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# Context for Safety in the Design and Construction of Underground Facilities

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Although various government bodies provide fundamental regulations, laws, and punitive consequences associated with safety violations, there are a great number of issues that remain unaddressed, unregulated, and unresolved, especially in the underground construction industry. Over the years, involvement with safety issues in underground construction related to personal injuries and wrongful deaths has required an identification of basic philosophies to address the shortcomings in the regulations which have not addressed a variety of situations.

Project design during construction and throughout the structure's operating life must specifically address the moral issues of protecting workers engaged in construction 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 that will be discussed in this paper.

## Introduction

The cases considered herein have been associated with bored tunnel excavation, shaft construction, blasting, and highway tunnel safety. When investigating and dealing with safety issues where no regulations are found to 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 to the respective parties.

In effect, regardless of regulations, laws, and institutions, the responsibility is ultimately distributed to the project construction managers, project designers, resident engineers, construction contractors, and sub-contractors. Case histories to be considered herein include:

1. Failure of blasting cap resulting in the detonation of a charge when a labourer drilled into it, detonating the unexploded blasting cap and charge, causing serious head and emotional injuries.
2. Rock slab falling from an unsupported tunnel crown during tunnel excavation resulting in the loss of a tunnel labourer's leg.
3. Wrongful death resulting from a pre-cast concrete segment falling on a tunnel labourer.
4. Wrongful death resulting from a false ceiling panel falling on a vehicle in a roadway tunnel, causing the death of an automobile passenger.

Nearly all of the cases were settled without trial, in all probability, because the fundamental principles of "eminent" and "imminent" danger clearly identified the responsible parties and the parties realized their tenuous positions.

Since safety regulations and laws are generally designed for the protection in the workplace and 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 principles:

1. "Eminent" danger.
2. "Imminent" danger.

The American Heritage Dictionary (third edition) defined the foregoing terms as follows:

- em·i·nent (ɪm"i·nənt) adj. 1. Towering or standing out above others; prominent.
- 2. Of high rank, station, or quality; noteworthy.
- 3. Outstanding, as in character or performance; distinguished.
- em"i·nent·ly adv.
- im·mi·nent (ɪm"i·nənt) adj. About to occur; impending. --im"mi·nent·ly adv. --im"mi·nent·ness n.

"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 heavyweight 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 "eminent" danger from manifesting and placing life in jeopardy. The elimination of an "eminent" danger would require 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 heavyweight 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 which would prevent complete failure when one element fails.

## Case History – Blasting Cap Failures

Manufacturing problems produced blasting caps that failed to detonate during the normal blasting process. The problems with the blasting caps were demonstrated in the field by the contractor's tests and reported by several contractors and mines (Exhibit 1). The manufacturer ignored and publicly denied having any problems, despite internal memoranda acknowledging the manufacturing flaw.

EVIDENCE FOR CAP FAILURE	
FACT	DRIFT WIDTH
FACT	DRIFT LENGTH
FACT	DRIFT HEIGHT
FACT	DRIFT AREA
FACT	DRIFT VOLUME
FACT	DRIFT PERIMETER
FACT	DRIFT SURFACE AREA
FACT	DRIFT SURFACE VOLUME
FACT	DRIFT SURFACE WEIGHT
FACT	DRIFT SURFACE MASS
FACT	DRIFT SURFACE DENSITY
FACT	DRIFT SURFACE STRENGTH
FACT	DRIFT SURFACE STIFFNESS
FACT	DRIFT SURFACE PERMEABILITY
FACT	DRIFT SURFACE SEISMICITY
FACT	DRIFT SURFACE THERMALITY
FACT	DRIFT SURFACE CHEMISTRY
FACT	DRIFT SURFACE BIOLOGY
FACT	DRIFT SURFACE COSMETOLOGY
FACT	DRIFT SURFACE AESTHETICS
FACT	DRIFT SURFACE HISTORY
FACT	DRIFT SURFACE LEGACY
FACT	DRIFT SURFACE HERITAGE
FACT	DRIFT SURFACE IDENTITY
FACT	DRIFT SURFACE CHARACTER
FACT	DRIFT SURFACE PERSONALITY
FACT	DRIFT SURFACE SPIRIT
FACT	DRIFT SURFACE SOUL
FACT	DRIFT SURFACE HEART
FACT	DRIFT SURFACE MIND
FACT	DRIFT SURFACE WILL
FACT	DRIFT SURFACE FORCE
FACT	DRIFT SURFACE POWER
FACT	DRIFT SURFACE ENERGY
FACT	DRIFT SURFACE ABILITY
FACT	DRIFT SURFACE SKILL
FACT	DRIFT SURFACE KNOWLEDGE
FACT	DRIFT SURFACE WISDOM
FACT	DRIFT SURFACE UNDERSTANDING
FACT	DRIFT SURFACE COMPASSION
FACT	DRIFT SURFACE KINDNESS
FACT	DRIFT SURFACE GENTLENESS
FACT	DRIFT SURFACE MERCY
FACT	DRIFT SURFACE GRACE
FACT	DRIFT SURFACE FAITH
FACT	DRIFT SURFACE HOPE
FACT	DRIFT SURFACE CHARITY
FACT	DRIFT SURFACE LOVE
FACT	DRIFT SURFACE PEACE
FACT	DRIFT SURFACE JOY
FACT	DRIFT SURFACE GLADNESS
FACT	DRIFT SURFACE HAPPINESS
FACT	DRIFT SURFACE CONTENTMENT
FACT	DRIFT SURFACE SERENITY
FACT	DRIFT SURFACE CALMNESS
FACT	DRIFT SURFACE COMposure
FACT	DRIFT SURFACE STABILITY
FACT	DRIFT SURFACE SECURITY
FACT	DRIFT SURFACE SAFETY
FACT	DRIFT SURFACE SOUNDNESS
FACT	DRIFT SURFACE SOUND MIND
FACT	DRIFT SURFACE SOUND HEART
FACT	DRIFT SURFACE SOUND BODY
FACT	DRIFT SURFACE SOUND SPIRIT
FACT	DRIFT SURFACE SOUND SOUL
FACT	DRIFT SURFACE SOUND FUTURE
FACT	DRIFT SURFACE SOUND PAST
FACT	DRIFT SURFACE SOUND PRESENT
FACT	DRIFT SURFACE SOUND MIND, HEART, BODY, SPIRIT, SOUL, FUTURE, PAST, PRESENT

Exhibit 1: Evidence for Blasting Cap Failures

crowns slabs resulting from sub-horizontal bedding planes. Had local geotechnical conditions been adequately identified, the designer could have required immediate temporary support behind the cutterhead in the specifications and prevented the injurious fallout.

A geotechnical condition of high likelihood rock slab failure is inherently an "imminent" 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 was utilized because the "eminent" danger had not been identified and the means and methods had not been designed for this unknown condition. The expert on the case insisted that the TBM manufacturer be removed from the list of defendants and the case was subsequently settled out of court on behalf of the plaintiff.

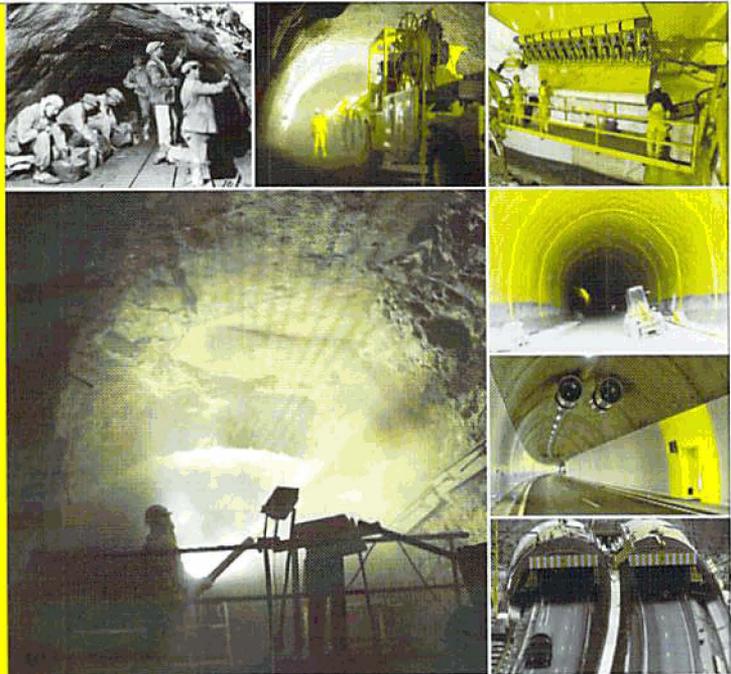
The undetonated blasting caps remained in the ground, despite extensive cleaning of debris. Subsequently, the cap and charge were detonated when drilling for the next round in the shaft excavation, seriously injuring, both physically and emotionally, the labourer drilling the holes.

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

**Case History –  
Falling Rock Slab from Tunnel Crown**

A tunnel in sub-horizontal sedimentary rock was being excavated with a used TBM not designed for the specific geological conditions on the project. The used TBM was designed for the conditions on a previous project and had no requirement or facility for temporary support between the cutterhead and the end of the primary conveyor. Rock bolts were being installed, a distance in excess of 10 metres behind the exposure of the rock crown. A similar open TBM design is illustrated in Exhibit 2. Needless to say, the tunnel crown slabs were able to loosen over a distance of 10 metres. In this case, a slab fell on the labourer installing rock bolts behind the end of the primary conveyor. A falling rock slab resulted in the loss of the individual's leg.

The project geotechnical engineer failed to alert the tunnel designer and tunnel contractor of very likely fallouts of tunnel



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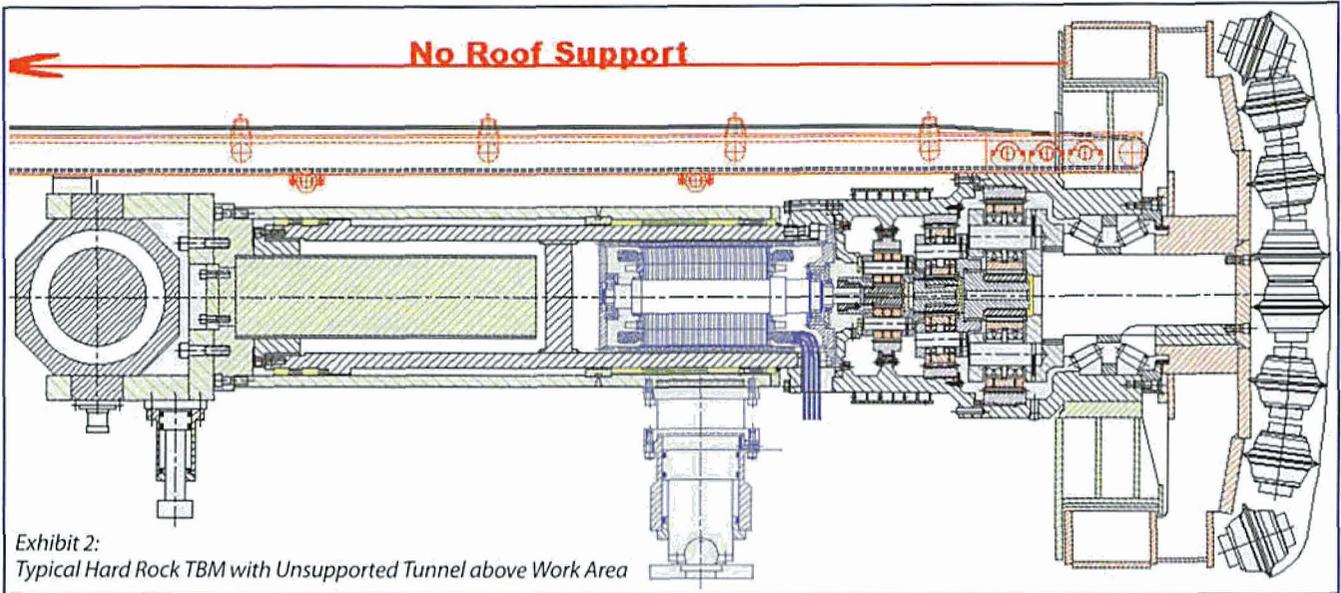


Exhibit 2:  
Typical Hard Rock TBM with Unsupported Tunnel above Work Area

**Case History –  
Falling Pre-Cast Segment**

An “imminent” danger consisting of a 3-ton 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 segment in place until installed and secured in place as a complete ring. This constituted an “imminent” danger. After the accident, the “imminent” danger was eliminated by adding a mechanical arm that would prevent the segment from falling even if the segment erector failed or was released. The TBM manufacturer recognized their responsibility in failing to provide initial redundancy and settled with the plaintiff’s family.

The project construction manager (PCM), with ultimate responsibility for safety was being paid \$8,015/day (Exhibit 3) for:

1. Review of the contractor’s means, methods, and equipment.
2. Providing a resident engineer and inspectors.
3. Providing a separate resident safety engineer and safety inspectors.
4. Daily safety audit by all PCM employees entering the tunnel.

Payment for the services imposes compulsory responsibilities to provide

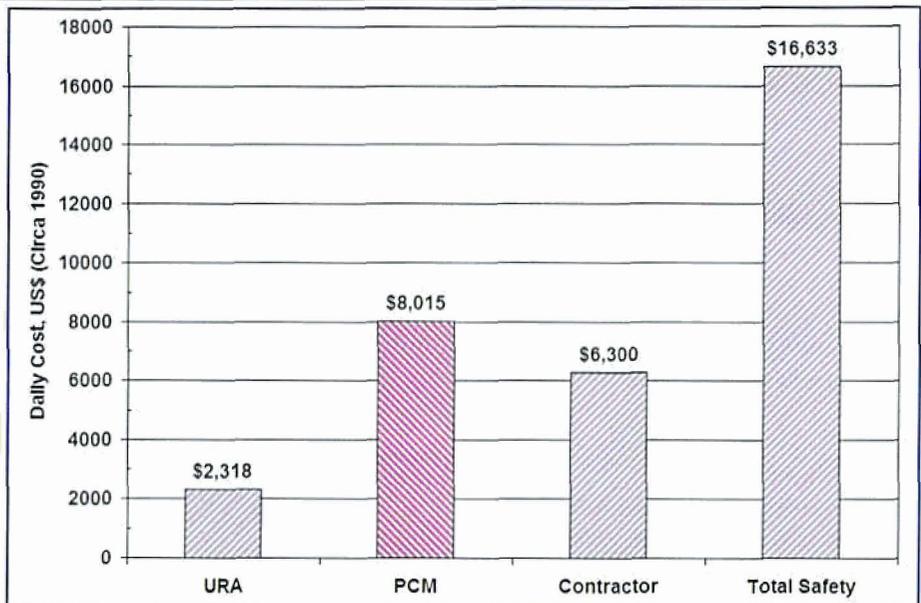


Exhibit 3: Daily Cost of Construction Safety

and implement a safe working environment. The PCM failed to provide a safe work environment by overlooking the “imminent” and “imminent” dangers throughout all stages of review, inspection, and daily safety audit. The case was settled to the benefit of the plaintiff.

**Case History – Falling Ceiling Panel**

A false ceiling consisting of 3-ton panels (“imminent” danger) to accommodate a space for tunnel ventilation was supported by single steel tieback bolts with epoxy glue (“imminent”

danger) into the concrete structural ceiling as illustrated in Exhibit 4. The bolts and the epoxy 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 3-ton panels (“imminent” danger) over an active roadway. Furthermore, the epoxy rock 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. This was a gross miscarriage of justice.

**Conclusions**

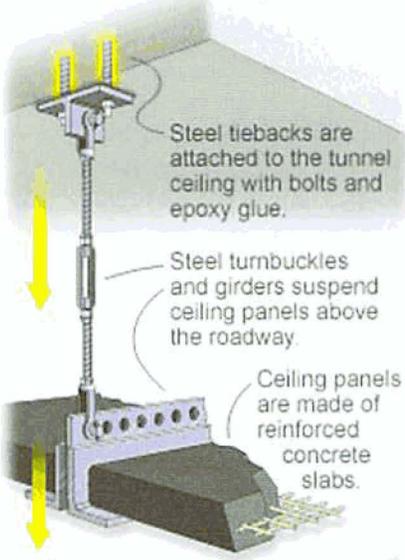
It has become obvious that both the design for safety and the evaluation of safety failures can be effectively addressed by the simple consideration of "eminent" and "imminent" dangers in the design, construction, and adjudication of personal injury and wrongful death cases in underground construction.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



Exhibit 4: Support Elements and False Ceiling Collapse



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



**...releasing four sections of concrete panels, each weighing three tons, onto a car, killing one passenger.**

Sources: AP, cbs4.boston.com, USA TODAY research  
By Anne R. Carey and Juan Thomassie

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