Debris Flow Mitigation Works, Foothills Bypass, Tuen Man

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ABSTRACT: Foothills Bypass (now re-named as Lung Fu Road) was officially opened in March 2002. This scheme provides a bypass road along the base of the Castle Peak Foothills to relieve the traffic burden along Lung Mun Road.

The large man-made cut slope immediately above the Castle Peak section of the new road (Tuen Mun Area 19) has experienced continuous displacement for more than 20 years. Channelised debris flows from the hills above the proposed route also present a significant geotechnical hazard, with the largest flow in 1990 involving some 10,000 m^3.

In response to these hazards the road was formed on an embankment that acted as a toe weight to stabilise the cut slope, with the road embankment also forming a dam to trap major debris flows from the hills above that might otherwise traverse the road in the future.

Although this arrangement served to address the direct hazards to the road at the design stage, it was considered prudent to construct check dams in the natural valleys above the man-made cut slope and surface drainage system in order to provide a degree of protection to the cut slope from smaller-scale, more frequent debris flow events. It was also anticipated that such an arrangement would encourage deposition of debris in large debris flow events, thereby reducing the potential for damage to the cut slope in such cases. Nevertheless it was accepted that in the event of a major debris flow event, such as that in 1990, the check dams could be irreparably damaged and might need to be replaced.

During construction it was established that rockhead was deeper at the proposed check dam locations than had been anticipated, requiring that piled foundations be introduced. In the light of this finding the opportunity was taken to conduct a cost-benefit assessment in order to determine the way forward. This assessment indicated that the construction of the check dams was not justified economically and, as a result, they were deleted from the works. In their place, less visually-intrusive debris flow deposition basins were constructed in each valley as a prescriptive measure.

This paper broadly describes the approach taken in the cost-benefit assessment, as well as outlining the debris flow mitigation measures that were finally implemented.

Whilst such an approach is not applicable to all cases, for example where there is a clear life-threatening risk, it is recommended that in future cost-benefit assessment form a more routine element of the design of mitigation measures against natural terrain failures.

1 INTRODUCTION

Scott Wilson Ltd. was commissioned in 1995 by the Territory Development Department of the Hong Kong SAR Government to investigate, design and supervise the construction of the Foothills Bypass (now re-named as Lung Fu Road). This scheme was to provide a bypass road along the Castle Peak Foothills, aimed at relieving the traffic burden along Lung Mun Road by diverting most of the heavy vehicles coming from Tuen Mun Area 38 and Tuen Mun southwest. Of its overall 2.6km length, 1.7km was to be below the foothills of Castle Peak (Tsing Shan).

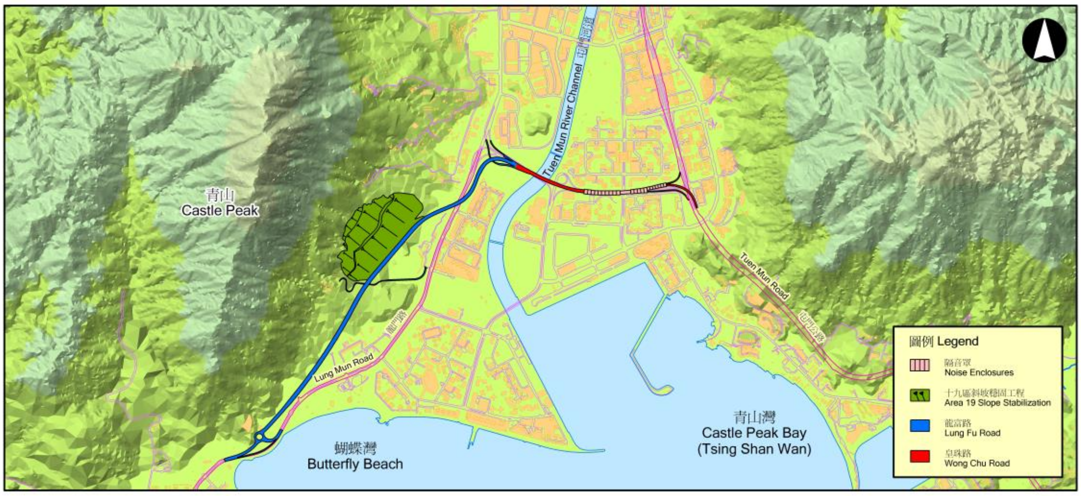

FIGURE 1: Plan of the route of Foothills Bypass (Lung Fu Road)

The large man-made cut slope immediately above the Castle Peak section of the proposed road (Area 19, as shown on Figure 1) has experienced continuous displacement for more than 20 years. Debris flows from the hills above the proposed route also present a significant geotechnical hazard, with the largest flow in 1990 involving some 10,000 cubic metres (see Plate 1). This event, with a return period of perhaps 100 to 1000 years, as well as the debris flood of 1992 served to focus attention on natural slope failures in this area and their potential to develop into destructive debris flows, floods and torrents at lower levels (Langford and Hadley 1990, Chan et al 1991, King 1996).

PLATE 1: 1990 debris flow

The upper very steep slopes of the Tsing Shan massif (see Plate 2) dominate the landscape of the study area and comprise megacrystic granites. The slopes are essentially devoid of any superficial surface cover other than local and generally shallow talus and colluvial deposits. The granite massif gives way downslope to a distinct set of rounded spurs and associated less steep slopes, typically between 30 and 40^o, which are underlain by meta-sediments of the Tsing Shan Formation. These moderately steep slopes are covered by a relatively thin mantle of immature hillwash, largely derived from the meta-sediments. Further downhill, and marked by another change in gradient, the footslopes of Tsing Shan form a subdued and gently sloping landform underlain by volcanics of the Tuen Mun Formation. These continue to the shore and recent reclamations. Large areas of the footslopes (ie Area 19 on Figure 1) are prone to landslip, despite the shallow angles. These slopes are also covered by large tracts of colluvium containing a high proportion of granite clasts, with both older, weathered and locally cemented colluvium and a younger looser colluvium being present. These materials have found their way onto the footslopes both by debris flow and by less intense transportation processes. Although the more recent events that can be identified from field mapping and aerial photographs have not been dated, most are considered to be old on an engineering timescale.

PLATE 2: Area 19 cut slope in the foreground and Tsing Shan massif above (before construction)

2 GEOTECHNICAL CHALLENGES

Key geotechnical objectives of the Foothills Bypass Project were to:

- Stabilise the man-made cut slope along the foothills above the proposed route (Area 19)
- Protect the new road from natural terrain hazards i.e. debris flows emanating from Castle Peak (Tsing Shan)

This paper concentrates on the latter.

Hazard assessment conducted during 1996 identified that large-scale debris flows emanating from Castle Peak could be anticipated and these would probably traverse the proposed route (SWK, 1996 and Hadley et al, 1998). It was also concluded, however, that such large-scale debris flows could not practically be prevented from traversing the man-made cut slope above the proposed road and that, if such an event occurred, there would be some associated damage to that slope.

The natural terrain hazards, and the marginal stability condition of the man-made cut slope immediately above the proposed route, were key components that dictated the final form of the road below Castle Peak.

In response to these geotechnical challenges it was determined that below Castle Peak the road should be formed on an embankment. This served two purposes:

- In addition to the embankment forming a toe weight that served to improve the stability of the cut slope,
- The road embankment would also form a dam that would trap the major debris flows from the hills above that would have otherwise traversed the road in the future.

Other components of the slope stabilisation included reducing the gradient of the man-made slope by placing fill over the lower levels, constructing 6m deep trench drains and installing a comprehensive surface drainage system

The road embankment was engineered so as to provide a retention volume that was more than sufficient to capture any debris flow that could be envisaged, including worst credible flows of a larger scale than the Tsing Shan debris flow of 1990 (Hadley et al, 1998). Consequently, by placing the bypass on an appropriately sized embankment, it was determined that the road itself would not be at risk.

Nevertheless, as there was to be significant investment in the slopeworks, during design it was considered prudent to include pragmatically-sized check dams as prescriptive elements in the four natural valleys above the man-made cut slope. The benefits of this decision were that:

- The check dams would serve to protect the cut slope below from the more frequent small-scale debris flow events;
- They would tend to promote deposition of debris flow material and, through this process, serve to inhibit the development of larger-scale events that might flow down on to the man-made slope below and, in the extreme, would eventually be trapped behind the road embankment at the foot of that slope. This would minimise the scope and cost of future slope maintenance.

It was accepted, however, that in the event of a major debris flow, such as that in 1990, the check dams could well be irreparably damaged and might need to be replaced.

The sizes of the check dams were constrained by the topography in each valley, with potential storage volumes ranging up to about 500m^3. These dams were designed to be founded on rock, which was anticipated to be at reasonably shallow depth.

The response to the natural terrain hazards at this site can therefore be seen as a two-tier system, with differing criteria applying to the design of the road embankment (primary defence) and check dams (secondary defence).

3 FINDINGS DURING CONSTRUCTION

Trial pits and boreholes were implemented to confirm the foundation requirements before construction of the dams commenced. This work proved that rockhead was considerably deeper at the check dam locations than had been anticipated.

In the light of this finding the design of the check dams was reviewed; the recommendations of SPR 1/2000 (GEO, 2000) coincidentally promulgated at this time were also taken into account in this review. This design review indicated that piled foundations would have to be introduced, considerably increasing the cost of the check dams. Given this conclusion the opportunity was taken to conduct a cost-benefit assessment in order to determine the way forward. This is outlined in the following section.

Before a conclusion had been reached on the way forward, a debris flow was triggered in Valley 4 on 14 April 2000 (see Plate 3). The debris flowed down onto the slopeworks being implemented below. Whilst such an event was well within contemplation (amounting to some 300m^3 in volume at the location of the proposed check dam, with a total volume of some 1500m^3), it provided further data on the likely return periods of channelised debris flows and also the damage that such events could cause.

PLATE 3: Debris flow of 14 April 2000 (left of centre)

4 COST-BENEFIT ASSESSMENT

The key assumptions made when conducting the cost-benefit assessment for the mitigation measures to be constructed in the valleys above the Area 19 slope were that:

- The small-scale debris flow event of April 2000 was likely to have a return period of the order of 10 years;
- The design event applicable to the debris flow mitigation measures in the four valleys (after SPR 1/2000) was therefore taken as 300 m^3 (ie comparable to the April 2000 event and anticipated to have a return period of 10 years);
- The mitigation measures (whether a check dam or other form of mitigation) would not be expected to cater for larger debris flows that would overtop the dams, traverse the Area 19 slope and be trapped behind the road embankment below.

Costs were estimated for a number of scenarios, covering:

- Check dam construction (ie non-recurrent cost)
- Regular inspection and routine annual maintenance (ie recurrent cost)
- Repair following a 1 in 10 year event (either with check dam in place, or otherwise as appropriate for each scenario)

Costs were then compared over the design life of the Bypass (120 years) in order to ascertain the most cost-effective solution.

The main elements of cost are summarized in Table 1.

Cost Element	Components
Check dam construction (ie non-recurrent cost)	Construction cost of the check dams, including provision of maintenance access to the areas behind the dams.
Regular inspection and routine maintenance (ie recurrent cost)	<u>Where check dams built</u>: • Annual inspections (routine) of check dams by IOW • Annual maintenance of check dams • Valley inspections by geotechnical engineer <u>Where check dams not built</u>: • More frequent inspections by IOW • Annual inspections by geotechnical engineer • Annual maintenance
Repair following a 1 in 10 year event (ie the design event for check dams)	<u>Where check dams built</u>: • Clearing of debris from behind check dam • Reinstatement <u>Where check dams not built</u>: • Removal of debris • Repair of damage in valley and on slope below
Repair following a major debris flow event that traverses onto Area 19 slope (ie greater than the design event for the check dams)	Not directly considered, as the cost of repairing such a major event would be the same for all scenarios. However, broad-brush estimates indicated that the cost of repairing a worst credible event (circa. 20,000m^3) might amount to \$70 to \$100 million.

TABLE 1: Main components of cost

These principal scenarios were considered in the cost-benefit assessment, with the results being presented in Table 2. The initial comparison made was between a scenario whereby a check dam was constructed in each valley (Scenario 1) as opposed to the case where check dams were not constructed (Scenario 2). This very clearly demonstrated that it was not cost-effective to construct check dams in all valleys i.e. it would be cheaper to repair the damage resulting from a 1 in 10 year event. However, as the highest hazard was considered to be posed by Valley 2 (the valley in which the large-scale 1990 event occurred), a further scenario was introduced whereby a check dam was only constructed in that valley (Scenario 3). This indicated that the decision was very finely balanced, with this third scenario being only marginally more expensive than the case where no check dams were constructed.

Scenario	Non-Recurrent Cost (HK$ M)	Recurrent Costs over 10 years (HK$ M)	Repair for a 1:10 year event (HK$ M)	Total Recurrent Cost over 10 years (HK$ M)	Total Cost over 120-year design life (HK$ M)
1 Check dam constructed in all four valleys	41.8	4.0	1.5	5.5	107.8
2 No check dams	0	1.0	2.5 (i.e. an event in any one valley)	3.5	42.0
3 Check dam constructed in Valley 2, but not in Valleys 1, 3 and 4	5.2	1.25	2.5 (i.e. an event in Valleys 1, 3 or 4)	3.75	50.2

TABLE 2: Estimated Costs for Various Scenarios

Given the magnitude of the associated costs compared to the benefits it was decided to delete the check dams. However, the opportunity was taken to explore more economically-justifiable forms of mitigation measures that would serve to constrain and reduce the damage that would otherwise result from small-scale channelised debris flows. The final form of mitigation measure that was adopted is outlined in the following section.

PLATE 4: Later Stages of Construction at Area 19, before construction of mitigation works

5 MITIGATION MEASURES FINALLY IMPLEMENTED

As a result of this review it was determined that the most appropriate form of mitigation would be to construct basins at the foot of each valley that would:

- retain debris flows up to the design volume;
- encourage deposition of debris in large events before traversing onto the cut slope below.

The prescriptive mitigation measures were designed to be as economical as possible utilising second-hand materials wherever possible and making use of the existing topography to maximise the depositional area above the drainage intakes at the head of the Area 19 cut slope.

The main elements of the debris flow deposition basins were to:

- Form each debris flow depositional basin a short distance above the intakes to the drainage culverts that run down the cut slope below;
- Encourage deposition by constructing 1m diameter, 0.8m high baffles staggered at a 2m spacing across the basin, thereby reducing the energy of the debris and promoting deposition;
- Implement as little cutting and filling as possible;
- Protect the floor of the basins with rubble stone pitching, tieing in with the headwall of the culvert intakes below;
- Protect the side slopes of the basins with grasscrete or gabion baskets depending on the gradient, with the stone used for the baskets won from excavation elsewhere on site;
- Construct boulder-straining structures in front of the drainage intakes to prevent blockage by large boulders that do not deposit in the basins. To reduce costs, these structures were formed using second-hand galvanised “I” beams, spaced 1.5m apart;
- Install trash screens on all intakes to retain cobbles and smaller boulders;
- Trim the natural valley sides upstream of the basins, together with the provision of erosion protection, in order to prevent local distress of the valley sides that could trigger failures and infilling of the basins.

The final form of the basins is illustrated in Plates 5 and 6.

PLATE 5: View of debris flow depositional basin looking upslope

PLATE 6: Downslop view of debris flow depositional basin

6 CONCLUSIONS

Cost-benefit assessment incorporating both construction costs and whole-life costs, has proved itself to be a valuable tool in the decision-making process for this Project. Whilst such an approach is necessarily broad-brush in nature (given the intrinsic uncertainties about the size and return period of debris flows and other assumptions that have to be made) it was an essential component of the decision to delete the check dams and to introduce debris flow depositional basins at this site. The decisions that were made as a result were defensible, with the long – term maintenance and repair implications and costs being clearly identified.

Whilst such an approach is not applicable to all cases, for example where there is a clear life-threatening risk, it is recommended that in future cost-benefit assessment form a more routine element of the design of mitigation measures against natural terrain failures.

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