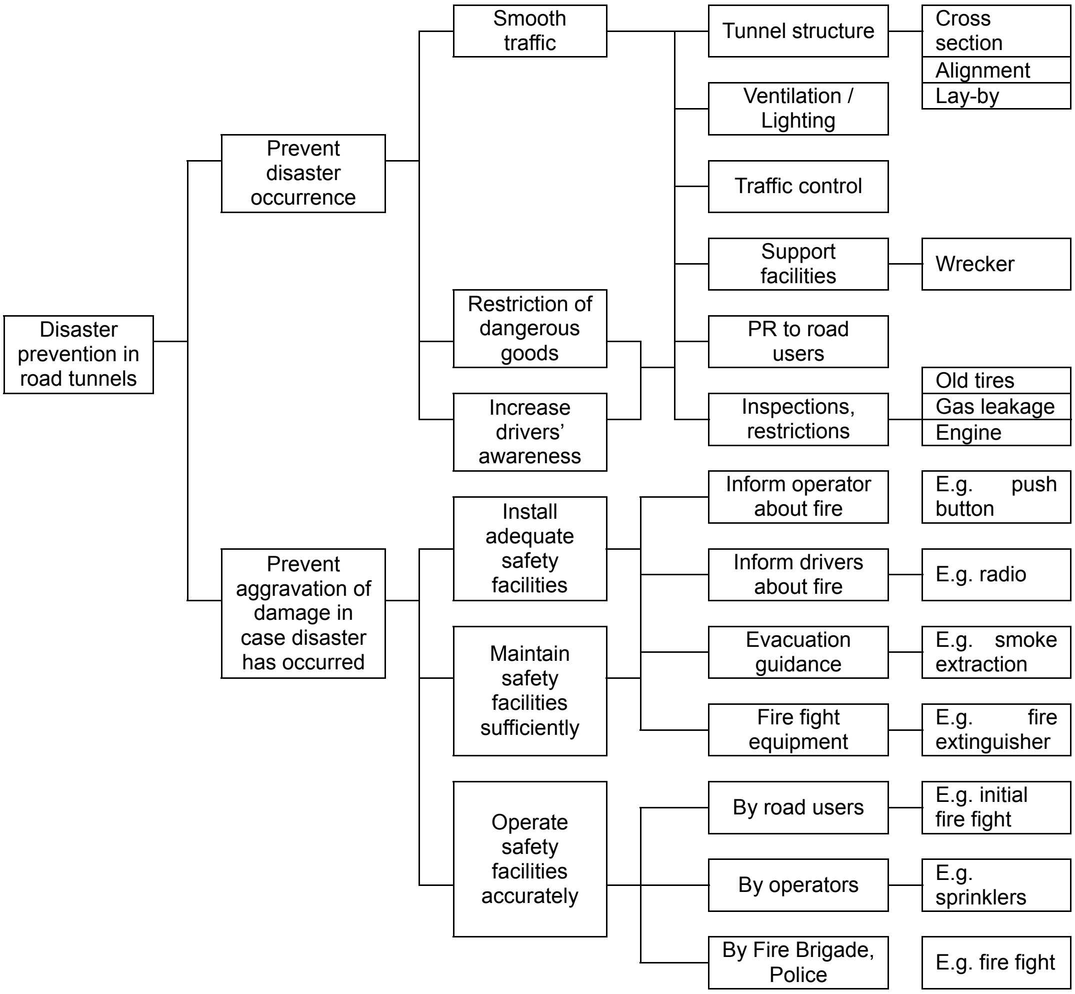

Figure 2-10 Structure of tunnel disaster prevention (JH)

– Standard for the installation of safety facilities [8]

This section describes the types of safety facilities, the tunnel classification, and the types/specifications of safety facilities per tunnel classification. The types of facilities and the classification of tunnels is the same as stipulated by the MOLIT guidelines. In the decision of the tunnel category, the estimated traffic volume after 10 years is used. In the decision of items that influence the tunnel structure (e.g. inspection routes, main water pipes etc.), the estimated traffic volume after 20 years is used. In case of stage construction or expansion of the road network in the vicinity of the tunnel, the traffic volume per tunnel may change considerably (implying higher or

[8] JH, Design Principles, Volume 3 (Tunnel) Part (4) (Tunnel safety facilities), 1998 (Japanese), p. 4-27

lower safety category of that tunnel), and after the tunnel is realized and opened to traffic, the traffic volumes of more points of time in between are considered, and the tunnel category and safety equipment is reviewed every 5 years, based on traffic volumes 10 years after that. Only for sprinklers, the review is based on traffic volume 5 years after the time of review (in order to limit installation costs). Figure 2-11 shows a flow of the considerations in case of stage construction.

The types/specifications of safety facilities per tunnel classification is more elaborate but still based on the MOLIT guidelines, as described in Table 2-3. Also the required specifications per safety facility are more detailed, as further described in Section 2-2 and 2-3.

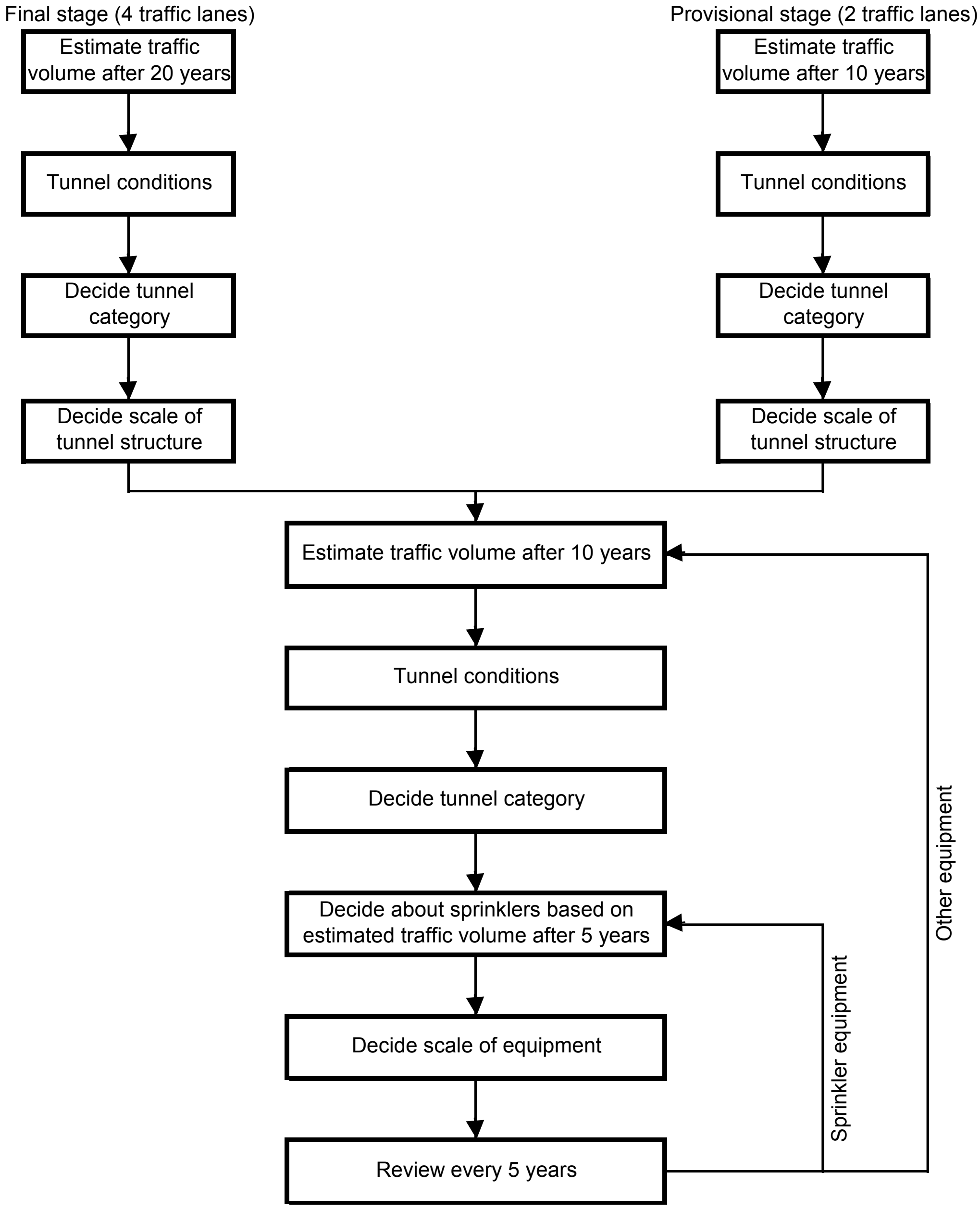

Figure 2-11 Flow for stage construction

Table 2-3 Safety facilities per tunnel category (JH)

Safety facility		Classification	AA	A	B	C	D	Remarks
Information and alarm	Emergency telephone		O	O	O	O	O	Not in D-Class tunnels with L<= 200m
	Push button		O	O	O	O		
	Fire detector		O	O				Not in tunnels without ventilation system
	Emergency alarm equipment	At tunnel entrance	O	O	O	O	O	Not necessary in tunnels with L<= 200m
		In tunnel	O	Δ				Necessary in A-Class tunnels with L>= 3,000m
Fire extinguishing	Fire extinguisher		O	O	O	O	O	
	Fire hydrant		O	O	Δ			To be installed in B-Class tunnels with L>= 1,000m
Escape and guidance	Emergency guidance panel	Emergency exit light	To be installed in tunnels with evacuation routes					
		Guide board (A)	To be installed in tunnels with evacuation routes					
		Emergency exit sign	To be installed in tunnels with evacuation routes					
		Guide board (B)	O	O	O			To be installed in tunnels without evacuation routes
	Smoke extractor, evacuation route		– Evacuation routes installed in tunnels with L>= 750m – Smoke extraction installed in tunnels with L>= 1,500m – Install evacuation routes in AA-Class tunnels and in A-Class tunnels with L >= 3,000m, with bi-directional traffic and longitudinal ventilation					
Other equipment	Water supply hydrant		O	O	Δ			To be installed in B-Class tunnels with L >= 1,000m (water ports near portal).
	Leaky feeder system	Coaxial cable	O	Δ				Necessary in A-Class tunnels with L >= 3,000m
		Entrance/exit telephone	O	O				
	Radio (re-) broadcast		O	Δ				Necessary in A-Class tunnels with L >= 3,000m
	Loudspeaker system		Installed in tunnels with radio (re-broadcasting equipment)					
	Water sprinkler		O	Δ				Necessary in bi-directional A-Class tunnels with L >= 3,000m and more than 4,000 vehicles/day
	Monitoring equipment	Type A (200m interval)	Installed in tunnels with sprinklers					
		Type B (at lay-by)		Δ				Necessary in A-Class tunnels with L >= 3,000m
	Emergency lighting equipment		Installed in tunnels with L >= 200m					
	Emergency power supply	Generator	Installed in tunnels with L >= 500m					
		Uninterruptible power supply	Installed in tunnels with L >= 200m					

O: must be installed, Δ: installed if deemed necessary

– System of safety facilities [9]

This section describes the required organization of safety facilities in the tunnel, and related facilities in the machine room at the tunnel portal, the tunnel control room and the regional traffic control room.

[9] JH, Design Principles, Volume 3 (Tunnel) Part (4) (Tunnel safety facilities), 1998 (Japanese), p. 28-29

Volume 7 Part 16-1 (Tunnel Emergency Facilities) consists of the following items:

– General stipulation [10]

In addition to similar general stipulations as stated in Volume 3 of the JH Design Principles, Volume 7 states that the safety facilities of road tunnels should be based on a planning, with basic steps as given in Figure 2-12.

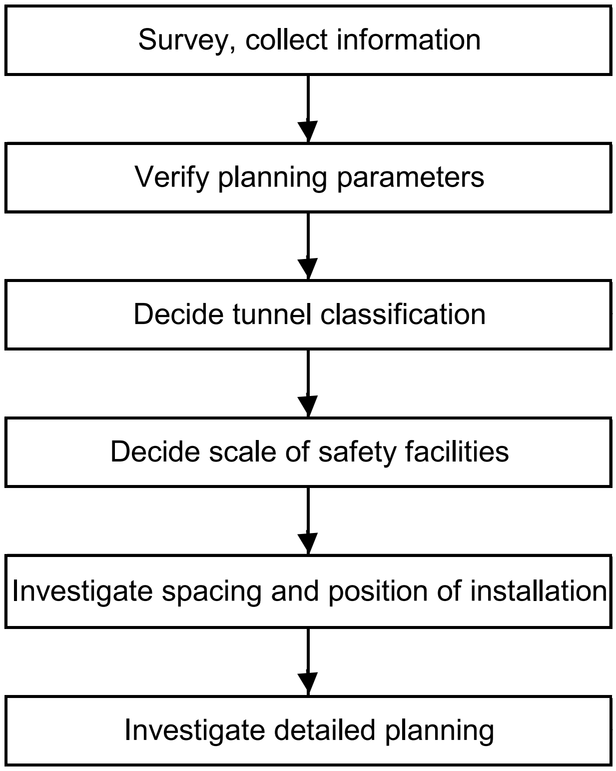

Figure 2-12 Flow for planning of tunnel safety facilities

The planning parameters to be verified for the planning of tunnel safety facilities include the following items:

a) Tunnel length, alignment, dimensions
b) Expected traffic volume (at time of opening to traffic, 5 years – 10 years – 20 years after opening)
c) Planned location, dimensions, landscape and geological conditions of machinery room and water basin
d) Water source for fire fight equipment
e) Temperature and humidity in vicinity of tunnel
f) Planning of related equipment

[10] JH, Design Principles, Volume 7, Part 16-1 (Tunnel Emergency Facilities), 1990 (Japanese), p.1-2

– Safety facilities[11]

This section gives requirements, basic drawings and other details for the design of safety facilities, including:

a) Communication facilities
b) Fire fight facilities (including sprinklers)
c) Drainage facilities (including stipulations for sprinklers)
d) Water supply facilities (including water supply for sprinklers)
e) Anti-freeze facilities (including stipulations for sprinklers)
f) Operation facilities (including stipulations for sprinklers)
g) Power supply facilities and wires (including stipulations for sprinklers)
h) Emergency exit

– Design examples for safety facilities design[12]

This section gives examples of design calculations for safety facilities, including:

a) Tunnel layout
b) Required water volume
c) Size of pipes
d) Power output
e) Etc.

3) MEPC

Based on the basic requirements concerning tunnel safety facilities stipulated in the MOLIT (at the time still MOC) guidelines, the MEPC has issued its guidelines. The most recent official guidelines are published in February 1982 [13]. In February 1993, a concept for renewed guidelines has been prepared by the MEPC [14]. Even though this concept has not been published as official guideline, the MEPC actually follows the stipulation stated herein, and it is this concept that is used in underlying report. It consists of the following items:

– General stipulation

The purpose of the guideline (concept) is defined as to stipulate principles and policies necessary for the installation of safety facilities in tunnels located on the roads operated by the MEPC. Its range is tunnels and similar structures located on the roads operated by the MEPC.

This section also includes the classification of tunnels. For tunnels with a traffic volume lower than 40,000 vehicles per day per direction, the classification is the

[11] JH, Design Principles, Volume 7, Part 16-1 (Tunnel Emergency Facilities), 1990 (Japanese), p.3-53

[12] JH, Design Principles, Volume 7, Part 16-1 (Tunnel Emergency Facilities), 1990 (Japanese), p.54-66

[13] MEPC, Guideline for the installation of tunnel safety facilities, February 1982

same as the one stipulated in the MOLIT Guidelines. For tunnels with a traffic volume higher than 40,000 vehicles per day (per traffic direction) the classification is as shown in Table 2-4.
The safety facilities for each tunnel class is as given in Table 2-5.

Table 2-4 MEPC tunnel classification for traffic volume > 40,000 / day

Classification	Tunnel length
AA	Longer than 1,000m
A	Between 300 and 1,000m
B	Between 100 and 300m

Table 2-5 Safety facilities per tunnel category (MEPC)

Facility		AA	A	B	C	D	Remarks
Information and alarm	Emergency telephone	OO	OO	OO	OO		
	Push button	OO	OO	OO	OO		
	Fire detector	OO	O	Δ			
	Emergency alarm equipment	OO	OO	OO	OO		
	Traffic light	O	O	O			Decide in cooperation with Safety Committee
Fire fight.	Fire extinguisher	OO	OO	OO	O		
	Fire hydrant (foam hose)	OO	OO	O			
Escape / guidance	Emergency exit	OO	OO				Investigate necessity for A class tunnels 300 – 400m
	Emergency guidance panel	OO	OO				
	Smoke extraction	O	O				Add to mechanical ventilation, if applicable
Other equipment	Water supply hydrant	OO	OO	O			
	Sprinkler	OO	Δ				
	Leaky feeder system	OO	OO	O			
	Radio (re-) broadcast	OO	O	Δ			
	Loudspeaker system	Δ					
	Monitoring equipment	OO	OO	O			
	Uninterruptible power supply	OO	OO	OO			
	Emergency power supply	OO	OO	O			
	Entrance for rescue vehicle	O	O				

OO: must be installed, O: installed if deemed necessary, Δ: only in special cases

– Installation of safety facilities
This section gives details and design principles of the required safety facilities, including information and alarm, fire fight, escape and guidance, other equipment, common equipment (water supply, pipes, electrical wires)

[14] MEPC, Guideline for the installation of tunnel safety facilities (Concept), February 1993

- Operation of safety facilities

  This section states that the operation should be such that the information in case of tunnel fire and other tunnel accidents, the type of accident and its location can be checked, and that suitable measures can be implemented immediately. It further states that the operation must be based on consideration of the situation in the tunnel, and the operation method must be laid down beforehand.

  The major part of this section is dedicated to details and flow charts for the operation of the different groups of safety facilities.

- Maintenance of safety facilities

  This section states that the safety facilities are to be inspected and maintained in order to enable sufficient their functionality in case of tunnel fire and other tunnel accidents. It further states that the inspection and maintenance are to be based on applicable regulations (see further Chapter 3), and that the inspection and maintenance method is to be defined beforehand, in sound consideration of the safety of workers who carry out the inspection and maintenance.

Table 2-6 shows the present tunnels of MEPC and their safety facilities. Figure 2-13 shows the location of these tunnels in the Tokyo Metropolitan Area.

Table 2-6 MEPC tunnels and their safety facilities [15, 16]

Prefecture	No	Tunnel name	Route name	Year of opening (m.y.)	Length (m)	Traffic volume (Average daily for two directions, weekday, October 2000)	Communications/ Warning equipment				Fire-fighting equipment				Evacuat. facilities	Others				
							Emergency telephone	Push button	Fire detector	Emergency guidance	Traffic signal	Fire extinguisher	Foam hydrant	Water sprinkler	Emergency exit	Radio re-broadcasting	Monitoring equipment	Ventilator	Fire-fighting water tank volume (tons)	Sprinkler water tank volume (tons)
Tokyo	1	Shiodome	Inner Circular Route	12.1962	270	143,210	4	12	22	2	-	12	12	-	-	O	18	O	20	-
	2	Iikura		7.1967	106	123,930	1	9	-	1	-	5	2	-	-	O	-	-	93	-
	3	Kasumigaseki		9.1964	780	126,220	16	16	62	2	O	30	30	O	2	O	43	O	225	**
	4	Chiyoda***		8.1964	1,900*	183,990*	40	40	117	2	O	69	69	O	6	O	81	O	70	280
	5	Kitanomaru		8.1964	160	37,600	2	4	-	3	O	8	-	-	-	O	-	-	-	-
	6	Yaesu***	Yaesu Circ. Rt.	2.1973	1,400	23,530	33	61	116	2	O	71	61	O	14	O	45	O	290	**
	7	Haneda***	Route 1	8.1964	300	99,660	4	10	24	2	-	10	10	-	2	O	15	O	60	-
	8	Aoyama	Route 3	10.1964	98	108,930	-	-	-	-	-	4	-	-	-	O	-	-	-	-
	9	Akasaka	Route 4	8.1964	520	106,000	6	24	43	2	O	24	24	-	1	O	25	O	27	-
	10	Shinanomachi		8.1964	110	106,000	2	4	-	2	O	3	-	-	-	O	-	-	-	-
	11	Yoyogi		8.1964	96	2,920	-	-	-	-	-	4	-	-	-	O	-	-	-	-
	12	Tamagawa***	Bay Shore Route	12.1994	2,170	73,540	46	90	190	2	O	176	88	O	68	O	46	O	350	**
	13	Kuko-Minami		12.1994	250	69,880	6	10	20	2	O	18	-	-	-	O	6	-	-	-
	14	Kuko-Kita***		9.1993	1,353	75,730	42	60	118	4	O	118	56	O	18	O	34	O	175	**
	15	Tokyo Port***		8.1976	1,325	123,350	58	118	114	5	O	120	58	O	47	O	22	O	200	130
Kanagawa	16	Higashi-Yokohama	Yokohane Route 1	3.1978	107	74,290	2	4	-	1	-	4	4	-	-	O	5	-	90	-
	17	Sakuragicho***		3.1978	339	74,290	7	14	28	1	-	11	11	-	2	O	13	O		-
	18	Hanazono		3.1978	206	74,290	4	17	-	1	-	13	9	-	-	O	5	-	90	-
	19	Hanazonobashi		2.1984	470	52,070	14	30	54	3	-	22	18	O	5	O	20	O		270
	20	Minami-Karuizawa	Mitsuzawa Route 2	3.1978	138	61,120	6	7	-	2	-	5	5	-	-	O	3	-		-
	21	Mitsuzawa		3.1978	445/347	61,120	10	18	32	2	-	19	17	-	2	O	12	O	80	-
	22	Nagata	Kariba Route 3	3.1990	187	5,100	6	7	-	2	-	8	-	-	-	O	6	-	-	-
	23	Kawasaki Fairway	Bay Shore Route	12.1994	1,954	72,170	38	80	173	2	O	157	79	O	62	O	43	O	350	**
	24	Namiki		7.1999	590	2,780	12	24	49	2	O	46	24	O	2	O	21	O	337	**

*Total of three bi-directional tubes (see further APPENDIX D)

** Combined with fire extinguisher

*** Transportation of dangerous goods (explosives, toxic substances, substances developing flammables on contact with water or air) are prohibited or restricted

[15] MEPC, “MEX Metropolitan Expressway Public Corporation” (pamphlet), 2000

[16] MEPC, (Pamhplets, Japanese)

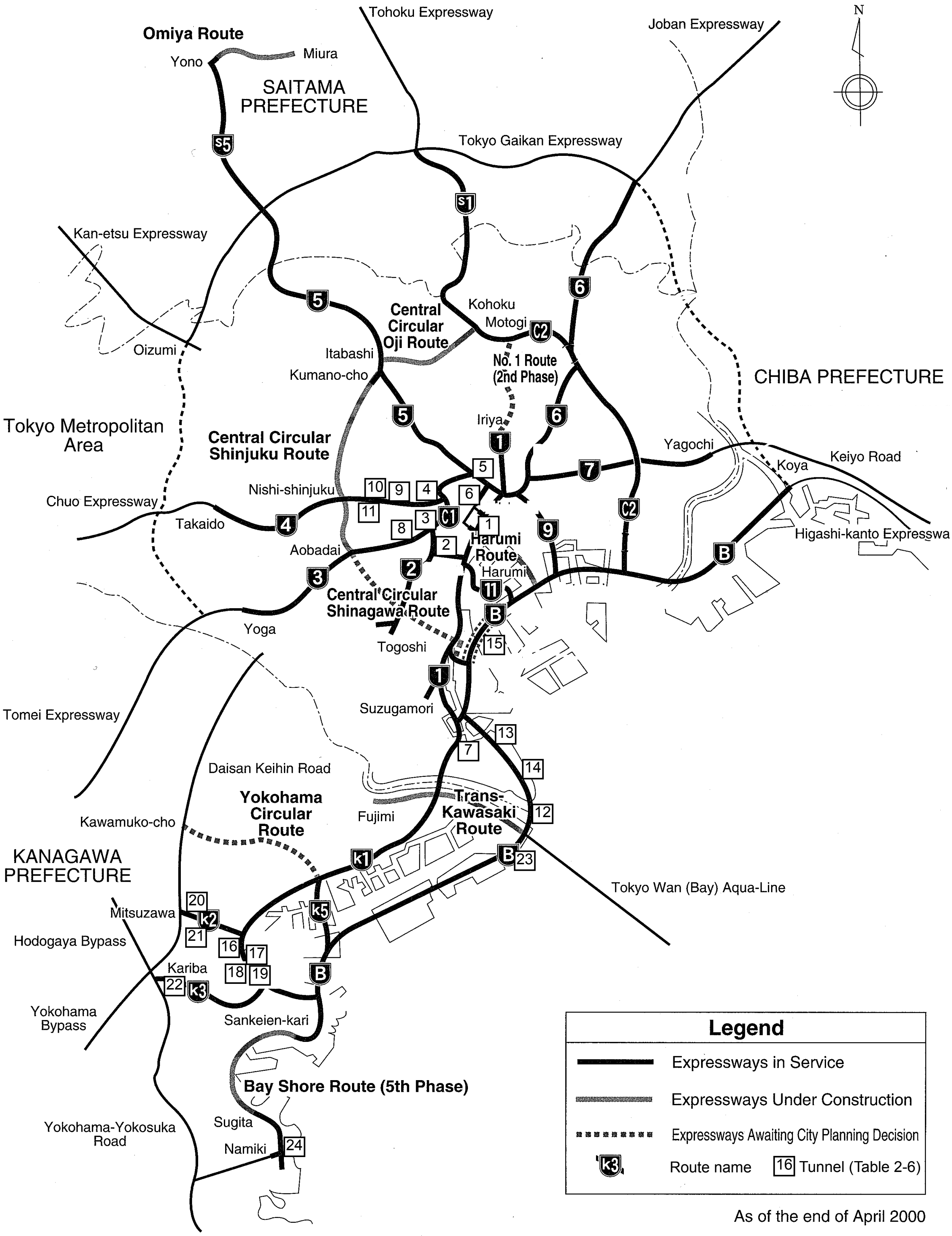

Figure 2-13 Location of MEPC tunnels

4) HEPC

Based on the basic requirements concerning tunnel safety facilities stipulated in the MOLIT (at the time still MOC) guidelines, the HEPC has issued its guidelines. Stipulations about tunnel safety facilities, including sprinklers, are given in Volume 1 (Planning) Part 7 (Tunnel safety facilities) of the HEPC Design Guideline [17]. This officially published version of this guideline used in this report is of 1992. In 1996 a concept version [18] for renewal was prepared, which is in actual use by the HEPC but which has not been officially published. Both guidelines consist of the following items:

- General stipulation

  This section defines that the guideline describes the principles concerning the installation of safety facilities for tunnels operated by the HEPC, and that investigation are necessary for structures similar to tunnels (shelters, semi-shelters etc.)

- Installation of tunnel safety facilities

  This section gives the tunnel classification, which is the same as the one stipulated by the MOLIT, with the addition that tunnels with sharp curves or tunnels with a steep longitudinal gradient are preferably to be chosen one class higher than the MOLIT classification.

  In order to provide communication means, prevent dangerous situations and aggravation of an occurred accident, each tunnel is to be furnished with safety facilities as stated in Table 2-7.

[17] HEPC, Design Guidelines, Volume 1 Part 7 (Tunnel Safety Facilities), 1992

[18] HEPC, Design Guidelines (Concept), Volume 1 Part 7 (Tunnel Safety Facilities), 1996

Table 2-7 Safety facilities per tunnel category (HEPC)

Facility		AA	A	B	C	D	Remarks
Information and alarm	Emergency telephone	OO	OO	OO	OO		
	Push button	OO	OO	OO	OO		
	Fire detector	OO	O				
	Emergency alarm equipment	OO	OO	OO	OO		
	Traffic light	Δ	Δ				
Fire fight.	Fire extinguisher	OO	OO	OO	OO		
	Fire hydrant (hose)	OO	OO	O			
Escape / guidance	Evacuation route	OO	O	O			
	Emergency guidance panel	OO	OO	OO			
	Smoke extraction	Δ	Δ				
Other equipment	Water supply hydrant	OO	OO	O			
	Sprinkler	OO					
	Leaky feeder system	OO	OO	O	Δ		
	Radio (re-) broadcast	OO	O				
	Loudspeaker system	Δ	Δ				
	Monitoring equipment	OO	Δ	Δ			
	Others	Δ	Δ	Δ			

OO: must be installed, O: installed in certain cases, Δ: installed if necessary

– Types of tunnel safety facilities
  This section describes the basic functions of each safety facility, necessary to gain immediate information about a tunnel incident, take necessary measures and prevent aggravation of damage.
– Design of tunnel safety facilities
  This section gives further details and requirements for each safety facility.
  For example, fire detectors are to be installed in consideration of the sprinkler sections.

2 - 1 - 4 Developments of specifications and guidelines for sprinklers

Table 2-8 shows an overview of the developments in specifications and guidelines about sprinklers for road tunnels [19]. It also gives basic information about the experiments that have been carried out for these developments.

[19] Based on information received from MEPC

Table 2-8(a) Developments in specifications and guidelines

Year	Specifications	First application	Guidelines / Experiments
1965	**Head:** Spray Volume: 6 liter per minute per m^2 Spray Area: 250 – 300 m^2 (or 35 – 45m long section) Water pressure: 3.0 kgf/cm^2		1961-1961: The Fire Brigade Research Department carries out a fire experiment in a scale model tunnel, and supplies basic information about the conditions for the introduction of water sprinklers
	Head: Standard spray volume: 6 liter per minute per m^2 Water pressure: 3.0 kgf / cm^2 Sprinkler method: Double side sprinkler Type: Spiral type Pitch: 4m **Automatic valve:** Diameter: 100 A (~100mm) [20] Opening method: Opening through pressure drop Pitch (=section length): 36m **Pilot valve:** Opening method: 2-direction, 2- position switch type Valve type: Opening through electrical excitation; closure through demagnetization	Nihonzaka Tunnel	1965: Japan's first guideline about the installation of tunnel safety facilities is published 1968-1969: Experiment is carried out in the old Tunnel, after closing to traffic, in order to verify the effect and influence of sprinklers. 1969: Experiment is carried out in Nihonzaka Tunnel, in order to provide underlying information about the cooling effect by sprinklers, and to verify the smoke flow conditions.
1972	**Head:** Water pressure: Change to 3.5 kgf / cm^2 Sprinkler method: Change to single side sprinkler Type: Spiral and deflector type Pitch: Change to 5m **Automatic valve:** Diameter: 80 A (~80mm) Pitch (section length): 25m **Pilot valve:** Opening method: Change to 3-direction, 2-position switch horizontal type	Kanmon Tunnel	1972: Experiment about spray method with single side sprinkler method is carried out in test tunnel at Menuma Factory of Nohmi Bohsai Ltd. Based on the experiment results, all tunnels planned since then basically apply this sprinkler method. 1973: Preliminary fire test is carried out in full-scale test tunnel at Menuma Factory of Nohmi Bohsai Ltd., in anticipation of full scale fire tests concerning the design of tunnel safety facilities. The test results show that cooling effect and CO decrease effect is favorable.
1975	**Head:** Type: Spiral type to **Automatic valve:** Diameter: 125 A (~125mm) Opening method: Change to opening method by pressure rise Pitch (section length): Change to 50m **Pilot valve:** Opening method: Change to 3-direction, 2-position switch horizontal type Valve type: Opening through 2 magnet electrical excitation; closure through demagnetization (apply water lock)	Enasan Tunnel	
1976	**Head:** Sprinkler method: Change to single side sprinkler with large diameter nozzle for far distance spray Pitch: 3.8m Others: First application to 3 traffic lanes per tube	Tokyo Port Tunnel	1976: Fire tests in Tokyo Port Tunnel about spray characteristics of sprinklers in tunnel with 3 traffic lanes per tube.
	Head: Sprinkler method: Change to single side sprinkler with large diameter nozzle for far distance spray Pitch: 5m	2nd Rokkosan TN	
1977	**Pilot valve:** Fixing method: Hanging from ceiling		

[20] Nominal inner diameter (see APPENDIX F)

Table 2-8 (b) Developments in specifications and guidelines (continued)

Year	Specification	Tunnel	Experiments
1979	**Head:** Sprinkler method: From ceiling in downward direction Pitch: 25m zigzag	Kawasaki Port TN	1981: Full-scale fire test with longitudinal ventilation (without duct ceiling) is carried out in test tunnel at Menuma Factory of Nohmi Bohsai Ltd., in order to verify head position and sprinkler method.
1982	**Head:** Sprinkler method: Single side sprinkler method Pitch: 5m Others: First application to longitudinal ventilated tunnel (no duct ceiling) **Pilot valve:** Material: Change material of piston rod (device to transmit water pressure and control water flow) to new type corrosion resistant copper based alloy (due to quality of natural/ground water for sprinklers in country side tunnels the strength of material sometimes worsened in course of time)		1981: Full-scale fire test for different fire sizes is carried out in test tunnel at PHRI, in order to verify influence of temperature and sprinkler method to the smoke behavior, and to evaluate sprinklers and their operation. One of the findings is that smoke may descend due to sprinkler and influence the evacuation. 1983: A fire experiment is carried out in the Kakeihigashi Tunnel of the Chugoku Highway, in order to evaluate sprinklers and their operation in large-scale tunnels.
1984	**Head:** Type: Combination of close range head and far range head (different types for tunnels with and without duct ceiling)	Kan'etsu Tunnel	
1986	**Head:** Material: Change material of deflector for far range head to **Pilot valve:** Structure: Sprinkler water is filtered before use, but due to some cases of clogging in country side tunnels (where surface water is collected in a pool near the tunnel), it was decided to change the valve exit from 2 holes of 0.8 diameter to 1 hole of 1.4 diameter		1985: Experiment is carried out in the second (new) tube of the Enasan Tunnel, before opening, in order to evaluate sprinklers and their operation in case of tunnel with one directional traffic and longitudinal ventilation with vertical shaft for supply and exhaust and electrostatic precipitator.
1989	**Automatic valve:** Type: New type automatic valve is introduced	Nihonzaka Tunnel	
1990	**Head:** Type: Development of head for extra far range, for 3 lane tunnels		

2 - 2 Basic descriptions and purpose of sprinklers

This section gives basic descriptions specific for sprinkler systems, as stated in the guidelines of MOLIT, JH, MEPC and HEPC.

1) MOLIT

The MOLIT guidelines stipulate that the sprinklers should be installed in order to:

- Cool down the fire heard and its surroundings
- Suppress (control) the fire
- Prevent fire spread
- Support the fire fighting activities

Sprinklers are to be installed in all AA-class tunnels (see Table 2-2), and in A-class tunnels if judged necessary after investigation considering items such as traffic type (uni- or bi-directional), availability of evacuation routes, tunnel operation system (24 hour management of monitoring system), etc. In case the tunnel management judges necessary, sprinkler systems can be investigated. In case sprinkler systems are installed, a monitoring system is preferable installed in the tunnel.

2) JH

The JH guidelines describe [21] the sprinkler system as a facility of which the nozzle is installed in the corner of the tunnel cross section, and which operation is based on a remote controlled pressurized water release in spray form that covers the fire. The function of sprinklers is stated as follows:

- Suppress (control) the fire heard
- Prevent other fires in the direct vicinity of the fire heard (fire spread)
- Protection of the tunnel structure
- Protection of the tunnel facilities

The JH guideline states that previously carried out fire tests with actual vehicles and fire pans confirm these functions, but at the same time that the activation of sprinklers produce a water film in mist form and cause the smoke to descend to the tunnel road surface, which reportedly may cause obstruction to the evacuation of vehicles or people. Therefore, sprinklers are to be activated with considerable caution and only after confirmation that the tunnel is evacuated. In addition, the installation of sprinkler facilities requires large investment.

Based on these reasons, sprinklers are in principle only installed in AA-Class tunnel, in which safety measures are especially important. Sprinklers are also installed in A-class tunnels with bi-directional traffic, length over 3,000m and traffic volume over 4,000 vehicles per day, because the above functions of sprinklers in these tunnels can be well expected.

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[21] JH, Design Principles, Volume 3 (Tunnel) Part (4) (Tunnel safety facilities), 1998 (Japanese), p. 13

3) MEPC

The MEPC guidelines describe the sprinkler system as a facility that discharges water in spray form, and states the purpose as follows:

- Suppress (control) the fire
- Cool down and protect the tunnel structure
- Alleviate the fire fight activities
- Prevent fire spread.

4) HEPC

Sprinklers are described as a facility that discharges water in spray form in order to:

- Suppress the fire
- Prevent fire spread
- Alleviate firefight activities

The sprinkler facility consists of sprinkler heads, automatic valve (valve to select compartment), pipes, pumps, water basin and operation equipment. Especially the automatic valve must operate with high accuracy, must be easy to maintain and inspect.

2 - 3 Specifications

2 - 3 - 1 Basic requirements

In its position to lay down the very basic national stipulations for tunnel safety facilities, to be followed by all Japanese authorities that operate tunnels, the MOLIT states the following basic requirements to sprinklers:

- The spray section should be at least 50m
- The standard water volume is 6 liter per minute per m^2. The water source should preferably be able to supply water for at least 40 minutes
- The control method of sprinklers should be decided in consideration of tunnel length, tunnel structure and ventilation system

These fundamental requirements form the basis of the guidelines by MOLIT, JH, MEPC and HEPC. They also form the basic assumptions for the design of sprinkler for tunnels of other authorities.

2 - 3 - 2 Design specifications

Table 2-9 and Table 2-10 show the location of sprinkler heads in longitudinal direction and lateral direction for MOLIT, JH, MEPC and HEPC.

Table 2-9 Location of sprinkler heads in longitudinal direction

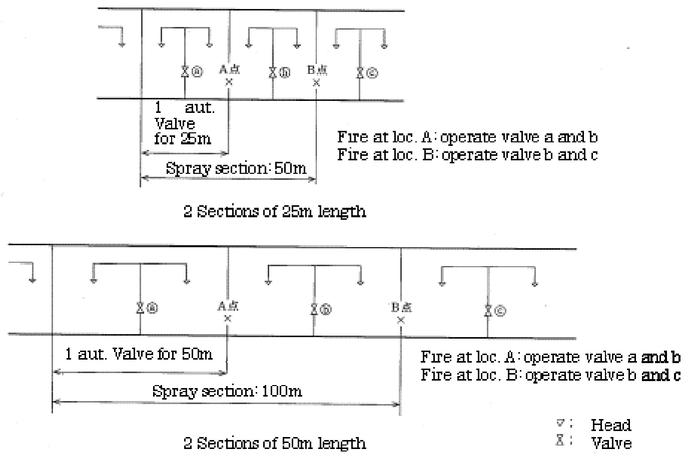
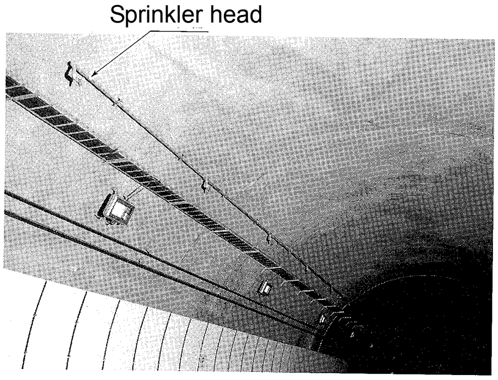
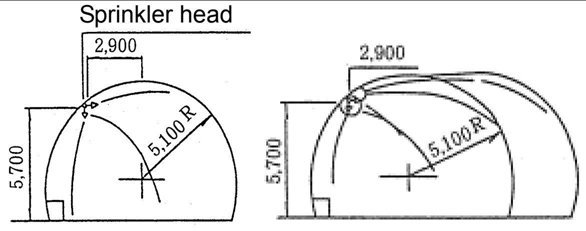
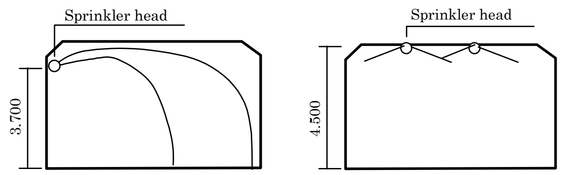
Owner	Distance between heads	Automatic valve	Example
MOLIT	(Not specified)	One automatic valve for 25m or 50m section	 (MOLIT)
JH	4-5m	One automatic valve for 50m section (10 heads per valve)	
MEPC	2.5 – 5m	One automatic valve for 25m or 50m section (10 heads per valve)	
HEPC	2.5 – 5m	One automatic valve for 25m or 50m section (10 heads per valve)	

Table 2-10 Location of sprinkler heads in lateral direction

Owner	Location	Example	Remark
MOLIT	(Not specified)		
JH	Top corner (H=about 6m), at side with inspection lane, between tunnel structure and road space profile	 Standard type Extra width (e.g. lay-by)	Most JH tunnels have horseshoe cross-section. Installation side is chosen to enable easy inspection and maintenance. Location is and type of head is decided based on tunnel layout (ventilation duct ceiling, lay-by, jet fans etc.)
MEPC	Top corner, at low speed lane, or at ceiling in case the corner position is not possible (3 traffic lane tunnels, locations with jet fans, etc.)	 Corner application Ceiling application	Most MEPC have rectangular cross-section. Installation side is chosen to enable easy inspection and maintenance. Location is and type of head is decided based on tunnel layout (lay-by, jet fans etc.)
HEPC	Not stipulated in standard		

Other specifications in the standards of MOLIT, JH, MEPC and HEPC are summarized as follows:

1) MOLIT

In addition to the basic specifications given above, the MOLIT standards state as follows:

- Tunnel require water supply for fire hose, fire hydrant and sprinklers.
- The principle water source is public service water, and where this is not available, natural water sources (ground water wells etc.) are to be used. The water source must be investigated and checked that basin can be completely filled within 12 hours.
- The volume of the water basin must be such that fire hose (3 locations simultaneous), fire hydrant (2 location simultaneous) and sprinklers (> 50m spray section) can be used for at least 40 minutes.
- The location of the water basin must be decided in such a way that the pumps have low power consumption, water can be easily taken, etc.
- The pumps must be designed in such a way that sufficient water pressure can be supplied for the required water volume for fire hose, fire hydrant and sprinklers.

2) JH

Based on the basic MOLIT requirements, the JH standards state as follows [22, 23]:

- Sprinklers are installed in such a way that 50m can be sprinkled with one automatic valve. Based on experiment [24], the range influenced by a fire is believed to be 20-30m, and the sprinkler section of 50m is chosen to cover this range. In order to cover fires that are located near the side of a section, sprinklers are designed in such a way that two sections of 50m (100m in total) can be used simultaneously.
- The type and spacing of the sprinkler heads is selected in such a way that the roadway space is sprinkled as uniformly as possible with at least 3 kgf/cm^2 and 6 liter per minute per m^2.
- The pipes to the sprinkler heads are separated from the main water supply pipes with a hydraulic piston type automatic valve (normally 10 heads per automatic valve). The pipes for sprinkler water supply are uniform for standard cross sections, but design for other sections requires adjustment and investigation at site.
- The automatic valve (open with pressure rise) includes a pilot valve, a butterfly valve for maintenance etc., and is installed together with the fire hydrant at the tunnel sidewall. It can be opened (activated) from the control room by the tunnel operator or manually at site. For accurate operation, the automatic valve is to be maintained and inspected regularly.

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[22] JH, Design Principles, Volume 3 (Tunnel) Part (4) (Tunnel safety facilities), 1998 (Japanese), p. 25-26

[23] JH, Design Principles, Volume 7, Part 16-1 (Tunnel Emergency Facilities), 1990 (Japanese), p.20-26

[24] Japan Fire Protection Association, "Report on fire experiment in the Tennozan Tunnel of Meishin Expressway", 1963

– The automatic valve to be opened is selected automatically based on fire detection activation (the fire detectors are installed at 25m interval). Figure 2-14 gives an example of how sprinkler sections to be activated are selected. The automatic valve is unlocked (to actually activate the sprinklers) only after the tunnel operator has reconfirmed the fire location with ITV cameras and others.

Traffic direction --->>>, Ventilation direction --->>>

Sprinkler section	1	2	③	④	5	6	7
Fire detection	1	2	③	④	⑤	6	7

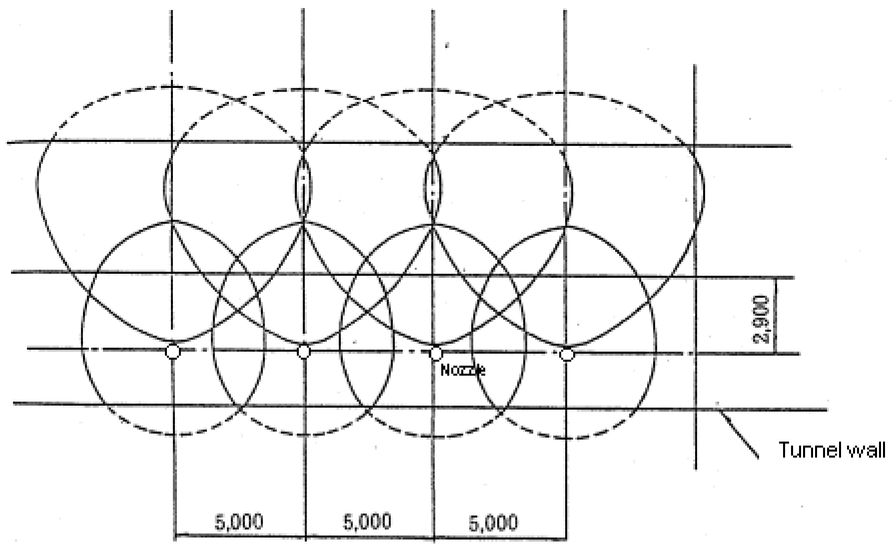
Example 1: Prevention of upstream fire spread

Sprinkler section	1	2	③	④	5	6	7
Fire detection	1	②	③	④	⑤	6	7

Example 2: Fire is estimated to be in the middle of the fire detection section

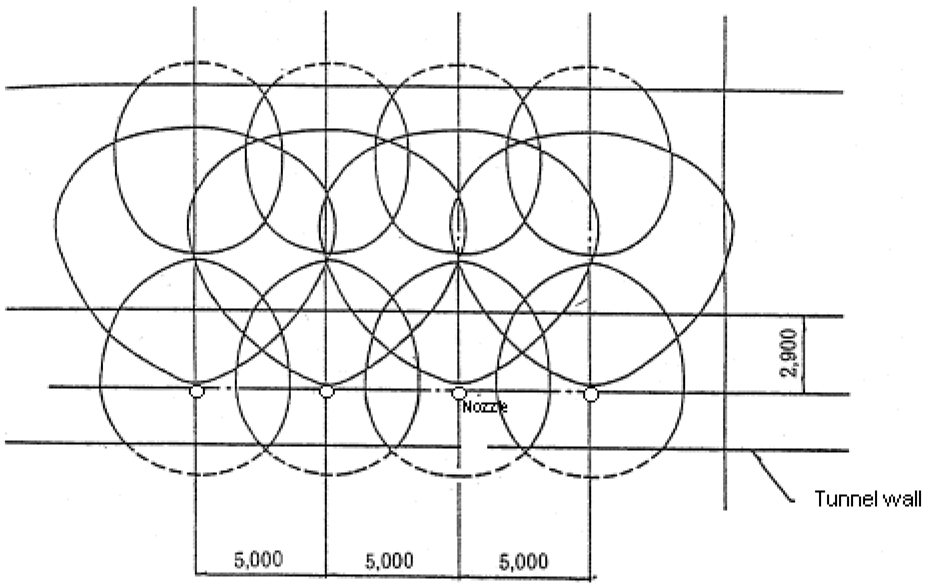
Figure 2-14 Examples of how sprinkler sections are selected (uni-directional tunnel)

– The required horizontal spray pattern is investigated after the type and installation height of the sprinkler heads is decided. Figures 2-15 and 2-16 show 2 examples of horizontal spray patterns.



(Compare JH “standard type” in Table 2-10)

Figure 2-15 Example of spray pattern with 2-combination nozzle (short, long)



(Compare JH "extra width type" in Table 2-10)

Figure 2-16 Example of spray pattern with 3-combination nozzle (short, long, super-long)

– The required water volume for sprinklers is calculated with the following equation, and taking into consideration tunnel conditions (lay-by, jet-fan, etc.).

$Q_1 = L * w * t$

Where,

Q_1 : water volume (liter per minute)
L : spray section (m)
w : roadway space width (m)
t : unit water volume (liter per minute per m^2)

In the typical case (L = 2 * 50m = 100m, w = traffic lane 2 * 3.5m + road shoulder 2 * 0.5m = 8m, t = 6 liter per minute per m^2), the required water volume for sprinklers is:

$Q_1 = 100 * 8 * 6 = 4,800$ (liter per minute)

– The pipes and automatic valves have a nominal inner diameter of about 80 A, 100 A, 125 A or 150 A [25], supplying water volume as follows:

- 80 A 0 - 1,200 liter/minute
- 100 A 0 - 1,600 liter/minute
- 125 A 0 - 2,500 liter/minute
- 150 A 0 - 3,300 liter/minute

For example, the typical case (see above) with section length of 50m requires

[25] Nominal inner diameter is indicated with capital A (see further under APPENDIX F)

125mm pipes (2 sections supply in total 5,000 liter per minute, which is sufficient for the required water volume of 4,800 liter per minute as stated above).

– The water to the fire hydrants and the sprinklers is supplied with one and the same pipe. The pumps are designed to enable water supply to fire hydrant and sprinklers. The water pressure is based on the required water pressure of the fire hydrant or sprinkler head located furthest away, as well as the friction loss in the pipes. The pumps are opened either manually or automatically based on fire detection. Figure 2-17 gives an example of sprinkler installation.

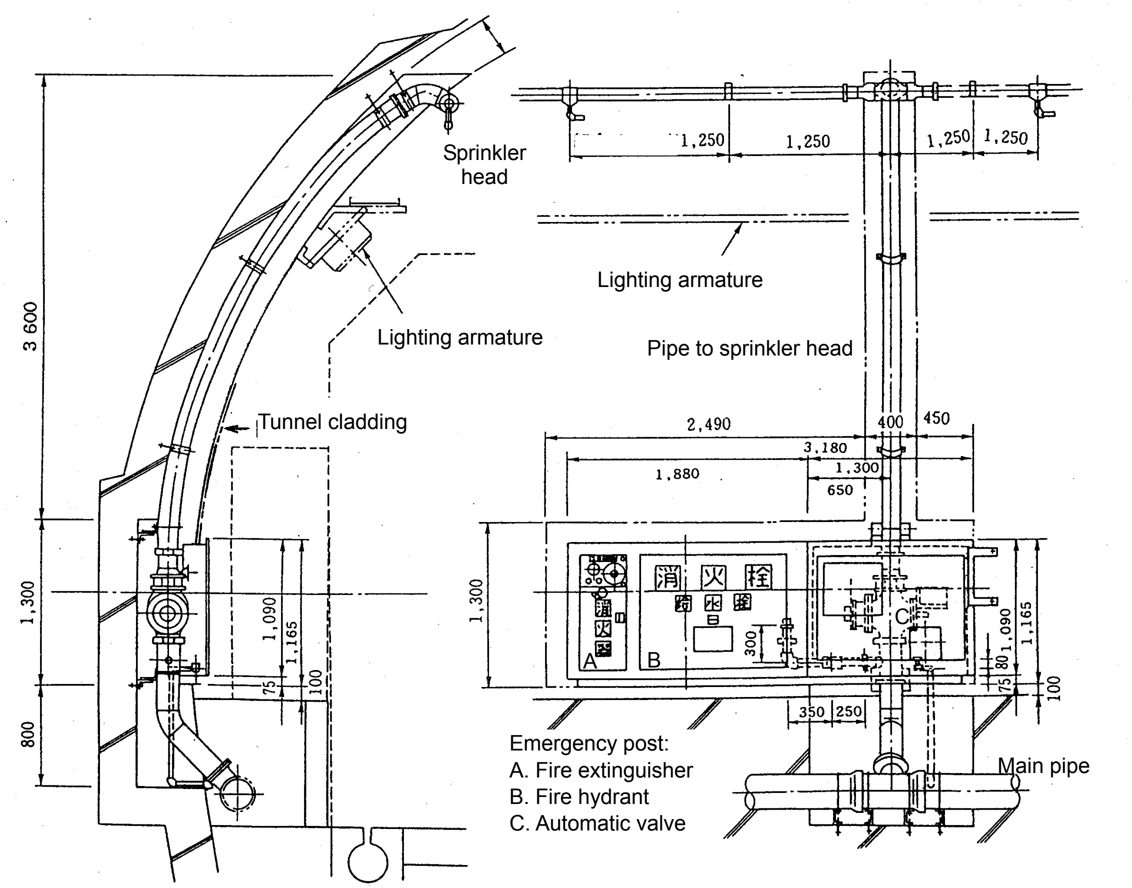


Figure 2-17 Example of sprinkler installation (JH)

– The water basin has a water volume of 20% in excess of the required volume to supply water to fire hydrants and sprinklers for 40 minutes.

– In cold areas, measures are taken to prevent freezing of water for fire hydrant and sprinklers, including the following:
  - Insulation of pipes
  - Heater box for valves
  - Heater to pipes
  - Ensure constant water flow

The decision to take such measures is based on meteorological investigation. The section length for such measures is 1000m from the tunnel entrance and from 500m before the tunnel exit. The objected facilities for freezing measures are pipes, valves and pumps. The operation of the heaters is based on thermometers for air temperature near the tunnel portal.

3) MEPC

Based on the MOLIT requirements, the MEPC has defined its standards, which are mainly similar to the JH standards. In the following points the MEPC standards and practices differ from the JH.

- MEPC mainly operates tunnels with rectangular cross section. This has influence on the type and installation height of sprinkler heads (as described above).
- The water for the fire hydrants and the sprinklers is supplied with separate main pipes. The main pipe for the sprinkler system is located near the ceiling at the same level as the sprinkler heads, and the main pipe for the fire hydrants is located at road level. Because the automatic valve for sprinklers is located at the road surface level, the main pipe for sprinklers is connected through a vertical pipe with the automatic valve, which is again connected through a vertical pipe with the sprinkler heads (Figures 2-18 and 2-19).

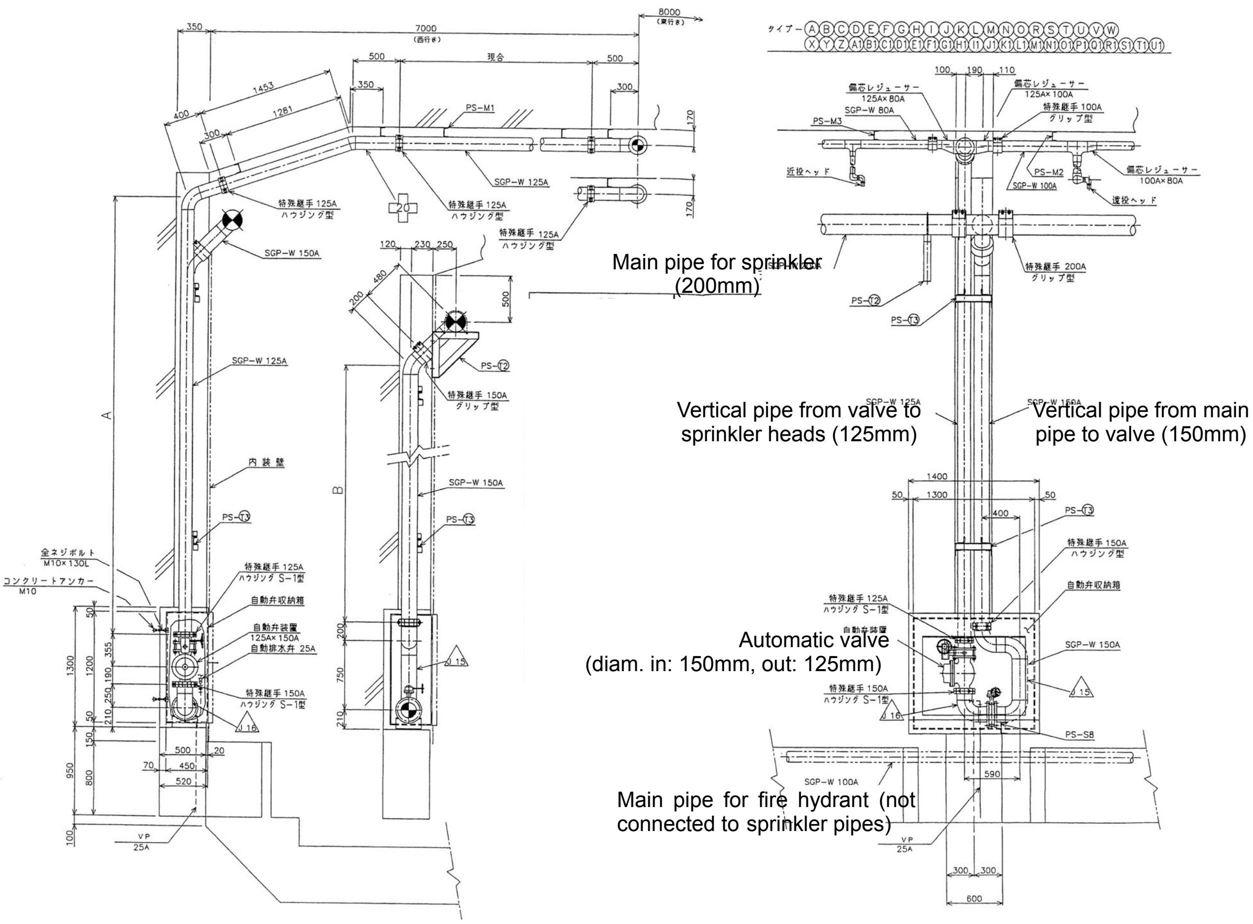


Figure 2-18 Example of sprinkler installation at ceiling (MEPC)

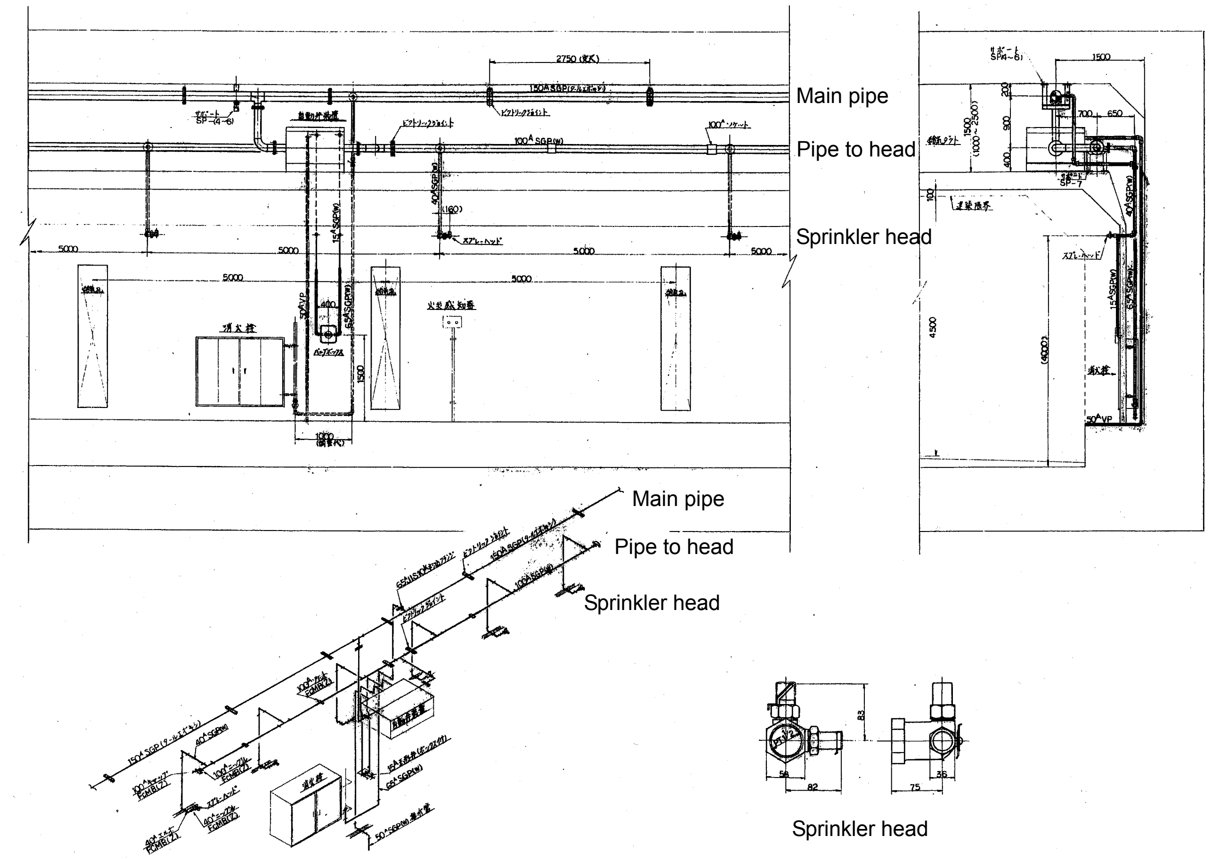


Figure 2-19 Example of sprinkler installation at corner between sidewall and ceiling (MEPC)

4) HEPC

Based on the MOLIT requirements, the HEPC has defined its standards, which are less elaborate than but in principle similar to the JH standards.

2 - 4 Operation specifications

This section summarizes the specifications stipulated in the standards by MOLIT, JH, MEPC and HEPC concerning the operation of sprinkler systems in case of tunnel fire.

1) MOLIT

The MOLIT guideline specifies the following concerning the operation of sprinklers:

– As described above, the purpose of sprinklers is to cool down the fire heard and its surroundings, to suppress (control) the fire, to prevent fire spread and to support the fire fighting activities. On the other hand, due to sprinkler activation a water mist film may occur and smoke may descend, which may be a hindrance for driving vehicles and evacuating people. Therefore it is recommended to first check by CCTV monitoring system or tunnel personnel at accident site that there are no people in the sprinkler section or downstream of that, before activating the sprinklers. In some cases the tunnel is filled with smoke making it difficult to check whether there are no people in the sprinkler section or downstream, and thus the decision when to activate sprinklers may be difficult.

- Therefore, the timing and the section to be sprinkled are to be decided in advance.
- It is important to discuss with related authorities to decide the operation of tunnel sprinklers.
- The general order of activities is stated as follows:
  - Report of tunnel fire (by fire detector etc.)
  - Selection of sprinkler section
  - Start pumps
  - Verify situation in tunnel (CCTV monitoring system or tunnel personnel at site)
  - Open automatic valve

2) JH

Based on the basic requirement by MOLIT, the JH has stipulated a network for tunnel safety facilities as shown in Figure 2-20 [26].

It is also stated that several tunnel safety facilities, including sprinklers, require special operation activities in case of tunnel fire, implying that tunnels with such facilities are to be operated through a 24 hour manned control room. Furthermore, it is stated that it is necessary to verify the situation in the tunnel before operating these facilities, because otherwise their effect may not be reached or even be adverse to their purpose. It is necessary to sufficiently consider the relation between these facilities and other tunnel facilities, their management and operation system, as well as their limitations.

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[26] JH, Design Principles, Volume 3 (Tunnel) Part (4) (Tunnel safety facilities), 1998 (Japanese), p. 28-29

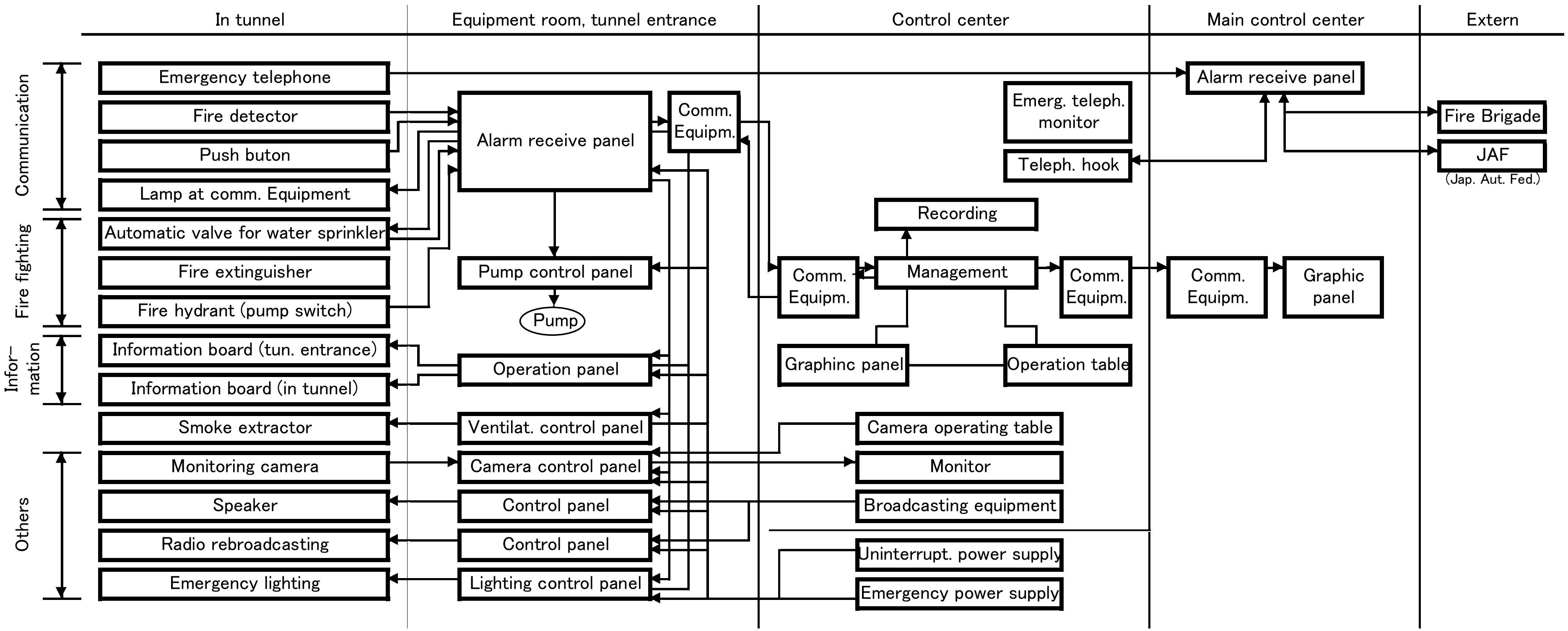

Figure 2-20 Network for tunnel safety facilities (JH)

3) MEPC

Based on the basic requirement by MOLIT, the MEPC has stipulated a network for tunnel safety facilities as shown in Figure 2-21.

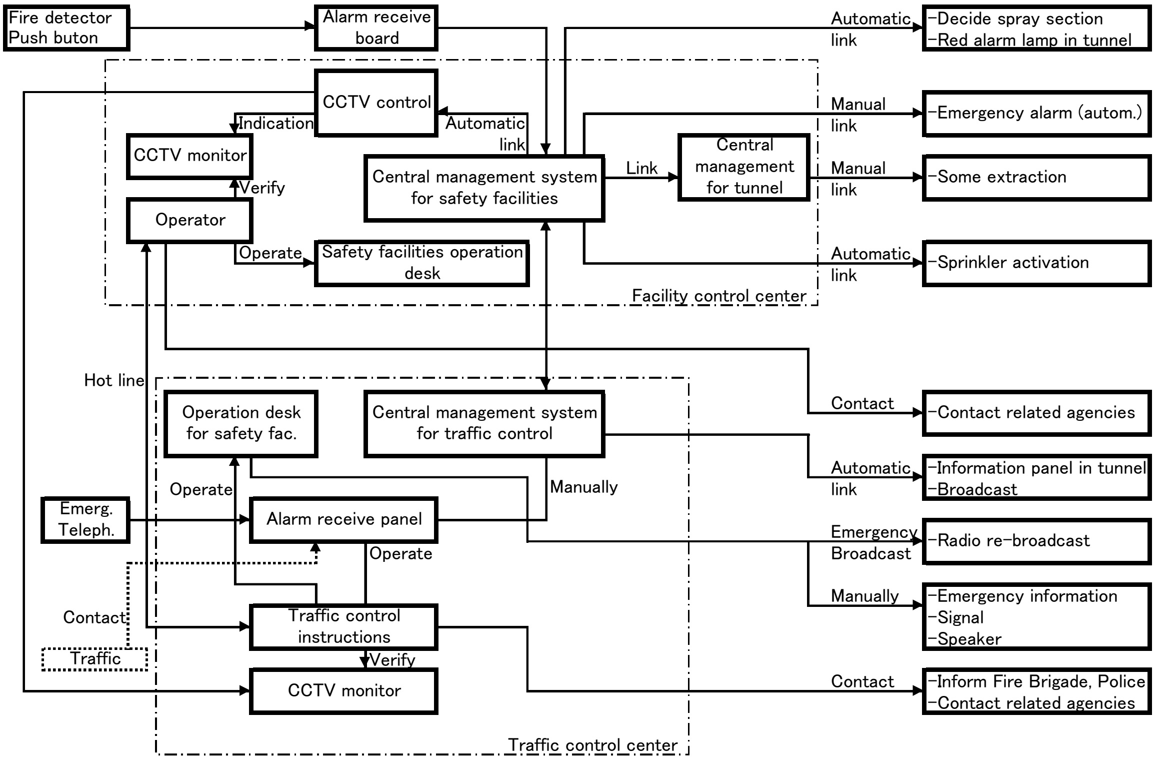

Figure 2-21 Network for tunnel safety facilities (MEPC)

The activities for the operation of sprinklers (Figure 2-22) are linked to fire detectors, CCTV monitoring system and pump equipment. The pumps are started by a signal from the fire detectors, and the activation of sprinklers (water discharge) can be carried out by opening the automatic valve, after the operator as received instructions from the traffic control center etc. Based on the conditions of the fire (fire size and location, situation of tunnel users, etc.), the operation of sprinklers may be adjusted manually or automatically, based on instructions by the traffic control center etc. The operation of sprinklers after the Fire Brigade has arrived at the tunnel site is based on deliberation between tunnel operator and Fire Brigade.

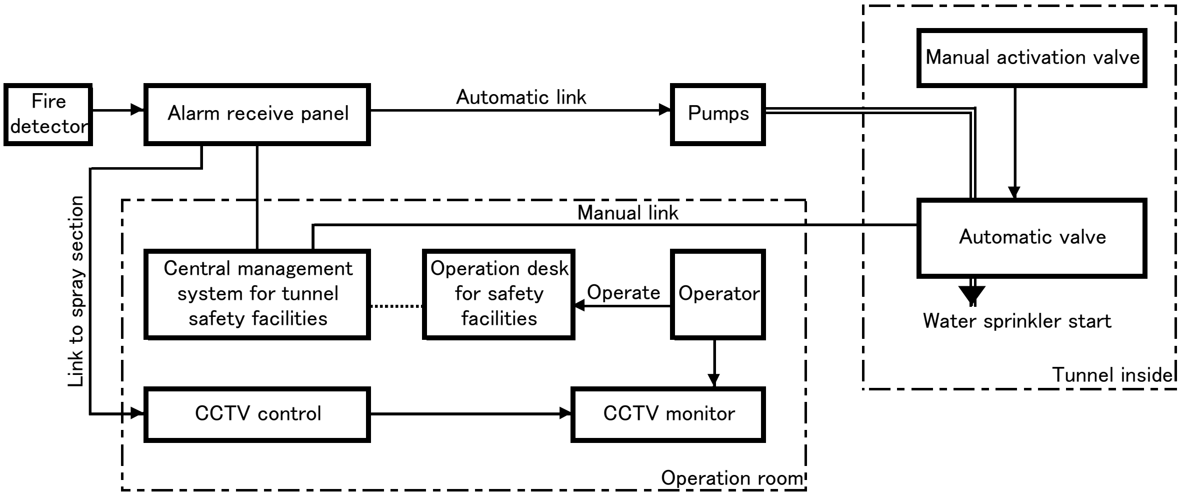

Figure 2-22 Activities for the operation of sprinklers (MEPC)

4) HEPC

Based on the basic requirements by MOLIT, the HEPC has stipulated its own guidelines concerning the operation of sprinklers.

The following order of activities is stated to be general:

- Detection of tunnel fire (by fire detector)
- Selection of automatic valve (i.e. selection of sprinkler section)
- Start pumps
- Verify fire and its location (with CCTV monitoring system)
- Open automatic valve to initiate water discharge

Therefore, tunnels with sprinkler installation require facilities to verify fire occurrence, such as CCTV monitoring system.

In order to prevent damage to the wires and cables caused by a tunnel fire, it is necessary to consider sufficiently the material and layout of wires and cables.

2 - 5 Maintenance specifications

This section summarizes the specifications stipulated in the standards by MOLIT, JH, MEPC and HEPC concerning the maintenance of sprinkler systems in tunnels.

1) MOLIT

The MOLIT guideline states that the maintenance of sprinklers is to be based on details given in a handbook by the JRA [27].

Tunnels require “normal inspection” and “periodical inspection”. Specification about “periodical

[27] JRA, Handbook concerning the maintenance of road tunnels, November 1993

inspection" includes statement for the maintenance of sprinklers to verify spray conditions and operation in relation with other tunnel safety facilities.

2) JH

JH inspects automatic valve 2 times a year, and carries out water discharge test 1 time a year. During water discharge test, water volume and fixing between sprinkler head and wall is checked.

3) MEPC

The MEPC states 4 levels of maintenance and inspection:

- Monitoring through control panel: based on index levels and warning messages, the operator can monitor the tunnel safety facilities on any defects.
- Routine inspection: with patrol car, a number of facilities are checked with the "5 senses" (visual check etc.). This can be accompanied by manual test operation and/or basic amendments of facilities.
- Periodic inspection: a number of tunnel facilities are periodically inspected. Periodic inspections do not include disassembly of facilities.
- Special inspection: carried out in case monitoring, routine inspection or periodic inspection indicates irregularities that require maintenance or repair.

Sprinklers are inspected as follows:

- Routine inspection: once a month, leakage and water pressure of pipes and pumps are inspected.
- Periodic inspection: once a year, activation process (pump activation, valve opening, signal to control room etc.) is tested, water discharge is inspected and general operation conditions are inspected (control equipment, related facilities such as fire detectors).

4) HEPC

Based on the MOLIT requirements, the HEPC has defined its standards, which are in principle similar to the JH standards.

3 Quality control

3 - 1 Production stage

In Japan, sprinklers for road tunnel use do not follow a certification system for quality guarantee. In the first stage of development, new sprinkler types have been tested on functionality and water discharge volume before installation. After that, reliability is established based on actual performance.

Up to date, no notable performance defects have been experienced with sprinkler installation in road tunnels. It is stated that regular maintenance and inspection by specialist technicians have been indispensable for this performance.

3 - 2 Operation stage (maintenance)

3 - 2 - 1 Description of maintenance

The method and contents of maintenance is specified in handbooks, published by the different tunnel authorities.

Maintenance is generally carried out by a specialized maintenance-company. The MEPC separates the functions of tunnel authority and maintenance-company as follows [28]:

Function of tunnel authority (MEPC):

- Investigate inspection method and planning, communicate with related parties, inform the public etc.
- Give order to maintenance company to carry out inspection
- Verify traffic control method during inspection, communicate with police
- Supervise inspection works, safety management
- Answer enquiries from public media, communicate with related parties, report to police

Function of maintenance-company:

- Produce plan of execution
- Carry out inspection and report to authority
- Safety management during inspection works
- Adjust and communicate with related parties

Safety management mainly includes the following items:

- Transfer method and timing of maintenance vehicles to and from tunnel site

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[28] MEPC, Inspection Handbook for Structures, April 2001

- Because a number of inspections are carried out simultaneously, the working space and traffic lanes are separated by orange cones and arrow signs
- Speed limit to vehicles, ensure that inspection workers do not enter the area with moving vehicles
- Emergency plan is set up in advance (in cooperation with fire brigade and police)

As example, APPENDIX D describes visit to inspection of the safety facilities in the Chiyoda Tunnel (operated by the MEPC), part of the Inner Circular Route in the center of Tokyo.

The MEPC divides Inspections for sprinklers into periodical inspections (twice a year) and general inspections (once a year), with items as shown in Table 3-1, and checklists as shown in Figures 3-1 and 3-2 [29].

Table 3-1 Items of inspection

Type of inspection	Items	Frequency	Checklist
Periodical inspection	Check water leakage, corrosion etc.	2 times per year	Figure 3-1
	Any obstacles hindering the sprinkler functionality		
	Check whether boards and signals for sprinklers are well fixed and not damaged		
	Check fixing of sprinkler heads, and whether sprinkler opening is not blocked		
	Check functionality of automatic valve		
	Check water pressure value		
General inspection	Spray test: check spray pattern and distribution uniformity, and measure water pressure	1 time per year	Figure 3-2
	Test automatic valve		

[29] MEPC, Inspection Handbook for Structures, April 2001

トンネル消火設備定期点検報告書
水噴霧（外観、機能、総合）

1. 設置場所　　　　1. 現場代理人　㊞
1. 点検年月日　　　1. 点検者　㊞

自動弁		現地自動弁			ヘッド			水噴霧制御盤		点検結果	処置及び見解
								自動弁			
区画No.	作動方式	弁類	パイロット圧力SW	電装品	取付角度	変形損傷	詰り等	開(sec)	閉(sec)		

－226－

Report sheet for periodical inspection of tunnel sprinklers (visual check)

1. Location　　　　1. Person in charge
1. Date　　　　　　1. Inspector

Automat. valve		Local valve			Head			Control		Inspection result	Measures
Section	Method	Type	Pilot		Angle	Damage	Clogging	Valve			
								Open	Close		

Figure 3-1　　Check list for visual inspection (example, MEPC)

トンネル消火設備定期点検報告書
（水噴霧設備合同試験）

1. 設置場所　　　　1. 現場代理人　㊞
1. 点検年月日　　　1. 点検　㊞

放水区画	中央盤・制御			防災盤・制御			点検結果	処置及び見解
No.	PV(開)	PV(閉)	PS	PV(開)	PV(閉)	PS		

－227－

Report sheet for periodical inspection of tunnel sprinklers (overall check)

1. Location　　　　1. Person in charge
1. Date　　　　　　1. Inspector

Discharge section	Central control			Control panel			Inspection result	Measures
	PV open	PV close	PS	PV open	PV close	PS		

Figure 3-2　　Checklist for overall inspection (example, MEPC)

3 - 2 - 2 Criteria for replacement / repair

The discharge conditions of each sprinkler head are verified with a water discharge test. If necessary, the angle is adjusted or the head is replaced.

The decision to replace or repair is made by the tunnel authority after the inspection company reports a defect. Depending on the level of defect, a construction planning for the replacement or repair is considered.

Replacement or repair is carried out on the same day as far as possible.

3 - 2 - 3 Measurement vehicle for sprinkler maintenance

Since 1999, the JH makes use of a measurement vehicle for maintenance of sprinklers in its road tunnels, after development period of 2 years. The sprinkler heads are separated in groups of ten heads to one automatic valve, and one total group (L=50m) can be inspected at once with 3 vehicles (4-3-3 pattern). An additional 4th vehicle is used for special locations of sprinkler heads (at lay-by, positions with jet fans etc.). The advantages of the measurement vehicle are stated as follows:

1) Sprinkler heads can be inspected with actual water discharge, while closing only one traffic lane.
2) The tunnel remains open to traffic.
3) The discharge volume of the sprinkler heads can be measured, and these data can be used to give an indication about the condition of the sprinkler heads.
4) The measured data can be stored in a database to give better understanding about long-term condition of sprinkler heads.

Figures 3-3 through 3-5 show photographs of the measurement vehicles, and Figure 3-6 gives an image of the operation condition of measurement vehicles.

Figure 3-3 Measurement vehicle in closed position

Figure 3-4 Measurement vehicle in open position

Figure 3-5 Measurement vehicle in operation

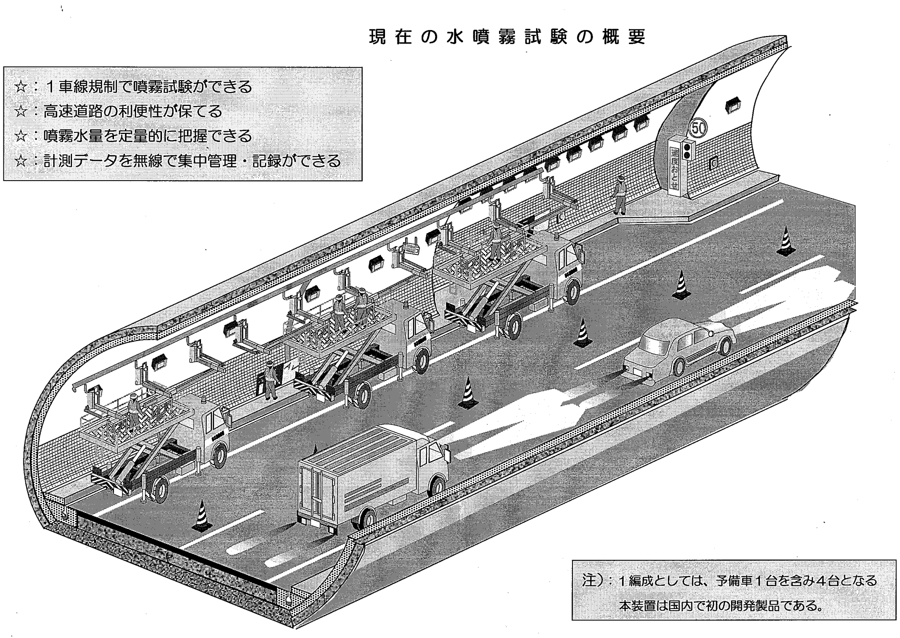

Figure 3-6 Measurement vehicles in operation while closing one traffic lane

4 Background and experience

4 - 1 General

In addition to the stipulations in the guidelines as described in chapter 2, interviews have been performed with JH, MEPC (the tunnel authorities that operate most tunnels with sprinkler systems) and Nohmi Bosai Ltd. (a major manufacturer of fire safety facilities, including sprinklers for tunnels).

The interviews are performed to give additional information about the actual experience with sprinkler systems in road tunnels during normal tunnel operation and during tunnel fire, background for the installation of sprinklers, inspection of sprinklers, and technical issues concerning sprinklers. The interviews are based on questionnaires prepared by Chiyoda in cooperation with RWS (the questionnaires are given in APPENDIX A).

4 - 2 From authority point of view

In case no reference is made to JH or MEPC, the information accounts for both authorities.

4 - 2 - 1 General

- In general, the tunnel authorities are satisfied with the functionality of sprinklers in tunnels.
- At the moment there is no discussion or investigation to further improve sprinkler facilities technically.
- A committee consisting of representative from tunnel authorities (including MOLIT, JH, MEPC, HEPC) and related institutions is investigating how tunnel safety systems can be further improved in general, and part of this investigation is the timing of sprinklers and the relation with other tunnel safety facilities.
- The costs for sprinkler installation are dependent on many factors, including structural conditions of tunnel. As rough indication, the costs are estimated (by Chiyoda) to be JPY 350,000 (EURO 3,000) per meter per tunnel, which includes water basin, pipes, valves, heads and control equipment.

4 - 2 - 2 Research and development

- The first tunnel in Japan in which sprinklers were installed is the Tennozan Tunnel (operated by JH), in 1963. The JH included sprinklers in its guidelines since August 1967.
- The first MEPC tunnel with sprinklers is the Tokyo Port Tunnel (installed in 1976). The first MEPC standards including sprinklers are of August 1981. In 1984, the

installation of sprinklers to all MEPC tunnels of AA class was completed.

- The main reason for specific developments for road tunnels is based on the differences with sprinklers for other purposes (buildings, chemical plants etc.). These differences are mainly stated as
  - Presence in tunnel of gasoline and in some cases dangerous goods
  - No compartmentation by tunnel structure
  - More difficult to verify location and size of tunnel fire
  - More difficult to operate sprinklers (in connection with human behavior)
- The size of the water drops from sprinklers is of influence to the heat absorption capacity of the sprinkler (the smaller the drop size the large the interface between water and air and the larger the absorption capacity) and of influence to the capacity to reach the fire heard (the larger the drop size the less drops are blown away by air flow in the tunnel and the better the fire heard is reached). The drop size is not decided as such, but is a result of experiments concerning equal water spread over the tunnel cross section and the spray reach (distance).
- A large number of experiments has been carried out for the development of sprinklers, including those as given in APPENDIX B.
- APPENDIX E gives an outline of 2 reports about tunnel fire experiments of the initial research period [30] [31].

4 - 2 - 3 Quality control

- Sprinklers do not follow a certification system for quality guarantee. The sprinklers installed in tunnels have been tested on functionality and water discharge volume (6 liter per minute per m^2), and since then actual performance indicates reliability.
- Until now, no notable defects have been experienced with sprinkler installation. Pipes have locally been replaced in JH and MEPC tunnels, but sprinkler heads show no defects.
- The main pipes of sprinklers have an estimated lifetime of more than 20 years.

4 - 2 - 4 Inspection

- JH inspects automatic valve 2 times a year, and carries out water discharge test 1 time a year. During water discharge test, water volume and fixing between sprinkler head and wall is checked.
- JH inspections are standardized (see Chapter 2), and up to about 2km of tunnel can be inspected in one day.

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[30] PWRI, Report on Road Tunnel Fire Test, PWRI Document No. 568, March 1970

[31] Tunnel Safety Facilities Committee, Experiment concerning Fire Safety Facilities of Meishin Expressway Tunnel, 1961

- Main reasons for repair and replacement of sprinkler heads is due to trucks that hit the wall and damage the heads. Another reason is stated as clogging of the heads (especially in country side tunnels due to quality of natural/ground water).
- As example, APPENDIX D describes inspection method of and reports visit to inspection works at Chiyoda Tunnel (MEPC).

4 - 2 - 5 Experience with sprinklers during normal tunnel operation

- Neither JH nor MEPC has experienced malfunctioning of sprinklers during normal tunnel operation (no sudden water discharge, no cases where water was not available in main pipes where it should be, no cases where pipes between valve and heads were filled with water where they should not be).

4 - 2 - 6 Experience with sprinklers during tunnel fire

- The JH experiences about 10 to 16 tunnel fires per year that require dispatch of Fire Brigade. In 2 or 3 cases per year sprinklers are activated.
- The MEPC has actually used sprinklers in 5 or 6 tunnel fire accidents, and it is believed that the fire heard was cooled and fire spread to other vehicles was prevented because of the sprinkler use.
- Fires are reported to the control room in different ways, including the following (in order of importance, JH):
    1. Emergency telephone
    2. Fire detector
    3. ITV camera
    4. Push button
    5. Patrol vehicle
    6. Others
- As example, the activities during an actual tunnel fire accident have been reported as follows [32] (this is an example, and types of activities as well as their order may be different case by case; a number of activities are carried out parallel):
    - Activation of fire detector
    - Detection of emergency in tunnel with ITV camera
    - Information to tunnel users (traffic signal at tunnel entrance to red; message at tunnel entrance to "Fire ! Do not enter tunnel ! "; message by speaker and radio to leave tunnel)
    - Request for Fire Brigade dispatch
    - Start sprinkler
    - Tunnel owner arrives at accident site

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[32] Based on information received from JH

- Fire Brigade arrives at accident site
- Start firefight activities by Fire Brigade
- Verify that fire is extinguished
- Remove vehicles in tunnel
- Remove burnt out vehicles
- Recovery, cleaning
- Reopen tunnel

– No cases are known of false operation, malfunctioning or only partly functioning of sprinklers during actual tunnel fire.

– Main pipes are filled with water; pipes between valve and heads are not filled. Therefore the time lag between opening of automatic valve and water discharge from sprinkler heads is fractional.

– Because pipes are filled with water, the influence of heat from fire and the risk of damage to pipes are limited. Pipes are normally SGP or STPG, based on cost consideration (MEPC).

4 - 2 - 7 Technical issues

– Based on experiment carried in March 2001 for the New Tomei Expressway, it is presently known that sprinklers have a cooling effect for fires that are similar to a $9m^2$ cargo fire (before March 2001, the cooling effect was verified for maximum $6m^2$ pan fire). The actual fire size during the experiment was 23MW.

– During the same experiment (of March 2001), the prevention of fire spread was verified with 3 passenger cars (1 on each side of burning vehicle), under 5m/s longitudinal flow-velocity.

– The relation with fire detectors is such that even in case the fire detector reports a fire, the operator will first verify the condition in the tunnel with the CCTV monitoring system, and then push a button to activate the sprinklers. Therefore the operation is not automatically linked to fire detectors. False alarm of fire detectors is prevented as much as possible by frequent inspection. No accuracy range (fault range) for fire detectors is specified in Japanese standards.

– The JH is investigating to change the operation of sprinkler systems in order to alleviate the responsibility of the tunnel operator. The newly proposed principle is to let the operator push the sprinkler activation button as soon as he confirms a fire on the monitoring screen (after report from fire detector etc.) and build in a time delay until the automatic valve actually opens (the time delay is the period between the time of button push and the time of opening of automatic valve). The time delay is different for uni-directional traffic tunnels and bi-directional traffic tunnels. For correction purposes, the operator can drawback (deactivate) the sprinkler push-button within the time delay period.

- The JH and MEPC use different layout of pipes for sprinkler water supply. The JH uses the same pipe for fire hydrant and sprinkler; the MEPC uses separate pipes. The JH main pipes are locate near the road surface, the MEPC pipes for sprinklers is located near the ceiling corner.

  Merits of the JH system include less space required and consequent lower costs. The location near the road surface and the fact that the pipes are imbedded in the concrete has the merit that temperatures will not rise as much as the ceiling corner part.

  Merits of the MEPC system include less risk that the total water supply is cut off at once if the one and only pipe is damaged.
- The reason not to use foam in sprinklers is high costs and cleaning works after actual use. The only tunnel in Japan that uses foam in its sprinklers is the Aqualine (Trans Tokyo Bay Tunnel), because of its special conditions (it is a very large scale underwater tunnel constructed with shield method, it is a prestigious project, etc.). Foam is supplied for 10 minutes, after that water for 30 minutes.
- The basic purposes of water sprinklers as stated by the JH (cooling effect, prevention of fire spread, protection of tunnel structure, protection of tunnel equipment, see further Chapter 2-2) are stated to be also valid for mountain tunnels.
- The influence of longitudinal flow velocity to sprinklers is limited because at time of tunnel fire the mechanical ventilation is not operated in bi-directional tunnels, and operated in uni-directional tunnels at 2m/s in order to prevent backlayer.
- Timing, method and decision of closure of sprinklers is based on communication with and advice from fire brigade after they arrive at site. Sprinklers can be closed when the fire fighting by the fire brigade starts, but sprinklers can also continue to play a supporting function for fire fighting.

4 - 2 - 8 Recent developments

- The JH is investigating to apply newly improved sprinklers to the tunnels with large cross section of the New Tomei Expressway, under construction between Tokyo and Kobe. The expressway will be a high standard expressway with 3 traffic lanes in one direction and high design traffic velocity requiring extra wide lanes, and therefore tunnels with extra width.
- For this purpose, the JH carried out experiments with sprinklers as part of a tunnel fire experiment concerning fire development, evacuation possibilities and smoke extraction during fire accidents in tunnels with enlarged cross section. One of the results of the fire experiment was the (re-)confirmation of the usefulness of sprinklers in case of a 23MW tunnel fire (9m^2 fire pan).

4 - 3 From manufacturer point of view

- Sprinklers have been developed in cooperation with and in anticipation of requirements by tunnel owners in charge.
- The first sprinklers for the Tomei Expressway and Meishin Expressway were installed at both sides of the roadway space. Due to high installation and maintenance costs, it was decided to improve the sprinkler installation in such a way that single side installation provided the same performance in terms of spray uniformity and reach.
- The spray section of sprinklers is decided based on experiments, carried out in the early days of the sprinkler development. Fire detectors had a reach of 12m section; 3 fire detectors formed a section length of 36m. A road width of 8m resulted in a spray surface of 288m^2.
- The shape of deflector attached to sprinklers is decided based on experiments about uniformity of sprinkle over the cross section of the tunnel and the reach of the water spray. Figure 4-1 shows the uniformity of the water spray (photograph taken during visit to inspection at Chiyoda Tunnel; see further APPENDIX D).

Figure 4-1 Uniformity of spray

- Because the pipes are normally filled with water up to the automatic valve, no special heat insulation is applied to the pipes. The pipes from the automatic valve to the heads are filled with water in a very short tome after the automatic valve is opened.
- In cold areas, the automatic valves near the tunnel portal are placed in heated boxes to prevent freezing. The heaters are operated automatically based on built in temperature meters.
- The effect by sprinklers to cool the fire and the effect to prevent fire spread, are confirmed with field experiments based on conditions of specific tunnels.

- The influence by sprinklers to the smoke stratification is limited to the sprinkler range (e.g. to 50 or 100m).
- The fire detectors are designed to detect a fire that is equal to $0.5m^2$ (0.70 by 0.70m) within 3- seconds from fire start. In case it is necessary to avoid false detection by natural light near the tunnel portal (depending on the tunnel conditions), it is possible to not install fire detectors in the first 15m after the tunnel portal (based on investigation case by case).

5 Examples

5 - 1 Sprinkler head

Following are representative examples of sprinkler heads, in use in most road tunnels in Japan. At present four types are in use, as shown in Table 5-1.

Table 5-1 Types of sprinkler heads and their specifications

No.	Objected cross section	Remark
1	Rectangular (2 lane)	
2	Rectangular (2 lane + extra width)	For sections with merge, branch or lay-by
3	Horse shoe (2 lane)	
4	Horse shoe (2 lane + extra width)	For sections with merge, branch or lay-by

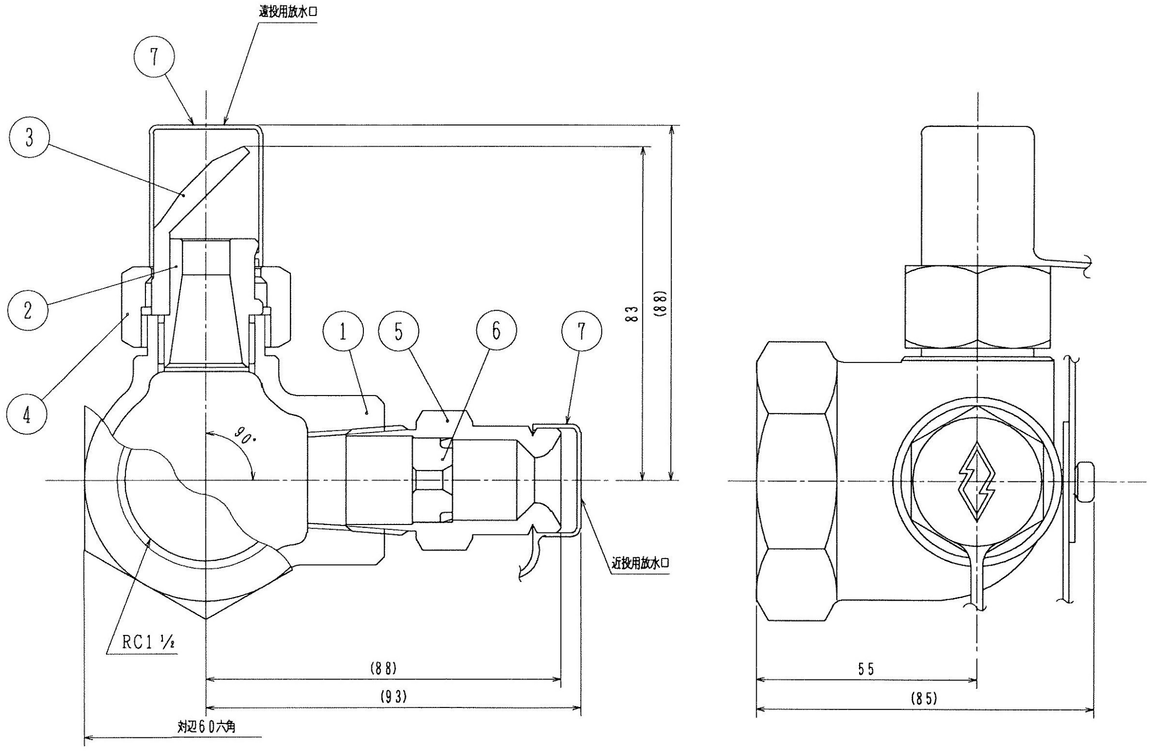
1) Rectangular (2 lane)

This type is for tunnel tubes with rectangular cross section and 2 traffic lanes (Figure 5-1). Table 5-2 gives details of this 2-combination nozzle type. Figure 5-2 and Figure 5-3 show drawing and spray pattern of this type.

Figure 5-1 Sprinkler head for 2 lanes

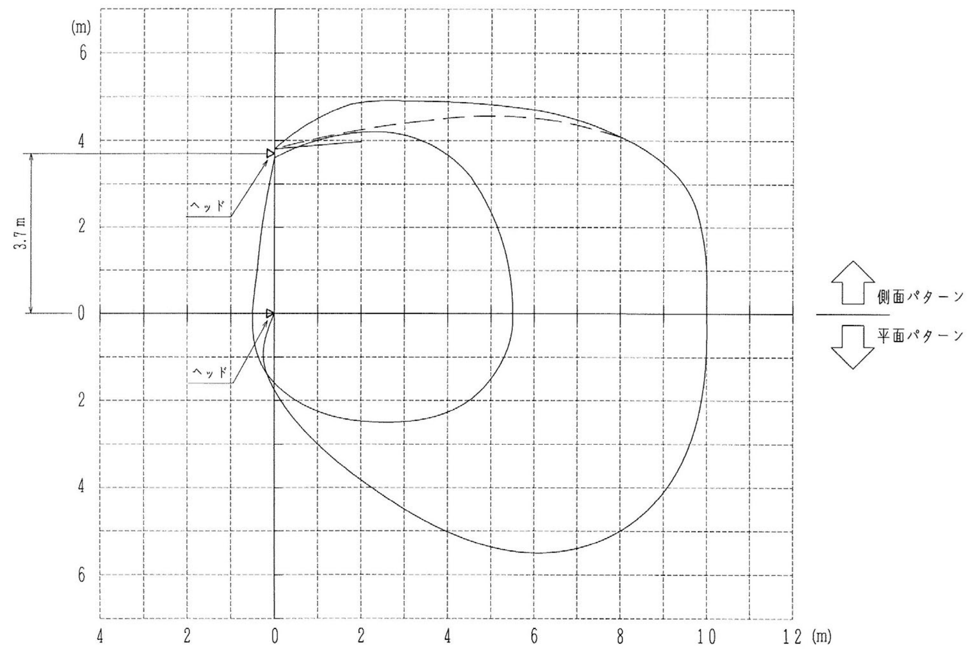
Table 5-2 Specifications for sprinkler head: rectangular cross section, 2 traffic lanes

Item	Specification	
Total water pressure	0.34MPa (3.5 kgf/cm^2)	
Discharge volume	Short range nozzle (spiral)	90 L/min (+10%, -0%)
	Long range nozzle (deflector)	160 L/min (+10%, -0%)
	Total	250 L/min (+10%, -0%)
Installation height	3.7m	
Remove pressure dustproof cap	0.29 MPa	



1: Body, 2: Long range nozzle, 3: Deflector, 4: Bolt, 5: Short range nozzle, 6: Spiral, 7: Dustproof cap

Figure 5-2 Sprinkler head for rectangular cross section, 2 traffic lanes



Upper half: side view
Lower half: top view

Figure 5-3 Spray patter for rectangular cross section, 2 traffic lanes

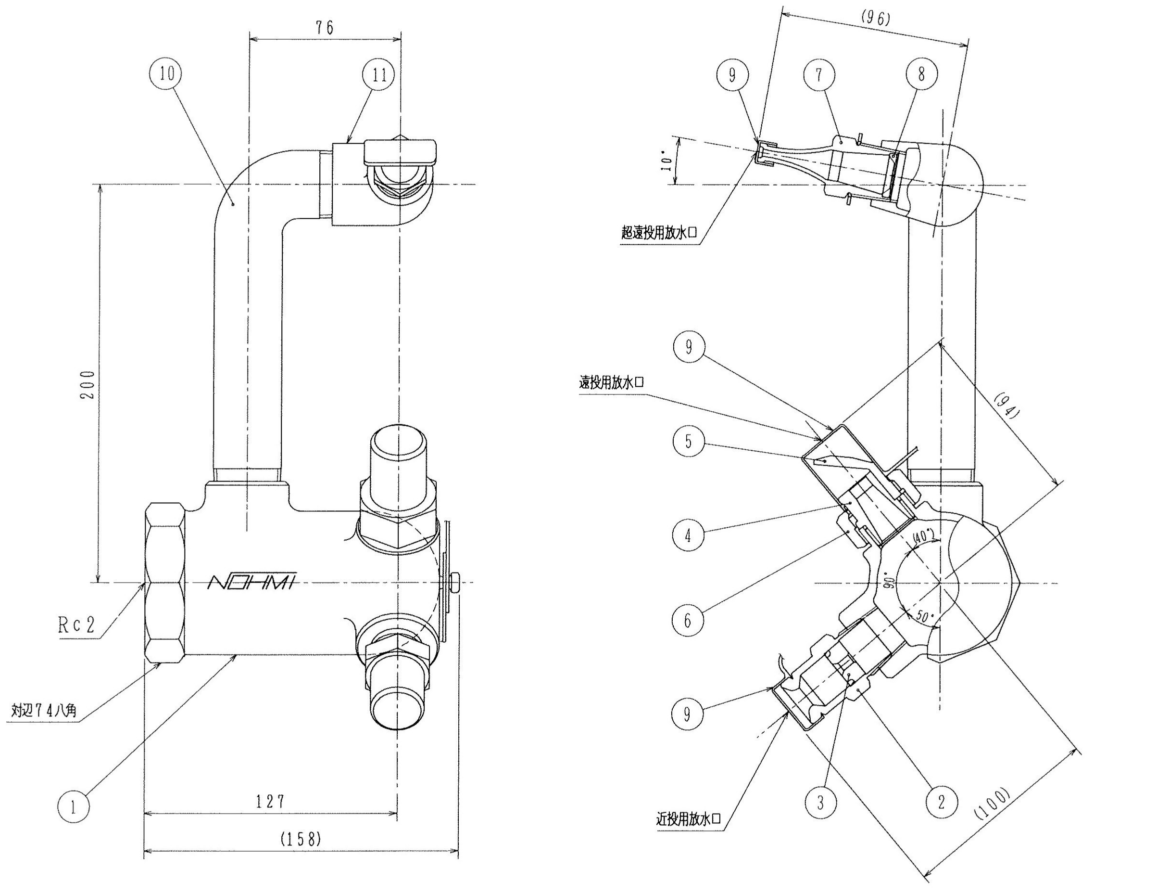
2) Rectangular (2 lane + extra width)

This type is for tunnel tubes with rectangular cross section and 2 traffic lanes and extra width, to be used at locations where the road merges or branches or at lay-by (Figure 5-4). Table 5-3 gives details of this 3-combination nozzle type. Figure 5-5 and Figure 5-6 show drawing and spray pattern of this type.

Figure 5-4 Sprinkler head for 2 lanes + extra width

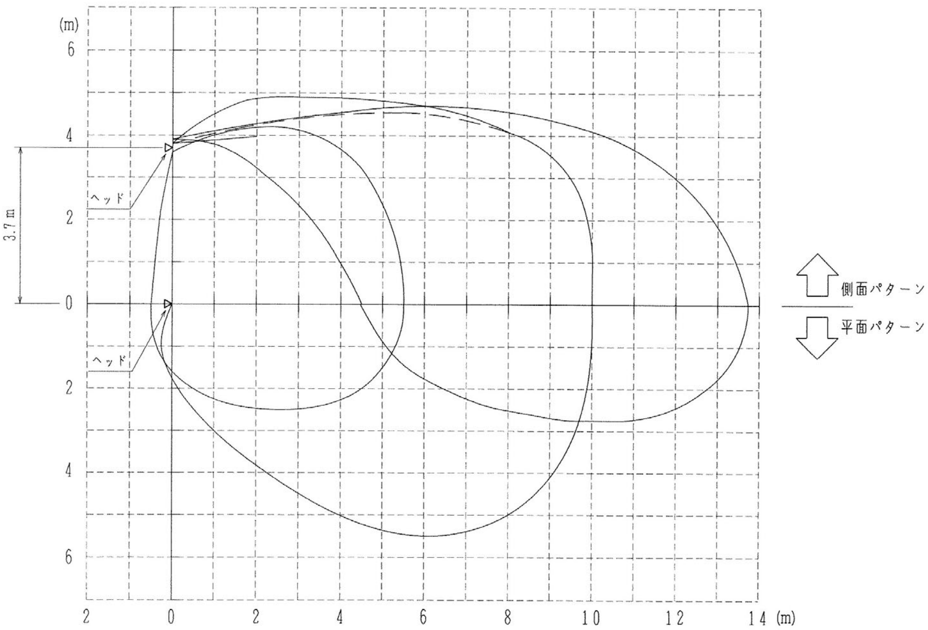
Table 5-3 Specifications for sprinkler head: rectangular cross-section, 2 traffic lanes + extra width

Item	Specification	
Total water pressure	0.34MPa (3.5 kgf/cm^2)	
Discharge volume	Short range nozzle (spiral)	90 L/min (+10%, -0%)
	Long range nozzle (deflector)	160 L/min (+10%, -0%)
	Super-long range nozzle	110 L/min (+10%, -0%)
	Total	360 L/min (+10%, -0%)
Installation height	3.7m	
Remove pressure dustproof cap	0.29 MPa	



1: Body, 2: Short range nozzle, 3: Spiral, 4: Long range nozzle, 5: Deflector, 6: Bolt,
7: Super-long range nozzle, 8: Orifice, 9: Dustproof cap, 10: pipe, 11: elbow

Figure 5-5 Sprinkler head for rectangular cross section, 2 traffic lanes + extra width



Upper half: side view
Lower half: top view

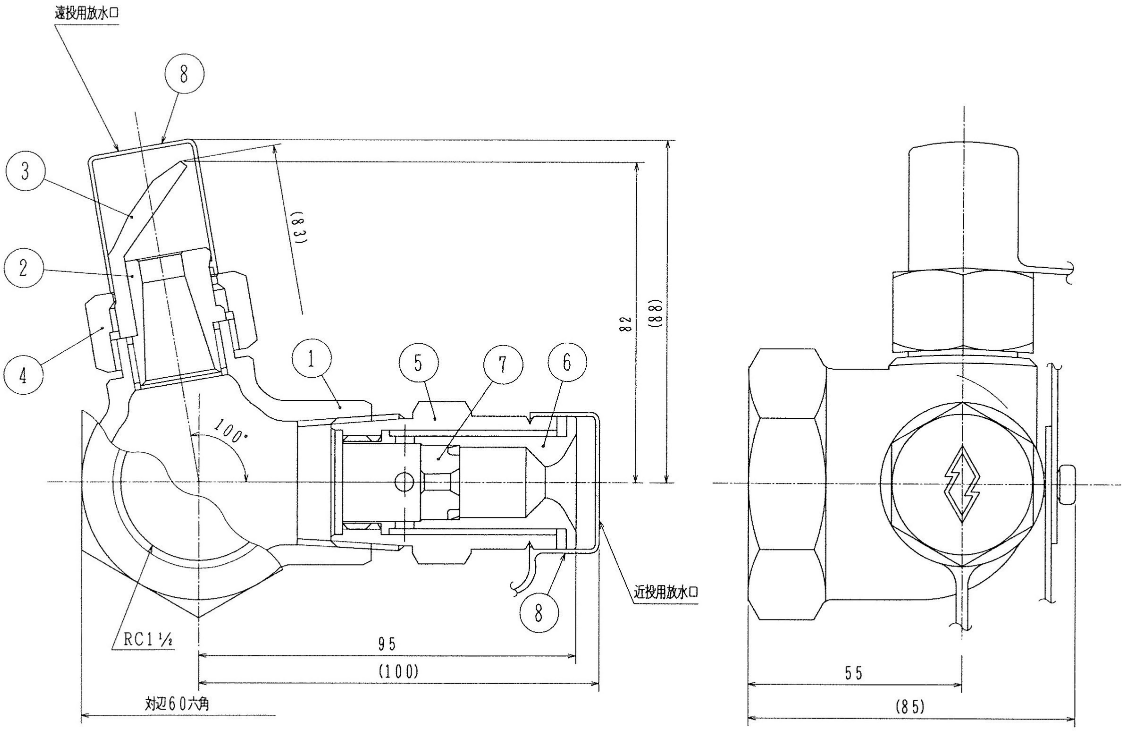
Figure 5-6 Spray patter for rectangular cross section, 2 traffic lanes + extra width

3) Horse shoe (2 lane)

This type is for tunnel tubes with horseshoe cross-section, 2 traffic lanes. Table 5-4 gives details of this 2-combination nozzle type. Figure 5-7 and Figure 5-8 show drawing and spray pattern of this type.

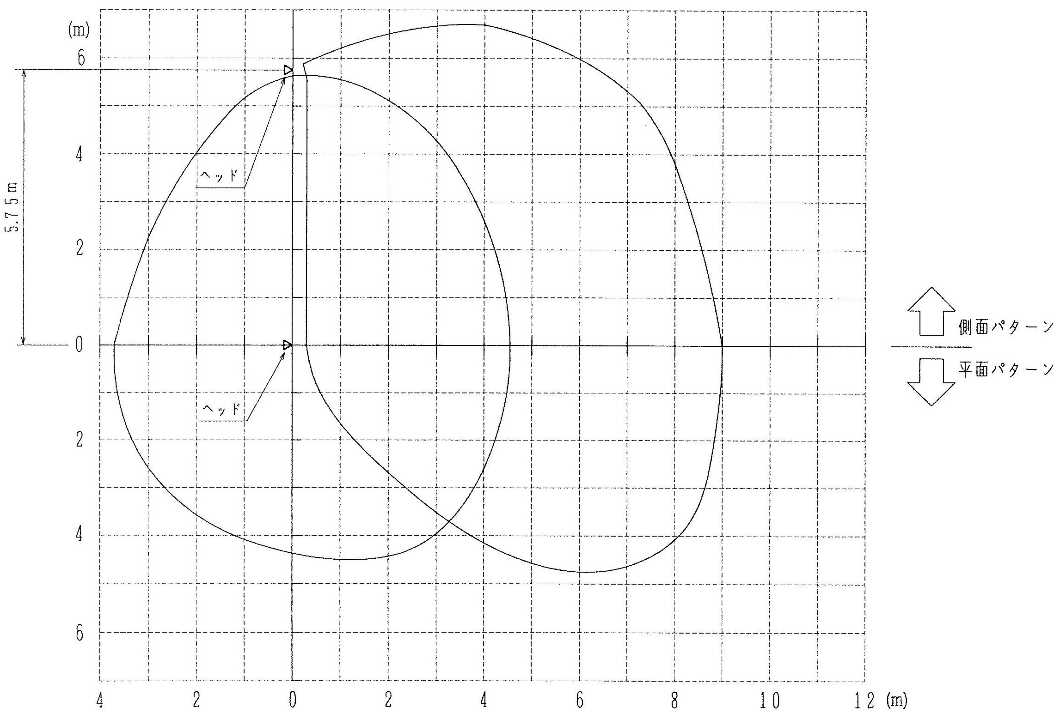
Table 5-4 Specifications for sprinkler head: horseshoe cross-section, 2 traffic lanes

Item	Specification	
Total water pressure	0.34MPa (3.5 kgf/cm^2)	
Discharge volume	Short range nozzle (spiral)	110 L/min (+10%, -0%)
	Long range nozzle (deflector)	140 L/min (+10%, -0%)
	Total	250 L/min (+10%, -0%)
Installation height	5.75m	
Remove pressure dustproof cap	0.29 MPa	



1: Body, 2: Long range nozzle, 3: Deflector, 4: Bolt, 5: Short range nozzle, 6: Nozzle, 7: Spiral, 8: Dustproof cap

Figure 5-7 Sprinkler head for horseshoe cross-section, 2 traffic lanes



Upper half: side view
Lower half: top view

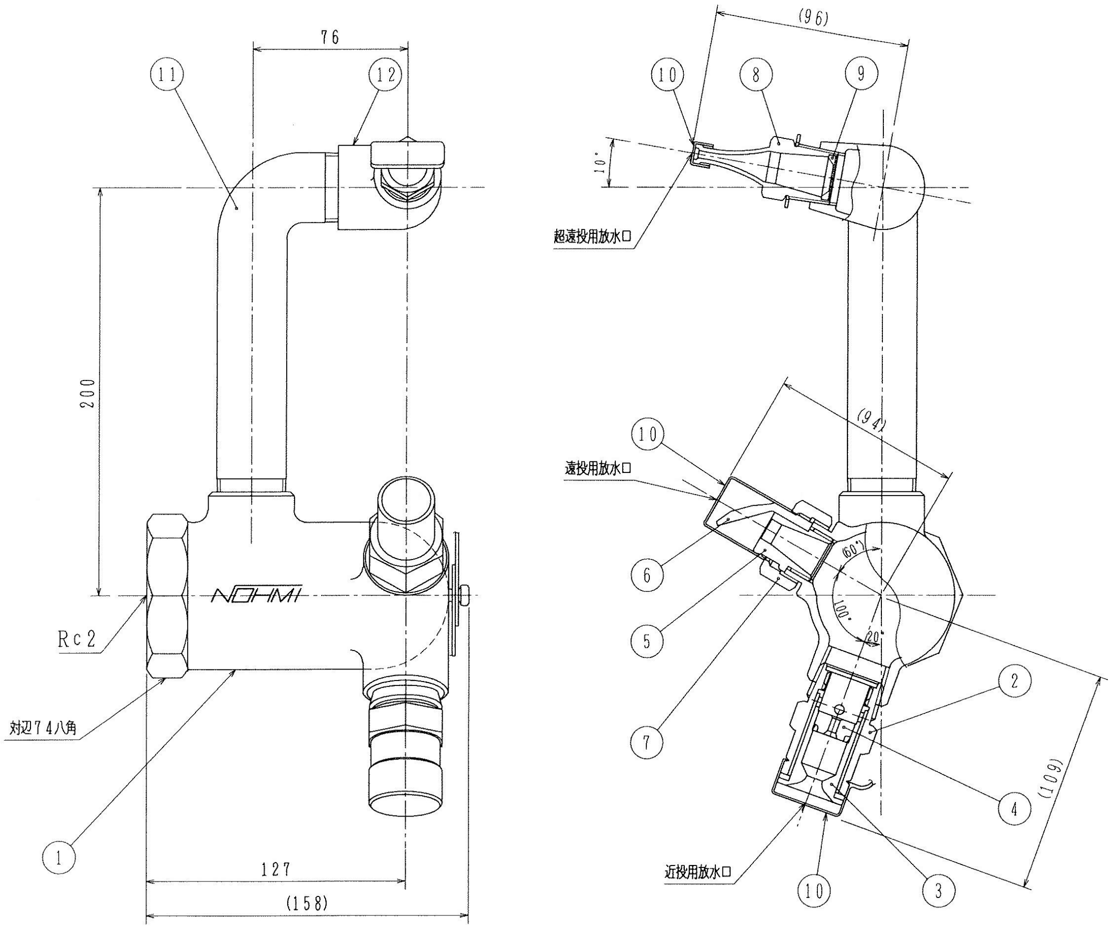
Figure 5-8 Spray patter for horseshoe cross-section, 2 traffic lanes

4) Horse shoe (2 lane + extra width)

This type is for tunnel tubes with horseshoe cross-section, 2 traffic lanes and extra width (at merge, branch or lay-by). Table 5-5 gives details of this 3-combination nozzle type. Figure 5-9 and Figure 5-10 show drawing and spray pattern of this type.

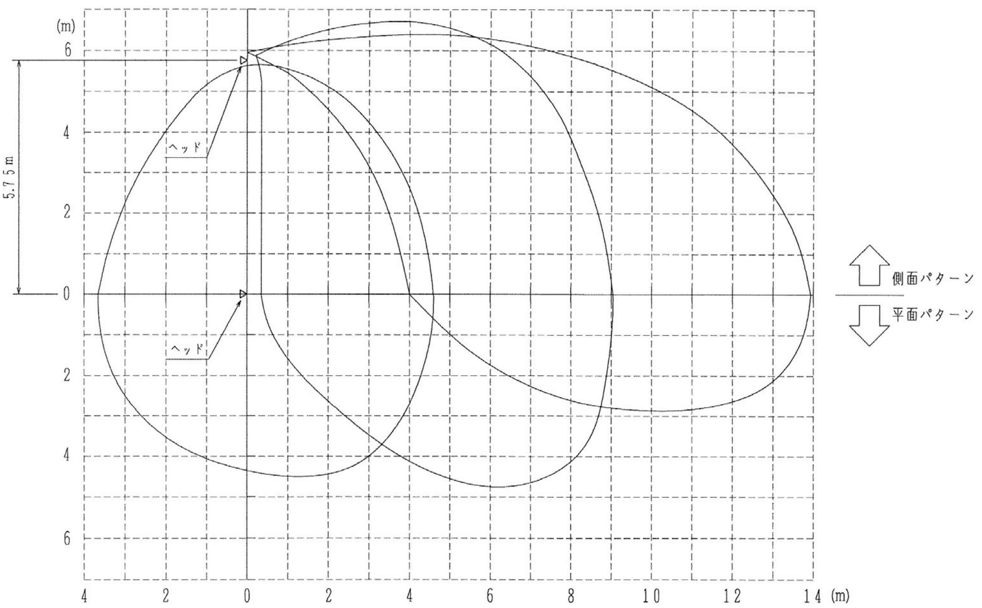
Table 5-5 Specifications for sprinkler head: horseshoe cross-section, 2 traffic lanes + extra width

Item	Specification	
Total water pressure	0.34MPa (3.5 kgf/cm^2)	
Discharge volume	Short range nozzle (spiral)	110 L/min (+10%, -0%)
	Long range nozzle (deflector)	140 L/min (+10%, -0%)
	Super-long range	110 L/min (+10%, -0%)
	Total	360 L/min (+10%, -0%)
Installation height	5.75m	
Remove pressure dustproof cap	0.29 MPa	



1: Body, 2: Short range nozzle, 3: Short range nozzle, 4: Spiral, 5: Long range nozzle, 6: Deflector,
7: Bolt, 8: Super-long range nozzle, 9: Orifice, 10: Dustproof cap, 11: pipe, 12: elbow

Figure 5-9 Sprinkler head for horseshoe cross-section, 2 traffic lanes + extra width



Upper half: side view
Lower half: top view

Figure 5-10 Spray patter for horseshoe cross-section, 2 traffic lanes + extra width

5 - 2 Automatic valve

Different types of automatic valves are in use for sprinklers in road tunnels. Typical nominal inner diameters are 100A [33], 125A and 150A, with pressure range 0.20 – 1.37 MPa (2.0 – 14 kgf/cm^2) and opening pressure of 0.08 MPa (0.8 kgf/cm^2).

Figure 5-11 and 5-12 show outer view and system of an automatic valve for sprinklers in road tunnels (125A). One automatic valve controls a total group of 10 sprinkler heads (at spacing of 5m, total range of 50m). Figure 5-13 gives a detailed drawing of an automatic valve (2,500 L/min flow volume, 2-18 kg/cm^2 high pressure range).

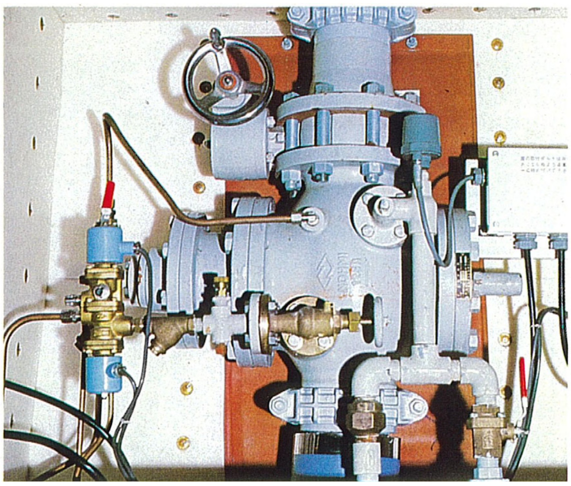


Figure 5-11 Automatic valve (125A), outer view

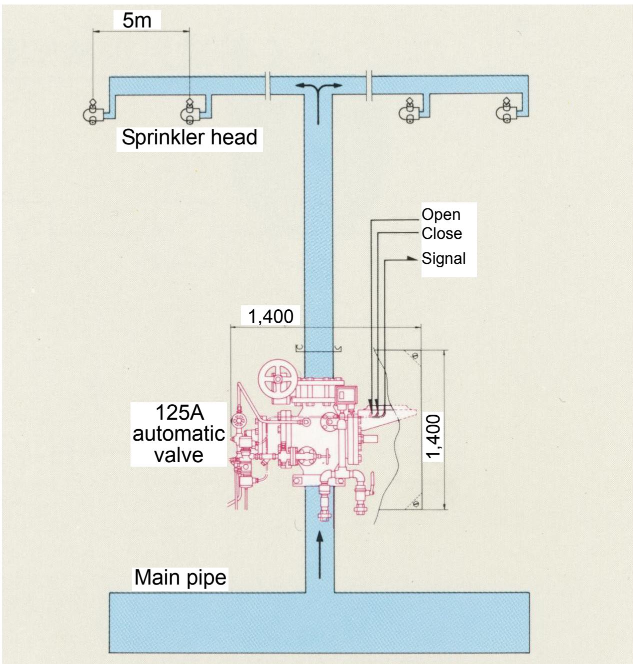
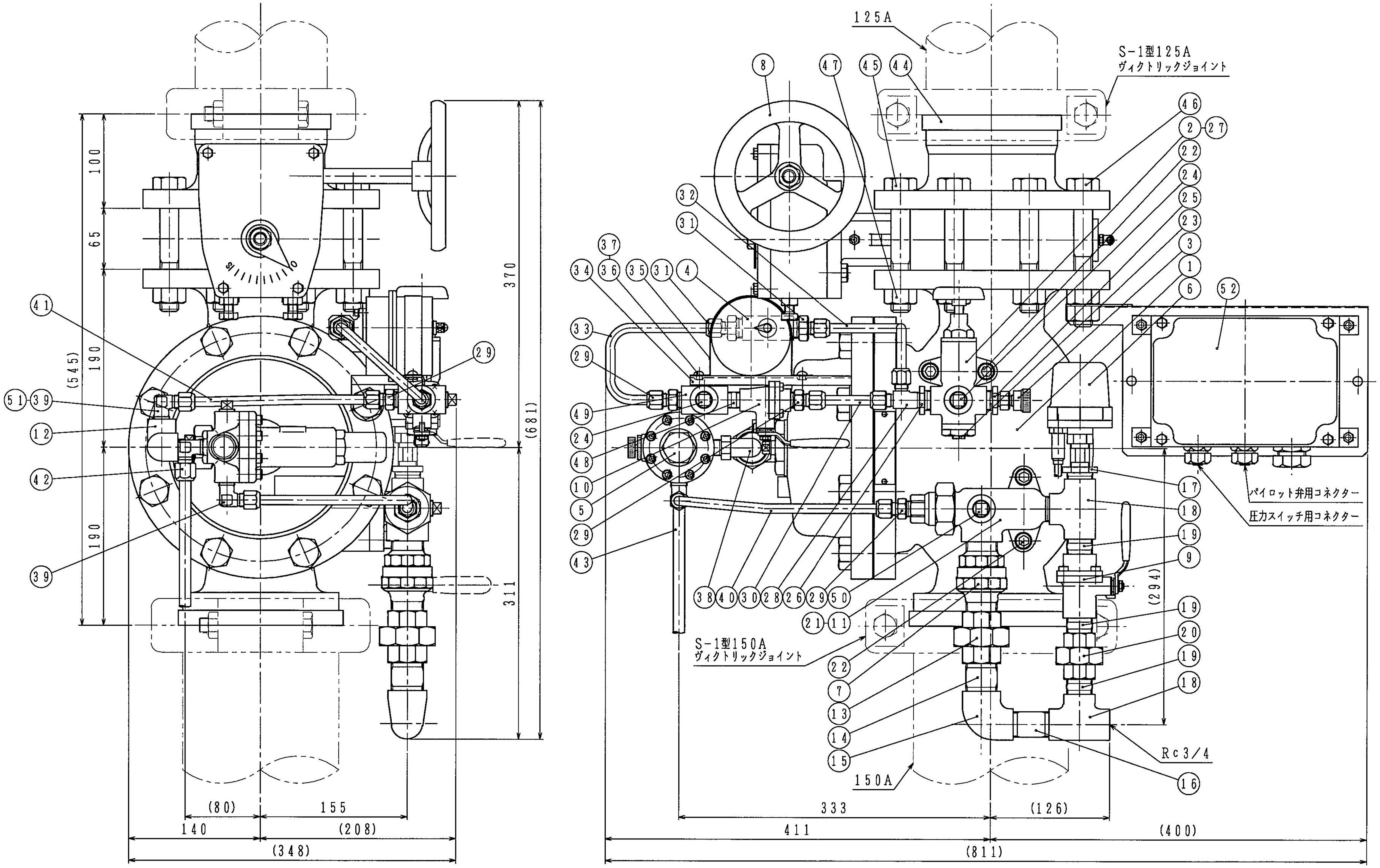


Figure 5-12 Automatic valve (125A), principle system

[33] Nominal inner diameter is indicated with capital A (see further under APPENDIX F)

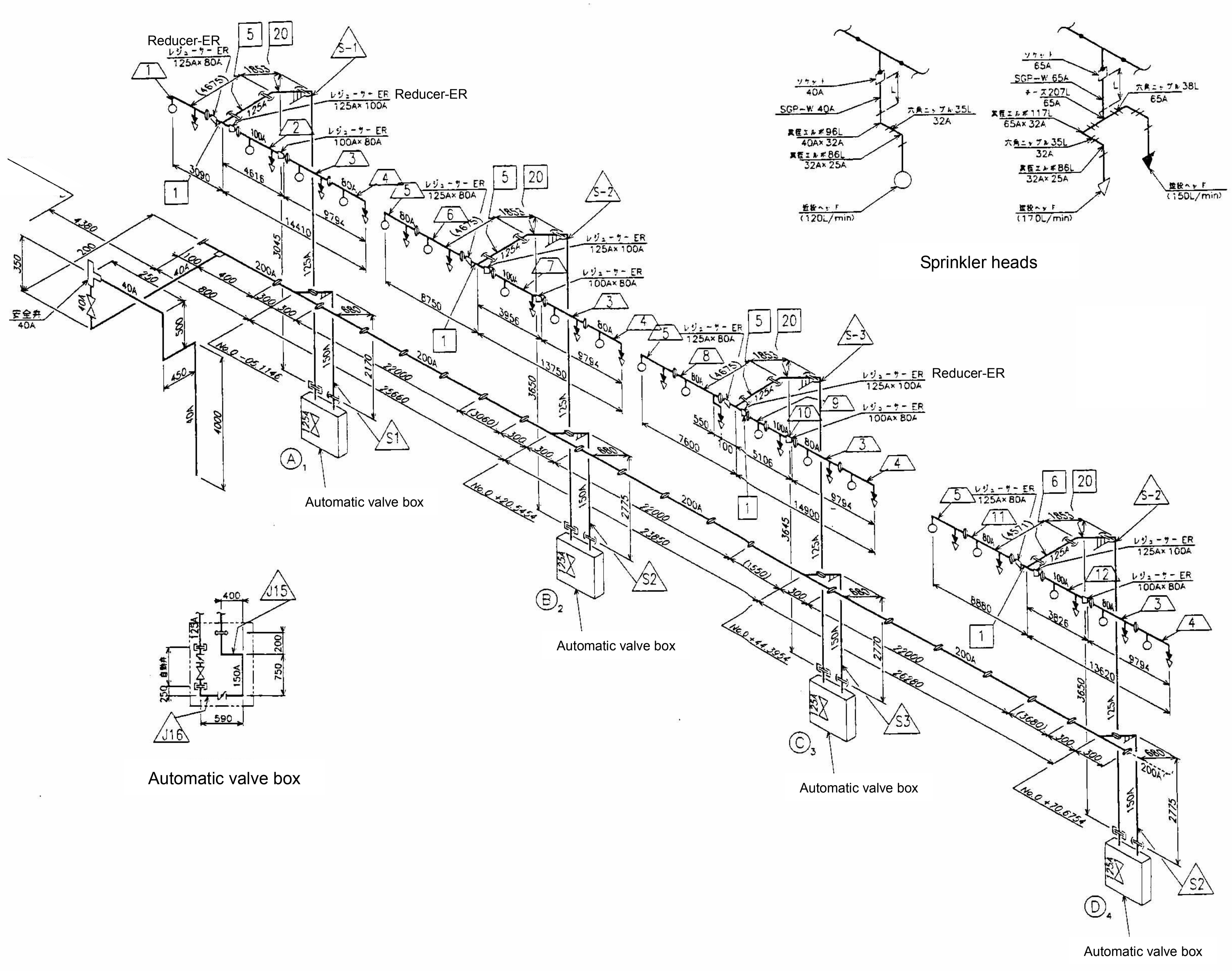


1: Automatic valve, 2: Stop valve, 3: Drainage valve, 4: Pilot valve, 5: Pressure control valve, 6: Pressure switch, 7: Automatic drainage valve, 8: Test control valve, 9: Test discharge valve, 10: Manual activator, 11: Strainer, 12: Orifice, 13: Union, 14: Short pipe, 15: Elbow, 16: Short pipe, 17: pushing, 18: cheese, 19: Barrel nipple, 20: Union F, 21: Ring, 22: Bolt, 23: Plug, 24: Plug, 25: Pushing, 26: Pushing, 27: Ring, 28: Service cheese union, 29: Half union, 30: Copper pipe, 31: Half union, 32: Copper pipe, 33: Copper pipe, 34: Plate, 35: Supporter, 36: Nut, 37: Washer, 38: Elbow, 39: Elbow union, 40: Copper pipe, 41: Copper pipe, 42: Elbow union, 43: Copper pipe, 44: Distance piece, 45: Bolt, 46: Bolt, 47: Nut, 48: Barrel nipple, 49: Cross, 50: Plug, 51: Orifice, 52: Terminal

Figure 5-13 Automatic valve for sprinklers

5 - 3 Layout

Figure 5-14 shows an example of sprinkler layout.



	Contents
△	Long range nozzle (170L/min)
▲	Long range nozzle (150L/min)
○	Short range nozzle (120L/min)
●	Short range nozzle (150L/min)
	Special joints
	Special pipes
	Automatic valve

Figure 5-14 Example of sprinkler layout

APPENDIX A: Questionnaires

In order to gain information for this report, discussions have been carried out with tunnel authorities (JH, MEPC) and the most important sprinkler manufacturer (Nohmi). Following are the questionnaires that have been used for these discussions. The information gained during the discussion based on these questionnaires is integrated in the main text of the report and not included in this Appendix.

A-1 Tunnel authority

Similar questionnaires for the discussions with JH and MEPC have been used. "JH/MEPC" refers to JH in the discussion with JH and MEPC in the discussion with MEPC.

1. General

1.1 Is JH/MEPC in general satisfied with the functionality of sprinklers in its road tunnels?

1.2 Are there wishes / thoughts in JH/MEPC to improve sprinklers in any way (technically, functionally, operationally)? If yes, what is the reason for such wishes / thoughts? Is JH/MEPC in contact with manufacturers for such improvements?

1.3 Are sprinklers "established", in terms that they are not under discussion anymore? If no, what are recent items of discussion?

2. Development

2.1 Since when are sprinklers in use in JH/MEPC road tunnels? Since when are sprinklers included in JH/MEPC regulations?

2.2 What institutions were in charge for the development / design of sprinklers for road tunnel purposes? Has JH/MEPC done own research in the development of sprinklers? What were the most important design criteria?

2.3 What are the main typical characteristics of sprinklers for road tunnels in comparison with sprinklers for other purposes?

2.4 How was the drop size and the number of drops sprinkled per time unit decided?

2.5 Have fire tests (scale model or full size) been carried out in the development of sprinklers? Is information available about such tests?

3. Certification

3.1 Is the sprinkler use based on a certification system?

3.2 If not, how is quality guaranteed? (in this case, skip questions 3.3-3.5)

3.3 How many (types of) sprinklers are certified at the moment?

3.4 How many of the certified sprinklers are in actual use at the moment?

3.5 Are there certified sprinklers that are not used (anymore)? If yes, which ones and why are they not used?

4. Inspection

4.1 Who carries out inspections? How often per year? In what order (all sprinklers per tunnel in one inspection, or partly and spread over more inspections?)

4.2 How is the responsibility for planning and execution of inspection divided between tunnel authority and inspector? How is the communication between them arranged?

4.3 What are the contents (items) of inspection?

4.4 Are there special safety measures, emergency plan for inspections?

4.5 What are the criteria to replace/repair sprinklers? What is the flow of activities in case of replace/repair (who decides, timing)?

4.6 Is it possible to arrange a meeting with inspectors? Is it possible to attend an inspection?

4.7 What kind of experiences does JH/MEPC have with inspections? What kind of repairs has been necessary? Where replacements in line with lifetime as guaranteed with certification (if not, what was the period of use)?

5. Normal situation

5.1 Has JH/MEPC experienced cases that sprinklers activated in normal traffic situations (non emergency case)?

5.2 Has JH/MEPC experienced problems with freezing in winter?

5.3 Are pipes normally filled with water? If yes, has JH/MEPC experienced cases that they were not filled? If no, has JH/MEPC experienced cases that they were filled?

5.4 Are water basins normally filled with water? If yes, has JH/MEPC experienced cases that they were not filled? If no, has JH/MEPC experienced cases that they were filled?

6. Actual use

6.1 How many times have sprinklers been used in reality? What kind of accidents / fires? What was the order of activities by the tunnel operator?

6.2 Has JH/MEPC experienced cases that sprinklers did not function at all or only function partly? Has JH/MEPC experienced tunnel fire / accident cases that sprinklers activated automatically when they should not (e.g. before people left tunnel)?

6.3 At what point of time did the tunnel operator activate sprinklers? How long did it take between activation by operator and actual start of water sprinkling from the sprinkler head? How long were sprinklers in use? Was that long enough in the opinion of JH/MEPC? When were the sprinklers stopped and based on what considerations?

6.4 Were these performances in line with the regulations, or (if not stipulated in regulations) sufficient in the view of the JH/MEPC?

A-2 Manufacturer

1. Sprinklers produced

1.1. What are the types of sprinklers for road tunnels manufactured at your company? What part of the sprinkler installation (consisting of sprinkler head, pipes, valves, water basins, pumps, operation equipment)

1.2. Relation between tunnel cross-section (rectangular, circular) and sprinkler (type of sprinkler, installation method, installation position, installation angle, etc.) and background.

1.3. Type of sprinkler heads (spiral type, deflector type, etc.).

1.4. Spray method (pilot valve type, fuse type as for building sprinklers).

1.5. Actuation method of automatic valve.

1.6. Actuation method and type of pilot valve.

1.7. Merits and demerits for types in use.

1.8. Characteristics of road tunnel sprinklers in contract to sprinklers for other use (buildings, plants etc.).

2. Research and Development

2.1. What is the background for the present guidelines that stipulate a discharge of 6 liter per m^2 per minute over a discharge area of 250-300m^2? Similar for the spacing between sprinkler heads?

2.2. Conditions, methods, result interpretation of fire tests for the development of sprinklers for road tunnels.

2.3. How did you cooperate with tunnel authorities and Fire Brigade for the development of sprinklers?

2.4. How was the drop size decided (drop weight, volume, surface area, cooling capacity?

2.5. How was the discharge time (volume) decided?

2.6. How was the shape of sprinkler head developed?

3. Technical issues

3.1. What materials are used in sprinkler installations and what are their characteristics (use of zinc alloy for pipes etc.)?

3.2. Heat resistance of materials, i.e. the influence to materials due to temperature rise between fire ignition and start of sprinkler activation (fire safety measures, fire protection measures).

3.3. Special anti-freeze measures for winter seasons and cold areas (Northern Japan), such as heating or insulation.

3.4. Understanding of cooling effect (influence of fire type, fire size, sprinkler type, sprinkler operation) and largest fire size that can be cooled by sprinklers.

3.5. Same as 3.4 for fire spread prevention effect.

3.6. Influence to smoke layer.

3.7. Influence to smoke extraction.
3.8. Relation between longitudinal flow (direction and velocity) in tunnel and sprinkler conditions)
3.9. Preservation of evacuation safe environment
3.10. Effect of sprinklers to visual environment in tunnel (surface luminance, signboards, roadway space, etc.)
3.11. Range of fire size (minimum and maximum) that can be attacked with sprinklers, method to detect fire size, operation range and error margin of fire detectors.
3.12. Measures to handle and prevent false alarm by fire detectors.
3.13. Measures to handle shift of location with highest temperature (due to tunnel ventilation, position and moving of fire vehicle, position and spread of fire), such as operation method of sprinklers and ventilation.
3.14. Merits and demerits of differences in water supply by JH and MEPC (JH supplies water for sprinklers and fire hose with one pipe, the MEPC supplies both with two different pipes)
3.15. Monitoring and recording of opening ratio, water level, water pressure and temperature of valves (automatic valve, pilot valve)
3.16. Merits and demerits of different types of sprinkler installation patterns (pitch, height, single side or double side) and water discharge patterns (discharge range and angle)
3.17. Method and installation of sprinkler in case of widened tunnel width (due to merge and branch, or emergency pit)
3.18. Combination between water / foam sprinkler, discharge time, example of actual installation.
3.19. Relation between drop size and shape of sprinkler head (shape and angle of deflector, opening surface, water pressure, etc.)
3.20. Inspection method (head, pipes, valves, etc.), conditions for replace/repair
3.21. Method to deactivate sprinkler, flow of activities, decision maker, timing
3.22. Use of sprinklers in cable ducts and evacuation routes.

4. Quality control

4.1. Method of quality control and guarantee (in terms of production).

APPENDIX B: List of fire experiments

Below is a list of fire experiments carried out in Japan [34].

Table B-1(a) Fire experiments carried out in Japan

Title	Date	Institute in charge	Tunnel		Contents								Fire size
			Scale model	Full scale	Sprinkler	Fire detector	Foam hydrant	ITV	Smoke extraction: Trans-verse	Smoke extraction: Semi-trans-verse	Smoke extraction: Longi-tudinal	Lighting	
Safety facilities for Meishin Expressway Tunnel	1960/61	Japan Fire Prevention Association	○	-	○	○	-	-	-	-	○	-	1960: Gasoline, methanol, max 1m^2 1961: Gasoline, max. 0.25m^2
Fire experiment in Tennozan Tunnel (Meishin Expressway)	1963	Japan Fire Prevention Association	-	○	○	-	-	-	-	○	-	-	Alcohol, max 8m^2
Fire ventilation experiment in Kanmon Tunnel	1964	JH	-	○	-	-	-	-	○	-	-	-	Gasoline, max 1m^2
Vehicle fire experiment for the design of tunnel safety facilities	1968	EHRF	○	○	○	-	-	-	-	○	○	○	Scale model: gasoline, max. 0.25m^2 Full scale: gasoline, max. 6m^2, bus
Vehicle fire in tunnel	1968/69	MOC	-	○	○	-	-	-	-	-	○	-	Test 1: Passenger car, 6t truck (cargo) Test 2: gasoline, max. 6m^2, truck, light van
Fire experiment in Nihonzaka Tunnel	1969	Nohmi	-	○	○	-	-	-	-	○	-	-	Methanol, max. 6m^2
Scale model experiment	1969/70	EHRF	○	-	○	-	○	-	-	○	○	-	Gasoline, max. 0.6m^2
Preparatory experiment with vehicle fire in tunnel	1973	JH	○	-	○	-	-	-	-	-	○	-	Gasoline, max. 4m^2
Preparatory experiment with vehicle fire in tunnel, No. 2, heat resistance	1973	JH	-	-	-	○	-	-	-	-	-	○	

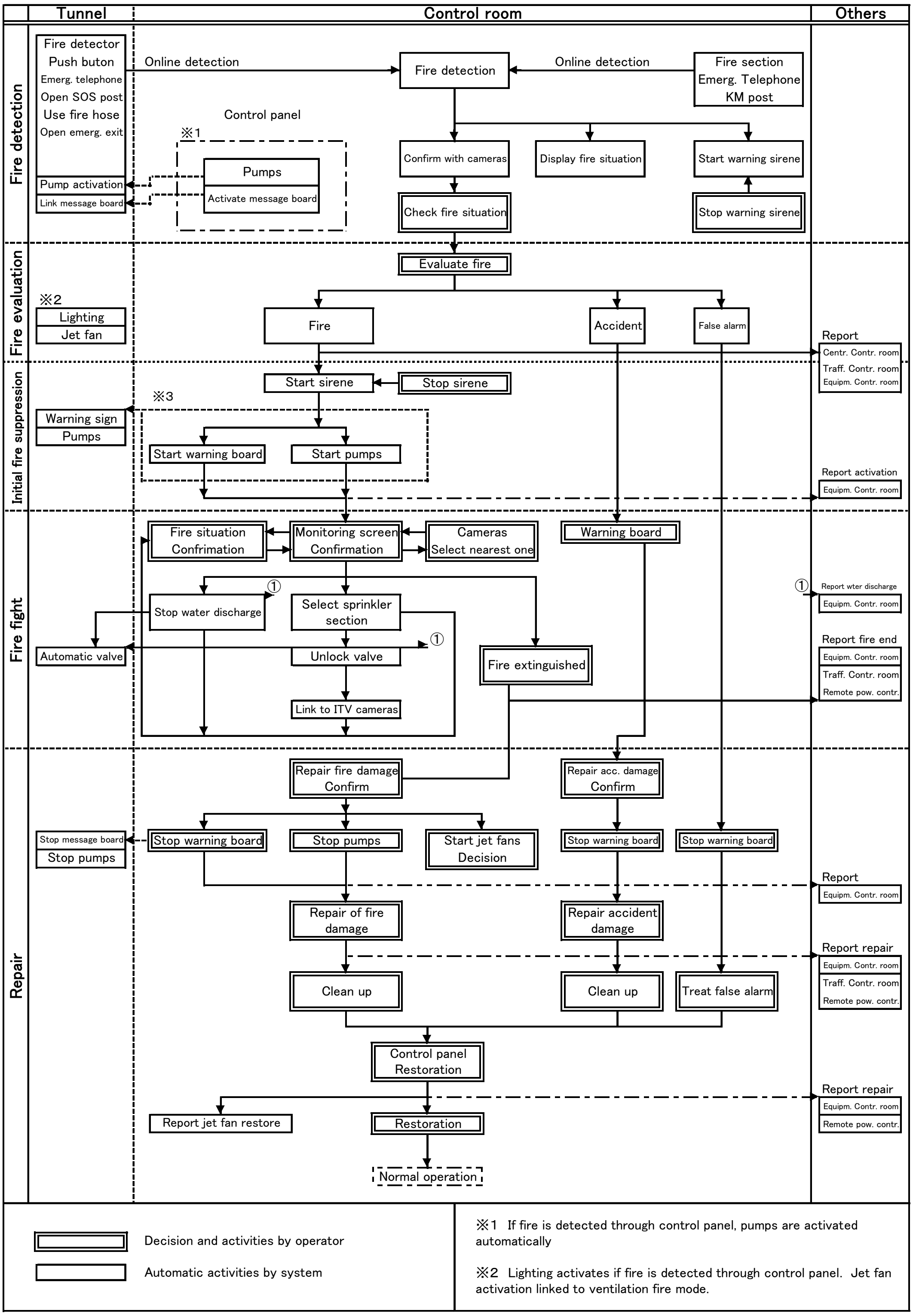
[34] Based on information received from JH

Table B-1(b) Fire experiments carried out in Japan (continued)

Title	Date	Institute in charge	Tunnel		Contents								Fire size
			Scale model	Full scale	Sprinkler	Fire detector	Foam hydrant	ITV	Smoke extraction			Lighting	
									Trans-verse	Semi-trans-verse	Longi-tudinal		
Experiment for smoke extraction in cases of fire in the Amikake Tunnel (Chuo Expressway)	1975	EHRF	-	○	-	-	-	-	-	○	-	-	Methanol, max. $4m^2$
Fire and sprinkler experiment in Tokyo Port Tunnel	1976	MEPC	-	○	○	○	-	○	-	○	-	-	Gasoline, max. $1m^2$
Experiment for fire detectors in tunnels of Tohoku Expressway	1979	JH	-	○	○	○	-	-	-	-	-	-	Gasoline, max. $1m^2$
Experiment concerning information facilities in tunnel	1980	EHRF	○	-	-	○	-	-	-	-	-	-	Gasoline, max. $4m^2$, passenger car, bus
Sprinkler experiment for tunnel with longitudinal ventilation in Chuo Expressway	1981	JH	○	-	○	-	-	-	-	-	○	-	Gasoline, max. $1m^2$
Experiment concerning vehicle fire in tunnel	1981	MOC, PWRI, JH	○	-	○	-	-	-	-	-	-	-	Gasoline, max. $4m^2$, passenger car, bus
Experiment concerning sprinklers at time of vehicle fire in tunnel, No. 2	1983	EHRF	-	○	○	-	-	-	-	-	○	-	Gasoline, max. $4m^2$, bus
Experiment concerning operation of ventilation at time of emergency in Enasan Tunnel	1985	EHRF	-	○	○	-	-	-	○	-	○	-	Test 1: gasoline, $1m^2$ Test 1: gasoline, $2m^2$
Experiment concerning operation of ventilation for Kan'etsu Tunnel	1985	EHRF	-	○	○	-	-	-	-	-	○	-	Gasoline, $4m^2$, bus

APPENDIX C: Example of activities flow in case of tunnel fire

Below flow is not included in standards as described in this report, but gives an example of how the different tunnel safety facilities are interconnected. It shows the principle layout as actually used [35].



[35] Prepared by Chiyoda

APPENDIX D: Inspection

Following is a selection of photographs taken during visit to inspection works of the Chiyoda Tunnel, part of the Inner Ring Road of Tokyo (carried out between October 21, 2001, 10:00 PM and 5:00 AM the following morning).
(in preparation)

D-1 Introduction

Inspection and repair works for one tube (one traffic direction) of the Chiyoda Tunnel and the Kasumigaseki Tunnel in the center of Tokyo (see Figure 2-13 for location) have been carried out in the night of 21-22 October 2001. These works also included verification of sprinkler performance. Below is a report of visit to the inspection works in the Chiyoda Tunnel.

D-1-1 Outline of tunnel

The Chiyoda Tunnel is located in the west part of the Inner Circular Route around the Imperial Palace in the center of Tokyo. The tunnel has the following specifications.

Tunnel name:	Chiyoda Tunnel
Route:	Inner Circular Route, Tokyo
Opening to traffic:	July 1964
Type of construction:	Cut and cover
Length:	1,900m
Traffic lanes:	2 tubes with 2 traffic lanes each (unidirectional traffic)
Traffic volume:	70,000 per day per direction
Large vehicle mix rate:	22.6% (weekdays), 8.7% (holiday)
Ventilation:	Transverse ventilation (ducts beside or above roadway space) (supply 908 m^3/s, exhaust 1,005 m^3/s)
Safety facilities:	Table D-1
Plan:	Figure D-1
Cross section:	Figure D-2

For further details, see brochure included in the Supplement to this Report (separate volume).

Table D-1 Safety facilities of Chiyoda Tunnel

	Facility	Remarks
Information and alarm	Emergency telephone	Every 100m
	Push button	Every 50m
	Fire detector	Carbon dioxide resonance, disperse attached, three wave length dispersion style
	Emergency alarm equipment	Before tunnel entrance
	Traffic light	Before tunnel entrance and at junction in tunnel
Fire fight.	Fire extinguisher	Every 50m, (1 powder type 6kg, 1 liquid type 8kg)
	Fire hydrant (foam hose)	Every 50m (at least 40mm, 130 liter/min, 3.0 kgf/cm^2
Escape / guidance	Emergency exit	Every 400m
	Emergency guidance panel	Every 50m
	Smoke extraction	Added to mechanical ventilation
Other equipment	Water supply hydrant	Every 50m
	Sprinkler	Groups of 10 heads at 2.5m interval
	Leaky feeder system	400MHz, 150 MHz
	Radio (re-) broadcast	AM / FM
	Monitoring equipment	Every 100-150m
	Uninterruptible power supply	Operate emergency facilities for at least 10 minutes
	Emergency power supply	1,250KVA diesel engine

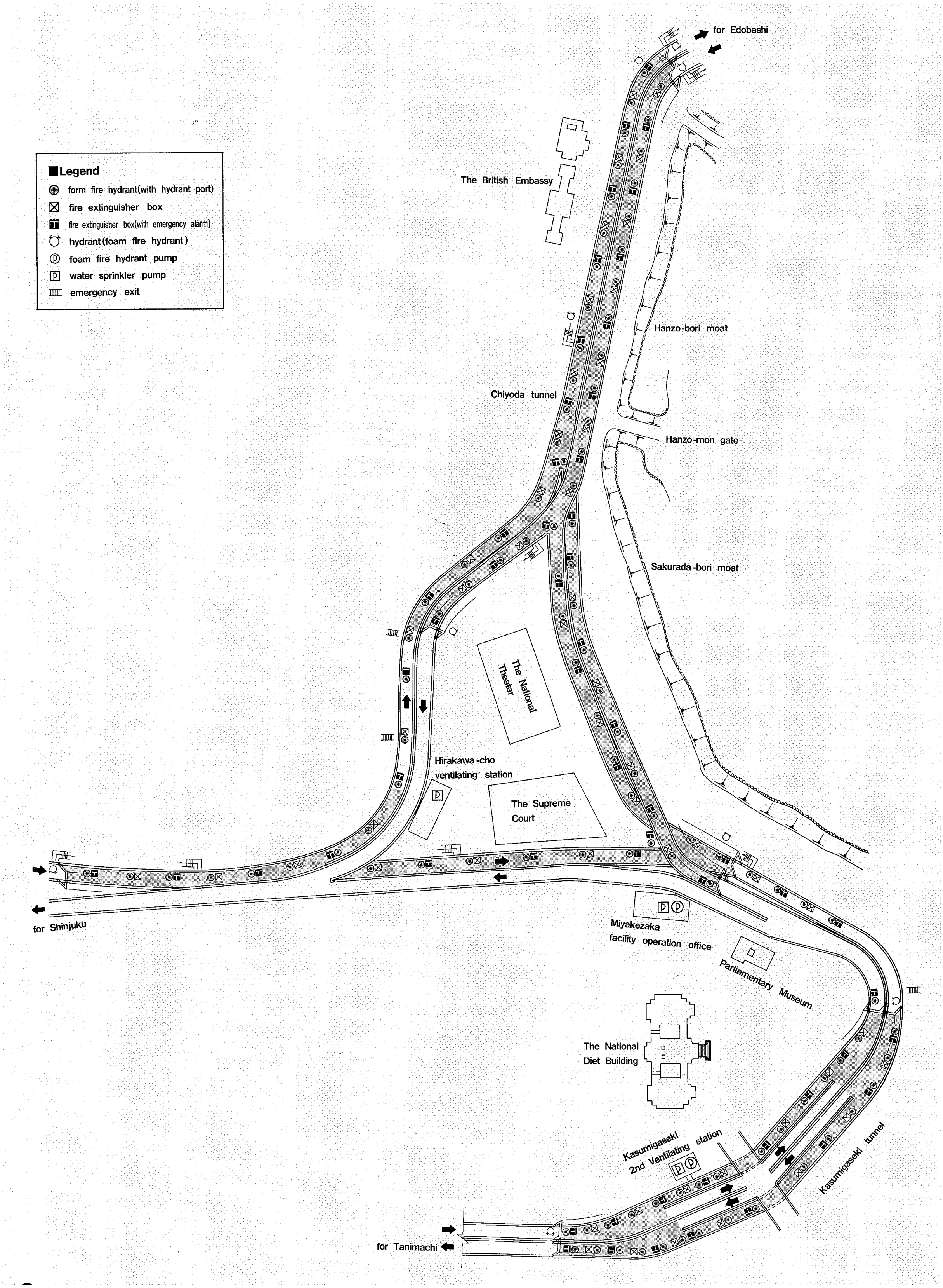


Figure D-1 Plan of Chiyoda Tunnel and location of safety facilities

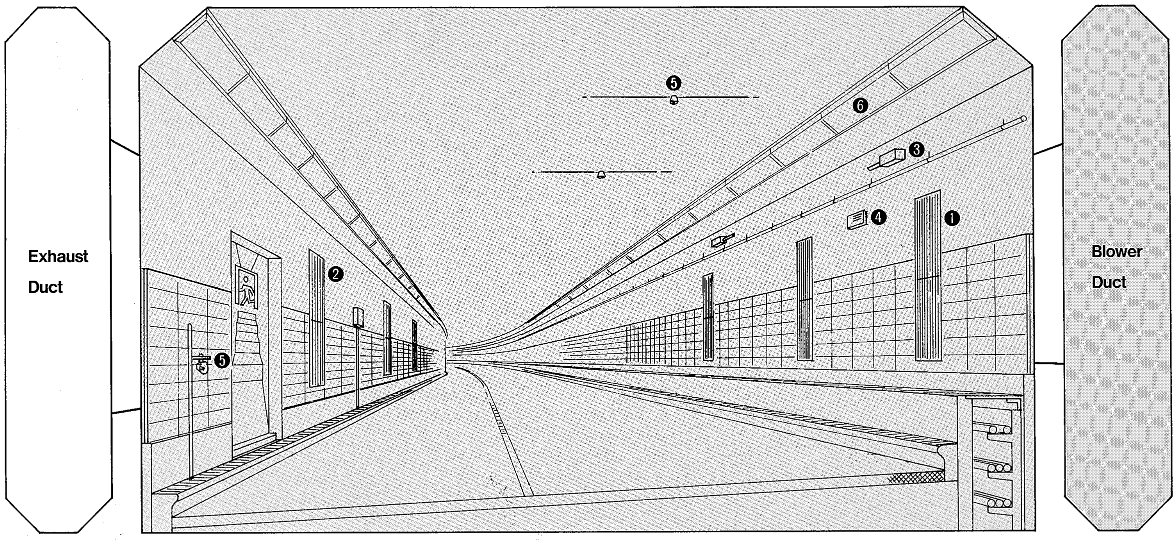


Figure D-2 Cross section of Chiyoda Tunnel

D-1-2 Outline of preparations for inspection

All tunnels of the MEPC, including the Chiyoda Tunnel as part of the Inner Circular Route, have an overall inspection once a year. In previous inspections, neither tube of this tunnel has ever been totally closed for traffic, because of its important function in the road network of Tokyo as link or crossing between the radial expressways towards the city center. Previously, only one traffic lane was stopped to enable inspection in that half of the tube, while the other traffic lane was in full use. For several reasons, including the decision to evaluate the use of sprinkler installation over the total cross section of the tunnel, it was this time decided to close the total tube (each tube on a different day) and enable full inspection.

One important preparation was the prediction of the traffic impact by closing about one-third of the heavy traffic Inner Circular Route in one direction. Based on database and traffic measurements, predictions were carried out about variations in traffic volume, traffic velocity and congestion. These results were used as basis for necessary measures, such as setting of date and time of inspection, selection of detour routes, planning of traffic management operation at neighboring roads and crossings, police activities (including clearing streets from wrongly parked vehicles), traffic light operation etc., establishment of an emergency plan. Fire Brigade and hospital have been informed and requested to be stand-by.

The road users have been informed by means of road facilities (variable message boards, fixed message boards), leaflets, posters, newspapers, radio (previous announcements, instructions before and during inspections), internet, etc.

D-1-3 Outline of inspection

The inspection carried out on October 21, 2001, in the southbound tube of the Chiyoda Tunnel formed part of general inspection and repair works for the (about 5km long) western part of the Inner Circular Route (only the anti-clock wise direction). A special feature of the inspections was that the whole tube was blocked for traffic, for the first time since opening to traffic in 1964. The inspection for the tunnel, carried out by a specialized inspection company and controlled by more than 50 personnel from MEPC, included the following items (carried out in this order):

- Inspection of pavement, ceiling
- Inspection and cleaning of lighting equipment in tunnel
- Inspection and test spraying of foam hoses
- Inspection and cleaning of equipment in SOS station (fire extinguishers, water hose etc.)
- Inspection, repair and cleaning of tiles to the side walls
- Inspection of fire detectors
- Inspection of sprinkler installation

The tunnel was closed to traffic between 19:00 of October 21 and 5:00 of the following day. The actual inspections started around 23:00 after preparations.
A number of independently acting groups carried out the inspections, moving in a fixed order from the north portal in southern direction.

D-2 Report of visit to inspection

D-2-1 Observations

The visit started at 22:00 of October 21 at the toll boots to the Kasumigaseki Tunnel, to observe how the tunnels were closed to traffic. The toll boots were closed off with orange pylons and guard men diverted any traffic attempting to enter the tunnel. Variable message boards on the roads towards the tunnel and above the toll boots read, “Chiyoda Tunnel closed in connection with inspection works”.

At 22:30, the local control center near the southern portal of the tunnel was visited. The number of operators was increased from 1 or 2 personnel (usual during the night) to 5 or 6, in order to control and observe the inspection activities. The main screen continuously showed the CCTV cameras inside the tunnel (normally the main screen changes to show the recordings of different cameras).

At 23:00, the southbound tube of the tunnel was entered from the south portal in accompany of personnel from MEPC, and walking towards the north portal the different inspection and cleaning works were observed. On reaching the north portal, the fire detection and sprinkler inspections were about to start. Walking behind the inspection team back in southern direction, the following activities were observed:

- Inspection of fire detection: a lighter was kept near the detector and signal to the control center was verified. The inspection was not linked with the inspection of the sprinkler equipment.
- Inspection of sprinkler equipment: one automatic valve was activated by hand, activating 10 sprinkler heads over a length of 50m. The time between valve activation and actual water spray was a few seconds (the pipes between the automatic valve and the heads are not filled with water). During the water spray, the water pressure at the sprinkler head was measured by connecting a hose between head and measurement equipment. One observer standing in the middle of the tunnel walked along the 10 head and inspected optically whether the heads operated regularly. Special attention was paid to the spray conditions of each head in the cross section of the tunnel (sufficient range, equal distribution). After all 10 heads were inspected and found sufficient, the automatic valve was stopped manually, and the team moved forward to the next automatic valve.

All inspections that were observed during the visit showed sufficient results of fire detectors and sprinklers. The visit ended at 1:45 in the morning of October 22.

D-2-2 Photographs of visit

Figure D-3 Message board at road towards tunnel: “Inner Circular Route closed to traffic”

Figure D-4 Message boards in front of tunnel entrance (toll boots): “Entrance closed due to works”

Figure D-5 Miyakezaka Facility Operation Office

Figure D-6 Miyakezaka Facility Operation Office

Figure D-7 Traffic control

Figure D-8 SOS station


Figure D-9 Preparation for hire hose inspection


Figure D-10 Fire hose inspection


Figure D-11 Fire hose spray inspection

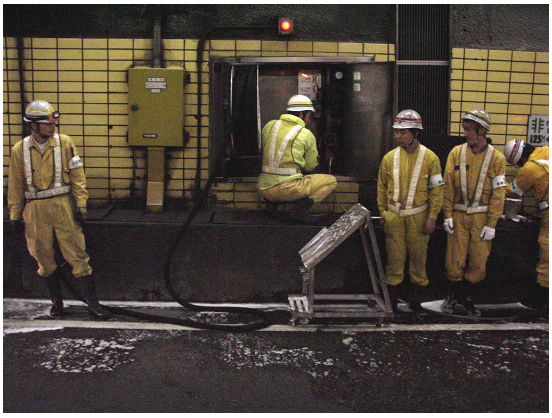


Figure D-12 Cleaning of SOS station


Figure D-13 Inspection of light armatures and ceiling

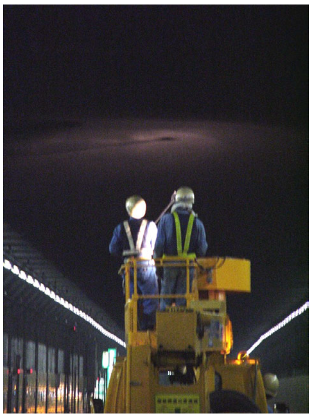


Figure D-14 Inspection of ceiling

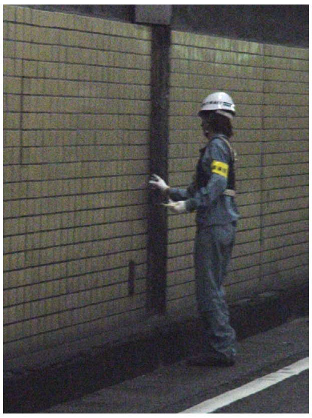


Figure D-15 Inspection of wall

Figure D-16 Border between 2 sprinkler sections (M29 and M30)

Figure D-17 Preparation for sprinkler test

Figure D-18 Contact with control center

Figure D-19 Water pressure measurement device

Figure D-20 Connection between measurement device and sprinkler head


Figure D-21 Inspection of fire detector

Figure D-22 Lighter against fire detector


Figure D-23 Fire detector

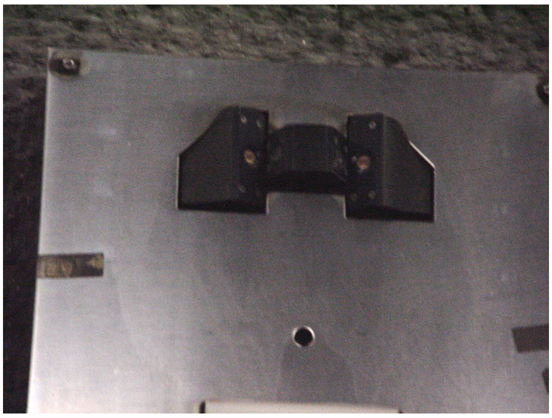


Figure D-24 Fire detector


Figure D-25 Before inspection spray test


Figure D-26 Start of spray test


Figure D-27 Water spray


Figure D-28 Detail of sprinkler head

Figure D-29 Water pressure measurement (left)

Figure D-30 Visual check of sprinkler function

Figure D-31 Check uniform spray pattern

Figure D-32 Uniform spray pattern

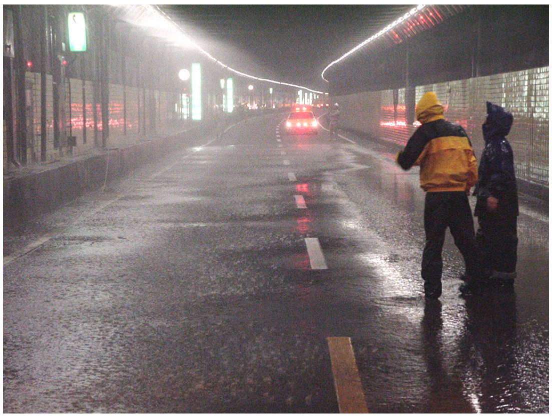


Figure D-33 Turning down sprinklers

Figure D-34 Closing down sprinklers

Figure D-35 Sprinkler head in final spray stage

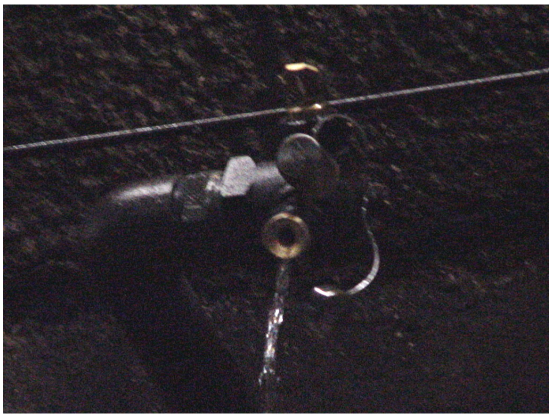


Figure D-36 Sprinkler head after spray end

Figure D-37 Remove pressure measurement device

Figure D-38 Clean up

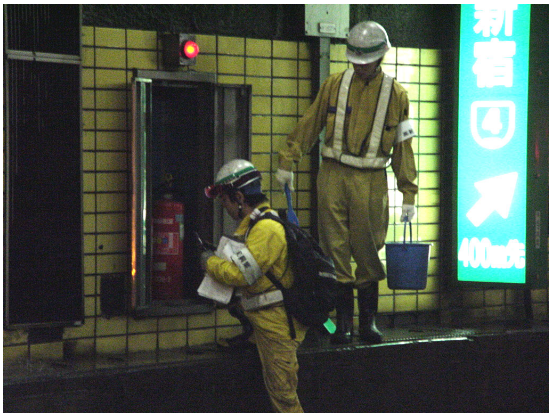


Figure D-39 Check SOS station

Figure D-40 Clean SOS station

Figure D-41 Wash SOS station

Figure D-42 Check water hose

Figure D-43 Fire extinguishers

Figure D-44 Message board for emergency telephone

Figure D-45 Preparation for sprinkler test in branch section

Figure D-46 Preparation of water pressure measurement

Figure D-47 Activation of sprinklers on one side

Figure D-48 Activation of sprinklers on other side

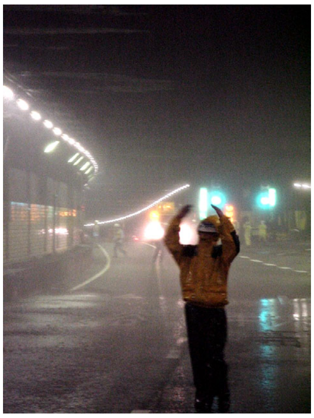


Figure D-49 “OK” sign for visual check

Figure D-50 “OK” sign for visual check

Figure D-51 End sprinkler test for branch section

Figure D-52 Clean up after sprinkler test

APPENDIX E: Early reports on tunnel fire tests

As described elsewhere in this report, a large number of tests and experiments have been carried out for the development of sprinklers. Below is an outline of two reports about such tests:

- Tunnel Safety Facilities Committee, Experiment concerning Fire Safety Facilities of Meishin Expressway Tunnel, 1961
- PWRI, Report on Road Tunnel Fire Test, PWRI Document No. 568, March 1970

It is to be noted that, whereas the age of these reports implies that some findings described may no longer be valid or applied today, they still form important parts of the fundamental of knowledge and technology concerning sprinklers in Japanese road tunnels. The information is included here to give an impression of the research carried out for sprinklers.

E-1 Experiment on Fire Safety Facilities of Meishin Expressway Tunnel

This report [36] describes a scale model experiment carried out by the former Fire Prevention Association of Japan on request by the JH in its preparation of the Meishin Expressway in Western Japan (L=188km, opened in 1962), which was designed with long 2-traffic-lane uni-directional tunnels and expected to carry large traffic amounts. The main purpose of the experiment is stated as to lay down specifications for a good functioning sprinkler system that activates automatically in case a fire occurs in the tunnel. With this sprinkler system it is objected to enable safe evacuation, and to protect the tunnel equipment from damage by the fire. At the same time, the experiment objected to clarify the combination between sprinklers, fire detection, water supply and others.

The cross section of the scale model tunnel (Figure E-1) is on scale 1:5, with a diameter of 1.96m a height 1.24m. The length of tunnel is 20m (Figure E-2). At the beginning of the experiment facility, a jet fan is installed to supply longitudinal flow up to 8m/s.

Four sprinkler heads each can be installed symmetrically at 13 cross sections (spacing 0.8-0.9m longitudinally), starting at 3.75m from the tunnel entrance.

The experiment items included the following:

- Performance of wind tunnel
- Performance of sprinkler heads
- Sprinkler spray experiment
- Fire test
- Sprinkler test during fire
- Measurement of radiation and fire detection performance

[36] Tunnel Safety Facilities Committee, Experiment concerning Fire Safety Facilities of Meishin Expressway Tunnel, 1961

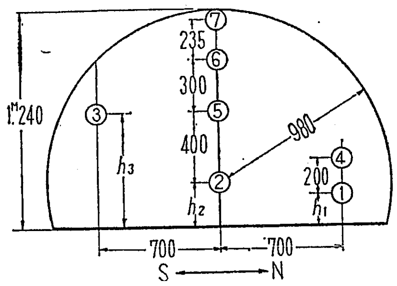


Figure E-2 Cross section of model tunnel

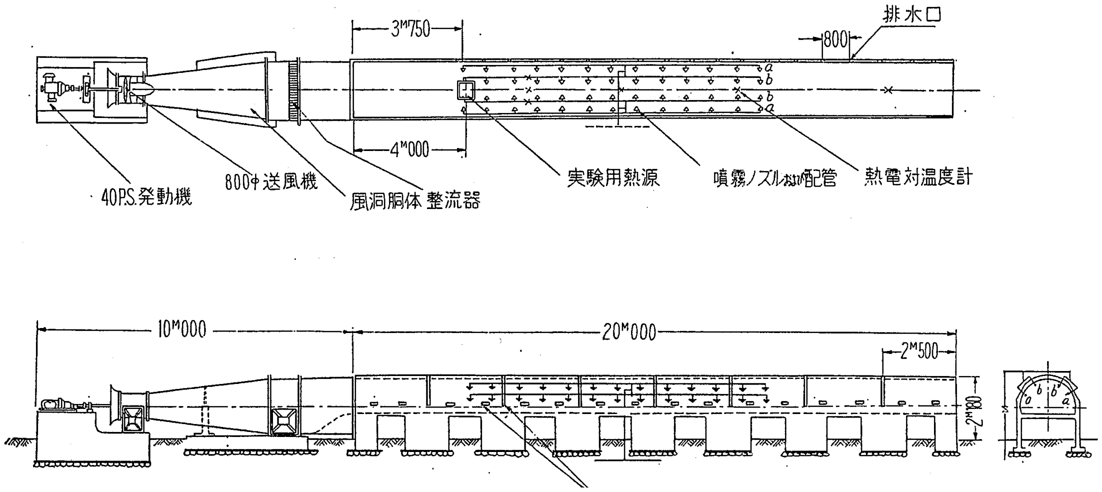


Figure E-3 Longitudinal section of model tunnel

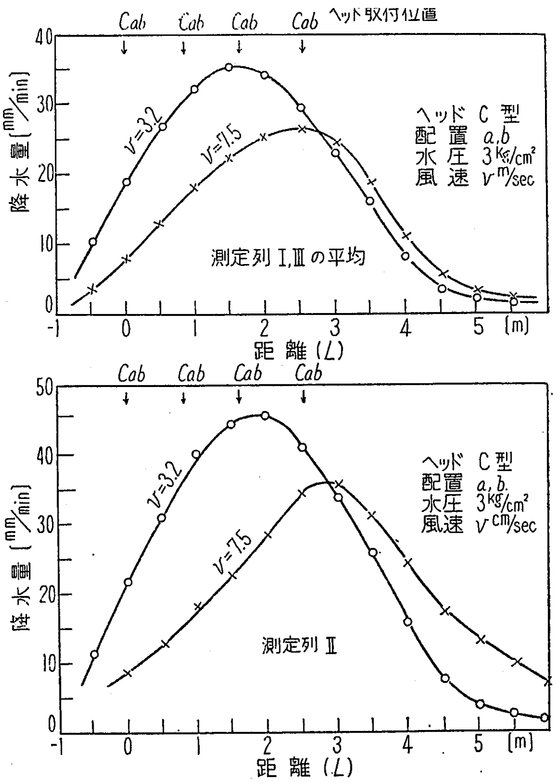
For the performance of sprinkler heads, three types were compared (water pressure, spray volume and spray angle), and for different installation heights the spray diameter, water drop diameter and spray velocity were measured (flow velocity 0 m/s), as shown in Table E-1.

Table E-1 Comparison of sprinkler heads

Water pressure (kg/cm^2)	Spray volume (liter/minute)	Spray angle (Degrees)	Installation heights (m)	Spray diameter (m)	Water drop diameter (mm)	Spray velocity (m/s)
2.0	14.7	90	0.5 1.0 1.5	0.9 1.6 2.1	0.8 – 1.5	11.3 10.1
3.0	18.0	90	0.5 1.0 1.5	0.9 1.6 2.1	0.5 – 1.0	13.9 12.1
4.0	20.8	90	0.5 1.0 1.5	0.9 1.6 2.0	0.3 – 0.7	15.5

The sprinkler spray experiment was carried out with different head types and different number of heads per cross section of tunnel, and the spray distribution was measured for different flow velocities and water pressures. Figure E-4 shows an example of the measurement results (horizontal distribution). It was concluded that the road center receive a larger amount of water than the sides, and that the water amount decreases if the flow velocity increases.

For the vertical distribution, Figure E-5 shows an example of the measurement results, which show that the concentration increases as the height decreases.



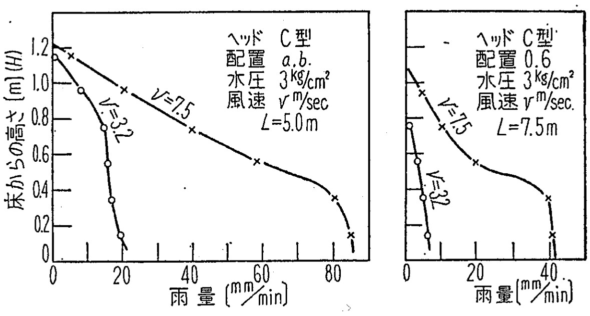
Horizontal axis: length (m), vertical axis: water amount (mm/min)

Above figure: sidewall results, below figure; center of road

Wind velocity 3.2 or 7.5 m/s, water pressure 3kg/cm2

C_{ab}: position of sprinkler head

Figure E-4 Measurement results for sprinkler spray experiment (horizontal distribution)

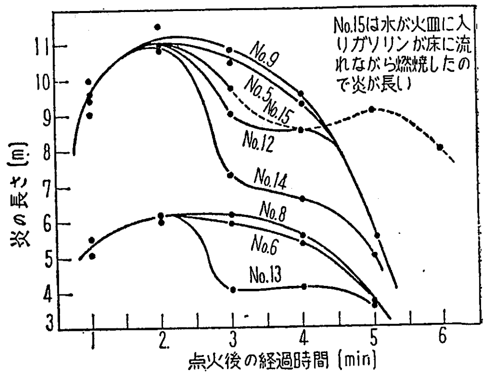


Horizontal axis: water amount (mm/min), vertical axis: height from road surface (m)

Left figure: 5.0m downstream from fire, right figure: 7.5m from fire

Figure E-5 Measurement results for sprinkler spray experiment (vertical distribution)

During the sprinkler test during fire (sprinkler activation 2 minutes after ignition as compared to no sprinkler activation), it was verified that the fire is cooled considerably on the downstream side of the fire, and also that the size (length) of fire decreases after sprinkler activation (Figure E-6).



Horizontal axis: time from fire begin (min), vertical axis: length of fire (m)

Figure E-6 Relation between sprinkler and length of fire (for 8 test cases)

E-2 Report on Road Tunnel Fire Test

This report [37] describes tests carried out between 25 and 30 August 1969 in the Futatsugoya tunnel (L=384m, Figures E-7 and E-8) of the old Kuriko National Expressway, including 3 trucks (Figure E-9), 3 light vans and fire pans (2, 4 and 6 m^2) with 50-300 liter gasoline. Two wind velocity cases in the tunnel were supplied with temporary jet fans (0 and 3 m/s). Experiments with and without sprinklers (temporarily installed over a length of 36m, of which 12m upstream the fire, spacing 4m between heads (Figure E-10), water pressure of 3kg/cm^2, spray volume 95 liter/minute) were carried out. The items of measurement were as follows:

- Temperature distribution and changes in time
- Concentration of poisonous gas (CO and NOx) and changes in time
- Smoke concentration
- Influence by flow velocity
- Influence by sprinklers
- Influence to concrete lining etc.

Concerning the sprinkler influence, the test results showed that the temperature in the tunnel decreased suddenly after the sprinklers were activated and that regions with extremely high temperatures disappeared. Therefore, the cooling effect of sprinklers has been confirmed. Furthermore, due to the water pressure from the sprinkler, the fire tends to expand less in vertical and more in horizontal direction.

Fire of wood and other open load on the truck was extinguished by the sprinklers, but fire within or below the truck as well as tires under the hood could not be extinguished at all (parts that were not exposed directly to the sprinklers). In case of gasoline fires, the fire heard could be more or less controlled, but the burning of gasoline could not be prevented.

Figure E-11 shows an example of test results for one of 16 test cases (2m^2 fire pan with 100 liter gasoline, 3m/s flow velocity, sprinklers activated after 4 minutes). In this figure, 5-c is the temperature at measurement location (H=1.5m, center of tunnel cross section) 5m downstream the fire heard, 10-c at 10m etc. This example shows a sudden temperature decrease from 400 to less than 100℃ after sprinkler activation.

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[37] PWRI, Report on Road Tunnel Fire Test, PWRI Document No. 568, March 1970

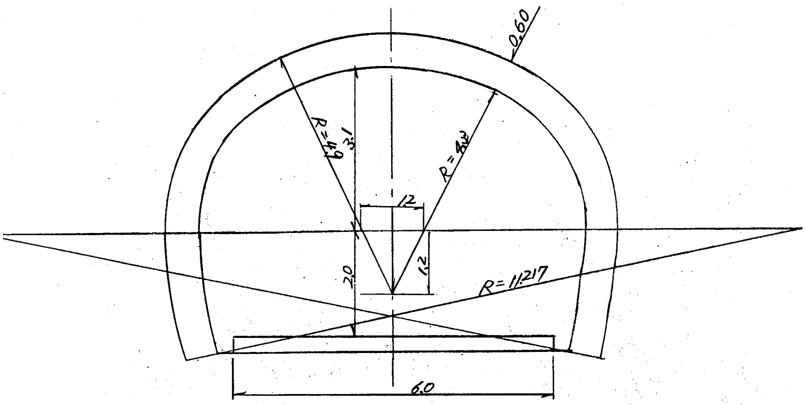

Figure E-7 Typical cross section of Futatsugoya tunnel

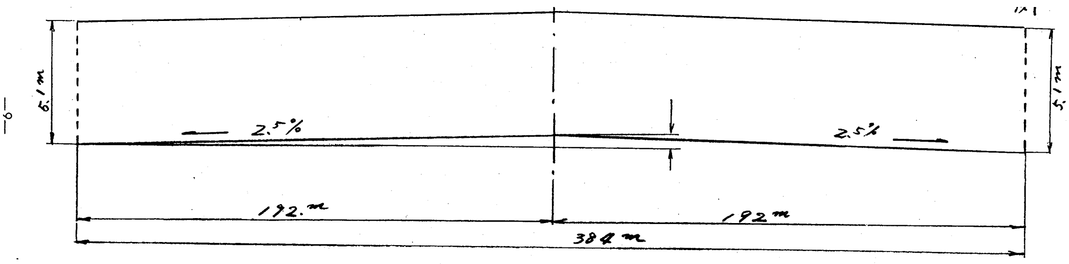

Figure E-8 Longitudinal cross section of Futatsugoya tunnel

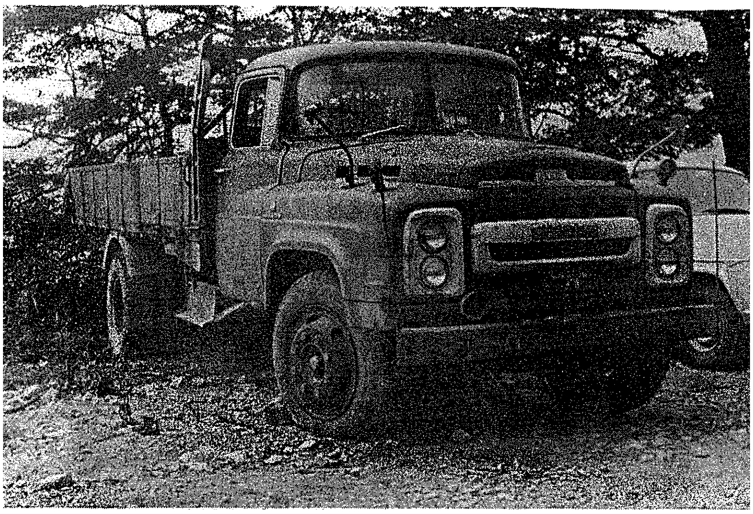

Figure E-9 Truck used in fire test

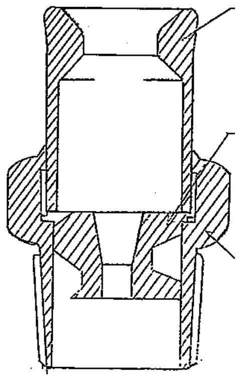

Figure E-10 Sprinkler head

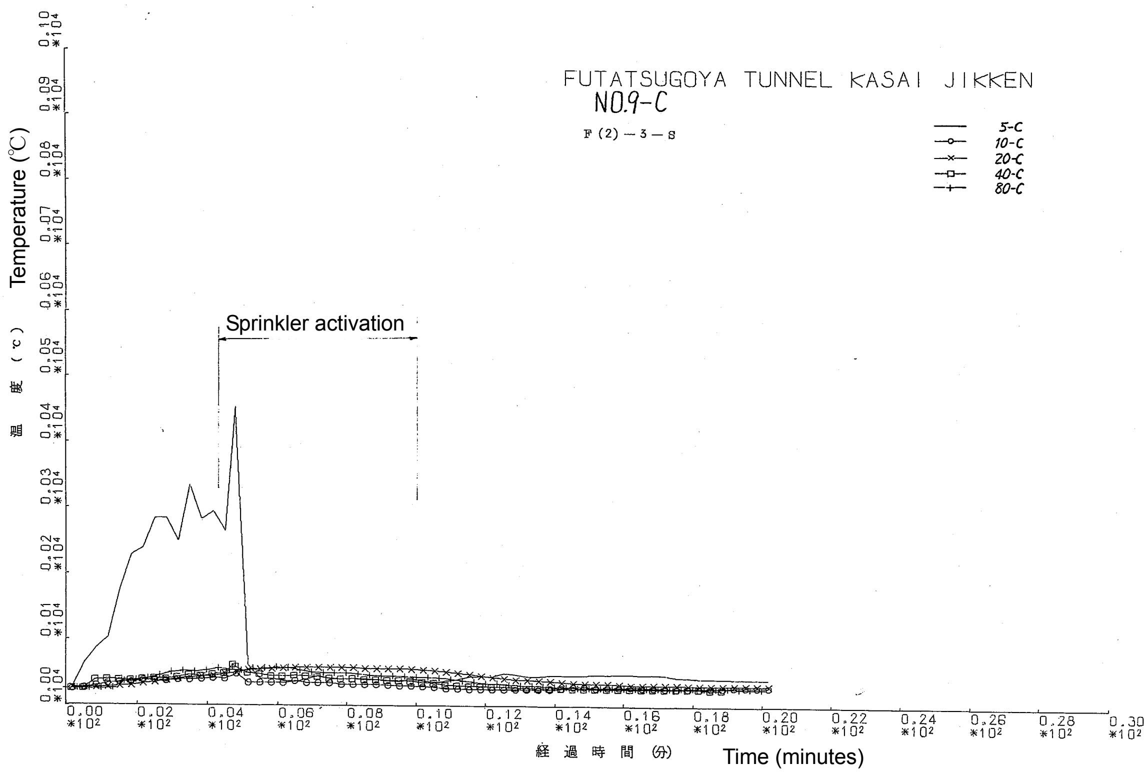

Figure E-11 Example of test result

APPENDIX F Nominal inner diameter

The term “nominal inner diameter” used in this report is the nominal inner diameter of pipes as used in Japan. The nominal inner diameter is represented with capital letter “A”, as in “80 A” which means an actual inner diameter of about 80mm. The actual inner diameter differs per material and purpose of pipes and is prescribed in applicable literature.

Below is an example of actual values of nominal inner diameters of pipes used for sprinklers.

Nominal inner diameter (example)

<table>
<tr><th rowspan="2">Nominal inner diameter</th><th colspan="2">Outer diameter</th><th colspan="2">Thickness</th></tr>
<tr><th>Value (mm)</th><th>Tolerance (mm)</th><th>Value (mm)</th><th>Tolerance (mm)</th></tr>
<tr><td>80 A</td><td>89.1</td><td>0.8</td><td>4.2</td><td rowspan="4">Upper tolerance: N.A
Lower tolerance: max. –12.5%</td></tr>
<tr><td>100 A</td><td>114.3</td><td>0.8</td><td>4.5</td></tr>
<tr><td>125 A</td><td>139.8</td><td>0.8</td><td>4.5</td></tr>
<tr><td>150 A</td><td>165.2</td><td>0.8</td><td>5.0</td></tr>
</table>

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(Author in alphabetic order)

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