1030

Laurie Richards

Rock Engineering Consultant

The Old School House • Swamp Rd • Ellesmere
RD5 Christchurch • New Zealand

Ph: +64 3 329 5663 • Fax: +64 3 329 5661
email: laurie.richards@attglobal.net

1030

TAURANGA DISTRICT COUNCIL

SLOPE STABILITY CRITERIA: B1/VM4 NZBC

Report prepared for:

Tauranga District Council
Private Bag 12022
Tauranga

Date: 19 November 2002
Reference: 10204.1.1

INTRODUCTION

1. This report has been prepared for Tauranga District Council (TDC) to provide guidelines and performance criteria for building consent applications under the Building Act 1991 where slope stability is an issue.

2. TDC's brief of 19 July 2002 for this work from their Land Development Engineer includes the following background comments:

   Changes to the NZBC approved documents, especially sB1/VM4, have removed any specific performance criteria from the approved document and have left the selection based solely on a practitioner's interpretation of the performance objectives and criteria of sB1-Structure of the Regulations. Formerly B1/VM4 included the requirement of a factor of safety (unfactored and static) of 1.5 for slope stability and settlement criteria were set at a maximum differential settlement of 25mm over a 6000mm (6m) length.

   You will note that the Verification Method relies heavily on prescription for the design of foundations but has removed from the text anything to do with the land on which the foundations bear. The former criteria now reside in the Appendices to this section and are listed as informative only with no requisite to adhere to in my opinion.

   It is our intention to have a set of robust criteria which takes into account varying situations from both a risk perspective and a geomorphic perspective that is appropriate and meets the performance criteria and objectives outlines in the regulations. It is expected that your completed work will provide us with guidelines that allow some flexibility in application without the need for a blanket criteria as was formerly the case (i.e. the blanket criteria of a FOS of 1.5 in all cases where a lesser FOS may be suitable where the geomorphic qualities of a slope, for instance, may allow for a lesser slope factor).

3. TDC has also drawn attention to the following quote from the Building Industry Association web page administered by Victoria University:

   All building work must comply with the Building Code.

   The Building Code is a performance-based code. It sets out objectives to be achieved rather than prescribing construction methods. The emphasis is on how a building and its components must perform as opposed to how the building must be designed and constructed.

   The Building Code is divided into clauses, and each clause begins with an objective. For instance, one objective is to "safeguard people from injury caused falling", another one is to "safeguard people from illness caused by infection from contaminated water or food ...". Specific performance criteria for each clause describe the extent that buildings must meet those objectives.

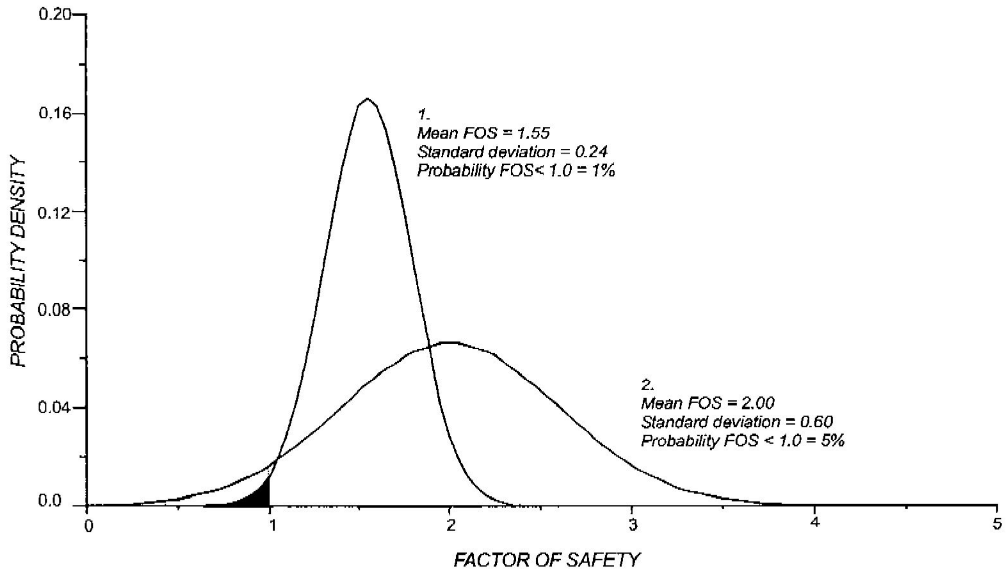
4. This report reviews previous NZ and overseas practice with respect to factors of safety for slopes, recent developments with the alternative of using probability-based criteria and provides some preliminary guidelines for discussion with TDC.

FACTORS OF SAFETY FOR SLOPES

5. The simplest definition of the factor of safety for slopes is that this is the ratio of the total force (0r moment) available to resist sliding to the total force (or moment) tending to induce sliding. The condition of limiting equilibrium (FOS = 1) occurs when the forces tending to cause instability are exactly the same as those resisting sliding. When the slope is stable, the resisting forces are greater than the disturbing forces and the FOS is greater than 1.

6. An alternative approach is to define FOS as the ratio of actual to mobilised shear strength. Shear strength involves a frictional as well as a cohesive component and the same or different FOS can be applied to these components.

7. The FOS does not necessarily provide a good indication of the probability that the slope will remain stable. The following figure[1] shows the probability distributions for two slopes with FOS = 1.55 and 2.00 respectively. The slope with the higher FOS = 2.00 would normally be regarded as safer than the slope with FOS = 1.55. However the FOS = 2.00 slope has about five times the probability of failure of the other slope (as indicated by the shaded areas under the curve for FOS ≤ 1.00).



8. The variations in the FOS of a slope arise from the variability of the input data for density, cohesion, friction, groundwater pressures, earthquake loading. Different results for the FOS will be obtained depending on which values from the range of possible values for input data are used in the stability analysis. General practice is to use the mean or expected values of the input data. However, the range of possible values is usually quite large so that there may be a tendency to manipulate the input data to obtain a desired FOS.

9. Further discussion on the factor of safety from Pierre Londe is given below:

> *The conventional assessment of safety in civil engineering works is obtained through a deterministic approach. . . In order to take account of the many uncertainties and of the scatter in the data, and also to cover the fact that models are necessarily approximate, a factor of safety is introduced. The margin between the real state and the minimum limiting state, which would be adequate in the absence of all uncertainties, is measured by the 'factor of safety', a scalar number supposed to lump together all imperfections in the data and the model.*
>
> *The numerical value of the factor of safety F has been determined empirically for different types of materials. It is common practice, for example, to use F = 1.50 in most of the stability analyses of geotechnical materials, soils or rocks. This numerical value has even been incorporated in many codes of practice, all over the world, and the argument is that a design which complies with such a standard must be completely safe. Unfortunately this is not the case. Firstly, because the value of the factor of safety will be different, depending on the mathematical model used and the associated definition of the factor of safety. Any reference to the value of a factor of safety therefore must state the method used in computing it.*
>
> *What is worse is that a given computed factor of safety represents a whole spectrum of widely differing failure probabilities, depending on the uncertainties in the input data (scatter, number of tests, quality of investigations and measurements, etc.). True safety may thus vary over a wide range.*
>
> *Figure 3 is a simple but striking example of how the failure probability may vary in a ratio of 1000 with the same factor of safety F = 1.5 if, for example, there are 5 instead of 20 tests (with the same scatter) or a scatter range of 0.10 to 0.30 over 10 tests. What conclusion is the engineer to draw in general, especially the rock mechanics engineer for whom stability is governed by a large number*

1 Riddolls & Grocott. *Quantitative assessment methods for determining slope stability risk in the building industry.* BRANZ study report no 83, 1999

of parameters? It is totally unjustifiable to base the stability assessment on a single figure bearing no relationship to rock engineering reality.

Safety Concepts Applied to Rock Masses

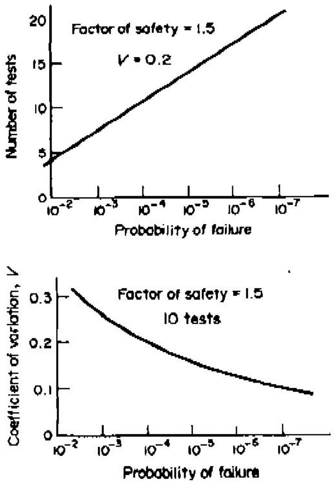


Figure 3 Probability of failure, for the same safety factor, *versus* number of tests and their scatter

PRECEDENT PRACTICE FOR FACTOR OF SAFETY

10. Hong Kong requirements for slope stability are summarised on Tables 1 and 2[2]. These make a distinction between *new slopes* and *existing slopes* where the performance history gives guidance as to their stability. The FOS requirements for these are quite different being 1.4 and 1.2 for new and existing slopes for a ten-year period rainfall.

11. Notably the guidelines include the requirement that *In addition to a factor of safety of 1.4 for a ten-year return period rainfall, a slope in the high risk-to-life category should have a factor of safety of 1.1 for the predicted worst groundwater conditions.*

12. It would not be appropriate to adopt the HK criteria to NZ for the following reasons:
    - HK geological conditions are generally more favourable and more uniform than the BOP
    - The HK guidelines are mostly for large developments where extensive geological investigations and laboratory testing are carried out as a matter of routine
    - Static and transient groundwater regimes under storm conditions are better understood than in the BOP
    - Designs are extensively checked and approved at various levels by the design engineers and the building authority
    - As-built plans and records are generally well kept
    - The public is well educated about the requirements for slope maintenance and there are established guidelines and procedures for regular slope maintenance and inspection[3]
    - The HK level of geotechnical input into slope engineering is several orders of magnitude more than in NZ for the same scale of problem

13. Recommendations by Hoek[4] for factors of safety of slopes are shown in Table 3. These recommend:
    - FOS > 1.3 for temporary slopes with minimal risk of damage
    - FOS > 1.5 for permanent slopes with significant risk of damage

14. For open pit mine slopes, factors of safety are sometimes lower than those used in civil engineering and typically range from 1.0 to 1.5 depending on the size and nature of the slope (see Table 4[5]). Earlier

[2] Geotechnical Control Office. *Geotechnical manual for slopes.* Engineering Development Department, Hong Kong, 1991

[3] Geotechnical Engineering Office. *Guide to slope maintenance.* Civil Engineering Department, Hong Kong, 1995

[4] Hoek E. *Rock engineering.* www.rocscience.com, 2002

[5] Sullivan TD. *Mine slope design – the chances of getting the answer right and the risk of getting it wrong.* Fourth Large Open Pit Mining Conf, Perth, 1994

recommendations by Priest and Brown[6] of FOS = 1.3 to 2.0 for mine slopes (Table 5) are now considered to be overly conservative. (For example, the resource consents for the Waihi Gold Mine open pit expansion were given for slopes designed to the guidelines in Table 4)

15. By way of comparison, the extensive remedial works for the landslides on the Clyde Power Project were designed to offset the stability reductions of 2 – 20% that would have been caused by lake filling. The final FOS of most of the landslides after remedial works was typically in the range from about 1.03 to 1.20. Failure of these slopes would have catastrophic consequences well beyond that caused by slope failures in residential subdivisions.

PROBABILITY OF FAILURE

16. Failure probability has been discussed in §7 above. Examples of design probabilities for mine slopes are shown in Table 6. These range from < 1% for overall slopes to 50% for bench slopes. Comparable guidelines for civil engineering are not as readily accessible, probably because of a reluctance to quantify the likelihood of failure. The BRANZ publication on quantitative risk assessment (QRA)[1] does not, for example, give any guidelines for failure probability.

17. Landslide QRA essentially involves determination of the probability of failure and an assessment of the potential number of fatalities arising from the event. The probability of fatalities is then compared a standard for acceptable societal risks (for example the amended interim ANCOLD criteria) to assess whether the risks are acceptable or unacceptable. For more details on a generic framework for risk management principles, reference should be made to Canadian Standard CAN/CSA-Q850-97, and Australia-New Zealand Standard AS/NZS4360:1999.

18. Given the complexities and difficulties involved in carrying out a proper QRA, it is unlikely that this process would be suitable for small subdivisions except in unusual circumstances.

COMMENTS AND SUGGESTIONS FROM NZ GEOMECHANICS SOCIETY MEMBERS

19. The subject of requirements for slope stability has been extensively covered for many years by NZGS discussions and papers (see Appendix A). Although there is a great variety of opinion on the subject, the nearest thing to an overall consensus is expressed in the Crawford & Millar paper (June 1988) and the Crawford suggested slope stability clauses (June 1999). These are summarised below:
    - An engineering geological evaluation is the first step in site stability assessment
    - A risk classification is used to determine the extent of investigation, analysis, design, supervision and monitoring
    - The FOS should be 1.5 for design conditions during the design life of the structure and 1.2 for extreme conditions including full saturation
    - If no detailed investigations have been undertaken, the FOS should exceed 1.5 for the case of full saturation of the slope
    - The slope FOS should be ≥ 1.2 for the 150 year return period earthquake. For retaining structures located further than 8m from the dwelling, a 50 year return period earthquake is considered.

20. Full saturation involves the groundwater surface being coincident with the slope profile. This is a very onerous requirement and one which would not often be achieved except in slopes subject to very heavy recharge and rainfall. Many high steep slopes would fail under this extreme groundwater condition. Despite the prevalence of tropical storm situations, HK guidelines do not require this extreme situation to be considered but predict design groundwater levels from extrapolation of observed piezometric responses during storms.

21. The Crawford and Millar paper together with the Crawford proposed clauses is a *de facto* NZGS guideline. It is consistent with international practice and is sufficiently conservative to be suitable for Building Code use. The requirement to consider full saturation may be unduly harsh in may cases but this is really intended to cover the situation where no detailed investigations have been undertaken.

RECOMMENDATIONS

22. The requirement for a quantitative slope analysis on all site works is debatable. Such analyses may be useless or misleading unless they are based on an adequate geological appraisal of the site. In many

---

6 Priest SD, Brown ET. *Probabilistic stability analysis of variable rock slopes.* Trans IMM Sect A, 1983

cases, a engineering geological assessment of the site by an experienced professional is preferable to the analytical approach.

23. The Council guidelines should not therefore presuppose that FOS calculations are always required or suggest that these should replace the engineering geological assessment.

24. For at least the last ten years, the NZGS has been discussing the matter of land subdivision and development engineering but, with the exception of the Crawford and Millar EQC paper, has made little progress with the development of guidelines on assessment of slope stability, review of risk classifications and other matters recommended back in 1988. As at December 2001, Standards New Zealand indicated that they would be approaching IPENZ with a view to setting up a case for new geotechnical standards for assessment of land stability, earthworks and foundation design. This would be an important step forward but will probably happen within a geological timescale. In the meantime, the Crawford & Millar proposals could effectively act as a *de facto* standard.

25. Proposals for FOS requirements are set out below. These are largely based on Crawford and Millar with modifications to the extreme groundwater conditions and allowing reduced FOS where there is high confidence in the geotechnical model.

CHECKLIST FOR STABILITY ASSESSMENTS

FACTUAL INFORMATION

1. INTRODUCTION
   - ☐ Report prepared for who?
   - ☐ Site Location
   - ☐ Outline of proposed development[(b)]
   - ☐ Comment on need for earthquake assessment
2. TOPOGRAPHY
   - ☐ Outline current landform (slope shape, height gradient, irregularities, erosion, soil creep/terracettes)
   - ☐ Outline surface drainage patterns[(b)]
   - ☐ Review aerial photos
   - ☐ Comment on any previous earthworks
   - ☐ Comment on any existing instability[(c)]
   - ☐ Additional site features (e.g. vegetation/trees structures[(b)] retaining walls, roads/driveways, services)
3. SITE HISTORY
   - ☐ Outline current/previous landuse
   - ☐ Comment on previous siteworks[(b)]
   - ☐ Reference "District Hazard Map"/GIS
   - ☐ Comment on previous instability[(c)]
   - ☐ Performance of existing structures
   - ☐ Review aerial photos
   - ☐ Comment on previous contamination[(c)]
4. GEOLOGY
   - ☐ Describe geological setting
   - ☐ Refer to relevant maps
   - ☐ Geological influences on stability (e.g. bedding, weak materials, faults)
   - ☐ Describe seismic setting
5. INVESTIGATIONS
   - ▸ FIELD
     - ☐ Inspection by geotechnical specialist
     - ☐ Descriptions of soils/rock in borelogs (Ref.1)
     - ☐ Outcrop/cutting descriptions[(c)]
     - ☐ Record Extent of any cracking[(c)]
     - ☐ Other field tests (e.g. CPT, etc.)
     - ☐ Monitoring of ground movements[(c)]
     - ☐ Groundwater measurements and observations (seepage, subsurface erosion)[(c)]
   - ▸ LABORATORY
     - ☐ Outline tests undertaken
     - ☐ Summarise results
     - ☐ Previous testing in local area
6. SUBSURFACE CONDITIONS
   - ☐ Geological interpretation[(c)]
   - ☐ Summarise subsoil conditions, e.g. extent of fill[(c)] topsoil, nature and distribution of soils/rock
   - ☐ Describe soil strengths/density, likely behaviour - refer to tests and logs
   - ☐ Highlight weak/sensitive/loose soils or rock defects
   - ☐ Describe groundwater conditions, subsurface drainage, expected seasonal fluctuations

APPENDICES

- ☐ Borelogs, Testpit Logs, Logs of Exposures (Ref.1)
- ☐ Laboratory Results
- ☐ Specifications for Remedial Works/Fills
- ☐ Site Photos

INTERPRETATION/DISCUSSION

7. SLOPE STABILITY (Ref. 2,3,4)
   - ▸ ENGINEERING GEOLOGICAL ASSESSMENT:
     - ☐ Discuss site features
     - ☐ Discuss geological setting/influences[(e)]
     - ☐ Influence of rainfall/groundwater
     - ☐ Reasons for landform (local, regional)
     - ☐ Likely slope failure mechanisms
     - ☐ Potential for Instability
     - ☐ Effects of the development on slopes[(f)]
     - ☐ Consequence of instability
     - ☐ Empirical assessment (qualitative)
     - ☐ Risk rating applied[(g)]
     - ☐ State whether stability analyses are required
   - ▸ GEOTECHNICAL ENGINEERING ANALYSES
     - ☐ Geotechnical slope model correct?
     - ☐ Analytical method stated
     - ☐ Determination of critical section of slope
     - ☐ Assessment of strength parameters
     - ☐ Assessment of groundwater profile/rainfall
     - ☐ Back analysis of any existing failures
     - ☐ External loads due to the development
     - ☐ State need for seismic analysis
     - ☐ Normal FOS requirements:
       - Static (Design gwt) FOS ≥ 1.5
       - Static (Extreme gwt) FOS ≥ 1.2
       - Seismic (150 year EQ) FOS ≥ 1.2
     - ☐ Sensitive analyses for parameters required?
     - ☐ Results and comments
8. GEOTECHNICAL EFFECTS OF DEVELOPMENT
   - ☐ Slope stability risk increased or reduced?
   - ☐ Is the development feasible?
   - ☐ Need to drain slopes (surface/subsurface)?
   - ☐ Need to remove/upgrade fill?
   - ☐ Subsurface drainage beneath fills?
   - ☐ Need to retain slopes/secure rock faces?
   - ☐ Foundation conditions/requirements
   - ☐ Effect of stormwater/effluent disposal
   - ☐ Effect of service lines rupture (e.g. SW, sewer)
   - ☐ Effect of river/coastal erosion
   - ☐ Seismic effects on development and slope
   - ☐ Maintenance requirements for life of the development

9. CONCLUSIONS AND RECOMMENDATIONS

10. STATEMENT BY GEOTECHNICAL ASSESSOR AS TO THEIR ABILITY & QUALIFICATIONS TO PREPARE THIS GEOTECHNICAL ASSESSMENT

DRAWINGS/FIGURES

- ☐ Site Plan[(d)]: ☐ Borehole/Testpit Locations
  - ☐ Outline of Proposed Development
- ☐ Site Engineering Geological Maps[(d)]
- ☐ Site Contours Maps[(d)] } Cuts and fills
- ☐ Cross Sections } indicated
- ☐ Geotechnical Model
- ☐ Stability Analyses Results

REFERENCES

1. Guidelines for the Description of Soils & Rock, NZ Geomechanics Society (1985)
2. Assessment of Slope Stability at Building Sites, BRANZ Study SR4, (1987)
3. Slope Stability in Urban Development, DSIR Series 122 (1981)
4. Stability of House Sites & Foundations, Earthquake & War Damages Commission, NZ Geomechanics Society (1980)
5. Land Assessment for Development Suitability, Burns & Farquhar, NZ Geotechnical Symposium (1996)

NOTES

(a) This checklist is intended as a guide for typical stability investigation & assessments for residential developments. There may be additional requirements for specifically difficult sites, large scale developments and regional hazards
(b) Indicate on site plan
(c) Indicate on site engineering geological map
(d) These plans/maps are best combined if possible
(e) Ref.3 provides a valuable outline of stability problems peculiar to selected areas of NZ
(f) Refer BRANZ document Fig 3 (ref.2 above), Stability House Sites and Foundations (ref. 4 above)
(g) See 6.6 -"Risk Rating", Design of Permanent Slopes for Residential Development, Crawford & Millar for EQC (1998)

Proposed requirements for slope factors of safety in land development and subdivision

				FOS if slope analyses are required (Note 1)	
BTR zone	Description	C&M risk zone	Extent of investigation required	Limited investigation, testing and monitoring, use of results from similar soils Good confidence in geological model	Extensive investigation, testing and monitoring, site specific test data High confidence in geological model
		Very high	Unlikely to be economic to develop		
Zone 1	Site includes probable landslide feature with clearly defined headscarp and hummocky debris and with indications of recent or current activity	High	Detailed engineering geological assessment Subsurface investigation Laboratory testing Groundwater monitoring	Detailed geological assessment FOS ≥1.5 Design GWT (Note 2) FOS ≥ 1.2 Extreme GWT (Note 3) FOS ≥ 1.2 150 year EQ (Note 4) FOS ≥ 1.1 Lower bound properties	Detailed geological assessment FOS ≥1.3 Design GWT (Note 2) FOS ≥ 1.1 Extreme GWT (Note 3) FOS ≥ 1.1 150 year EQ (Note 4) FOS ≥ 1.0 Lower bound properties
Zone 2	Site includes interpreted slope movement feature with either or both of the following • clearly or poorly defined headscarp • hummocky debris **or** building is located within 2.25H:1V slope line or 4H:1V runout distance from slope	Medium	Walkover survey Subsurface investigation Laboratory testing Groundwater monitoring		
Zone 3	No evidence of landslides **and** building is located outside 2.25H:1V slope line and 4H:1V runout distance from slope crest	Low	Walkover survey Possible some limited subsurface investigation	Analyses not likely to be required	
		Very low	Walkover survey	Analyses not likely to be required	

Notes:

1. Analyses based on average or best estimate values for shear strength and bulk density
2. Design groundwater table (GWT) = maximum seasonal GWT with extrapolation to 20 year return period rainfall
3. Extreme GWT = maximum seasonal GWT with extrapolation to 100 year return period rainfall
4. GWT for EQ conditions is static GWT without storm effects
5. 150 year return period EQ taken from zoning requirements of NZS4203

TABLE 1: HK RECOMMENDATIONS FOR FACTORS OF SAFETY FOR NEW SLOPES

RECOMMENDED FACTORS OF SAFETY FOR NEW SLOPES FOR A TEN-YEAR RETURN PERIOD RAINFALL

		Recommended factor of safety against loss of life for a ten-year return period rainfall		
		Risk to life →		
Recommended factor of safety against economic loss for a ten-year return period rainfall	***Economic risk ↓***	*Negligible*	*Low*	*High*
	Negligible	>1.0	1.2	1.4
	Low	1.2	1.2	1.4
	High	1.4	1.4	1.4

Note: (1) In addition to a factor of safety of 1.4 for a ten-year return period rainfall, a slope in the high risk-to-life category should have a factor of safety of 1.1 for the predicted worst groundwater conditions

(2) The factors of safety given in this table are recommended values. Higher or lower factors of safety might be warranted in particular situations in respect of economic loss.

TABLE 2: HK RECOMMENDATIONS FOR FACTORS OF SAFETY FOR EXISTING SLOPES

RECOMMENDED FACTORS OF SAFETY FOR THE ANALYSIS OF EXISTING SLOPES AND FOR REMEDIAL AND PREVENTIVE WORKS TO SLOPES FOR A TEN-YEAR RETURN PERIOD RAINFALL

	Recommended factor of safety against loss of life for a ten-year return period rainfall		
	Negligible	*Low*	*High*
Risk to life	>1.0	1.1	1.2

Note: (1) These factors of safety are minimum values to be used only where rigorous geological and geotechnical studies have been carried out, where the slope has been standing for a considerable time, and where the loading conditions, the groundwater regime and the basic form of the modified slope remain substantially the same as those of the existing slope.

(2) Should the back-analysis approach be adopted for the design of remedial or preventive works, it may be assumed that the existing slope had a minimum factor of safety of 1.0 for the worst known loading and groundwater conditions.

(3) For a failed or distressed slope, the causes of the failure or distress must be specifically identified and taken into account in tine design of the remedial works.

From Manual for Slopes, Geotechnical Engineering Office, Hong Kong

TABLE 3: HOEK'S RECOMMENDATIONS FOR SLOPE FACTORS OF SAFETY

Table 1 : Typical problems, critical parameters, methods of analysis and acceptability criteria for slopes.

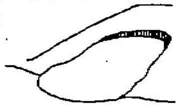
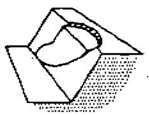
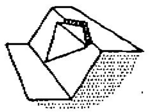
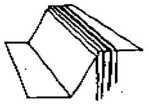
STRUCTURE	TYPICAL PROBLEMS	CRITICAL PARAMETERS	ANALYSIS METHODS	ACCEPTABILITY CRITERIA
 Landslides.	Complex failure along a circular or near circular failure surface involving sliding on faults and other structural features as well as failure of intact materials.	• Presence of regional faults. • Shear strength of materials along failure surface. • Groundwater distribution in slope, particularly in response to rainfall or to submergence of slope toe. • Potential earthquake loading.	Limit equilibrium methods which allow for non-circular failure surfaces can be used to estimate changes in factor of safety as a result of drainage or slope profile changes. Numerical methods such as finite element or discrete element analysis can be used to investigate failure mechanisms and history of slope displacement.	Absolute value of factor of safety has little meaning but rate of change of factor of safety can be used to judge effectiveness of remedial measures. Long term monitoring of surface and subsurface displacements in slope is the only practical means of evaluating slope behaviour and effectiveness of remedial action.
 Soil or heavily jointed rock slopes.	Circular failure along a spoon-shaped surface through soil or heavily jointed rock masses.	• Height and angle of slope face. • Shear strength of materials along failure surface. • Groundwater distribution in slope. • Potential surcharge or earthquake loading.	Two-dimensional limit equilibrium methods which include automatic searching for the critical failure surface are used for parametric studies of factor of safety. Probability analyses, three-dimensional limit equilibrium analyses or numerical stress analyses are occasionally used to investigate unusual slope problems.	Factor of safety > 1.3 for "temporary" slopes with minimal risk of damage. Factor of safety > 1.5 for "permanent" slopes with significant risk of damage. Where displacements are critical, numerical analyses of slope deformation may be required and higher factors of safety will generally apply in these cases.
 Jointed rock slopes.	Planar or wedge sliding on one structural feature or along the line of intersection of two structural features.	• Slope height, angle and orientation. • Dip and strike of structural features. • Groundwater distribution in slope. • Potential earthquake loading. • Sequence of excavation and support installation.	Limit equilibrium analyses which determine three-dimensional sliding modes are used for parametric studies on factor of safety. Failure probability analyses, based upon distribution of structural orientations and shear strengths, are useful for some applications.	Factor of safety > 1.3 for "temporary" slopes with minimal risk of damage. Factor of safety > 1.5 for "permanent" slopes with significant risk of damage. Probability of failure of 10 to 15% may be acceptable for open pit mine slopes where cost of clean up is less than cost of stabilization.
 Vertically jointed rock slopes .	Toppling of columns separated from the rock mass by steeply dipping structural features which are parallel or nearly parallel to the slope face.	• Slope height, angle and orientation. • Dip and strike of structural features. • Groundwater distribution in slope. • Potential earthquake loading.	Crude limit equilibrium analyses of simplified block models are useful for estimating potential for toppling and sliding. Discrete element models of simplified slope geometry can be used for exploring toppling failure mechanisms.	No generally acceptable criterion for toppling failure is available although potential for toppling is usually obvious. Monitoring of slope displacements is the only practical means of determining slope behaviour and effectiveness of remedial measures.
 Loose boulders on rock slopes.	Sliding, rolling, falling and bouncing of loose rocks and boulders on the slope.	• Geometry of slope. • Presence of loose boulders. • Coefficients of restitution of materials forming slope. • Presence of structures to arrest falling and bouncing rocks.	Calculation of trajectories of falling or bouncing rocks based upon velocity changes at each impact is generally adequate. Monte Carlo analyses of many trajectories based upon variation of slope geometry and surface properties give useful information on distribution of fallen rocks.	Location of fallen rock or distribution of a large number of fallen rocks will give an indication of the magnitude of the potential rockfall problem and of the effectiveness of remedial measures such as draped mesh, catch fences and ditches at the toe of the slope.

TABLE 4: FACTORS OF SAFETY FOR OPEN PIT MINES (From Sullivan 1994)

DESIGN FACTORS OF SAFETY FOR MINE SLOPE DESIGN

Design situation		Factors of safety commonly used or accepted in practice	
Applicability	*Geotechnical conditions*	*Range*	*Preferred value*
General slope design	Simple geological and geotechnical conditions	1.2 to 1.3	1.2
	Complex geology, soil or soft rock, groundwater		1.3
	Stabilisation of moving slope	1.0 to 1.3	1.1
	Rigorous back analysis of large failure available		1.1
Slope below haul road or important infrastructure		1.2 to 1.5	1.3

TABLE 5: FACTORS OF SAFETY FOR OPEN PIT MINES (From Priest and Brown 1983)

Probabilistic slope design criteria

Category of slope	Consequences of failure	Examples	Acceptable values Minimum Mean F	Maxima $P(F < 1.0)$	$P(F < 1.5)$
1	Not serious	Individual benches; small* temporary slopes not adjacent to haulage roads.	1.3	0.1	0.2
2	Moderately serious	Any slopes of a permanent or semi-permanent nature.	1.6	0.01	0.1
3	Very serious	Medium-size and high slopes carrying major haulage roads or underlying permanent mine installations	2.0	0.003	0.05

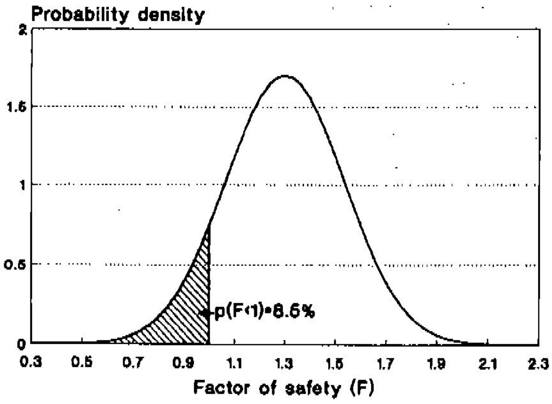
*Small, height < 50 m; medium, height 50–150 m; high, height > 150 m.

Guide to interpretation of slope performance

Performance of slope in Table 4	Interpretation
Satisfies all three criteria	Stable slope
Exceeds minimum mean F, but violates one or both probabilistic criteria	Operation of slope presents risk that may or may not be acceptable; level of risk can be reduced by comprehensive monitoring programme
Falls below minimum mean F, but satisfies both probabilistic criteria	Marginal slope: minor modifications of slope geometry required to raise mean F to satisfactory level
Falls below minimum mean F and violates one or both probabilistic criteria	Unstable slope: major modifications of slope geometry required; rock improvement and slope monitoring may be necessary

TABLE 6: DESIGN PROBABILITIES OF FAILURE FOR MINE SLOPE DESIGN (From Sullivan 1994)

Design situation		**Probabilities of failure commonly used or accepted in practice**		
Design element	*Applicability*	*Geotechnical condition*	*Range %*	*Preferred value %*
Bench slope	General		10 to 50	
		Continuous defects	0 to 10	10
		Discontinuous defects	10 to 50	20 to 30
Overall or inter-ramp slope	General		1 to 3	
Overall or inter-ramp including haul road or key infrastructure			< 1	



APPENDIX A: RELEVANT INFORMATION IN NEW ZEALAND GEOMECHANICS NEWS

NO 48 DECEMBER 1994

1. The majority of this issue was devoted to the results of a survey on approaches to slope stability assessments for land development. A questionnaire was sent to every Territorial Local Authority and to the principal geotechnical engineering and engineering geological consultants in NZ. Responses were received from 20 of the 73 Territorial Authorities and 29 of the consultant firms. The introduction to the questionnaire stated that:

   Slope stability assessment as part of land development consents is well established in our country. However the geotechnical community is aware of difficulties between consultants and Territorial Authorities in agreeing on a consistent approach to stability assessments. The problems are exacerbated by the specification in the Building Code Approved Document of a Factor of Safety of 1.5 for land stability, without any explanation or qualification. This is not a mandatory requirement and alternative solutions may be accepted by Territorial Authorities. Building consents are also Issued under Section 36(2) of the Building Act. However, each Authority seems to have its own interpretation of both the application of the factor of safety and the application of Section 36(2) to land stability, and much time has been wasted debating the issues on an ad hoc basis.

2. Summary responses are indicated below to some of the questions in the newsletter:

From whom are assessments acceptable?				
Summary of results	*Territorial Authority*	*Geotechnical Engineers*	*Engineering Geologists*	*Firm of engineers & geologists*
Registered Engineer (civil)	12	3	3	0
Registered Engineer (geotechnical specialist)	18	18	6	5
Engineering Geologist	12	12	6	5
Firm of Engineering Geologists	10	11	6	4
Firm of Consulting Engineers:	9	4	1	0
Without geotechnical specialist	14	14	6	4
With geotechnical specialist				
Total no of replies	21	18	6	5

Is an engineering geological (non-analytical) assessment of stability acceptable?				
Summary of results	*Territorial Authority*	*Geotechnical Engineers*	*Engineering Geologists*	*Firm of engineers & geologists*
Yes	4	6	5	1
No	4	0	0	1
Sometimes	12	13	4	3
Total no of replies	20	18	6	4

Is a numerical slope stability analysis that produces a factor of safety always necessary?				
Summary of results	*Territorial Authority*	*Geotechnical Engineers*	*Engineering Geologists*	*Firm of engineers & geologists*
Yes	5	3	1	1
No	14	15	6	4
Total no of replies	19	18	7	5

A minimum factor of safety of 1.5 is acceptable for the following conditions				
Summary of results	*Territorial Authority*	*Geotechnical Engineers*	*Engineering Geologists*	*Firm of engineers & geologists*
Groundwater profile:				
High	2	4	1	3
Average	8	6 ½	0	2
Low	0	2 ½	1	0
Soil strength:				
Upper Bound	1	½	½	0
Average	10	9 ½	½	2
Lower Bound	0	2	0	3
Total no of replies	18	18	6	5

Note: Many respondents qualified their answers

Is strength testing of soils required to establish strength parameters for each specific site?				
Summary of results	*Territorial Authority*	*Geotechnical Engineers*	*Engineering Geologists*	*Firm of engineers & geologists*
Yes	4	3	0	0
No	7	3	1	0
Sometimes	9	11	4	5
Total no of replies	20	18	5	5

Can parameters established by testing of similar soils for other sites be used?				
Summary of results	*Territorial Authority*	*Geotechnical Engineers*	*Engineering Geologists*	*Firm of engineers & geologists*
Yes	14	17	4	5
No	5	0	0	0
Total no of replies	20	18	4	5

Is a factor of safety less than 1.5 acceptable for extreme conditions (excluding earthquakes)?				
Summary of results	*Territorial Authority*	*Geotechnical Engineers*	*Engineering Geologists*	*Firm of engineers & geologists*
No	11	1	0	0
Yes	5	13	6	6
Total no of replies	16	14	6	6

If drainage works are used to stabilise land, should their failure to operate be considered?				
Summary of results	*Territorial Authority*	*Geotechnical Engineers*	*Engineering Geologists*	*Firm of engineers & geologists*
No	0	2	1	0
Yes	15	14	6	5
Total no of replies	15	16	7	5

3. As a general comment, many respondents disliked the blanket approach of FOS = 1.5 particularly in view of the difficulty of defining the likely variations in shear strength and groundwater parameters.

NO 49 JUNE 1995

4. A letter from Don Taylor notes that:
   - The results of the questionnaire show a wide range of opinion amongst those who responded and significant differences amongst professional people as to the appropriate means of assessing stability and as to who shall make the assessment
   - The range of opinions bodes ill for the professional justifying him/herself against opposing witnesses in a Local Body public hearing or court action
   - Geomorphological/geological assessment of the site is an essential first part of slope stability investigation
   - A quantitative slope analysis is useless or even misleading unless it is based on accurate definitions of the geology, soil properties and groundwater pressures at the site. Such definitions are expensive to achieve

NO 51 JUNE 1996

5. Letters from NS Luxford and MJD Stapledon drew attention to the Building Industry Authority Determination No 95/005: *Construction of a house on a steep site.* The writers considered that this determination inferred that:
   - Drilling and testing of several location on a small site and computer analyses of a large number of potential slip circles
   - The combination of drillholes and computer analysis leads to a competent geotechnical assessment regardless of whether computer analyses adequately model the slope in question.

6. This newsletter also included a paper by Don Taylor on *Geotechnical issues in land development.*

NO 55 JUNE 1998

7. This issue includes an important review of the slope designs for residential development[7]. The conclusions of the paper were as follows:

- The nationwide survey carried out in 1994 by the NZ Geomechanics Society indicates there is a wide variation in opinions on stability issues amongst Territorial Land Authorities and to a lesser extent amongst Geotechnical practitioners. It is generally agreed amongst the profession that there is a need for a set of guidelines on assessment of slope stability for NZ.

- The current NZ Building Code (B1/VM4) does not adequately address issues of slope stability and geotechnical investigation. It is proposed that minor modifications to this document be made including a reference to a new set of guidelines on assessment of slope stability.

- This paper outlines the issues to be covered by the new set of guidelines namely risk/hazard assessment, extent to investigations, FOS and parameter requirements for numerical slope stability analyses and the role of peer review.

- Reviews have been carried out on the nationwide questionnaire survey and documents covering slope stability for Hong Kong and NSW, Australia. The risk classification approach outlined in these latte documents needs further development for NZ conditions. These aspects are currently under review by the NZ Geotechnical Society.

- There is ongoing Liaison with the Australian Task Force on Landslides and Hillside Construction as they develop guidelines after the Thredbo Landslip Incident.

- District hazard registers are required of each Territorial Land Authority by the RMA. However, this approach has produced a fragmented coverage of NZ. Standardization and coordination of "District Hazard Maps" is required to produce a nationwide register. It is suggested that the NZ Geotechnical Society/EQC be funded by the Ministry of Local Government to undertake the relatively small task of coordinating these maps by means standard map legends and national key maps. It may be preferable to utilise the QMAP and GIS approach outlined by Isaac & Turnbull (1997) to allow open access to a national hazard mapping system. Access can be via the Internet.

- There is a wide variation of opinions on the place of engineering geological assessment and the parameters to be used in numerical slope stability analyses.

- A review of opinions amongst the geotechnical profession of requirements for earthquake design loadings has been undertaken and again variation found amongst those who apply and approve seismic slope design for residential development. More guidance is needed in the NZ Building Code.

- There is an inconsistent approach across NZ to the use of peer review for approving stability assessments.

- There is a variance of opinion on the responsibilities of TLA's, consultants and owners/developers when applying the consents under Section 36(2) of the Building Act. However, there is apparent agreement that the developer/owner carried the risk, that the TLA accepts no risk and that limited risk is accepted by the geotechnical professional, and this needs to be defined in the consultant's terms of engagement.

- EQC may decline a claim if the title is noted under Section 36(2) of the Building Act. This is generally when the damage is caused due to the nature of the site rather than through a specific event, for example a storm or an earthquake, in these cases the claim would normally be accepted.

8. The recommendations of the paper are as follows:
   - The results of this research and the draft guidelines included be used as input to the preparation of the national guidelines for stability assessments. This work is to be undertaken by the NZ Geotechnical Society.

[7] Crawford S, Millar P. *The Design of Permanent Slopes for Residential Building Development*. NZ Geomechanics News, No.55 June 1998

- The NZ Building Code (BI1/VM4) be modified slightly including a reference to the new above national guidelines. References (2, 3, 5 & 7) be updated to include technical advancements, changes in legislation and to incorporate hazard maps and geotechnical requirements for specific local areas where conditions vary widely from the norm, e.g. Onerahi Chaos, Port Hills loess, etc.

- An engineering geological assessment should be made as the first step in a site stability assessment.

- The use of a risk/consequences classification system (namely very low, low, medium, high and very high) be adopted for NZ, firstly for hazard mapping and secondly as one of the conclusions reached in a stability assessment. A suggested format is presented in Table 1 but further work is required to prepare a system for NZ, and this should be covered by the NZ Geotechnical Society national guidelines.

- The risk classification applied to each site be used as one of the means of determining
  i) the minimum requirement or extent of geotechnical site investigations
  ii) the need for numerical slope stability analyses for a site
  iii) the requirements for geotechnical design
  iv) the level of construction supervision
  v) the extent of post-construction site monitoring and slope maintenance.

- The risk classification could be assessed by prospective property purchasers of hillside properties to assess the level of risk associated with a particular site.

- Factors of safety (against instability) be adopted for defined soil strength, groundwater and earthquake conditions (refer sections 6.7 and 6.8 of this paper). This requires a minimum FOS of 1.5 for design conditions and a lesser minimum FOS of 1.2 under extreme conditions.

- The use of geotechnical review by TLA's (or developers) be carried out as suggested in Table 2: Peer Review Requirements.

- When applying Section 36(2) of the Building Act, the responsibilities and liabilities need to be clearly defined between landowner and consultant and these should be written into the consultant's terms of engagement.

- The draft "Checklist for Stability Assessments" be adopted for normal practice by TLA engineers/approvers and geotechnical practitioners throughout NZ.

- These guidelines be published in NZ Geomechanics News June 1998 and constructive comment be sought from the geotechnical community and Territorial Land Authorities throughout NZ.

9. There has been little if any progress with the development of guidelines on assessment of slope stability in NZ, review of risk classifications and other suggestions made in the above conclusions and recommendations.

NO 56 DECEMBER 1998

10. Letters from Baunton and Scott (TDC), Taylor, Murray, Farquhar, Grocott, Morris, Stapleton, Vautier and Gunson comment on the Crawford and Millar paper.

NO 57 JUNE 1999

11. Stephen Crawford (then Editor of NZ Geomechanics News) provided suggested slope stability clauses for B1/VM4 revisions. These are included in full as an attachment to this review.

NO 58 DECEMBER 1999

12. The letters to the Editor includes a query and response as to the term "full saturation".

NO 60 DECEMBER 2000

13. This includes a discussion paper by Laurie Wesley[8] and a detailed document on landslide risk management[9]. The latter paper also includes extracts from the Australian guidelines for hillside construction.

NO 61 JUNE 2001

14. This includes a discussion document on Section 36 of the Building Act and some discussion on factors of safety of slopes.

NO 62 DECEMBER 2001

15. Relevant articles include:
    - Submission on review of Building Act
    - Submission on DZ4404:2001 Land subdivision and development engineering

    The latter document notes the weaknesses in the current draft and suggests a re-draft with input from NZGS. The Technical Committee responded that Standards New Zealand should consider developing new standards for specialised geotechnical assessments of land stability, earthworks and foundation design. It was indicated that IPENZ would be approached with a view to setting up a case for new geotechnical standards.

8 Wesley L. *Quantitative and non-quantitative methods of estimating slope stability.* NZ Geomechanics News, December 2000

9 Australian Geomechanics Society. *Landslide risk management concepts and guidelines.* . NZ Geomechanics News, December 2000

Table 1: RISK CLASSIFICATION FOR SITES SUBJECT TO INSTABILITY

(This table has been produced to provide a simplified classification which can be readily understood by a lay person and to provide a uniform code of terms for geotechnical professionals)

RISK OF INSTABILITY	EVIDENCE/ TYPE OF INSTABILITY	CONSEQUENCES OF INSTABILITY	IMPLICATIONS FOR DEVELOPMENT	EXTENT OF INVESTIGATION REQUIRED
VERY HIGH	Evidence of active or past instability - landslip or rockface failure; extensive instability may occur within site or beyond site boundaries.	High risk of loss of life. Catastrophic or extensive significant damage or economic loss.	Unsuitable for development unless major geotechnical work can satisfactorily improve the stability. Risk after development may be higher than normally accepted (includes Building Act Section 36(2)).	Extensive geotechnical investigation required.
HIGH	Evidence of active creep, potentially progressive/regressive/minor slips or minor rockface instability; significant instability may occur during and after extreme climatic conditions and may exceed beyond site boundaries	Low risk of loss of life. Significant damage or economic loss	Development restrictions and/or geotechnical works required. Risk after development may be higher than normally accepted (may include Section 36(2)).	Engineering geological assessment drilling investigation required.
MEDIUM	Evidence of possible soil creep or a steep soil covered slope; significant instability can be expected if the development does not have due regard for the site conditions.	Virtually nil risk of loss of life. Moderate damage and economic loss	Development restrictions may be required. Engineering practices suitable to hillside construction necessary. Risk after development generally no higher than normally accepted.	Visual assessment. Hand and possible drill investigation methods.
LOW	No evidence of instability observed; instability not expected unless major site changes occur.	Minor damage, limited to site unless major development occurs.	Good engineering practices suitable for hillside construction required. Risk after development normally acceptable.	Visual assessment. Possible hand investigation method.
VERY LOW	Typically shallow soil cover with flat to gently sloping topography.	Virtually nil.	Good engineering practices should be followed.	Visual assessment.

Table 2: Peer Review Requirements: When is a Peer Review Required?

Scale of Project	Risk Classification*	Requirement for Review by Geotechnical Specialist
Small Scale (Lot Specific)	**Very Low to Low Risk**	Review by non-specialist / TLA engineer
	Medium Risk	Peer review preferred
	High to Very High Risk	Peer review required
Medium Scale (Small Subdivision, 2 to 20 lots)	**Very Low to Low Risk**	Review by non-specialist / TLA engineer
	Medium to Very High Risk	Peer review required
Large Scale (Subdivision, > 20 lots)	**Very Low to Low Risk**	Peer review optional
	Medium to Very High Risk	Peer review required

*Note: Risk Classification to be determined by the geotechnical professional preparing the assessment and to be in accordance with NZ Geotechnical Society Guidelines. (Refer Table 1 of this report)

SUGGESTED SLOPE STABILITY CLAUSES FOR B1/VM4 REVISIONS

Soil Strength Parameters Groundwater Assumptions and FOS

It is essential that an engineering geological assessment is carried out for the whole of the site, and extended area affecting the stability of any development.

A suitable geotechnical model must be formulated for analyses. This model should be referenced to drawings showing surface & subsurface site data.

If no detailed investigations have been undertaken, the requirement for a factor of safety (FOS) exceeding 1.5 for full saturation is generally reasonable.

A less conservative approach can be adopted where full saturation is only likely to occur under extreme conditions and a good understanding of ground conditions is available due to the:

- Detailed engineering geological mapping and subsurface investigations
- Groundwater conditions being defined by monitoring of water levels or geohydrological assessment
- Slope geometry being defined
- Defined drainage conditions including permeability of strata being well known
- Extent of recharge and catchment area being limited
- Back analysis of existing failures being carried out to determine soil properties or groundwater conditions.
- Soil properties being known within reasonable confidence limits. These should be compared to typical parameters for local materials based on published information and previous laboratory testing. If site specific tests indicate lower strengths then the lower bound soil properties should be used.
- Precedence of low incidence of instability in the area.

A minimum factor of safety of 1.5 is recommended for the conditions which may be expected to occur during the design life of the structure - 100 years for dwellings and 50 years for retaining structures beyond 8 m from the dwelling. A reduced minimum factor of 1.2 is applicable for extreme conditions. These extreme conditions include:

- Failure of stabilisation measures and drainage systems (provided the latter includes access for maintenance)
- Full saturation where investigations indicate that there is a high confidence level this condition will not occur during the design lifetime of the structure. ie. A check on full saturation may still be applicable to ensure that failure should not occur under this extreme condition.

Factors such as limited catchments, natural drainage conditions such as permeable strata and slope geometry may preclude full saturation under design conditions. In these cases a reduced groundwater level can be determined for the design case from extrapolation of monitored seasonal levels, seepage analyses or observation of geological evidence such as weathering, staining, etc.

The designer is responsible for providing convincing evidence that a reduced groundwater condition can be used for the design condition (ie. FOS ≥ 1.5). In such cases a check on the extreme design condition of full saturation, or failure of any installed slope drainage measures, is also required to confirm that the FOS > 1.2.

Variation from these factor of safety guidelines is possible but should be based on an assessment of the level of economic risk and risk to life. Such variations should be subject to specific geotechnical peer review and approval.

Earthquake Provisions

The design loadings for a numerical analysis of a slope affecting residences should be consistent with the zoning requirements of the NZ Loadings Code NZS 4203 and a 150 year return period. It is noted that section 4.11 of this code allows for a 0.25 structural performance factor for soil loads on structures rather than the 0.67 factor for building loads. A 50-year return period should be applied for retaining structures located further than 8 m away from a dwelling.

For numerical analyses of the seismic slope stability, a FOS $\geq$ 1.2 should be adopted for the above return periods. Potential slope failures that do not extend to within 8 m of a dwelling or cross a property boundary do not need to be analysed for seismic slope stability.

Stephen Crawford