Landslide risk assessment for residential dwellings on known landslides

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ABSTRACT

This paper presents the method and outcomes of two risk assessments undertaken in general accordance with the Australian Geomechanics Society "Landslide Risk Management Concepts and Guidelines", 2000. Risk assessments were undertaken for residential dwellings on two recognised landslides within weathered Devonian age acid volcanics and within weathered Tertiary age basalts.

Desk studies and engineering geological mapping were undertaken for the two known landslides to assess the failure mechanism, likely frequency of slipping and elements at risk from future landslides. The results suggest that, within the weathered acid volcanics a rapid landslide had previously occurred, and is a feasible future event. However, the landslide was assessed to be greater than 10,000 years old and relatively stable suggesting a low likelihood of future landslides. Within the weathered Tertiary basalts, reactivation of the existing landslide was identified as an event with a high likelihood. However, it was assessed that this event was likely to be very slow moving, with low consequences.

Prior to the risk assessments being undertaken, the local regulatory authority had generally considered residential development on recognised landslides as unacceptable. However, based upon an understanding of the landslide mechanisms, controlled residential development within tolerable or acceptable risk levels may be allowed on the landslides.

1 INTRODUCTION

The Shire of Yarra Ranges (Shire) is located on the eastern outskirts of Melbourne, Victoria. Historically, land use in the Shire has consisted of forestry and agriculture. However, since the 1950's and 1960's, Melbourne's population growth and urban sprawl has led to increased land use for residential purposes.

The majority of the Shire is underlain by Tertiary and older aged rocks. These rocks have been subject to intense tropical weathering up until the onset of climate change associated with cooling of the Southern Ocean and formation of the Antarctic Ice Cap about 5 million years ago. Consequently, the rocks within the Shire have developed deep lateritic weathering profiles. Landsliding within these residual soils has been reported for almost as long as there has been human settlement within the Shire (Lundy-Clark 1981). Much of this recorded landslide activity is thought to be associated with land clearance for forestry and agricultural purposes.

The Ben Cairn Estate in Don Valley was subdivided in the 1950's on land that had been previously cleared through forestry and agriculture activities. Development began in the 1970's when roads and some 16 houses were built. During initial excavation works, concerns were raised about the geotechnical stability of the Estate. A study by the Geological Survey of Victoria identified an ancient landslide covering an area of some 130 hectares (Nielson 1978). A subsequent geotechnical investigation comprising boreholes and surface seismic surveys supported these findings. Consequently, the governing Shire at the time halted all further development within the Estate. This ban on development has been in place ever since. However, houses within the Estate remain occupied.

In the 1990's and as part of studies to zone the Shire of Yarra Ranges in terms of landslide potential, a landslide covering an area of approximately 30 hectares was identified in Silvan South on the basis of observed geomorphological features (Coffey, 1999). At the time the extent of the landslide was delineated, there were a number of occupied houses on the landslide.

Under the Shire of Yarra Ranges erosion management overlay, recognised landslides are classified as "H", high risk from landslide. Under this classification, development is generally not permitted, However, residents in occupied houses in both the Ben Cairn Estate and in Silvan South have challenged the development restrictions prompting the Shire to commission further studies of both areas. A risk assessment in accordance with "Landslide Risk Management Concepts and Guidelines" (AGS 2000) was undertaken by the authors for both Ben Cairn and Silvan South.

This paper summarises the methods adopted in the landslide risk assessments, describes the conceptual models developed and presents the outcomes. It has not been possible to include full details on the selection of parameters used to develop the risk assessments. It is the authors intention to present this information separately at a later date.

2 CONCEPTUAL MODELS OF LANDSLIDES

In both cases a conceptual model of the landslides was compiled from information obtained in desk studies, geological and geomorphological mapping. The following describes the conceptual models that were formed using these techniques:

2.1 Ben Cairn Estate

As shown in Figure 1, the Estate is on the foot of a mountain, bounded by a river on its downslope side. Slope angles within the Estate are typically about 10°, steepening up to about 32° higher up the mountain.

Evidence that a large scale landslide has occurred includes the following:

- Drilling undertaken in 1979 and material exposed in road cuttings within the Estate suggest that the Estate is underlain by a layer of colluvium up to 10 m thick comprising subrounded cobbles of rhyodacite within a silty clay matrix. Geological mapping suggests that such material underlies the entire Estate.
- The ground surface within the Estate has a characteristic hummocky appearance.
- Although there is no distinct scarp, outcrops of relatively fresh rock are exposed on the hillside upslope of the Estate suggesting that the weathered mantle may have slipped off this material at some time in the past.

Evidence for small scale landslides within the Estate included the following:

- Two small scarps, about 10 m across within colluvium upslope of the Estate on slopes of about 20° were observed. Debris derived from the landslides was not observed. However, channels originating at the scarp were apparent, suggesting that material may have moved downslopes as debris flows.

Evidence for the mechanics of the landsliding includes the following:

- Colluvium exposed in road cuttings does not show any distinct grading. It comprises gravel to boulder sized rhyodacite fragments, generally slightly weathered to fresh and randomly distributed within the silty clay matrix. This implies deposition of a relatively fluid material through somewhat turbulent means. Possibly a debris flow or fast moving landslide.

Evidence for the timing of the landslide includes the following:

- There is no evidence of a landslide scarp suggesting that if it did exist after the initial landslide that it might have been eroded.

- Topsoil of up to 300 mm has developed above the colluvium over most of the Estate.
- There has been slumping within the colluvium, one significant slump associated with a road cut. However, there has been no report of major landslide movement within the Estate. Similarly the existing structures within the Estate do not appear to show any evidence of structural distress.
- The Don River has carved a channel of up to about 5 m deep in the colluvium at the base of the slope.
- The smaller scarps within the colluvium are well defined and show little or no evidence that they have been subdued through erosion.

Based on these observations, it was assumed that the major landslide occurred at least 10,000 years ago, probably more. This was a time when rainfall within eastern Australia was inferred to be higher than it is today. It was assumed that the landslide probably occurred in response to saturation of weathered rhyodacite comprised of cobbles and boulders within a silty and clay matrix. It moved rapidly from the slopes of Ben Cairn into the valley below, causing mixing of debris and deposition of the hummocky, colluvial deposit observed in the valley floor. The extent of the landslide is defined by this colluvium. However, the area on the slopes of Ben Cairn from which the colluvium derived is less well defined. The rock outcrops on the slopes above the Estate, suggest that the weathered mantle that typically overlies the rhyodacite has been removed and that it could be the source of the colluvium in the valley floor. The area defined by the rock outcrops is much less than that defined by the colluvium on the valley floor. It is possible that debris from a smaller area fanned out as it moved down the slope and was deposited on the valley floor.

The colluvium is a poorly consolidated, weak deposit. The smaller scarps, on steeper parts of the colluvial deposits, appear to be recent events, possibly having occurred in response to land clearing, logging activities and periods of high or prolonged rainfall.

A conceptual sketch of the landslide is shown in Figure 1, below.

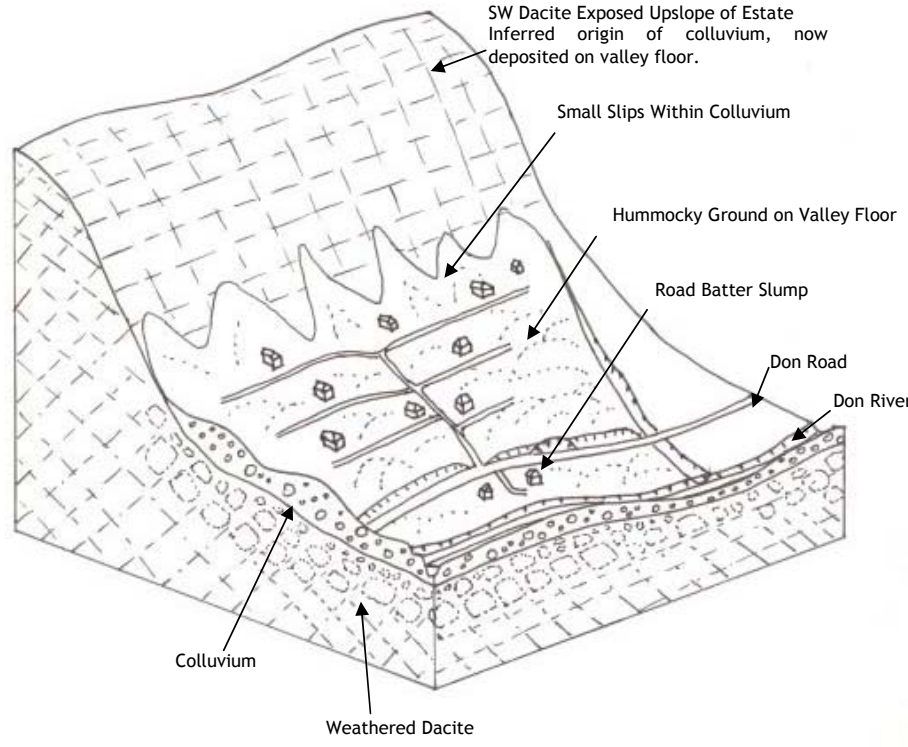

Figure 1: Conceptual Sketch of Ben Cairn Landslide

2.2 Silvan South

Evidence that a large scale landslide has occurred includes the following:

- Dinstinct terracettes and hummocky ground and
- Clearly defined scarps, exposing high plasticity residual basaltic clay.
- Reported landsliding within the vicinity. Ground movement within the preceding 10 years on adjacent properties has been reported and investigated (unpublished reports, Golder Associates 1993 and 1996).

Evidence for the mechanics of the landslide includes the following:

- Rate of ground movement associated with landsliding on adjacent properties and within the same material was reported to be relatively slow; less than 1 m per hour. Ground movement resulted in breakage of pipes and pavement cracking.
- The authors are not aware of rapid landsliding of natural slopes within Tertiary Basaltic Clay elsewhere within Victoria.

Evidence for the timing of the landslide includes the following:

- Geomorphologic features mapped on the landslide included sharp scarps and clearly defined hummocky ground. The lack of erosional features superimposed on those features inferred to have been formed by the landsliding suggest that they formed relatively recently. Probably within the past 200 years.
- Recorded ground movement within a similar geological and geomorphological setting on adjacent land.

Based on the geomorphological evidence it was assumed that the Silvan South landslide probably occurred within the past 1000 years. The clearly defined scarps and terraces within the landslide suggest retrogressive landsliding within the cohesive weathered Tertiary Basalt. Movement is likely to have been slow, incremental and triggered by heavy or prolonged rainfall. A conceptual sketch of the landslide is shown in Figure 2, below.

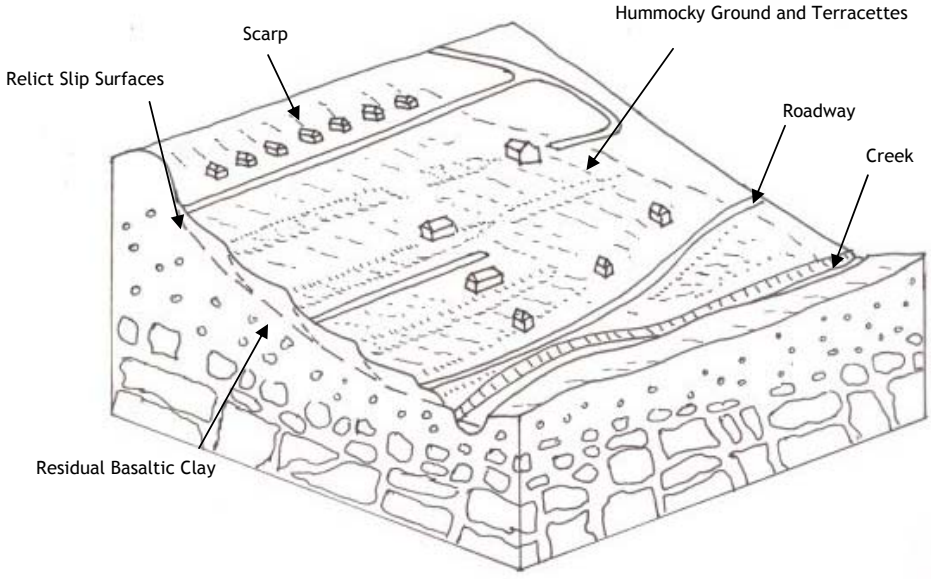

Figure 2: Conceptual Sketch of Silvan South Landslide

3 RISK ASSESSMENT

A risk assessment was undertaken in general accordance with Australian Geomechanics Society "Landslide Risk Management, Concepts and Guidelines", 2000 (AGS 2000) for both landslides. The following summarises how the conceptual models compiled for both landslides were used to assess the hazards and associated risks that the landslides present to life and property.

3.1 Hazards

Reactivation of the Ben Cairn Estate Landslide was not considered a hazard as the nature of its deposition did not form relict slip surfaces. Rather, recurrence of a similar landslide was assessed as a hazard. Additionally, the occurrence of new smaller landslides and possible debris flows within the colluvium, within and upslope of the Estate was considered to be a possible hazard.

Conversely reactivation of the Silvan South landslide was considered a hazard as the retrogressive mode of slipping was inferred to have formed numerous relict slip surfaces.

.2 Likelihood of Hazard

For reactivation of the Ben Cairn Landslide to occur, the rock upslope of the Estate would need to weather to clay. The initial weathering occurred during warm wet tropical climates that existed in eastern Australia for millions of years prior to the onset of the ice ages about 5 million years ago. For reactivation to occur, it was assumed that weathering over hundreds of thousands of years would be required and consequently a low likelihood of reactivation was adopted.

The smaller landslides were inferred to have occurred within the past 200 years. However, they appeared to have occurred on the steeper land within the Estate. The spatial probability of such a smaller landslide occurring was assessed by undertaking limit equilibrium analysis based upon strength properties that were measured as part of the 1979 geotechnical investigation. A baseline water table level based on standpipes installed in 1979 and springs observed within the Estate was established and a potential future 5 m rise in groundwater level assumed. Based on the analysis a landslide likelihood map was produced based upon current slope angles and the results of the limit equilibrium analysis. Where the factor of safety against failure given a 5 m rise in ground water level was less than 1.4, a high risk was assumed. Based on the topography within the Estate, areas downslope of areas designated as 'H' that could be impacted by debris flows were also identified and designated 'H'.

Reactivation of the Silvan South landslide was considered to be an event that could occur at least once within a 100 year period. This assessment was made by considering the apparent age of the landslide and through comparison of geomorphological features with adjacent landslides on which recent movement has been observed.

.3 Consequences of Hazard

The consequences of recurrence of the Ben Cairn Estate Landslide were assumed to be catastrophic, that is, most life and property destroyed. The consequences to a house from impact of a small scale debris flow within the colluvium was considered to be major in terms of both life and property.

The consequences of reactivation of the Silvan South landslide were considered to be very low in terms of loss of life, but high in terms of property. It was assumed that a residential dwelling founded upon land that moves slowly as a result of landslide reactivation could suffer structural damage. However, there would be adequate warning to allow evacuation prior to building collapse.

.4 Assessed Risk Levels

For each hazard identified on both landslides studied, the assessed risk levels were estimated both quantitatively (in terms of life) and qualitatively (in terms of property). Risk levels that were considered to be acceptable or tolerable were chosen on the basis of discussion with the Shire of

Yarra Ranges, consideration of risk levels used elsewhere in Australia, the risks that people are exposed to in everyday life and suggested levels published in AGS 2000. The following levels for annual probability of loss of life were adopted: $>10^{-4}$ –Unacceptable, 10^{-5} to 10^{-4} Tolerable, $<10^{-5}$ – 10^{-6} -Acceptable. For risk to property, the guidelines given in AGS (2000), Appendix G were used as the basis for establishing acceptable and unacceptable risk levels.

For the hazards assessed in the Ben Cairn Estate:

- The annual probability of loss of life given a large scale landslide at the Ben Cairn Estate was assessed quantitatively as between 1.8×10^{-5} and 7.5×10^{-5}, tolerable. Although this would be a catastrophic event, geological and geomorphological evidence suggests that the likelihood of the event would be sufficiently low. The risk to property was also assessed as tolerable.
- For the risk posed by a small scale landslide, those areas where the factor of safety against failure given an assumed 5 m rise in groundwater levels is less than 1.4, or those areas that could be impacted by a small scale landslide originating further upslope were considered unacceptable. Correlation between factor of safety and probability was made using the methods outlined by Lee and Jones (2004). Similar risk levels were assessed for property.

It was recommended that controlled residential development could be allowed on areas of the Estate where the risk level in terms of small scale landslides was considered acceptable.

For the hazards at Silvan South the annual probability of loss of life given reactivation of the landslide was assessed qualitatively as between 7.5×10^{-5} and 9.0×10^{-5}; tolerable. The risk to property was assessed to be HIGH. It was suggested to the Shire of Yarra Ranges that although the risk to life could be maintained within tolerable or acceptable limits through engineered means, it would be unlikely that ground movement could be prevented and thus the risk to property would remain high. The Shire is investigating ways of managing the high risk to property whilst allowing restricted development to proceed.

4 CONCLUSIONS

The outcomes of two risk assessment case studies on known landslides have been summarised. These demonstrate that with an understanding of the age, origin and mechanics of the landslides, controlled residential development may be undertaken within tolerable or acceptable risk levels. These studies introduce an alternative approach to development planning on or within areas of known landslides within the Shire of Yarra Ranges.

5 ACKNOWLEDGEMENTS

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