ACCEPTABILITY OF NATURAL HAZARDS IN TRANSPORTATION CORRIDORS

by

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ABSTRACT

The rational approach to evaluating risk due to natural hazards comprises a two-part procedure. The first step is to measure or document the hazards; the second step is to consider or judge acceptability.

Using landslides and debris torrents as examples, methods of documentation are discussed, including probability of occurrence.

In considering acceptability of risk, a comparison is made with other voluntary and involuntary risks that society assumes. It is possible, if only broadly, to quantify risks from natural hazards in terms of the individual, the workman, and the travelling public. One can distinguish between risk to the resident in the hazard area and the traveller passing through. Sensitivity to changing or deteriorating conditions can also be assessed. Several case histories are provided.

There is no procedure that can be rigorously applied and there are many exceptions to the norm. However, the development of a rationale for accepting hazards is all to often overlooked.

Keywords: natural hazards, acceptability of risks, highway and railway location

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INTRODUCTION

As engineers, we are expected to possess a considerable level of expertise that the remainder of society does not have, and we are one of the few professions where incompetence and poor judgment can lead to loss of life and substantial property damage. As a consequence we have paid dearly for our mistakes, and are likely to continue to do so.

In 1901, the Code of Hammurabi, who ruled Babylonia around 1800 BC, was uncovered. This code contained some 300 legal provisions carved in stone. Included in these we find (Adcock, 1978):

> "If a builder builds a house for a man and does not make its construction firm and the house which he has built collapses and causes the death of the owner of the house, that builder shall be put to death. If it causes the death of the son of the owner of the house, they shall put to death a son of that builder.
>
> "If it (the collapse) destroys property, he (the builder) shall restore whatever it destroyed, and because he did not make the house ..... firm ..... he shall rebuild the house which collapsed at his own expense."

We can assume that more than a few builders of those times learned the hard way.

Today's society can be equally harsh.

In 1963 in Northern Italy, 250 million m^3 of rock moved rapidly into a reservoir creating a large wave of water which overtopped the Vajont Dam. Although the 265 m high arch dam remained relatively intact, the wave which reached a height of 90 m above the crest of the dam descended on and destroyed the town of Longarone, 2 km downstream on the banks of the Piave River. Some 2000 lives were lost. The tragic aftermath of this catastrophe lead to the 13-month trial of 8 engineers on charges of manslaughter; 3 were convicted.

Perhaps the most common way for society to register its displeasure today is through the increasing number of legal actions against the engineering profession Most engineers carry insurance against errors and omissions; the latest figures show approximately 1 claim for every three policyholders. In 1985 in Canada, almost $6 million was paid out to successful plaintiffs, and a further $7 million was paid to lawyers and expert witnesses for defence. The largest claim in Canada to date is $86 million (Muto, 1986).

From the standpoint of accountability, the geotechnical engineer finds himself in a particularly vulnerable spot. By definition he works with the interface between natural conditions and man-made structures. On transportation projects which traverse extensive rural areas, his problems are exacerbated. In comparison to more design-intensive structures he has little hard information and his judgment is continuously taxed. He is commonly called upon to identify and define natural situations that are potentially hazardous to the users of highways or railways and to at least initiate a decision process as to whether those hazards are acceptable or not. Time and time again we read of investigations of rock slides and falls, of foundation and abutment failures, which even though carried out after the fact are either inconclusive or attribute the failure to some easily overlooked geologic condition. His task, to say the least, is a challenging one.

The engineer obviously cannot eliminate risks, so what do we mean when we describe a project as safe? In 1976, W.W. Lowrance (a chemist, not an engineer) responded, "Only when ..... risks (are measured) ..... and weighed on the balance of social values can safety be judged; a thing is safe if its attendant risks are judged to be acceptable."

Thus the rational approach to deciding if a natural hazard, mitigated or unmitigated, is acceptable comprises a two-part procedure. The first step is to measure the hazard. This essentially consists of assessing the pertinent aspects of the hazard and the probability of an event, and expressing them in a meaningful way. Here the role of the geotechnical engineer is paramount. The second step is to judge the acceptability of the hazard(s). On most enginering projects, including transportation projects, this judgment can be made at three levels depending upon the perceived magnitude of the risk:

- The location and design engineering level with input from the geotechnical engineer.

- The owner's senior management, sometimes with the help of a review board of experienced engineers.

- The governmental level, often through regulatory bodies and sometimes involving public hearings.

DOCUMENTING A NATURAL HAZARD

One cannot accept a risk without knowing what it is. It is thus important to identify those aspects of a natural hazard which govern its acceptability and to clearly document them.

British Columbia is a province of mountains. As such, many of its highways and railways must pass through areas that have a history of falling rock, slides, and debris torrents. These areas are commonly described as active and it is incumbent upon us to address the threat of future activity. Pertinent geotechnical aspects of such hazards are:

- the magnitude of a future significant event, and the location and extent of the area threatened by the event;
- velocity (in the case of landslides); and
- the probability of occurrence of an event.

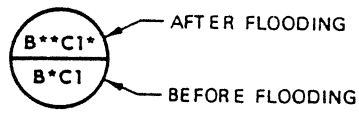
Other non-geotechnical factors governing acceptability are discussed later.

The following methods of documenting landslides and debris torrents are drawn from the author's experience.

Earth and Rock Slides

The last 25 years have seen the creation of several large reservoirs for hydroelectric development in British Columbia. Some sections of these reservoirs have been located in developed areas where any shoreline instability and regression would have been a threat to the security of roads, railways, utilities and buildings, and to the users of these facilities. Planners and engineers needed to become informed about the risk and probability of occurrence of landslides. In response to this need a shoreline stability classification system has been established as outlined on Figure 1.

EXAMPLE



PROBABILITY OF OCCURRENCE

(designated using asterisks)

Two asterisks(**) – high probability of occurrence

One asterisk (*) – not imminent, but assumed to occur at sometime during the life of the development.

No asterisk – possible, but low probability

SLIDE VELOCITY

Rapid	– greater than 3m/sec.
Moderate	– 0.3 to 3m/sec.
Slow	– 10m/year to 0.3m/sec.
Creep	– less than 10m/year

SLIDE TYPE

Designation

A – Segments of shoreline where regression of the shoreline due to erosion and/or sloughing will be slight; also covers slopes where slides may occur but are not expected to affect the slope above full pool.

B – Segments of shoreline where small slides on terrace slopes (normally not higher than 50m) or minor slumping of higher slopes may occur (involving not more than 100,000 m^3 in one slide). Also includes reactivation of slide debris at the toe of higher slopes, provided the above volume limit is not exceeded.

C – Segments of shoreline where large slides may occur involving failure through bedrock either totally or in part. Such slides could range in size from 100,000 m^3 to several tens of millions m^3. The slides could affect any portion of a high slope and are not restricted to toe failures. Type C slides are subdivided into Type C1 signifying a capability of up to moderate movement, and C2 signifying a rapid movement capability.

D – Segments of shoreline where large slides may occur involving overburden only or slide debris (reactivation). Otherwise, the Type C definition applies.

FIGURE 1: Typical Stability Classification of Reservoir Shoreline (Morgan, 1982)

An example of a classification of a large slope in excess of 50 m high consisting of overburden overlying bedrock is given below:

B** C1 D2*

A segment so classified indicates activation of up to 100,000 m^3 of slide debris is highly probable and can be expected over the short term; further a large rapidly-moving slide of the overburden (involving more than 100,000 m^3) may occur within the life of the development; there is also a possible but low probability of a large slow-moving slide involving the underlying bedrock.

This classification can readily be adapted to a transportation corridor, applying it (as with a reservoir shoreline) segment by segment. The slide type designation can be altered to suit the specific case.

For engineering applications the term 'rapid' is applied to those slides that have the potential for moving at greater than 3 m/s. A person may be able to outrun or escape from a slide moving at a lesser rate; it also coincides with the threshold velocity required to generate significant waves in lakes or reservoirs.

The probability of occurrence of landslides cannot be expressed statistically. There is no parallel with flood frequency analyses which are usually based on several decades of annual peak flow measurements. With an active landslide, we are fortunate if we have knowledge of one or two events in a lifetime. In recently-developed areas, we often have to resort to dendrochronology, early air photographs, and other similar dating techniques to establish the timing of the last event. Occasionally, a road or railway passes through or close to a large active slide and a record of ground movements is maintained, but this is a rarity. Thus, the probability of occurrence of a landslide is judgmental and can only be expressed relatively. For example, the proposed Site C Reservoir shoreline has been classified as follows (Thurber, 1978):

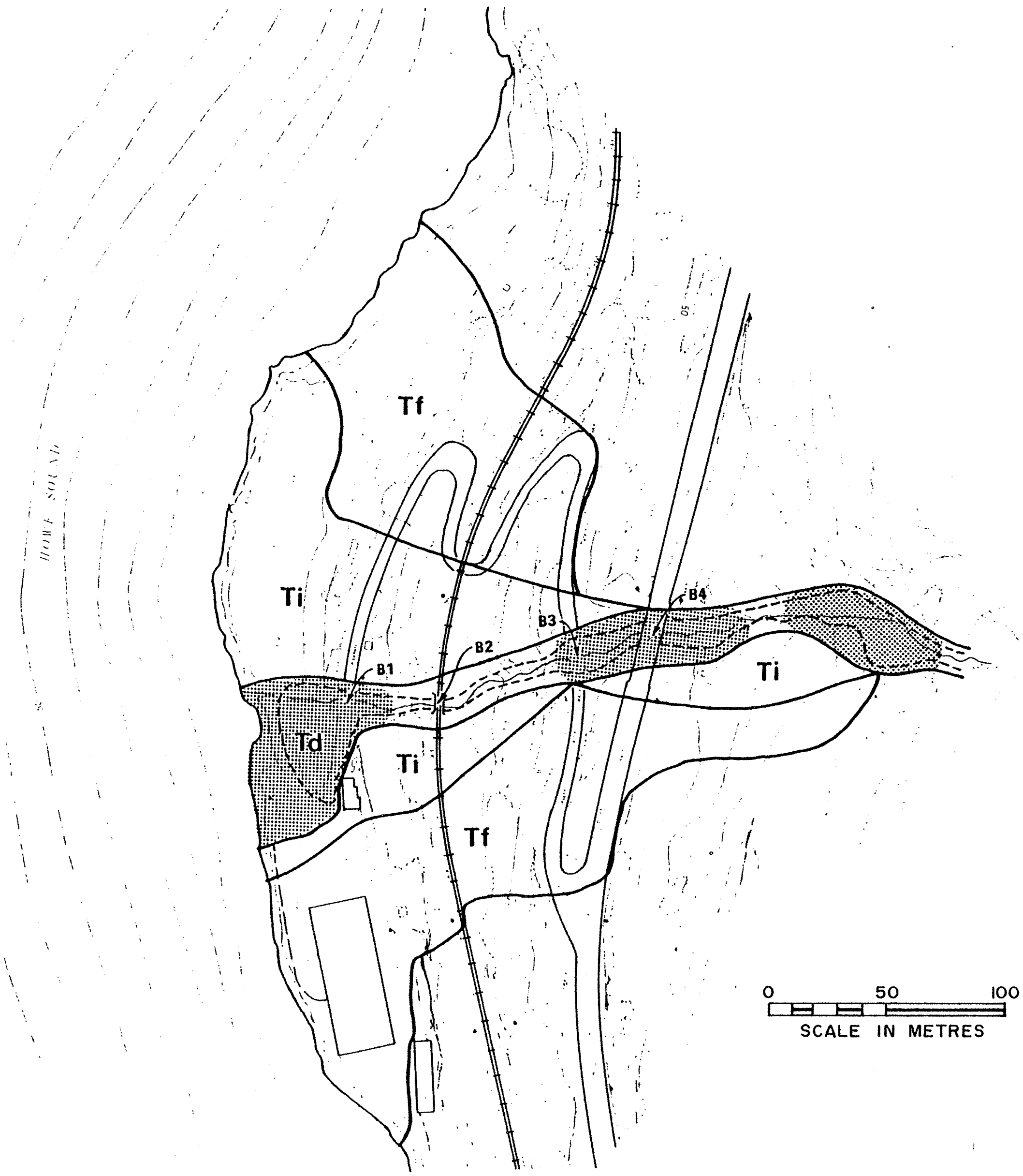
> Two Asterisk (**) indicate(s) high probability and is usually applied to those slopes which are known to be presently active.
>
> One Asterisk (*) is applied to those areas where a slide or slides of a designated classification should, for the purpose of studies concerning wave hazards, land use and safelines, be assumed to occur during the next 70 years or within the life of the development. Overburden slopes showing no current signs of instability but which are appreciably steeper than long term slopes are usually put into this category. Bedrock slopes where there is reasonable evidence that their stability is uncertain or could become uncertain are also placed in this category.
>
> No Asterisk indicates a possible potential, but one of low probability. Except for residential safeline studies, it may be assumed that slide(s) would not occur within the next 70 years. Overburden slopes which are steeper than long term slopes but not appreciably so, and bedrock slopes which have a lengthy history of stability are placed in this category.

Debris Torrents

Debris torrents are rapidly-moving channelized debris flows and are a major natural hazard on many smaller mountain creeks in British Columbia. The section of Highway 99 between Horseshoe Bay and Britannia Beach is traversed by 26 mountain streams. At least 14 debris torrents have occurred during the last 25 years, resulting directly and indirectly in the death of 12 persons and considerable property damage including 11 bridges. The single most important characteristic of a debris torrent is that the peak discharge, which lasts only tens of seconds can be an order of magnitude larger than that of a design flood. The estimated maximum discharge of the November 1983 Charles Creek event on Highway 99 approximated 300 m^3/s and lasted for less than 10 seconds. This was based on eye witness accounts and mud-line analysis. The 200 year flood for Charles Creek is estimated to be 32 m^3/s.

Defining debris torrent hazards comprises assessing the magnitude and discharge of future events, and the probability of occurrence. Plans are also prepared designating areas that would be affected by a torrent. A typical assessment is shown on Figure 2. Determining the magnitude and discharge of future events can only be carried out on a narrow regional basis. Nevertheless, it is important to do so as reliably as we can, as we are increasingly called upon to design and construct mitigative measures. The current approaches employed in British Columbia in this regard have been described by Hungr et al (1984). The probability of occurrence of a debris torrent is not only dependent on climatic conditions. It is currently assumed that sufficiently high precipitation to trigger debris torrents can occur (locally) in relatively common (2 to 5 year return) storm events combined with snowmelt (Thurber, 1983). Since debris torrents do not generally occur this frequently, it is apparent that a creek must also be debris-"ripe". We can attempt to rank creeks regionally on the basis of known activity, creek gradient, fan geometry and other ambient factors. The result is again a classification based on relative probability. The procedure and classification used on Highway 99 has been described by VanDine (1985). This approach must be used with caution, since some creeks in Europe are reported (Hungr et al, 1984) to have become active after lying dormant for up to 200 years.

Debris torrent hazard zone plans are commonly prepared in Europe and Japan. The typical arrangement used for Highway 99 (Figure 2) is comparable to that used in Europe. The boundaries of a specified hazard zone cover the area threatened by a 'design' debris torrent. It is important to



ASSESSMENT SUMMARY

PROBABILITY OF DEBRIS TORRENT OCCURRENCE: Category 4; very high

DESIGN DEBRIS TORRENT: Magnitude 20,000 m^3
Discharge 350 m^3/sec

DESIGN FLOOD (200 year return period): 32.2 m^3/s

BRIDGE	PERFORMANCE OF CROSSING	
	DESIGN DEBRIS TORRENT	DESIGN FLOOD
B1	Overridden or destroyed	Destroyed
B2	Blocked; overridden and damaged	Adequate opening
B3	Destroyed	Destroyed
B4	Damaged or destroyed	Adequate opening, potentially damaged

HAZARDS

Td Direct impact zone of debris torrent: Zone through which the high energy debris front may travel. The risk of impact damage from one or more surges is threfore high. Material transported through this zone could include boulders and rock fragments up to several metres in diameter and logs that are tens of metres long.

Ti Indirect impact zone of debris torrent: Zone through which later surges may potentially be diverted and/or through which after-flow may travel. Therefore the risk of impact damage is lower. Material could include large rock and log debris, but is more likely to contain rock of less than 1 m to fine-grained material and organic mulch.

Tf Flood zone due to debris torrent: Zone that is potentially exposed to flooding as a result of blockage of the main channel by debris torrent deposit. The risk of impact damage is low. Fine-grained material and mulch could be contained in the flood water.

Area of potential deposition of debris

Outline of area directly affected by known previous event

Flood zone due to high runoff not shown. Flood hazard is limited to zones of debris torrent hazards.

FIGURE 2: Debris Torrent Hazard Assessment
Newman Creek, Hwy. 99, (Thurber, 1983).

note that the entire area falling within a specified hazard zone is unlikely to be affected by any one event. Zoning allows for a spectrum of events over a long period of time. With events smaller than the design event, the hazard zones would be less extensive than shown. Floodwater paths are not readily predictable since they are often affected by embankments and ditches. Thus local flooding can occur beyond the torrent hazard boundaries.

ACCEPTABILITY OF RISK

Living has always been a risky proposition. As we reduce one risk, progress initiates another. There is however for any particular situation a level of risk that is generally acceptable to society. Interestingly, risk to life or property is not by itself the single most important factor. Society tolerates a very large toll stemming from vehicular accidents. In British Columbia alone almost 33,000 persons were injured or killed during 1984; a motor vehicle accident occurred every 5 minutes (MOTH, 1984). The individual British Columbian who annually drives 10,000 km runs a 1:3500 risk of being involved in a fatal vehicular accident in a given year. By comparison this same driver runs a $1{:}2 \times 10^6$ risk of being killed by a landslide or debris torrent or about the same risk as being struck by lightning. Of course locally in time and space the risk may be higher, however it seems it is not the number of people injured or killed as it is whether these injuries occurred during a single event and what caused the event.

Society makes a very definite distinction between voluntary and involuntary risks in allocating responsibility for any injury that may result from taking risks. A voluntary risk is one over which the taker has some control such as the speed of a vehicle in negotiating a bend (or failing to do so). An involuntary risk is one over which he has no control such as his vehicle being hit by a rock falling from a natural or cut face. This distinction can be expressed quantitatively. Table 1 shows a difference between voluntary and involuntary risks of approximately three orders of magnitude.

The probabilities quantified on Table 1 are useful as a yardstick for comparison of other risks that can be quantified. If a planner or engineer attempts to impose on society a risk with a probability comparable to voluntary risks, he can expect some resistance. We are indeed 'loathe to let others do unto us what we happily do to ourselves' (Starr, 1969).

ACTIVITY	*PROBABILITY OF DEATH/yr (approx.)
VOLUNTARY INDIVIDUAL RISKS:	
Air Travel (crew)	1:1000
** Car Travel (B.C., 1984)	1:3500
Construction	1:6000
Air Travel (passenger)	1:9000
INVOLUNTARY INDIVIDUAL RISKS:	
Fire	1:50 x 10^3
Drowning	1:100 x 10^3
Lightning	1:5000 x 10^3
Structural Failure	1:10,000 x 10^3

* Relative to the population employed in, or exposed to, the activity

** For an individual travelling 10,000 km/yr.

Sources: Ministry of Transportation and Highways, 1984; Kinchin, 1978; Rodin, 1978.

TABLE 1: Annual Probability of Death of a Selected Individual from Various Activities

Acceptance of Natural Hazards

Natural hazards fall into the category of involuntary risks and as will be seen later, the engineer and the agency he serves cannot always dismiss them as an "Act of God", much as they may wish to.

The transportation engineer commonly lives with a myriad of uncertainties and associated risks. He contrasts with the dam builder who will pursue his entire career hopefully without having a failure. The consequences of an event involving the failure of a dam are normally so unacceptable that they outweigh all other considerations. This difference is reflected in the extent of site exploration and fact-finding. The proposed Site C Dam will cover a 2.5 km^2 area; the investigation carried out to date includes 330 exploratory holes totalling some 25,000 m of drilling, 30 large diameter (0.9 m) holes, and 4 adits totalling almost 1000 m of excavation (Imrie et al., 1985). The cost of this work amounted to approximately $20 million. By contrast, the exploration for a typical 10 km section of the Coquihalla Highway comprises the drilling of some 50 holes totalling some 500 m of drilling which together with test pitting and geophysical work may cost $125,000.

The factors governing whether a risk from a natural hazard in a transportation corridor is acceptable or not, appear to be:

1. The consequences of an event; normally the number of lives or value of property affected by an event, or the uniquity of the route and the difficulty of re-establishing service.

2. The ability to predict the onset of an event within sufficient time to take protective action.

3. The probability of occurrence; depending on how reliably this can be estimated.

4. The extent of our knowledge of the existence of a hazard, and our understanding of its mechanics.

5. The ability to avoid or mitigate the hazard, which leads to an assessment of residual risk after mitigation, and often a choice between alternative forms of mitigation.

6. Joint considerations, such as the proximity of a community.

The transportation engineer considers all of the factors listed above, and where the consequences of a failure are low he will more readily accept the possibility of a failure. Casagrande (1965) recognized the need to adopt low safety factors (at least initially) when he described the construction and failure of the fill causeway carrying the Southern Pacific railway across Great Slave Lake. Had the designers adopted an overly cautious approach, he argued, the causeway would probably have been too costly to construct.

It frequently helps to attempt to quantify the risk of a known hazard in a corridor in terms of probability, if only as a guide to one's judgment. In doing so one normally uses the following method:

$$\text{Risk} = P_{(\text{event})} \times P_{(\text{consequence})}$$

where Risk is the overall probability that a selected individual will suffer some loss due to an event in a given year

$P_{(\text{event})}$ is the probability of the event occurring in that year

and $P_{(\text{consequence})}$ is the probability that an individual will suffer some loss due to an event, should that event occur in the given year.

This computation concerns a selected individual, as opposed to any individual within the group exposed to the risk. However, group probabilities can be similarly computed.

SOME CASE HISTORIES

An 'Act of God'

An 'Act of God' requires total ignorance. If there is substantial knowledge of a hazard, its effects and probability, and it is within the power of the owner or engineer to do something beneficial, then responsibility descends to a more appropriate level.

On May 26, 1973 a large slide ocurred suddenly and rapidly on the south bank of the Peace River at Attachie, 40 km west of Fort St. John. The slide (Figure 3) involved some 11 to 17 million m^3 of overburden and the river was blocked for 10 hours. The pond behind the slide reached a depth of 7 m prior to overflowing and re-establishing a channel through the failed mass. The detailed mechanism of failure remains a matter of conjecture. Since the slide occurred above the shales and gravel exposed at river level, it is obvious that river action had no direct effect. This finding was important because the previously completed upstream W.A.C. Bennett Dam had altered the pattern of river flows. Other than seismic lines on the plateau above, there were no man-made changes in the area. No one had reason to anticipate this event and it truly was an 'Act of God'. Fortunately, no significant damage resulted.

The area immediately downstream of the slide is traversed by a large number of fresh cracks and scarps, a condition which also existed prior to the slide. Subsurface investigations and limited monitoring of surface movments

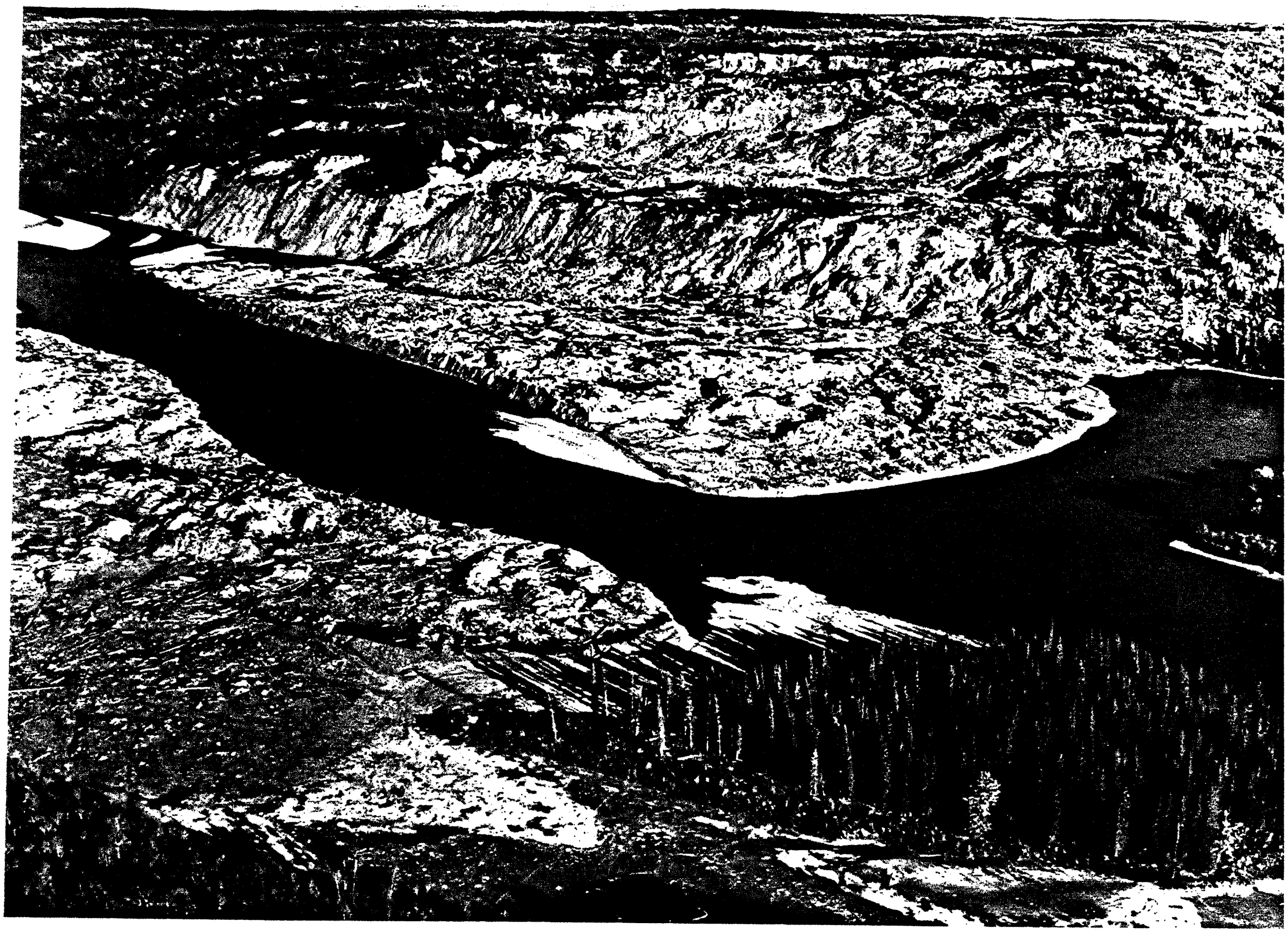


FIGURE 3: The Attachie Slide, Peace River

carried out subsequent to the event, particularly in the late 1970s by B.C. Hydro as part of their Site C Reservoir Studies, showed that there was a high probability of this area also failing. Should such a failure occur it could readily be of the same order of magnitude as the 1973 slide. It became apparent that the hazard was not just restricted to the proposed reservoir (and the prospect of the generation of a large wave), but that the existing highway and bridge over the Halfway River across from the slide area was also threatened.

As a result the Ministry of Transportation and Highways (MOTH) was brought in and with the closing of the Site C studies became the prime agency involved. In the early 1980s, a study of the surface movements increased concerns that failure may be imminent and suggested that work be carried out to "define with greater assurance what was actually happening at the site". Highway 29 is not a well-travelled road (AADT for 1984 was estimated at 500 or less), but these concerns equated to a 1:3000 probability of a daily traveller being involved in a future slide.

The Ministry clearly recognized their position, and arranged for 24 hour watchmen and gates on the highway for the April - June period when the risk of the failure occurring was considered highest. The failure did not materialize and the Ministry set up an on-going program to record and interpret movements.

The procedure of patrolling and watching bridge sites for debris torrent problems is also followed by the Ministry on the Squamish Highway (Hwy 99). Based on weather forecasts and creek flow observations, yellow followed by red alerts are intiated. With a yellow alert, a mobile patrol is commenced and stationary watchmen are assigned to all timber bridge structures. A red alert precedes highway closure and comprises the requirements of a yellow alert plus manning barricades at certain locations.

Residential versus Transportation Concerns

We seemingly adopt a much more conservative attitude when dealing with hazards to communities or residences than with highway routes through rural areas. The consequences of a failure is often quoted to account for this. However, the fact that the vehicle is normally moving along the highway, very much reduces the risk to the individual driver because he is exposed to the hazard a much shorter period of time.

The well-known Rubble Creek Landslide on Highway 99, 80 km north of Vancouver illustrates this point rather well. The slide, an estimated 25 million m^3 of lava rock, is known to have occurred in or around 1855 and there is evidence that more than one failure has occurred at this location during the last 11,000 years (post-glacial period). The risk of a new slide occurring in any year has been placed as high as 1:3500 (Moore et al., 1978). In 1973 Mr. Justice Berger considered these odds* and upheld the earlier refusal of the Provincial Government to approve the second phase of a subdivision. He found that approval of the development would encourage the growth of a community in this area and that occupation should be measured in hundreds of years rather than the period of occupancy of a building. As such, he ruled that the risk to future life would be unacceptable. Subsequently, the Provincial Government also moved on the first phase of the development, declaring the entire location as unfit for residential use and buying out the property owners.

The highway passes through the area and there is no suggestion that it is unsafe to do so. The annual risk to a daily traveller of being hit by a future Rubble Creek Slide as he moves through the slide area at 50 km/hr is in the order of $1:7 \times 10^6$, substantially less than the voluntary vehicular risks he is assuming.**

A comparison of the debris torrent control structures on the Squamish Highway through Lions Bay and adjacent communities with those on the recently completed Coquihalla Highway provides another example. The estimated $25 million expenditure on 5 creeks on the Squamish Highway is justified by the requirement that they also protect the communities. The southern portion of the Coquihalla Highway and adjoining Trans Canada Highway traverses some 50 debris torrent-prone creeks; the estimated expenditure on control structures totals less than $5 million.

Similarly, it is often acceptable for a highway along a new reservoir to traverse the area between the safeline and the shoreline, since safelines are primarily concerned with the residential use of land (Morgan, 1982).

Changing Conditions

Natural conditions change, and often for the worse. A landslide may result from progressive failure which has been going on for decades prior to the slide. Throughout this period the probability of the slide has been increasing.

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* Estimated to be 1:10,000 at the time of the trial.

** Not to be confused with the overall annual risk to the travelling public through the slide area. With current AADT values approaching 3000, an average 3.2 cars would be in the slide area during the normal travelling period of each day Thus, the risk of a car (as opposed to a particular car) getting hit is 1:2200.

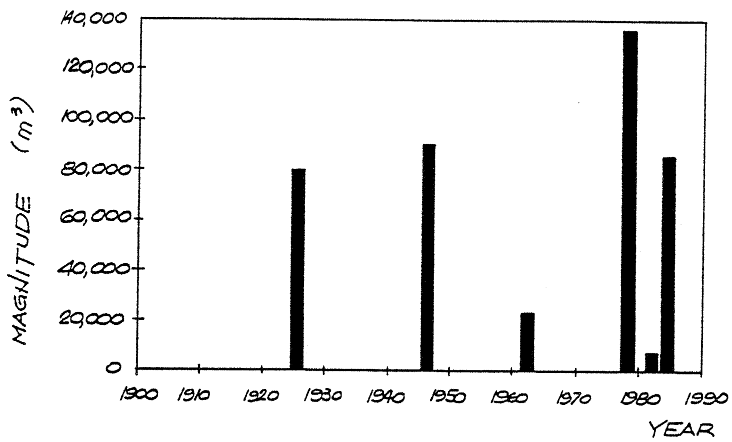

FIGURE 5: Documented Debris Torrents, Cathedral Mountain

Similarly debris torrent-prone creeks will progressively accumulate debris over varying periods of time and the probability of an event will increase just as progressively throughout these periods. To anticipate and estimate the rate of change is a most frustrating and difficult task. The previously described Attachie Slide is a case in point; the Cathedral Mountain Debris Torrent is another.

Cathedral Mountain (Figure 4) is located in Yoho National Park on the south side of the Kicking Horse River. A small glacier close to the summit, 1800 m above the river, discharges occasional meltwater down the slopes of the mountain along a course between the Spiral Tunnels of the CPR. As such, it intersects 3 levels of the railway and the Trans Canada Highway. The railway was first constructed in 1884 and was realigned in 1909 when the Spiral Tunnels were built. Since 1925, there have been 6 major debris torrents (Figure 5). The largest, 136,000 m^3, occurred in 1978. It is most probable that these torrents have all been mobilized by glacial meltwater and are therefore related to the performance of the glacier. The glacier constitutes the changing condition. There is documented evidence (Thurber, 1985) that the glacier has been retreating since 1925. The frequency of debris torrents currently being experienced appears to be atypical. The total amount of debris deposited in the fan is estimated to be only 2 to 4 times the combined volume of all the events since 1925.

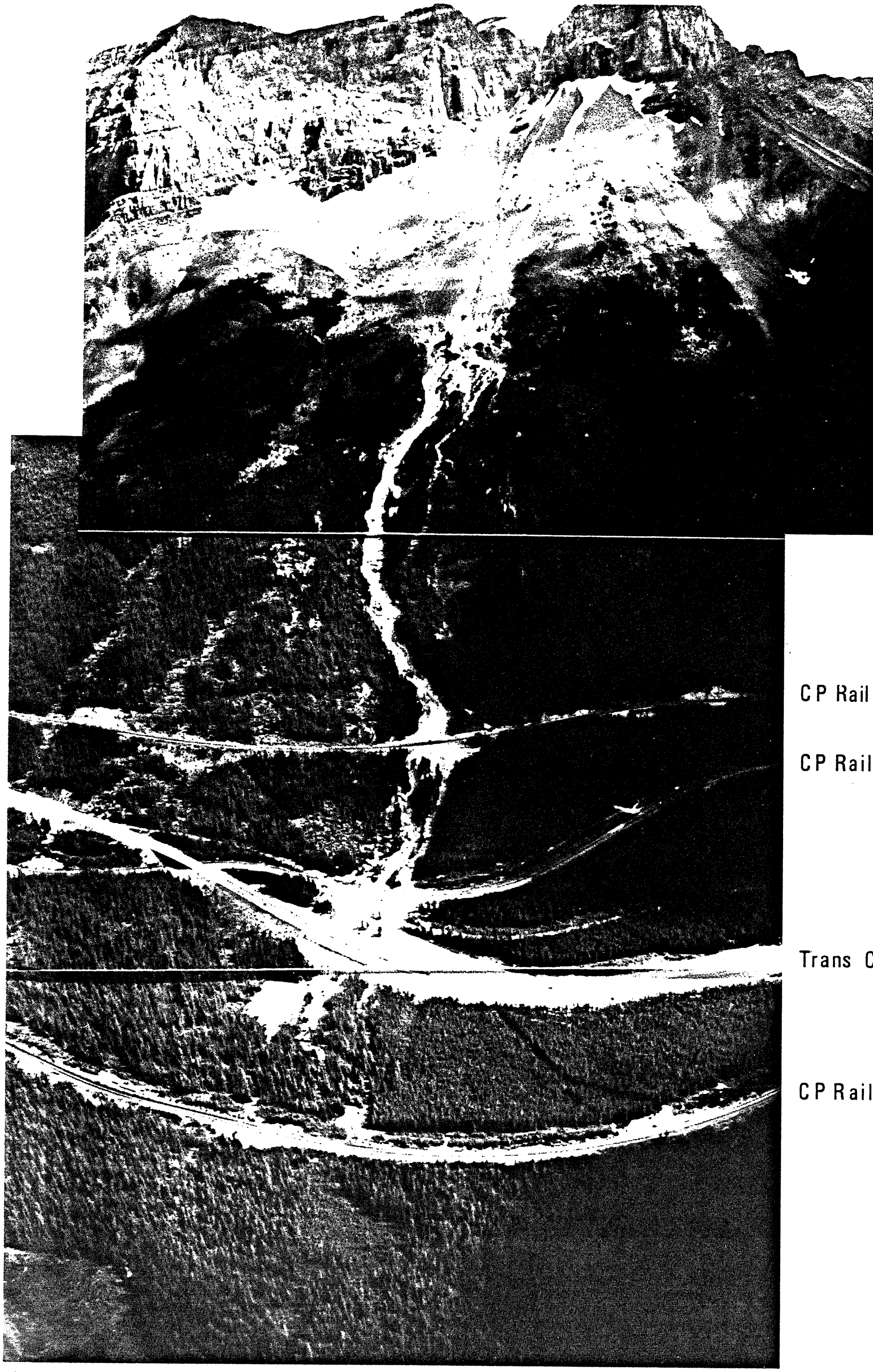

FIGURE 4: Cathedral Mountain Debris Torrent.

SUBJECT	ASSUMED PROBABILITY OF EVENT	
	1:17	1:3
Any Passenger Train	1:4000*	1:750
Any Freight Train	1:150	1:25
Any Locomotive/Caboose	1:800	1:150
Individual Monthly Passenger	1:650,000	1:115,000
Individual Crew Member (assuming 200 trips/year)	1:40,000	1:7500

* Approximated values have been used throughout.

TABLE 2: Annual Probability of Involvement with a Future Debris Torrent, Cathedral Mountain

Based on 1982 records (CP Rail, 1982) an estimated 5000 to 6000 trains per year pass through the area. This includes 2 passenger trains per day. Table 2 summarizes the probability of a train being involved with future debris torrents from two viewpoints. The owner (CPR) is interested in the probability of any of its trains being involved. The individual is more interested in the probability of a selected train being involved. It is assumed that a combined total of 600 m of track are exposed to torrents. Table 2 indicates a prime concern with freight traffic stemming from both direct involvement of a train and interruption of service while the tracks are cleared and repaired.* In fact, 2 trains have been hit by recent torrents and a third train has collided with slowly-moving debris. Faced with an apparent increase in frequency of the torrents, the owner is currently considering various protective measures.

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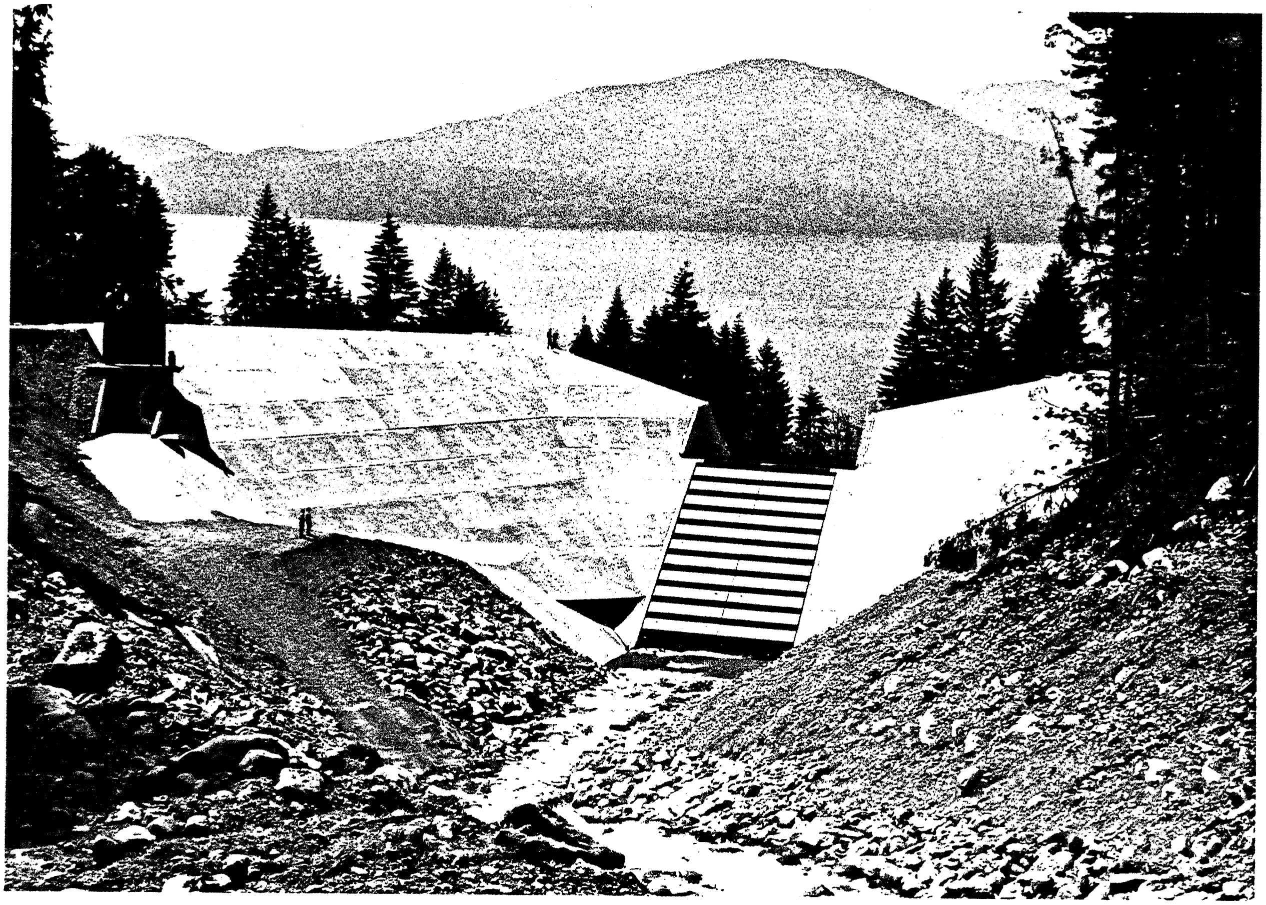
* The probabilities given in Table 2 are not intended to quantify risk to life. The torrents passing over the middle (Yoho) and lower (Cathedral) tracks can, except for very large events, be expected to be low in energy and velocity.

Mitigation

To mitigate a hazard is to reduce or alleviate it to an acceptable level. Sometimes a proposed method of mitigation may involve introducing another risk or even exposing a different group of people to the risk.

To date two similarly designed earth fill debris barriers have been constructed (Charles and Harvey Creek). The Harvey Creek Facility in the community of Lions Bay is shown on Figure 6. It is large; some 30 m high from crest to toe. The basin upstream of the barrier is sized to take 80,000 m^3 of debris. At any stage of filling, water may pass down through the central decant structure and through the outlet conduits. Should the basin become full, any torrent would pass over the top of the decant structure and down the emergency chute on the downstream face. In this case, the reduction of the hazard is dependent on the size of the basin, and the angle at which the debris comes to rest in the basin. However, of greater importance in the context of this paper is the possibility that such a structure could itself become a hazard if inadequately designed. Although unlikely, it is possible that both conduits could block and the structure would then have to survive as a dam. The designers recognized this possibility and adopted a zoned embankment with downstream relief wells (Figure 6: Sections).

The design of mitigative measures for Alberta Creek which flows adjacent to Harvey Creek illustrates a second problem. In February 1983, a large debris torrent descended the creek destroying 3 houses and damaging another (Figure 7). The timber trestle highway bridge was also destroyed together with 5 culverted crossings. Two lives were lost. The maximum discharge was conservatively estimated from banked mud lines to be 250 m^3/s. An early design concept for coping with future torrents comprised a complete diversion of Alberta Creek into Harvey Creek on a location above the community. The diverted debris, along with any debris torrents on Harvey Creek, would be stored in the Harvey Creek basin. The scheme had obvious attractions in that it removed future (Alberta Creek) debris torrents from the community and resolved the problem of safely passing torrents beneath 5 road bridges and a railway bridge (construction of a separate debris basin on Alberta Creek was not considered feasible). Recognizing the consequence of a failure, the diversion channel was designed conservatively so that it was to be capable of transporting 3 to 4 times the 1983 event. An application to the Provincial Comptroller of Water Rights to construct the diversion was declined on the grounds that the residual risk was not



Upstream Face

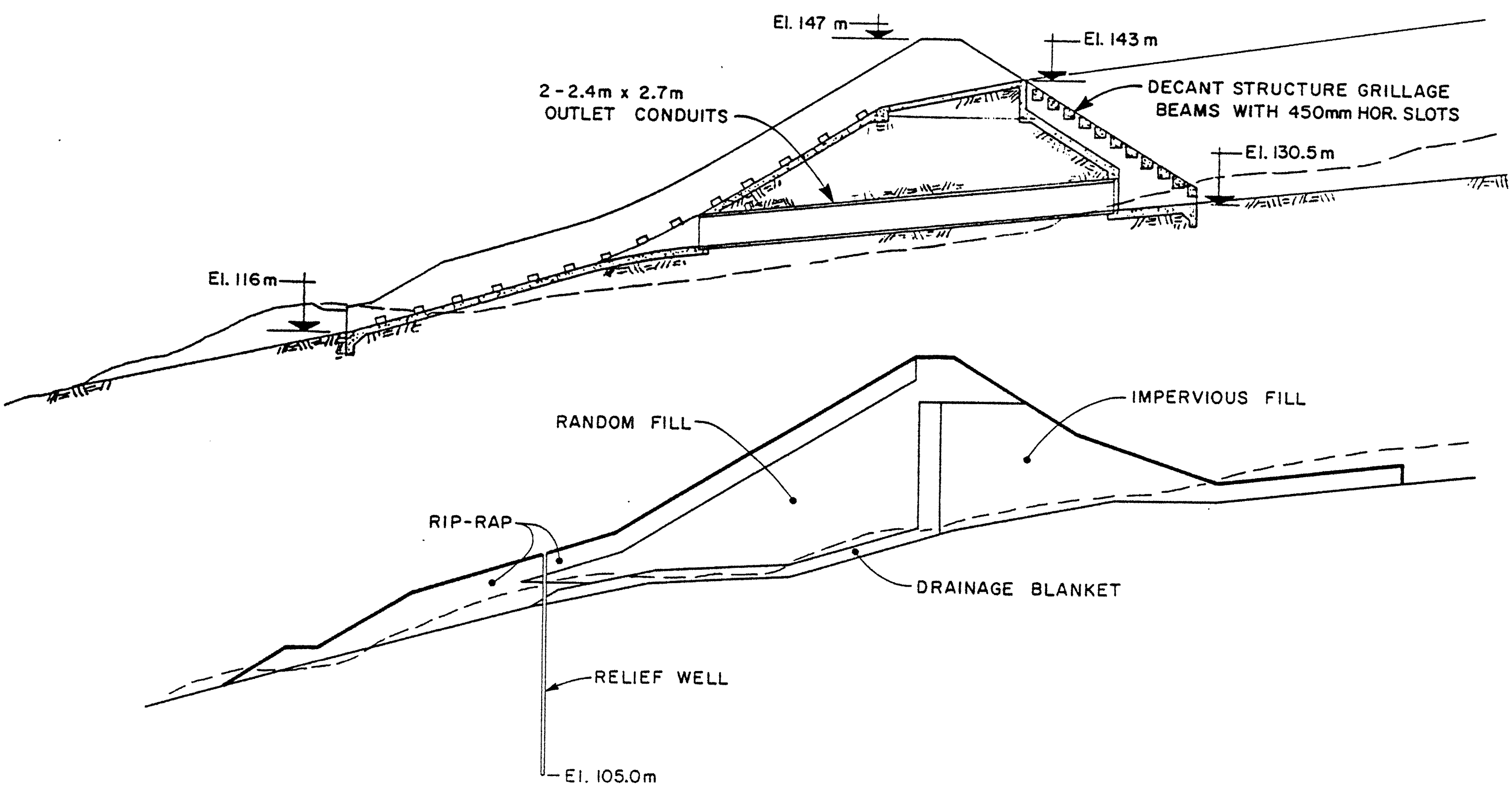
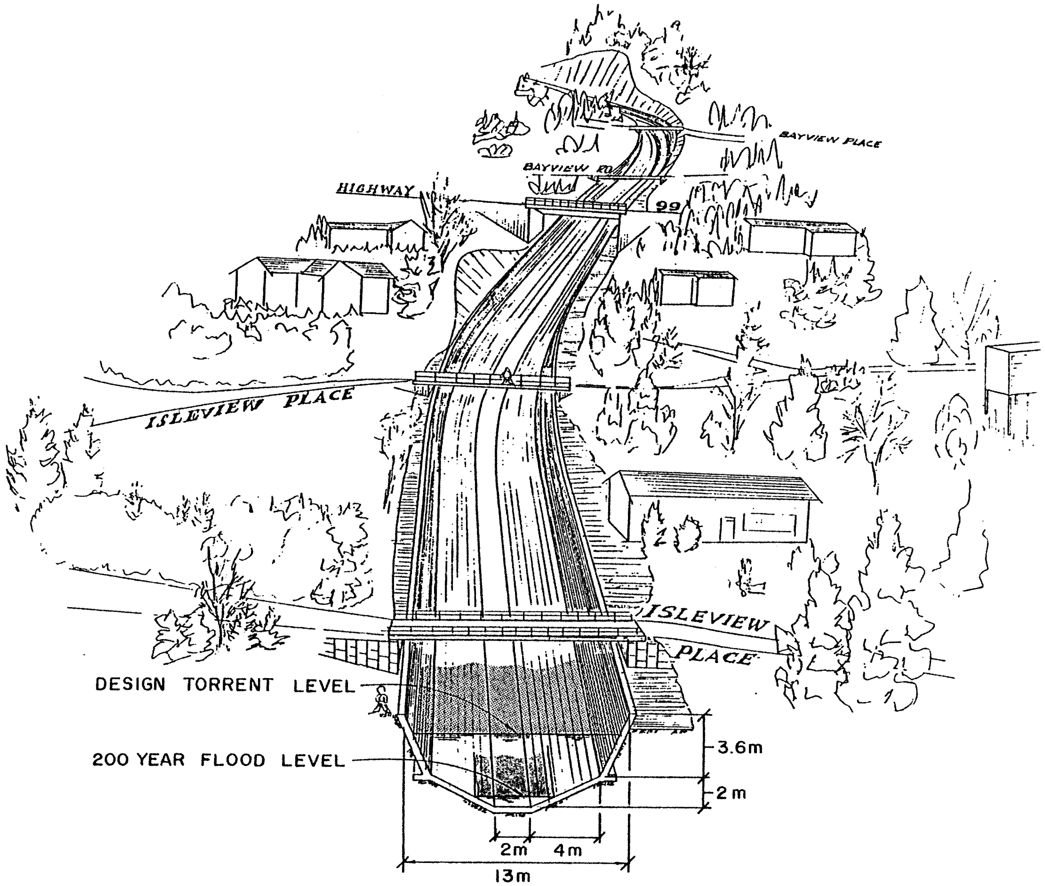


FIGURE 6: Harvey Creek Debris Barrier.

Destruction resulting from
1983 Debris Torrent



Proposed Channelization

FIGURE 7: Alberta Creek, Lions Bay

determinable and constituted a transferred risk to the residents located downslope of the diversion channel, who were not currently threatened by debris torrents. The alternative method of upgrading the existing channel was preferred. This comprised deepening and widening the channel and installing a concrete liner or chute (Figure 7). The 16° gradient of the channel is maintained by excavating the shoreline.

CONCLUSIONS

Geotechnical engineers involved in transportation projects are frequently called upon to evaluate the acceptability of risks from natural hazards. The most common hazards are landslides, avalanches, debris torrents and creek floods. Whether a risk is acceptable or not is commonly said to be a "matter of judgment". But one's judgment can be questioned if it is found to be lacking a logical thought process or rationale. The benefits of developing a rationale should be obvious and yet it is a procedure that is often poorly applied and even overlooked.

This paper shows that many risks from natural hazards can be broadly quantified and compared to other risks that society commonly assumes. The engineer should also be aware of precedents that have been established either by the courts or by public authorities who are responsible for ruling on safety.

Applying a good rationale will bring into focus situations where risk is unacceptable and identify those requiring mitigation. Further, it could indicate a need to involve others in the decision process. At the very least, it will provide a better defence against inevitable accusations after the event.

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