Building on Marginal Land - Some New Zealand Experiences

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Summary Marginal land is here defined as a building site that is affected by one or more geotechnical hazards with a severity or frequency such that during its design life damage may occur to the structure. Marginal land may be suitable for residential use provided that adequate investigations are undertaken to define the geotechnical constraints, that appropriate remedial or protection works are implemented, and that the owner accepts a degree of risk to the property. Examples of successful building on marginal land include dormant landslide complexes, coastal areas, and flood-prone sites; whilst land subject to rockfall or erosion hazards may similarly be built on if appropriate protection measures are implemented. Professional advisers have important obligations to clients in such situations, and administrative authorities are encouraged to make greater use of s36(2) of the Building Act 1991 when approving such developments.

1. INTRODUCTION

New Zealand has a long history of residential development on so-called "marginal land", which is here defined as land subject to one or more of erosion, subsidence, landslide, debris deposition, and inundation hazards. The principal implication of building on marginal land is that damage may occur to the dwelling during its design life, and/or by inference to the site itself, but it is also clear that the occupants of the building or land could be injured (or even killed) if inadequate warning is given of an impending hazardous event. The definition is not meant, however, to imply that the land is necessarily unsuitable for residential development, nor that site-specific remedial, protection and/or warning measures cannot be put in place to effectively minimise the risk to the building and its occupants. The scale of the problem may range from inundation of a township by floodwaters to the impact of a debris flow on a single house site in a remote rural setting; and from the threat to a cliff-top dwelling as a result of ongoing toe erosion to landslide movement affecting dozens of houses within an urban area such as that at Abbotsford, Dunedin, in August 1979. This paper reviews building on marginal land in New Zealand, briefly considers the adequacy of existing legislation, addresses the acceptability of geotechnical risk in such situations, and examines the role of both the professional adviser and the administering authority.

2. GEOTECHNICAL HAZARDS

2.1 Basic Terminology

A hazard in the present context may be regarded as "the potential or actual danger (= threat) to human life or property which is posed by a natural process having a particular (often large) magnitude" (Bell, 1994, p3385), and not as the probability of its occurrence which is the definition used by some authors (see, for example, Varnes 1984; Einstein, 1988). The term "geotechnical hazard" recognises both natural and human-induced phenomena "which may pose a danger to life, property, or engineering works, or which may otherwise seriously impact on a local community" (Bell, 1994, p3388), and following Bell (1987) these can be grouped under seven major headings as settlement, landslide, erosion, flood, seismic, volcanic and loss of resources.

2.2 Relevant Legislation

Current legislation in New Zealand requires evaluation of land that is subject to erosion, falling debris, subsidence, slippage or inundation at the subdivision stage (s106; Resource Management Act 1991), with consent to be refused in cases where the territorial local authority is not satisfied that adequate provision has been made for protection of the land or buildings. Similar requirements exist for building consents issued under the Building Act 1991, and s36(2) provides additionally for granting of approval in situations where the land is subject to one or more of the specified hazards (as for the RMA s106 plus alluvion and avulsion) but the building work itself will not "accelerate, worsen, or result in" the hazard(s). In such cases the property title is to be suitably annotated by the District Land Registrar, ensuring that relevant information on the hazard(s) is available to future owners or purchasers, and subsequent subsections deal with removal of the annotation in certain circumstances and the liability of territorial authority staff in the event that damage occurs to a "tagged" property.

3. EROSION IN LOESS SOILS

3.1 Erosion Problems

Loess soils consist predominantly of silt-sized particles with varying amounts of clay and fine sand, having formed by glacial grinding processes and subsequent wind transport and deposition. They are extensively developed in the South Island and southern North Island, and are characterised by surface (sheet and rill) and subsurface (tunnel-gully) erosion in both direct airfall (in situ) and colluvial loess deposits (Bell & Trangmar, 1987). The processes involved include clay mineral dispersion, slaking, and physical entrainment of fine sediment, and chemical stabilisation methods have been developed to minimise soil erodibility (Bell et al, 1990). Residential development on the Port Hills in Christchurch involves much land that is "marginal" because of the potential for erosion and/or landsliding under natural conditions or as a consequence of construction on steep (15°+) side-slopes. Geotechnical concerns include shallow landsliding in the loess soils from concentrated seepage flows, subsurface tunnel erosion and enlargement resulting in ground subsidence, and siltation due to both overland flow on bare ground and tunnel-gully discharges.

3.2 Geotechnical Evaluation

Measures to minimise geotechnical problems in loess soils on the Port Hills include pole-frame foundations for houses, careful control of stormwater discharges, and the use of both hydrated and quick lime for soil stabilisation. Engineering geology evaluation of loess-covered slopes is normally required as part of the subdivision or building consent process, including site mapping (refer Figure 1 for a typical example), subsurface data on soil depth and properties, and laboratory testing to establish erodibility characteristics (Bell & Trangmar, 1987; Bell, 1994). Christchurch City Council frequently requires geotechnical data input and reporting prior to, during and following completion of engineering works to ensure that all constraints are adequately addressed, and close residential development of such "marginal" land is certainly geotechnically feasible.

4. ROCKFALL HAZARDS AND MITIGATION

4.1 Geotechnical Problems

"Falling debris" is specified as a geotechnical hazard requiring evaluation at both the subdivision and building consent stages of development, and the design and construction of mitigation measures should clearly form part of the approval process because of the potential dangers associated with the sudden mobilisation of rock or soil debris. Rockfalls may involve one or more of free-fall, bouncing, rolling or sliding depending on the slope geometry and other factors, and specific events can range from the release of an individual boulder on a slope to cliff failures involving hundreds of cubic metres of rock material. Geotechnical evaluation of rockfall hazards requires estimation of trajectory and runout zone characteristics, cliff-face inspection may be difficult because of access problems, and it is not feasible in most cases to predict the timing of failure. Typically remedial and/or prevention measures involve one or more of scaling of loosened blocks, construction of concrete buttreses, anchoring of individual blocks, protection fences or barriers, drainage installation and/or infiltration control, and slope revegetation. It can, of course, be argued that prudent planning would normally avoid building in areas such as talus slopes or active debris accumulation zones, whilst setback distance from the top of a cliff or bank is another matter requiring geotechnical judgement and careful investigation.

4.2 Christchurch Example

Rockfall hazards have been relatively important in Christchurch City since settlement first moved onto the Port Hills, where jointed lava flows and associated ash deposits are extensively exposed on steep slopes. In 1987 a building permit was issued by Council for a site in the suburb of Redcliffs which was located on the talus apron below a 50m (±) cliff face in basaltic lavas (Figure 2A), and the house subsequently suffered minor damage from rockfalls necessitating the erection of a wire mesh rockfall protection fence by the owner. In June 1992 some 50m^3 of rock failed suddenly onto the adjacent vacant section from the cliff face above, causing minor damage to a neighbouring dwelling that required the installation of ditch, bund and fence protection measures as well as extensive planting of the steep (30°+) talus slope (Figure 2B). The owners of the first property subsequently sued Christchurch City Council on the grounds that consent should have been refused for the original dwelling because the land was unsuitable for residential purposes, but the legal decision in late 1995 effectively endorsed the geotechnical evidence from both parties that the site was safe for occupancy with suitable rockfall protection measures (specifically a ditch, bund and fence system similar to that installed on the neighbouring property).

4.3 Kaikoura Example

In Kaikoura the University of Canterbury constructed a research facility within 4m of the base of a 45m high cliff in closely fractured (bedded and jointed) limestones dipping into the face (Figure

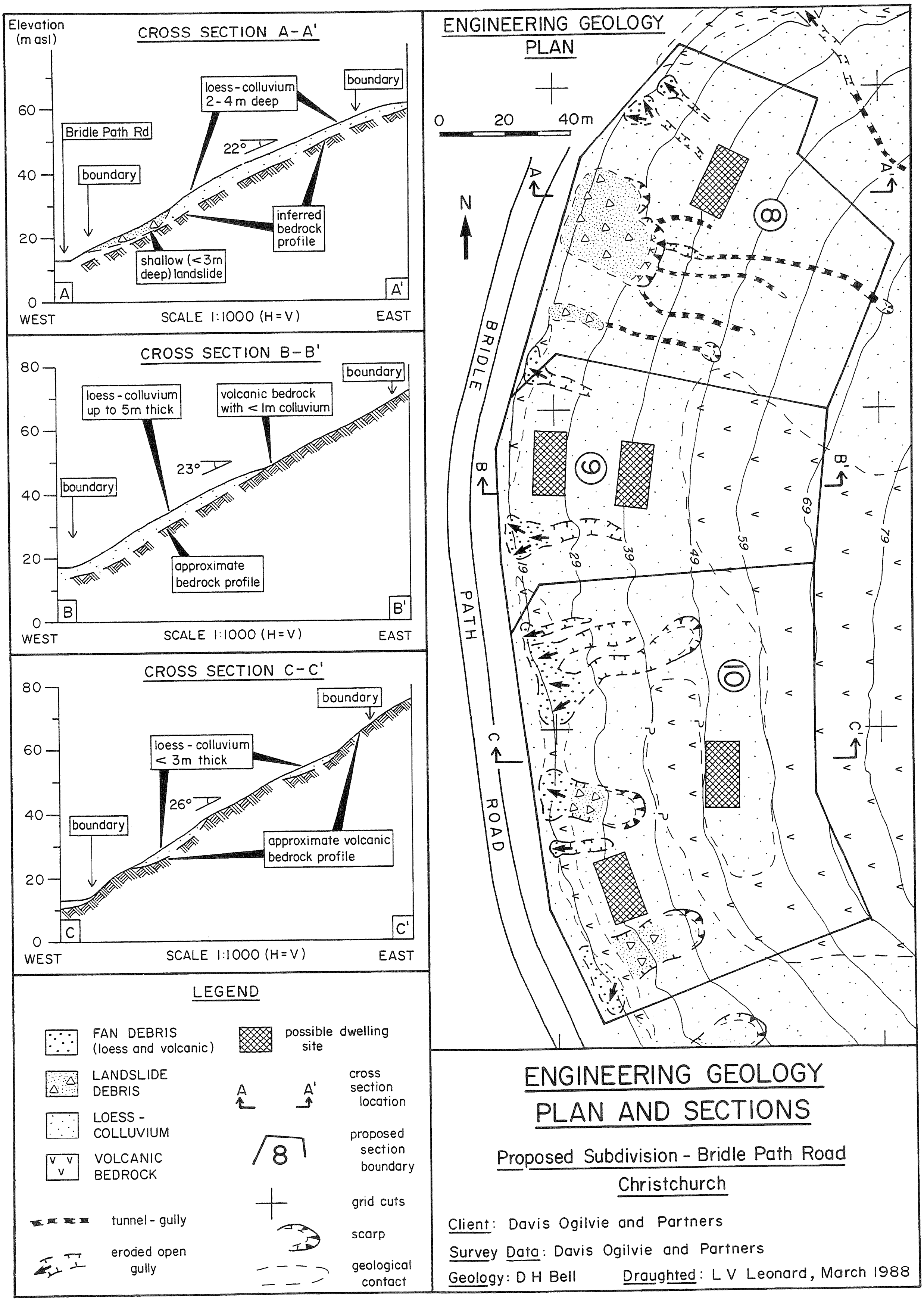

Figure 1. Example of engineering geology plan and sections for development on erodible leossial soils in Christchurch. (From Bell, 1994).

3A). In July 1992 two limestone blocks each of mass 100-150kg fell through the roof of the building following an intense rainstorm, causing minor damage and necessitating partial closure of the research facility. Immediate temporary protection of the building was achieved by placing hay bales on the roof, the face was then scaled by hand using a crane for access, and a rockfall protection canopy was subsequently cantilevered over the rear half of the building to provide additional security (Figure 3B). The wire mesh canopy is designed to deflect by 1m under an impact loading of 150kg, the rear of the building has been similarly protected with vertical wire mesh to deflect any boulders falling or bouncing from the lower slopes, and scaling will be carried out every 5-10 years in order to minimise the risk of future large rockfalls (Figure 3B). Although the building permit was issued under the previous Local Government Act 1974, similar provisions existed concerning hazards from "falling debris" and it appears that neither the local Council nor the designers of the research facility considered the possibility of rockfalls at this site despite its location at the base of a high cliff.

5. CONSTRUCTION ON LANDSLIDES

5.1 Problem Definition

Many dwellings in New Zealand have been, and continue to be, built on landslides, one of the better known cases being the Tahunanui Slump in Nelson City where some 120 houses are located on a well-defined pre-historic 26ha slide complex (Johnston, 1979). Movement was first observed in 1893, approximately 2ha was reactivated in 1929 by the Murchison Earthquake, and in 1962 a further 1ha moved following a prolonged wet period: the local Council has since installed and maintained a stormwater system and has implemented strict controls on earthworks which have effectively stabilised the feature, although its stability is clearly "marginal". In the present context emphasis is being placed on the construction of residential housing on dormant or relatively inactive landslide features, rather than on sites undergoing obvious movement or areas involving first-time slides. The 1979 Abbotsford Landslip in Dunedin can be regarded as an example of the latter, with triggering factors including the site geology, the presence of a low shear strength failure surface at depth, an elevated (and rising) water table, and substantial excavation in the toe area (Bell, 1987; Smith & Salt, 1988).

5.2 Queenstown Examples

Engineering geology evaluation of land in the Queenstown area has been required at the subdivision approval stage since 1981 because of concerns about the stability of the steep till-covered schist slopes (Bell & Pettinga, 1985), although there is no history of slope failures affecting residential properties there except for localised foliation-controlled failures in excavated schist batters. Pressure for urban expansion has, however, resulted in residential development proposals for some of the very large dormant landslide complexes in the District, notably the Coronet Peak Landslide which has an estimated volume of about $10^9 m^3$. (Bell & Riddolls, 1992). A condominium development proposal was approved in 1988 on the lower slopes of the landslide complex following an engineering geological assessment of the site which concluded that there was no evidence for present or recent slope instability, and that the construction would not cause any further instability if adequately engineered (Figure 4). On the nearby Arthurs Point Landslide approximately 12 houses had been built before recognition of the feature, and further development has now been approved on the more stable parts of the complex subject to strict engineering controls that include compaction, drainage, foundation slab reinforcement, and batter retention. These two Queenstown examples demonstrate that dwellings can be constructed successfully on dormant landslides, but clearly there remains a risk of renewed movement in the longer term even though the geomorphic evidence suggests that it is several hundreds to probably thousands of years since the last significant movement.

6. COASTAL HAZARDS

6.1 Problem Definition

Many residential developments in New Zealand are located in close proximity to the sea, either within dune complexes or at the base or top of cliffs, and geotechnical problems such as erosion and instability have arisen in a number of instances (Bell, 1987). In Christchurch City 12 dwellings had been permitted on South Brighton Spit seawards of the 1950 shoreline position, and although the shoreline is prograding there is a significant risk of short-term storm-induced erosion on what is a very dynamic geomorphic feature (Kirk, 1983): now further building development is strictly controlled within a designated Residential Coastal Zone, and elsewhere a minimum 20m wide hazard zone has been adopted with preservation and maintenance of the foredune area. A variety of approaches have in fact been adopted for coastal hazard mitigation in New Zealand, the most common being that of Gibb (1981) whereby a 100-year hazard zone is defined from historic data, but geotechnical problems remain in what is a dynamic natural environment involving clearly "marginal" land. Attempts have also been made to establish criteria for setback distances from cliff tops, for example in the Tauranga area by Houghton & Hegan (1980), but there are serious difficulties with such an approach as the rate of cliff retreat may vary over time.

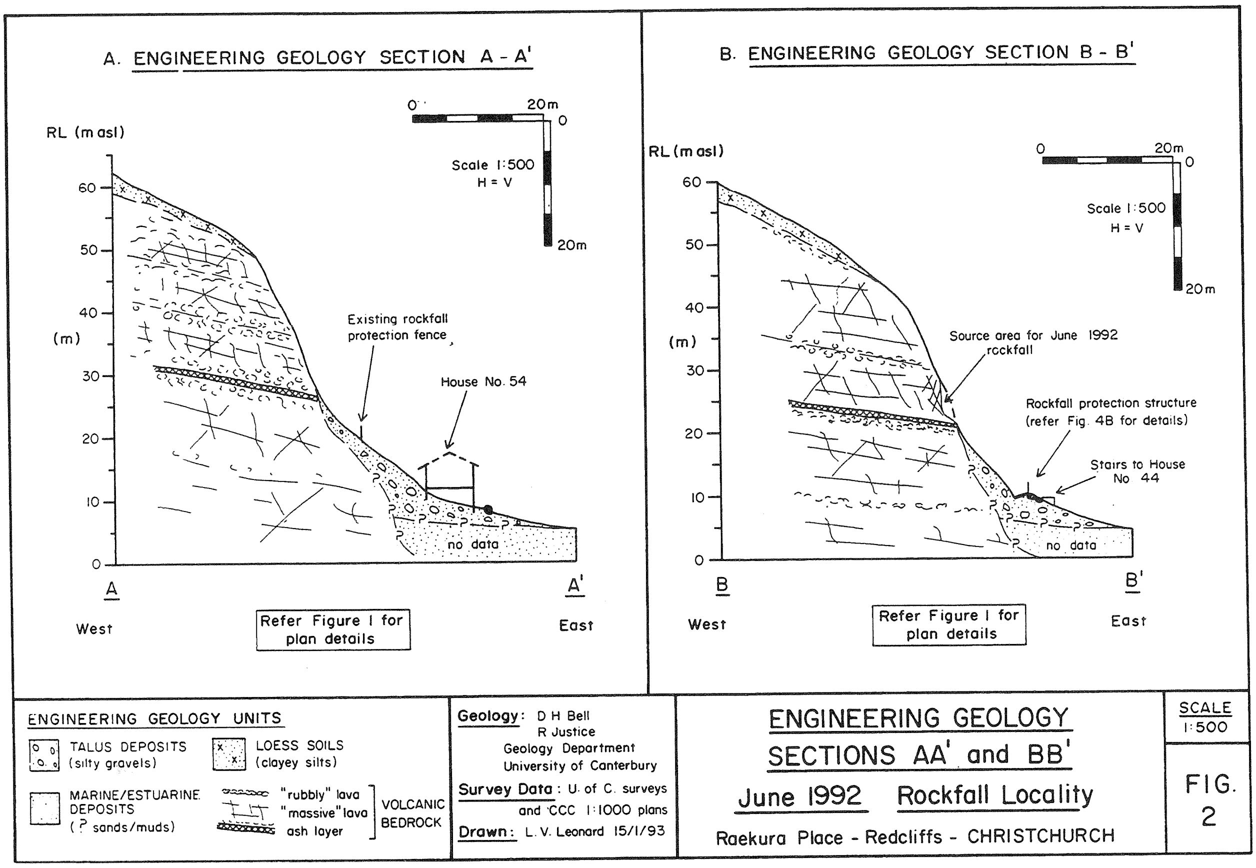

Figure 2. Engineering geology sections, Raekura Place rockfall site, Christchurch.

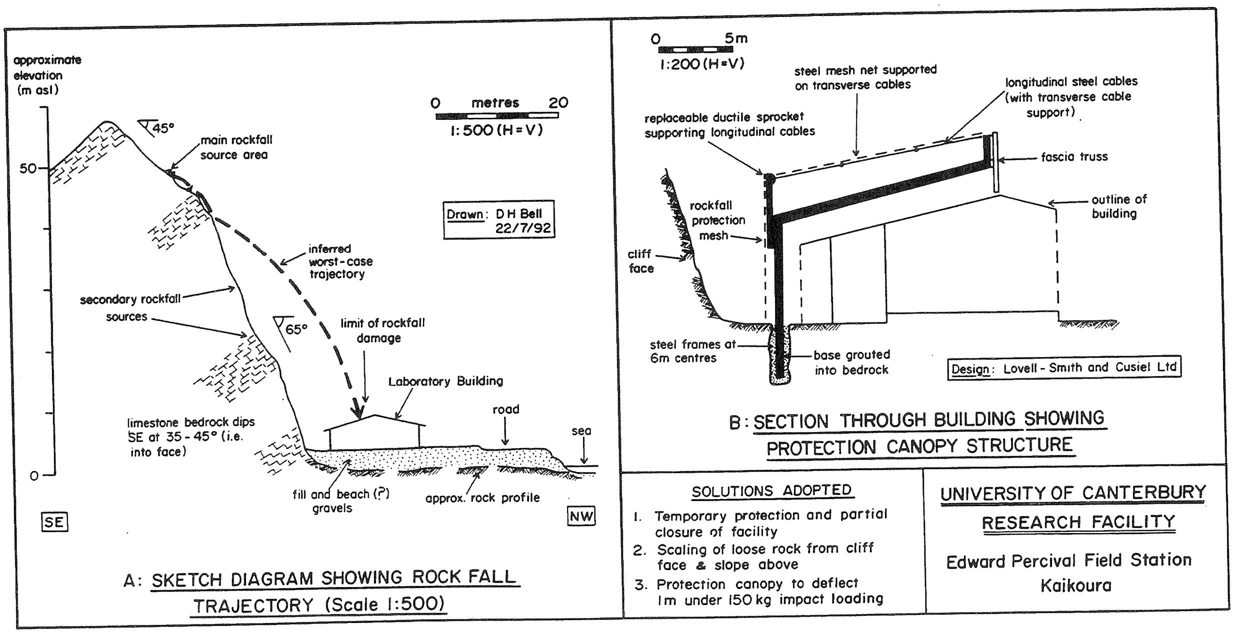

Figure 3. Rockfall hazard and protection measures, University of Canterbury research facility, Kaikoura.

6.2 Motunau Example

At Motunau Beach, North Canterbury, some 20m of cliff-top retreat has occurred in the last 20 years necessitating the relocation of one dwelling, although in the period 1890-1975 there had been no significant erosion (Bell, 1994). The 30-40m high cliffs are developed in essentially massive (ie unbedded) Pliocene mudstones and the failure mechanism involves shear fracturing within isolated columns greater than about 25m high, with subsequent removal of failed debris by slaking of the uncemented weak rocks (Figure 5). Cliff instability concerns have resulted in the establishment of a coastal hazard zone within which further subdivision and/or building is strictly controlled, whilst an attempt was made to construct a gabion basket wall some 15m out from the toe of the cliff in order to establish a buttress. The Motunau case study clearly illustrates the difficulties in predicting rates of cliff retreat as a planning tool, and also the significant effect that hazard recognition has on property values independently of any geotechnical evaluation or concern.

7. DISCUSSION

7.1 Geotechnical Assessment

The identification of geotechnical hazards and the provision of data on magnitude-frequency relationships are fundamental to any engineering project, including land subdivision, and engineering geology assessment of a site or area should therefore form the first stage of a geotechnical assessment (Bell & Pettinga, 1984). A systematic approach to the evaluation of land for residential use in New Zealand was developed as a result of the Abbotsford Landslip (Bell & Pettinga, 1985), with the methodology involving air-photo interpretation, engineering geology mapping typically at scales between 1:500 and 1:2000, subsurface data collection by trenching or hand augering, and limited characterisation of material properties using laboratory or field methods. Such investigations result in the formulation of engineering geology site models, the identification of geotechnical (and other) constraints to residential development, the specification of further site-specific investigations if or where appropriate, and recommendations concerning subdivision layout including access, building envelopes and foundation design requirements. The method is clearly applicable to any residential land, not simply that here identified as "marginal", and an engineering geology report on a proposed development is now a relatively common requirement by territorial authorities as part of the consent process.

7.2 Recurrence Intervals

The design (or useful) life of a residential dwelling can be taken nominally as 50 years, although a period of 100 years is often considered for the purposes of hazard analysis, and there may be considerable uncertainty in assigning magnitude-frequency data for a particular hazard affecting a specified site. In the present context "marginal" land has been defined as a building site (or sites) that <u>may</u> be affected by one or more geotechnical hazards during its design life, and this implies that approval should be given (or have been given) in terms of s36(2) of the Building Act 1991. However, many residential areas in New Zealand are subject to one or more of the hazards specified on a 50-100 year time-frame, and there is not undue community concern over problems such as inundation by floodwaters which is in fact the most frequently occurring geotechnical hazard in New Zealand. Similarly territorial authorities are reluctant to use the provisions of s36(2) except for sites subject to extreme geotechnical problems such as an actively deforming landslide or an eroding shoreline, and the intent of the words "subject to" in the relevant legislation remains unclear as there is no attempt to specify recurrence intervals or magnitudes for the particular hazards (except for 10% and 2% probabilities of inundation in the Building Regulations 1991). From a pragmatic viewpoint an evaluation of residential land that establishes its geomorphic development over time, and inter alia the frequency with which damaging events can be anticipated, is a realistic basis on which to issue consents and require specific mitigation measures where appropriate.

7.3 Setback Distances

One of the most difficult geotechnical issues for building sites on marginal land is the determination of setback distances from the top or base of a cliff or bank, whilst in gully areas there is also a requirement to adequately define runout distance (for example of debris flows). Given the geology and topography in New Zealand, and the increasing use of geotechnically more difficult land for development purposes, this matter will become even more important because of the professional judgement that is required in establishing realistic setback criteria. In Tauranga, for example, a zone defined by 2H:1V has been used to control cliff-top building envelopes (following the work of Houghton & Hegan, 1980), but geotechnical problems have continued as erosion and retreat of cliffs in soft volcanic soils is inevitable over time and there are also complicated groundwater factors involved. Whilst a knowledge of historic changes is clearly a realistic basis for assessment, experience suggests that natural processes may be rather more variable than might be expected and there is an

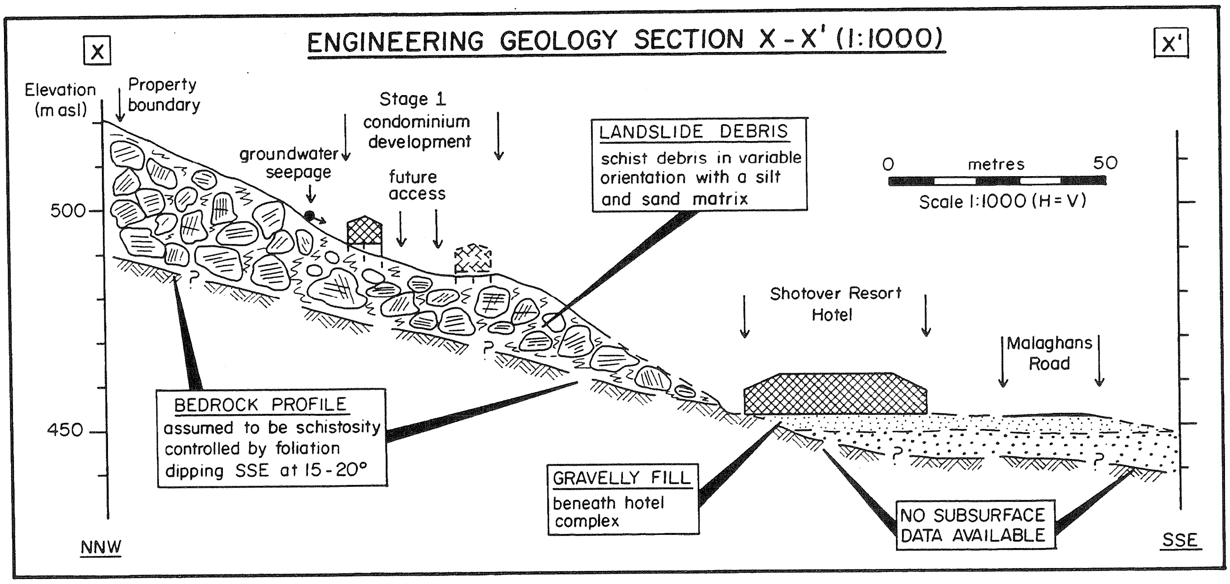

Figure 4. Engineering geology section through Coronet Peak Landslide, Shotover Resort Hotel site, Queenstown. (From Bell, 1994).

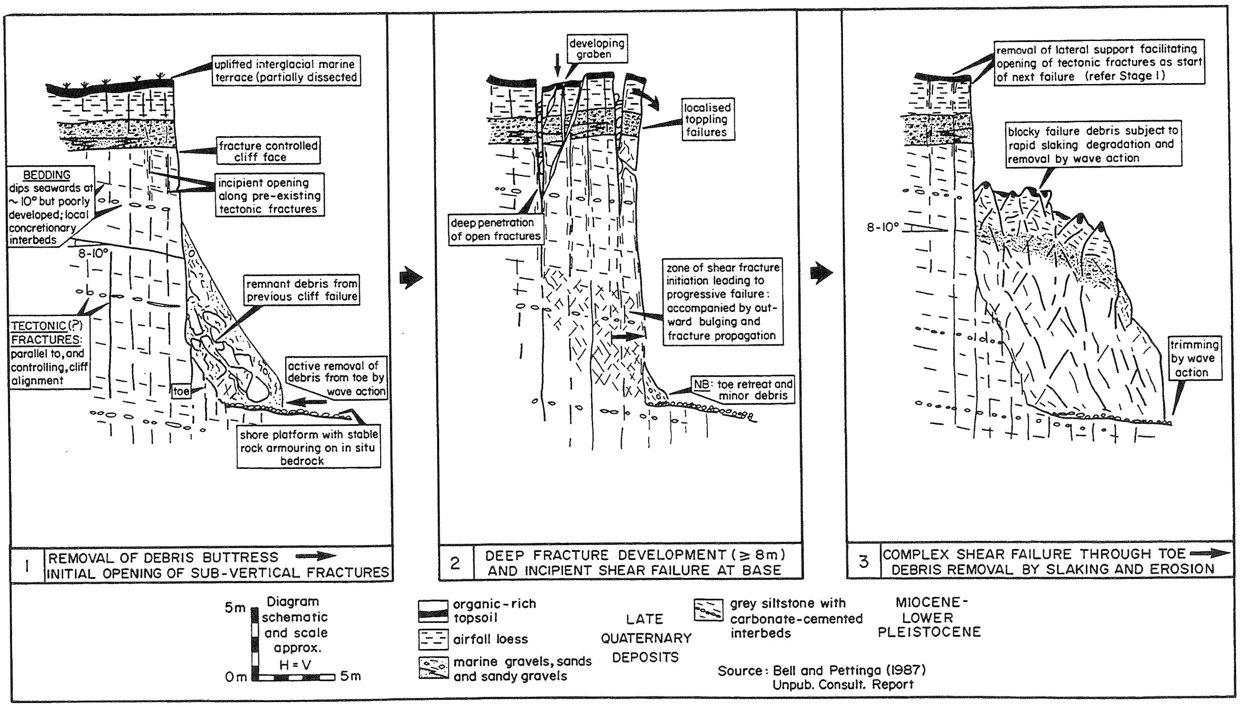

Figure 5. Engineering geology cliff failure model, Motunau Beach, North Canterbury. (From Bell, 1994).

obvious need for ongoing review and monitoring in areas where hazard zones have been identified and implemented for the control of residential development. Avoidance of areas such as the talus apron at the base of a cliff for residential purposes clearly has merit as a planning approach, at least unless site-specific geotechnical investigation and design of protection measures is required, but once land has already been zoned residential there is a reluctance on the part of territorial authorities to refuse consent and the impacts of consent refusal on property values can be severe in such cases.

7.4 Existing Developments

Where land that is subject to one or more hazards, such as flooding or landslip, has already been developed for residential purposes there are clearly administrative and related problems apart from the geotechnical issues involved. In such cases the costs of relocation or abandonment of "developed" marginal land are usually too great for community acceptance, even though the building sites and/or occupants may be at significant risk, and the perception only changes following a major disaster. Local authorities are now required under the Resource Management Act 1991 to establish "hazards registers" for all sites within their jurisdiction, but again if these are not compiled accurately the effects on property owners can be severe and may significantly affect resale potential and/or market value of the buildings or land. This area will remain an extremely difficult one for the geotechnical professional given that community perceptions of risk may differ significantly from those of the expert, and the continued use of "marginal" land within an existing residential area may in fact be the outcome.

7.5 Professional Issues

The role of the geotechnical professional in the development of "marginal" land is to clearly identify the nature of the site and any associated hazards or constraints, and to advise the client about the implications of building including the need for (and likely effectiveness of) any remedial or protection measures. Engineering geology has a key role in the assessment of such sites because of relevance to understanding the geomorphic history of the site or area, and the consequential implications for hazard recurrence. The risks of building on marginal land have clearly to be understood by all the parties involved, and care must be exercised in the wording of geotechnical reports so that all the issues are identified and addressed in a balanced manner. A recommendation not to proceed with a development proposal on land already zoned residential would require strong justification given the wording of s36(2) of the Building Act 1991, whilst support for such a proposal would similarly require careful wording so that the geotechnical professional was not subsequently found negligent or liable. If real concerns do exist about the suitability of a specific site or proposal then peer review is an option provided that the client agrees to the added costs, whilst involvement with a situation where the geotechnical hazard has already materialised requires considerable skill and understanding on the part of the professional adviser. An ultra-conservative approach would require that all land "subject to" geotechnical hazards be either refused consent or approved under s36(2) of the Building Act 1991, but this is clearly impractical given the commercial and other pressures for development on marginal land in New Zealand.

7.6 Administrative Matters

To date there has been a reluctance on the part of territorial authorities to approve developments under s36(2) of the Building Act 1991, in part because of some uncertainties regarding the new legislation. However, s36(2) is little different from s641A of the Local Government Act 1974 which it effectively replaced, and it is clear that building on "marginal" land has been taking place in New Zealand for many years with or without the benefit of geotechnical advice. Given this precedent it is possibly understandable that Councils are reluctant to unduly burden potential ratepayers, and no doubt developers and their legal advisers would oppose a s36(2) designation because of the implications for property values, resale potential, mortgage finance and insurance premiums (or even cover). In fact s36(4) of the Building Act 1991 effectively removes all liability from the Council officers if approval is given in terms of s36(2) and the hazard subsequently materialises, and it would therefore seem prudent for the use of a s36(2) approval until such time as all remedial and preventative measures are in place. A further problem with the current situation in New Zealand is that the Building Code, which came into effect at the same time as the Building Act 1991, specifies a factor of safety of 1.5 for all permanent slopes and this is clearly not feasible in the case of land having marginal stability on which it may be geotechnically feasible to construct a dwelling. It is therefore apparent that there are a number of administrative issues which must be addressed, as some confusion clearly exists with the current legislative requirements and also with the implications for the geotechnical profession.

8. CONCLUSIONS

1) "Marginal" land is here defined as a building site (or sites) affected by one or more geotechnical hazards with a frequency or severity such that during its design life damage may occur to the

structure, but this does not necessarily imply that the land is unsuited to residential development because it may be feasible to put in place appropriate protection measures.

2) Examples of residential development on marginal land in New Zealand include construction on dormant landslides, building in flood-prone areas, erection of dwellings in locations subject to rockfall or erosion/deposition hazards, and coastal housing in cliff-top and foredune areas.

3) Important professional responsibilities (and potential liabilities) exist for the geotechnical adviser when involved with development on marginal land, including the need for a thorough evaluation of the hazards and risks associated with the proposal and the careful reporting of any assessment or specific recommendations.

4) From an administrative viewpoint s36(2) of the Building Act 1991 clearly encourages residential development of marginal land as here defined, and greater use should be made by territorial authorities of this approval mechanism because of the clear identification of potentially hazardous the land and liability limitations on the part of the consent authority.

9. REFERENCES

Bell, D.H. (1987) Urban development practices in New Zealand. *Geological Society of Hong Kong, Bulletin 3,* pp. 43-65.

Bell, D.H. (1994) Surface engineering geology: a review. *Keynote Lecture to Sixth IAEG Congress, Amsterdam, August 1990. Proceedings,* pp 3381-3430.

Bell, D.H. and Pettinga, J.R. (1984) Presentation of geological data. Proceedings Technical Groups IPENZ, Vol. 9, Issue 4(G), I 4.1-4.35.

Bell, D.H. and Pettinga, J.R. (1985) Engineering geology and subdivision planning in New Zealand. Engineering Geology, Vol 22, pp. 45-49.

Bell, D.H. and Trangmar, B.B. (1987) Regolith materials and erosion processes on the Port Hills, Christchurch, New Zealand. *Fifth International Conference and Field Workshop on Landslides, Christchurch, August 1987.* Proceedings, pp. 93-105.

Bell, D.H., Glassey, P.J. and Yetton, M.D. (1990) Chemical stabilisation of dispersive loessial soils, Banks Peninsula, Canterbury. *Proc. 5th IAEG Congress*, Buenos Aires, pp. 2193-2208.

Bell, D.H. and Riddolls, B.W. (1992) Slope instability and residential development in the Queenstown area. *Field Trip Guide, Sixth International Symposium on Landslides,* February 1992, 16p.

Einstein, H.H. (1988) Special lecture: Landslide risk assessment procedure. *Fifth International Symposium on Landslides,* Lausanne, July 1988. Proceedings, pp. 1075-1090.

Gibb, J.G. (1981) Coastal hazard mapping as a planning technique for Waiapu County. *Water & Soil Technical Publ. No. 21*, NWASCO, Wellington.

Houghton, B.F. and Hegan, B.D. (1980) A preliminary assessment of geological factors influencing slope stability and landslipping in and around Tauranga City. *New Zealand Geological Survey Engineering Geology Report* EG 348, 18p.

Johnston, M.R. (1979) Geology of the Nelson Urban Area. *New Zealand Geological Survey Urban Series* Map No. 1, 52p.

Kirk, R.M. (1983) Public policy, planning and the assessment of coastal erosion. *New Zealand Geographical Society Miscellaneous Series* No. 8, pp. 182-196.

Smith, N. and Salt, G. (1988) Predicting landslide mobility - an application to the East Abbotsford Slide, New Zealand. *Fifth Australia-New Zealand Conference on Geomechanics,* Sydney, Proceedings, pp. 567-572.

Varnes, D.J. (1984) Landslide hazard zonation: a review of principles and practice. *UNESCO,* Paris, 63p.