

Responsible foundations

US-based geotechnical consultant Dr Peter Tarkoy maintains that identifying and categorising dangers can minimise accidents during tunnel construction

THE most serious safety issues in underground construction causing severe injuries and death are not addressed by safety regulations. The reason is that many underground projects have unique conditions, such as means and methods, site-specific tunnel boring machine design, unique support installation systems, project-specific geological conditions, and site-specific management and operational systems.

Nevertheless, the owner, engineer, designer and contractor remain responsible for providing a safe work environment and project-lifetime safety. Standard safety regulations fail to address the specific and unique variations and character of these systems. Therefore, it is necessary to define a working hypothesis from which safety can be established for those underground works with unique conditions.

GeoConSol's 40 years of association with safety issues in underground construction relating to personal injury and wrongful death cases have required an identification of basic philosophies to address the shortcomings of governmental regulations. Methods during construction and project design for the structure's operating life must address protecting both construction workers in the short term and the public in the long term. The context necessary to address

issues where no specific regulations exist must be based on two essential concepts.

SCALE OF THE PROBLEM

Fatalities in heavy construction in the US are some of the highest of any industry. Yearly, the fatalities range between 700 and 900. The cases considered here are associated with bored tunnel excavation, shaft construction, blasting and highway tunnel safety. When investigating and dealing with safety issues where no regulations apply, one has to resort to fundamental philosophies and simple logic to come up with the assignment of the underlying cause of failures and the distribution of responsibilities.

In effect, regardless of regulations, laws and institutions, the responsibility is ultimately distributed to the project designers, project construction managers, resident engineers, construction contractors and sub-contractors.

All of the case histories considered here were settled without trial, probably because the principles of 'eminent' and 'imminent' danger clearly identified the responsible parties and their tenuous defensive positions.

Since safety regulations and laws are generally designed for the protection in the work place and of the public in general, the starting perspective is necessarily philosophical. We have found that the consideration of safety must be based on the following fundamental philosophical principles: eminent danger and imminent danger.

Eminent danger is defined as a danger "towering or standing out above others" – prominent and outstanding. In other words, an eminent danger is significant, of consequence, grand and likely to have a major effect. Therefore, an eminent danger would be one that would cause serious injury and/or death.

For example, a heavy weight suspended above a work area or public thoroughfare must be considered an eminent danger. Consequently, an eminent danger would require a significant design effort to prevent the danger from materialising and putting life in jeopardy. The elimination of an eminent danger requires a redundancy in design.

An imminent danger is inherently impending, in other words, with little or no obstacle between the existing stability and failure. For example, an imminent danger would be a heavy weight over a work area or heavily travelled route with only a single element preventing a movement from stability to failure. An imminent danger must be eliminated by design. This can only be done by providing a redundancy that would prevent complete failure when one element fails.

CASE HISTORY: FALLING PRE-CAST SEGMENT

An eminent danger consisting of a 3t pre-cast segment fell on, and caused the death of, a tunnel labourer. The segment erector was directed by a control box at the end of a hanging cable.

The segment erector was the only means of holding the last segment in place until installation of the key segment to make a completed ring. This constituted an imminent danger. After the accident, the imminent danger was eliminated by adding a mechanical cam to prevent the segment from falling even if the segment erector failed or was released. The TBM manufacturer recognised its responsibility in failing to provide initial redundancy and settled with the plaintiff's family.

The project construction manager (PCM), with

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Case history: over-excavation of tunnel crown

A contractor was engaged to heighten a tunnel to accommodate double-stack freight trains by removing the arch concrete, removing rock from the arch, installing temporary support and installing final support.

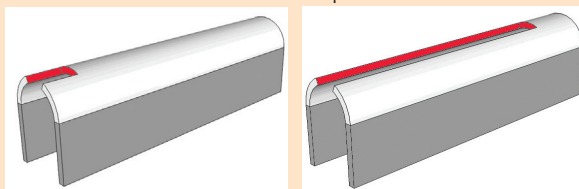
The length of excavation was limited to 3m-sections (Figure 1a) to allow concrete removal, rock excavation and installation of support, without placing the operator of equipment under the excavated crown. All equipment for the foregoing operations could reach the unsupported arch without exposing the operator to danger. However, once the contractor excavated, the absent resident

engineer allowed the excavation of 13m of crown (Figure 1b), thus placing the operator of the equipment under the unsupported arch. A slab of concrete dislodged, resulting in the death of the impact-hammer operator.

The extensive exposure of unsupported tunnel constituted both an eminent and an imminent danger, with no protection provided to the machine operator. The role of GeoConSol geotechnical and tunnel consultants was to confirm that the design engineer had no responsibility for the accident. The contractor's insurance company settled with the plaintiff.

Fig 1a (left): excavation limited to 3m sections;

Fig 1b (right): excavation of 13m of crown, leading to death of worker beneath unsupported arch



Case history: blasting cap failures

Manufacturing problems produced blasting caps that failed to detonate during the blasting process. The problems were demonstrated in the field by the contractor's tests and reported by several contractors and mines. The manufacturer, however, publicly denied having any problems, despite internal memoranda acknowledging the flaw.

The undetonated blasting caps remained in the ground, despite extensive cleaning of debris. Subsequently, the cap and charge were detonated when drilling for the next round in the shaft excavation, seriously injuring the labourer drilling the holes.

The use and nature of explosives is an inherent eminent danger. The imminent danger occurred despite a controlled manufacturing process, failure of quality control and complaints about the product, because the manufacturer ignored known problems. The case settled on the first day of trial when the defendant saw the exhibits prepared by GeoConSol, the plaintiff's expert.

ultimate responsibility for safety, was being paid US\$8,015/day for construction management services and an additional US\$2,896 for coffee and decorative plants, for:

- review of the contractor's means, methods and equipment;
- providing a resident engineer and inspectors;
- providing a separate resident safety engineer and safety inspectors, and
- daily safety audit by all PCM employees and executives entering the tunnel.

Payment for services imposes compulsory responsibilities to provide and implement a safe working environment. The PCM failed to provide a safe work environment by overlooking the eminent and imminent dangers throughout all stages of review, inspection and daily safety audit. The PCM provided additional settlement for the benefit of the plaintiff.

CASE HISTORY: FALLING ROCK SLAB FROM TUNNEL CROWN

A tunnel in sub-horizontal sedimentary rock was being excavated with a used TBM that had not been designed for the specific geological conditions on the project. The TBM was designed for conditions on a previous project and had no requirement or facility for temporary support between the cutterhead and the end of the primary conveyor.

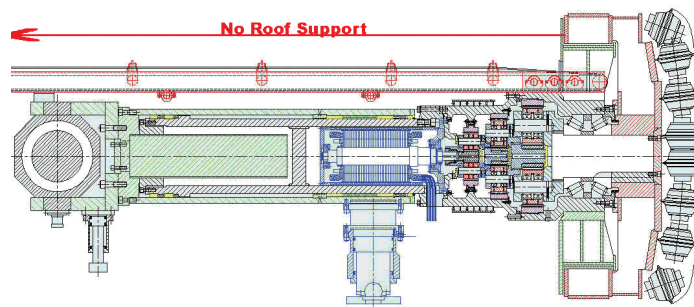


Fig 2: an open TBM design

Rock bolts were being installed at a distance in excess of 10m behind the exposure of the rock crown. A similar open TBM design is illustrated in Figure 2. Needless to say, the tunnel crown slabs were able to loosen along the bedding over the 10m distance. In this case, a slab fell on the labourer installing rock bolts behind the end of the primary conveyor, resulting in the loss of his leg.

The project geotechnical engineer failed to alert the tunnel designer and tunnel contractor of very likely fallouts of tunnel crown slabs resulting from sub-horizontal bedding planes. Had local geotechnical conditions been adequately identified, the designer could have prevented the injurious fallout by requiring in the specifications the immediate temporary support behind the cutterhead.

A local geotechnical condition having a high likelihood of producing rock slab failure is

inherently an 'eminent' danger. The elimination of the imminent danger would have required a roof shield or temporary support installed behind the cutterhead. Neither of these methods to eliminate imminent danger were utilised because the eminent danger had not been identified and the means and methods had not been designed

"Payment for services imposes responsibilities to provide a safe working environment"

for this known condition. GeoConSol insisted that the TBM manufacturer be removed from the list of defendants and the case was subsequently settled in favour of the plaintiff.

CONCLUSIONS

It has become obvious that both the design for safety and the evaluation of safety failures can be effectively addressed by the simple consideration of eminent and imminent dangers in the design, construction and adjudication of personal-injury and wrongful-death cases in underground construction. The same principles apply to design and construction above ground.

Case history: falling ceiling panel

A suspended ceiling enclosing a ventilation space comprised 3t reinforced concrete panels supported by single steel tieback bolts secured by epoxy glue into the concrete structural ceiling (Figure 3). The bolts and glue failed, four ceiling panels fell, and caused the death of an automobile passenger.

It is clear that a single structural element (imminent danger) supported the 3t panels over an active roadway (eminent danger). Furthermore, the epoxy and bolts were never intended for this type of application.

Unfortunately, the authorities held the bolt supplier responsible rather than the designer of the inappropriate system of support.

Fig 3: mechanism of failure showing support elements and collapse of false ceiling

Tieback bolts pulled free from the tunnel's concrete ceiling...

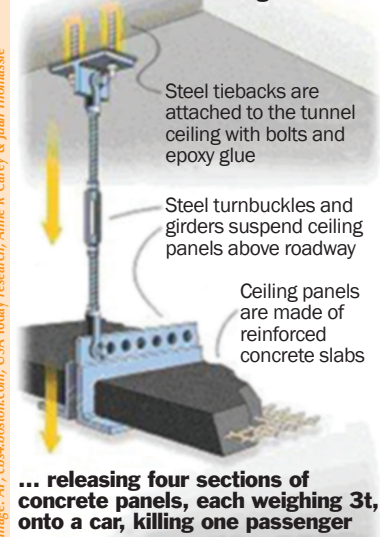


Image: AP, cbs4.boston.com, USA Today research, Anne R. Carey & Juan Thomassie

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