

Analysis of labour accidents in tunnel construction and introduction of prevention measures

Naotaka KIKKAWA^{1*}, Kazuya ITOH², Tomohito HORI¹, Yasuo TOYOSAWA³
and Rolando P. ORENSE⁴

¹Construction Safety Research Group, National Institute of Occupational Safety and Health, Japan

²Department of Urban and Civil Engineering, Tokyo City University, Japan

³National Institute of Occupational Safety and Health, Japan

⁴Department of Civil and Environmental Engineering, The University of Auckland, New Zealand

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Abstract: At present, almost all mountain tunnels in Japan are excavated and constructed utilizing the New Austrian Tunneling Method (NATM), which was advocated by Prof. Rabcewicz of Austria in 1964. In Japan, this method has been applied to tunnel construction since around 1978, after which there has been a subsequent decrease in the number of casualties during tunnel construction. However, there is still a relatively high incidence of labour accidents during tunnel construction when compared to incidence rates in the construction industry in general. During tunnel construction, rock fall events at the cutting face are a particularly characteristic of the type of accident that occurs. In this study, we analysed labour accidents that possess the characteristics of a rock fall event at a work site. We also introduced accident prevention measures against rock fall events.

Key words: Tunnel construction, NATM, Cutting face, Rock fall, Labour accident

Introduction

In Japan, the rate of fatal injury per 100,000 construction workers is much worse than that in the United Kingdom (UK), as shown in Fig. 1. One of the reasons is the Construction (Design and Management) Regulations 2007 introduced in UK, which put safety responsibility to the clients who in turn should use the money and the time to ensure health and safety (H&S) of the workers. On the other hand, in Japan, we do not have such legislations which put responsibility to the clients which could then allow the contractor and the sub-contractor to manage the H&S of the workers by themselves. Therefore, it is easy

to reduce the cost of H&S of workers in order to win a construction project and accidents sometimes happen as a result of such cost reduction. In this situation, the clients seem to be left out of the picture and the contractor and/or the sub-contractor appear to be the only ones thinking about H&S. It would be best if clients are really involved in H&S using their money and time and they should have partnership with designers, contractors, sub-contractors and workers as well as with CDM coordinators. This is the macro prevention measures in order to reduce the fatalities and casualties in construction industry.

Next, we focused on the tunnel construction industry in detail. In Japan, tunnel construction industry has developed from the timber support and steel arch support methods to the NATM (New Austrian Tunneling Method) and shield tunneling method as a result of safety measures, lower cost and higher efficiency. NATM is the major method in moun-

*To whom correspondence should be addressed.

E-mail: kikkawa@s.jniosh.go.jp

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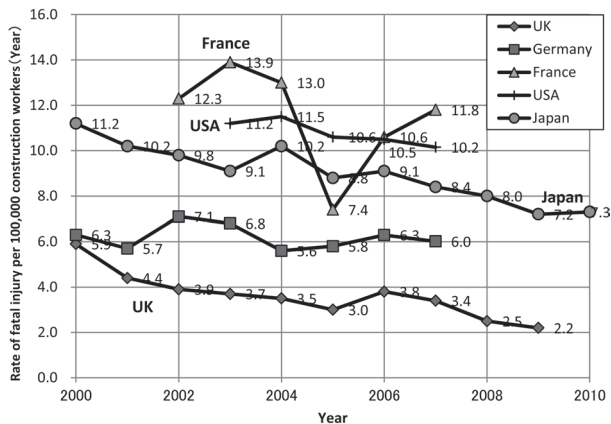


Fig. 1. Rate of fatal injury per 100,000 construction workers.

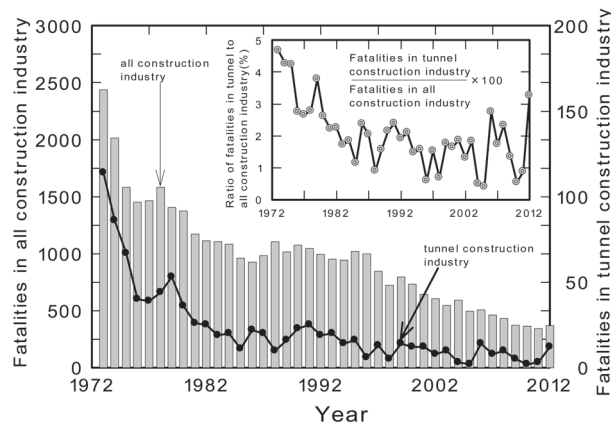


Fig. 2. Annual number of fatalities in tunnel construction industry and all construction industry.

tain tunneling. Figure 2 shows the fatalities in tunnel construction industry as well as all construction industry from 1972 to 2012. The annual fatalities in tunnel construction industry were more than 50 until the NATM was applied in Japan in 1978. After the NATM was applied, the number of fatalities was reduced to around 10–20; however, the ratio of fatalities in tunnel to all construction industry has been almost constant since 1987, with the ratio being around 2%. Therefore, we need to reduce not only the fatalities but also injuries because any accident resulting in injury could be linked to a fatal accident.

In this study, we analysed the labour accidents in tunnel construction industry and introduced accident prevention measures, especially in mountain tunnels.

Trends of Labour Accidents in Tunnel Construction Industry

The number of casualties in tunnel construction industry from 2008 to 2012 is shown in Fig. 3. In each year, the number is classified in terms of the tunnel construction method employed, such as NATM, shield tunneling method, micro-shield tunneling method, etc. NATM is the worst case, but the number of NATM tunnels under construction is also higher than that of other tunnels. The data was supplied by the Ministry of Health, Labour and Welfare in Japan.

The casualties related to NATM and mountain tunneling methods were higher, and so we focused on their trends. Figure 4 shows the relationship between the number of casualties in all mountain tunnel constructions and the places where the accidents happened. Each bar in the figure represents the causes that triggered the accidents, such as mobile plants, scaffoldings, materials, environments,

etc. It is noticed that almost all accidents happened at both cutting face and gallery. In both cases, the environments and mobile plants are the worst cases. The environments include rocks fall events while the mobile plants include drag-shovels hitting the workers while turning or reversing. We analysed the accidents due to rock fall in details in this study.

Trend of Labour Accidents due to Rock Fall in Mountain Tunnel Construction Industry

We collaborated with the Association of Nihon Tunnel Construction Sub-contractors (ANTCS) to analyse the labour accidents due to rock fall. ANTCS sent questionnaires to their members about cases of accidents involving rock fall and 44 cases from 2000 to 2010 were collected and analysed.

Figure 5 shows the relationship between the number of casualties involved in labour accidents due to rock fall and natural ground classification (tunnel support pattern) in mountain tunnel construction. Not only soft rock but also hard rock and medium-hard rock fall occur in tunnel cutting face or gallery. Figure 6 shows the stages during the operation cycle of mountain tunnel construction when rock fall occurred. To mount a steel arch support and to set up blasts are the worst cases because workers approach a tunnel cutting face and then rock fall occurs and workers are injured.

Prevention Measures against Rock Fall in Mountain Tunnel Construction

Several prevention measures against rock fall in moun-

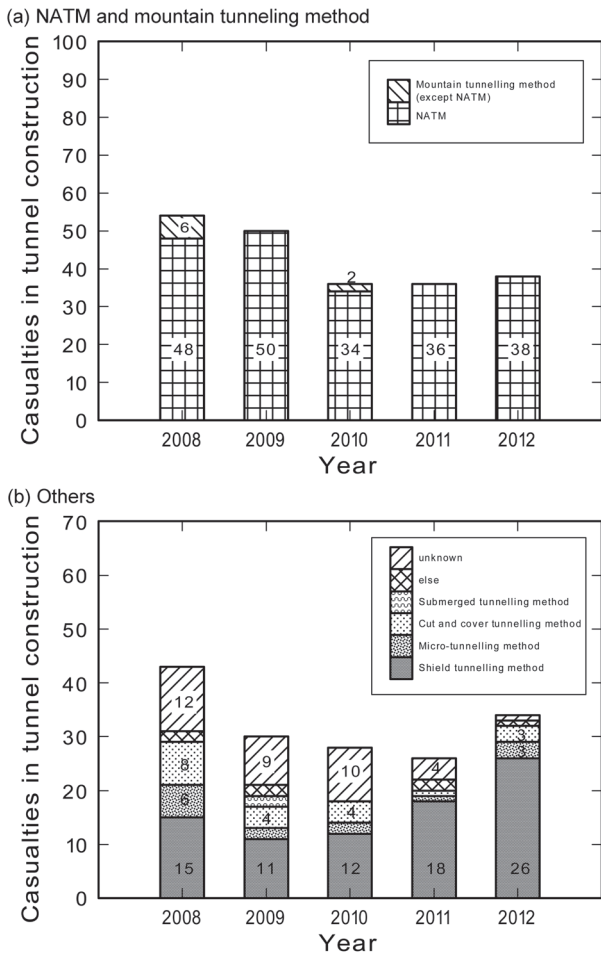


Fig. 3. Number of casualties in tunnel construction industry from 2008 to 2012.

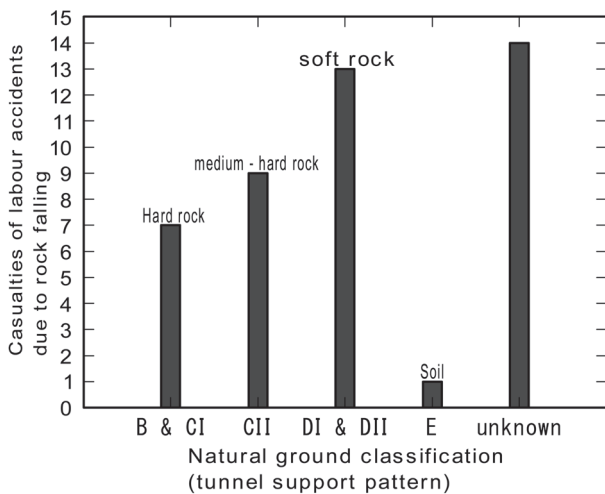


Fig. 5. Relationship between casualties in labour accidents due to rock fall events (2000–2010) and natural ground classification (tunnel support pattern) in mountain tunnel construction.



Fig. 4. Relationship between number of casualties and places where accidents happen with the causes which trigger the accidents in NATM and mountain tunneling methods.

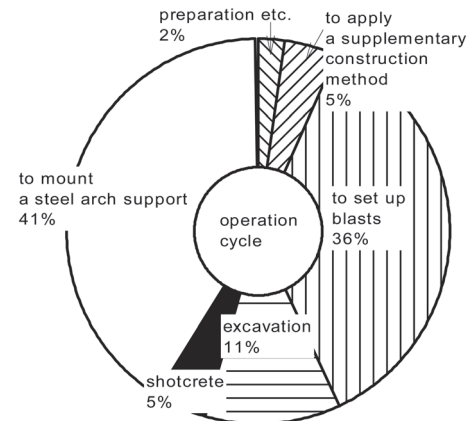


Fig. 6. Stages in the operation cycle of mountain tunnel construction when accidents due to rock fall happen (2000–2010).

tain tunnel construction are introduced as follows:

(1) Shotcreting the excavated face (Sprayed Concrete Lining; SCL)

Shotcreting is to spray an excavated surface with a concrete. It is important to shotcrete not only the tunnel cutting face but also all excavated surface after blasting or digging by mobile plants. The British Standard (BS6164:2011)¹ “Code of practice for health and safety in tunneling in the construction industry” states the following: “As soon as possible after excavation, an initial coat of sprayed concrete should be applied to the excavated

faces as a rapid means of temporary support, to stop deterioration of the ground surface, secure any loose material and minimize changes in the self-supporting characteristics of the ground. Remote means of controlling the excavation and sprayed concrete profile should be considered.”

Shotcreting is also effective in observing the deformation of ground because all excavated surfaces change to concrete colour, and therefore it is not too difficult to find out new cracks generated. In addition, the excavated surface could be protected against exposure to air and groundwater.

However, accidents due to rock fall still happen even though shotcreting is applied because the thickness of shotcrete is not sufficient to provide temporary support and the strength of the shotcrete can be weakened by water seepage. Hence, it is necessary to ensure sufficient thickness of shotcrete and to remove water seeping in.

(2) Bolting to cutting face

The British Standard (BS6164:2011)¹⁾ also mentioned that “while rock bolts can be used merely to tie back loose slabs which would otherwise be liable to fall, their more fundamental use is in preventing separation across discontinuities such as joints, fissures and bedding planes so that the integrity of the exposed rock structure can be maintained. The pattern and type of bolting, and the length and diameter of the bolts, should be determined after study of the particular circumstances, which can vary rapidly as tunnelling progresses.”

The standard mentioned about not only temporary rock bolts but also permanent ones. It could also be applied in bolting temporary cutting face.

It is also effective to use both bolting and shotcreting together.

(3) Removing rock masses

In order to prevent rock fall due to separation across discontinuities such as joints, fissures and bedding planes, the detached rocks portions should be removed by mobile plants, such as breaker, before shotcreting.

(4) Removing water by drilling

This measure involves finding out a water vein and leading the water to the drilling hole before water seeps into the excavated surface. Sprayed concrete could not be pasted on the excavated surface if the surface is wet due to seeping water. It is therefore important to remove water from as far as reasonably practicable.

(5) Monitoring the displacement of tunnel cutting face and overseeing it

This involves monitoring the displacement in the tunnel cutting face by laser displacement transducers, etc.

It is necessary to arrange a guard who should oversee the tunnel cutting face in order to observe new cracks generated and deformation of the face. The guard should be positioned while the workers set up blasts or steel arch support on the face. In addition, in order to detect very small displacement that could not be determined visually, it is recommended to monitor the displacement of the face with laser displacement transducers.

(6) Sufficient illumination

British Standard (BS6164:2011)¹⁾ also mentioned that the level of lighting is 100 lux and illumination should come from at least two widely separated sources in order to avoid shadows in the tunnel face and excavation areas.

The work process with the main prevention measures are summarised in Table 1. It would be easy to import the measures into conventional work process and it is significant to reduce the risk of rock fall accidents using combinations of various measures.

In addition, clients should consider spending time and money to adopt and apply the above measures against rock fall accidents.

Summary

The results of this study are summarized as follows:

(1) It is clear that many of the labour accidents due to rock fall events happen when workers set off explosive charges or install steel arch supports in the cutting face during tunnel construction using the mountain tunneling method, especially NATM.

(2) Prevention measures that were proposed against labour accidents due to rock fall events during tunnel construction include shotcreting the cutting face, bolting to the cutting face, removing rock masses in the cutting face, drilling the cutting face for drainage, measuring the displacement of the cutting face, and sufficient lighting in order to observe the cutting face.

(3) In the prevention measures against labour accidents due to rock fall events during tunnel construction, shotcreting the cutting face is very effective because it can control any weakness in the integrity of the mountain rock, protect against exposing mountain rock to the air, and makes it easier to observe new cracks and deformations in the rock face. In addition, shotcreting the cutting face is

Table 1. Flowchart of the work process in mountain tunnel construction (NATM), including the main prevention measures

Work Process	Summary and Prevention measures
① Drilling hole (exploration drilling, if necessary.)	Drill hole into the cutting face using a drill jumbo. If water leaks from an excavated surface, then explore the source of water by drilling hole. Workers should not be close to the cutting face and the drill jumbo.
② Charging (Setting up the protection system, if necessary.)	Set up detonators and blasts into the cutting face. This work has high risk to cause rockfall and may hit workers who are close to the cutting face. Workers should wear helmet, protector, safety boots, etc. Nets and mats supported by both the right and left arms of the drill jumbo and guard fences at the bottom of the aerial work platform of the drill jumbo could be used to protect workers from rock fall. This is called "protection system."
③ Blasting	Ignite the detonators and blasts. Workers should comply with the Explosives Control Act, etc.
④ Mucking	Remove the excavated soils and rocks. This work should be done using shovel loader or similar. Workers should not be close to the excavated surface. It is necessary to have sufficient illumination around the excavated surface.
⑤ Trimming	Remove rocks loosened from the excavated surface after blasting. This work should be done using a rock breaker mobile plant or similar. Workers should not be close to the excavated surface. It is necessary to have sufficient illumination around the excavated surface.
⑥ Scaling	Make sure if that there is enough space to mount a steel arch support in the excavated surface, otherwise chip the excavated surface. This work should be done using a rock breaker mobile plant or similar. Workers should not be close to the excavated surface. It is necessary to have sufficient illumination around the excavated surface.
⑦ Monitoring the displacement of tunnel cutting face and overseeing the process	Monitor the displacement, velocity or acceleration of the cutting face and a watcher must oversee the alteration of the cutting face. Laser distance measurer and total station should be mounted on the drill jumbo and the steel arch support that is already mounted on the excavated surface. It would be necessary to measure the displacement, velocity and acceleration of many points on the cutting face. When the measurement system detects rapid increase in displacement, velocity or acceleration, then alert signal is issued automatically. It is necessary to have sufficient illumination around the excavated surface for a watcher to oversee the process.
⑧ First spraying of concrete lining (with shotcrete against the cutting face)	Spray concrete to the excavated surface, including the cutting face. This work should be done using a mobile plant for shotcrete and workers should remotely control the nozzle of the shotcrete machine without being too close to the cutting face.
⑨ Erecting a steel arch support	Mount a steel arch support around the excavated surface. This work has high risk to cause rock fall and may hit workers who are close to the cutting face. Workers should wear the helmet, protector, safety boots, etc.
⑩ Second spraying of concrete lining	Spray concrete to all surfaces, including the steel arch support. This work should be done using a mobile plant for shotcrete and workers should remotely control the nozzle of the shotcrete machine without being too close to the cutting face.
⑪ Driving rock bolts	Drive rock bolts into the ground radially from the perimeter of the tunnel. This work should be done using the drill jumbo. This work is high risk to cause rock fall and may hit workers who are close to the cutting face. Workers should wear the helmet, protector, safety boots, etc.

very useful in terms of construction and economic aspects. It is, however, more important to use shotcreting in combination with other prevention measures because some labour accidents due to rock fall events occur even after shotcreting is implemented. The cause of such accidents is thought to be the insufficient thickness of the shotcrete or a weakening in the cohesive strength due to the upwelling of groundwater.

(4) Therefore, not only shotcreting alone, but also sufficient lighting in order to observe the cutting face, removing rock masses from the cutting face, and measuring the displacement of the cutting face, should be used in combination to ensure that all prevention measures work

synergistically.

(5) In situations where the risk of rock falls remains high even after the above prevention measures have been applied, it is preferable for the client, contractor and the construction operator to engage in discussions to consider prevention measures from the design stage and other supplementary measures, including forehand piling to a tunnel roof, and bore holing for drainage.

References

- 1) British Standard (BS 6164:2011) Code of practice for health and safety in tunneling in the construction industry.