Characterization and numerical modelling of intermittent slope displacements and fatigue in deep-seated fractured crystalline rock slopes

M. Smithyman, E. Eberhardt and O. Hungr
Geological Engineering – Earth and Ocean Sciences, The University of British Columbia, Vancouver, BC, V6T 1Z4, Canada

ABSTRACT
Deep-seated landslides along well-defined sliding surfaces often exhibit slow, intermittent accelerating and decelerating movements. This behaviour often relates to seasonal changes in pore pressures at depth. Distinct-element modelling is used here to investigate the temporal characteristics of a landslide's deformation response to annual changes in groundwater levels. Elements of fatigue, localization, internal shearing and progressive failure are examined to project the behaviour of the landslide with further cyclic loading, including the potential for sudden acceleration.

RÉSUMÉ
Les glissements de terrain profonds le long de surfaces de rupture bien définies présentent souvent des mouvements lents avec des accélérations et décélérations intermittentes. Ce comportement est habituellement relié aux changements saisonniers des pressions interstitielles en profondeur. Une modélisation par éléments distincts est utilisée afin d'étudier les caractéristiques temporelles de ces glissements de terrains en réponse aux changements annuel du niveau des eaux souterraines. La fatigue, l'emplacement, le cisaillement interne ainsi que la rupture progressive sont étudiés afin de prédire le comportement du glissement de terrain lors de futurs chargements cycliques, incluant la possibilité d'une accélération soudaine.

1 INTRODUCTION

Large unstable rock slopes with well-developed basal slip surfaces generally show a tendency to move slowly and intermittently downhill. These movements occur in response to changing equilibrium conditions within the slope, often related to varying groundwater levels, for example through seasonal precipitation patterns, and/or strength degradation and progressive failure of the rock mass. Other external loading factors such as oscillating temperatures or frequent loading/removal of material can have a similar effect.

In several notable cases (e.g., Vaoint, Italy), these creep-like movements have been observed to accelerate suddenly leading to catastrophic failure. Due to the danger imposed and high consequences of such failures, it is important to gain an understanding of this behaviour to allow for better early warning and/or hazard mitigation.

This paper reports the findings from a preliminary numerical modelling study, which uses the distinct-element code UDEC (Itasca 2004) to investigate the evolution of internal deformations, strength degradation, localization and rock mass shearing through fatigue failure. These mechanisms are further analyzed with respect to their potential for both localized and global accelerations of the modelled slope mass. Data from the Campo Vallemaggia landslide in Switzerland (Bonzanigo et al. 2007) was used to develop the models used in this conceptual study.

The objective of this research is to bridge the gap between rock slope monitoring systems, that largely record displacements as a function of time (Franklin 1990), and numerical models, which generally rely on stress-strain constitutive relationships to represent the rock mass. This points to a fundamental disconnect between the data sources used for early warning purposes and the models needed to gain understanding of the underlying failure mechanism and processes contributing to the slope movements. This paper will attempt to address this problem by implicitly including time in the models using cyclic loading, where each cycle represents a seasonal change in the average groundwater level.

2 LARGE BASAL DETACHMENT LANDSLIDES

Large landslides in natural rock slopes are often bounded by a deep-seated rupture surface, or basal detachment, that is on a similar scale to the slope itself (Agliardi et al. 2001). Secondary, smaller landslides within the moving block may also be observed (Cronin 1992). Together these are referred to as a compound landslide. In many cases the majority of the landslide movement is seen to concentrate along these secondary surfaces, but in others the movement may be found to occur mainly along the basal detachment. The Vaiont Slide is an example of a slide where failure localized predominantly along the basal detachment surface (Sitar et al. 2005). The Zentoku Landslide in Japan (Furuya et al. 1999) and the Hochmais-Atemkopf slide in Austria (Zangerl et al. 2007), are examples of those where ongoing movements occur more along secondary sliding surfaces than the basal detachment zone.

Typically the movement rate of large rock slopes is slow, on the scale of millimetres to centimetres per year, and the total movement, although potentially large, is small relative to the scale of the sliding mass (Agliardi et al. 2001). In general, the movement of these slides is not well understood, as they often appear to be moving on a consistently slow basis at a relatively constant velocity. Yet, concern is ever-present that these movements could potentially accelerate, threatening infrastructure and communities located on or below the slope (e.g. Campo Vallemaggia; Bonzanigo et al. 2007). An understanding of the causes of the movement, and changes in the rock slope that result (e.g. strength degradation) is imperative to assessing the continuing safety of these large landslides.

Intrinsic creep of intact rock is better understood than that of large rock masses, and some parallels may be drawn between the two behaviours in order to increase understanding of the slow downslope movement of a rockslide. True rock creep typically involves three stages (Fig. 1): Primary creep, which involves a decelerating strain rate with time; secondary creep, also known as steady state creep, which follows an approximately linear trend on a strain *vs.* time graph; and tertiary creep, which involves an accelerating strain rate leading to failure (Jaeger 1979).

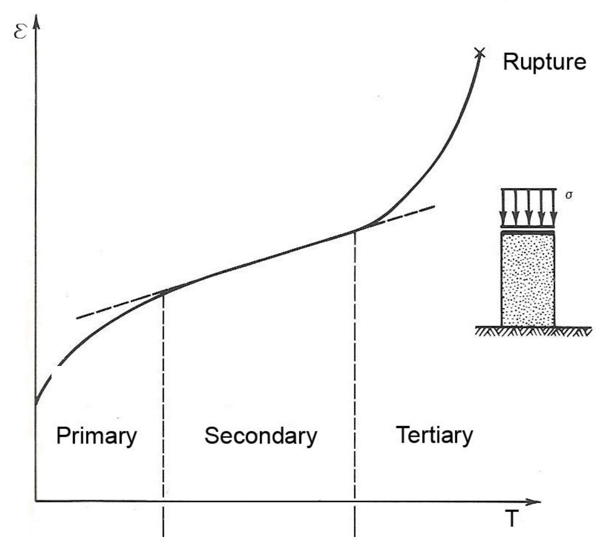

Figure 1. Standard creep curve showing the primary, secondary and tertiary stages of creep, as observed in a typical creep test (Jaeger 1979).

The velocities of large landslides with basal detachments are often equated to the same stages of strain rate behaviour seen in these creep curves (e.g. Saito 1965). The Primary acceleration phase in a landslide represents the stage of basal surface nucleation, localization and formation. Once cohesion along this path is largely destroyed and the basal sliding surface is mostly formed, frictional sliding dominates as the landslide moves into the Secondary steady state phase of behaviour. This is the state where most landslides are detected and concern raised. The final stage (tertiary) represents acceleration to failure, such as that seen in the Vaiont landslide. Two things complicate the use of this analogy as a tool for interpretation of deep-seated landslide movement. The first is time scale. Many of these landslides have been sliding for thousands of years, often since glacial retreat, making it difficult to reference for how long the slide has been moving in a secondary stage. Secondly, in sliding rock masses, recorded displacements are rarely linear over the short timeframe in which they are recorded. An example of this can be seen in Figure 2, which shows the velocities of the Campo Vallemaggia landslide (Bonzanigo et al. 2007) over a five year monitoring period. These velocities appear to spike in late 1993 but did not accelerate to failure, indicating that despite appearances this was not the start of tertiary creep. This is discussed in more detail in the next section.

2.1 Apparent Time Dependence

When rock slope displacements are monitored at infrequent intervals (e.g. annually), the resulting displacement-time curve may take on the appearance of a steady state creep curve as smaller perturbations resulting from external factors acting on a shorter timescale, such as precipitation (or in some cases temperature; Watson et al. 2006), would be filtered out. This is illustrated in Figure 3. Depending on these external factors, viewing displacement rates at a smaller time scale such as mm/month, may allow variations that better capture the temporal characteristics of the slide's behaviour to be more clearly resolved.

Apparent time dependence of rock slope displacements may therefore be influenced by meteorological affects (Glawe and Lotter 1996), as well as anthropogenic effects such as changing dam reservior levels at the foot of the slope. While these events may be time dependant, it would not be strictly accurate to say that the downslope movement is time dependant in the sense of material creep behaviour. Instead, these movements take the form of 'stick-slip' displacements.

Although internal deformations of the intact rock occur and contribute to the overall displacement profile, especially in weaker rocks with lower deformation moduli, the largest component of movement involves through slip along joints, shears and other discontinuities cutting through the rock. Joint slip may happen simply due to the effects of gravity, or, more likely, changes in the stresses acting on them (Leroueil et al. 1996).

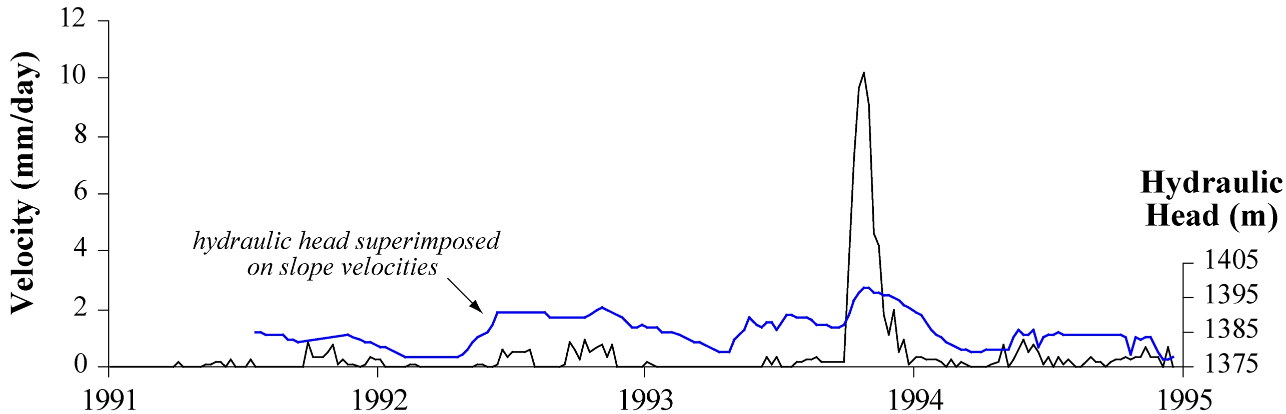

Figure 2. Intermittent downslope velocities of the Campo Vallemaggia landslide as a function of pore pressures measured at depth. Slide velocities were measured using an automated geodetic station; pore pressures are expressed as the hydraulic head (i.e. elevation of the water column in the piezometer). After Bonzanigo et al. (2007).

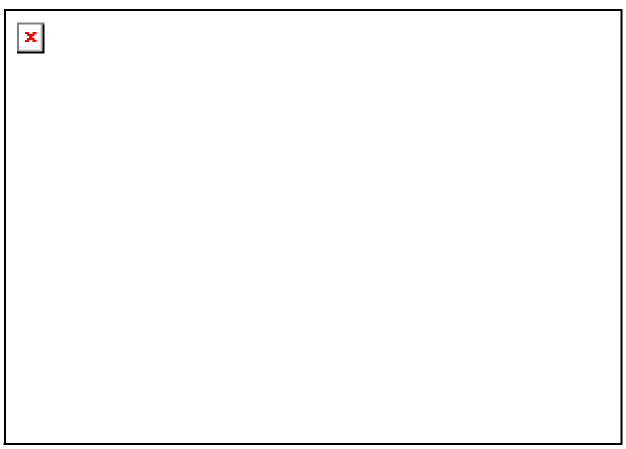

Figure 3. Example of how infrequent sampling of slope displacements filters out stick-slip movements, producing a signal that appears to be a smooth time-dependant motion.

2.2 Fatigue

Many of the external factors that promote landslide movements affect the rock mass in a cyclical manner. Obvious examples include climatic factors like wet winters and spring snow melt transitioning into dry summers, which respectively raise and lower the groundwater levels in the slope. These seasonal cycles vary the effective stresses acting along critically stressed shear surfaces within and bounding the slide mass, causing stick-slip movements that in turn can lead to fracture propagation, degradation of the rock mass strength and internal shearing. Together, these processes act as a form of fatigue (i.e. progressive weakening with cyclic loading), that increases the tendency towards time-dependant movement (Goodman 1980).

This breakdown due to cycling can be seen in situations such as the occurrence of highly weathered rock in regions where thermal and/or moisture cycling are active processes (Hall 1999; Halsey et al. 1998). Changes in temperature and moisture cause expansion and contraction of the rock, inducing compressive and tensile stress gradients within the intact rock (as well as between discontinuities distributed within the rock mass). The frequency of these stresses (or strains), greatly affect the extent of the fatigue-effect upon the rock (Halsey et al. 1998). The number of load cycles and the magnitude of the cyclic stresses (i.e. amplitude) are also extremely important (Bagde and Petros 2005).

2.3 Failure Prediction

Several empirical methods have been reported in the published literature designed to predict the failure of a landslide based on measured slope displacements and accelerations (e.g. Terzaghi 1950; Fukuzono 1985; Saito 1965; Voight 1989). The Fukuzono method is one of the more commonly used approaches, and involves predicting the time to failure based on the forward projection of a line or curve of an inverse velocity plot. Full details of the Fukuzono method and its application are provided in Fukuzono (1985), Crosta and Agliardi (2003) and Rose and Hungr (2007). Empirical methods like Fukuzono, however, tend to generalize a complex data signal making it difficult to differentiate between short temporary periods of acceleration, perhaps related to localized changes in the slide mass, and those that may evolve into catastrophic failure of the slope (e.g. Fig. 4).

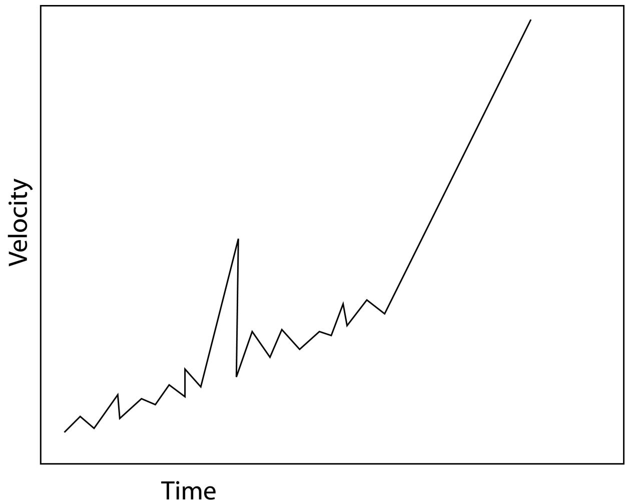

Figure 4. False acceleration to failure can be seen in the first above average spike in the velocity data, followed by a subsequent similar spike that then does precede failure.

3 CONCEPTUALIZED CASE HISTORY

To investigate the role of fatigue in deep-seated rock slope failures, a conceptualized model of a large landslide was used as a basis for analyzing the effects of cyclic loading on the downslope movements. The Campo Vallemaggia landslide in the southern Swiss Alps is a well-documented 800 million m^3 sliding mass in fractured crystalline rock. It is known to have complex compositional layering and artesian pressures contributing to the temporal sliding characteristics of the mass (Bonzanigo et al. 2007). The study by Bonzanigo et al. (2007) reports the history of movement, with displacements being documented for almost 200 years, as well as the geometry, geology and subsequent stabilization of the landslide in 1995 through the construction of a drainage adit.

The primary rupture surface of the Campo Vallemagia landslide dips at approximately 20º. This is believed to be a well-defined basal detachment zone at the base of the slide along which the landslide moves. There are several internal shear surfaces present within the slope that complicate the movement pattern. A geologic cross section of the landslide taken from Bonzanigo et al. (2007) is provided in Figure 5. The basal shear surface and internal faulting of the mass can be identified in this figure.

The movements described above have a history of being both intermittent and related to changes in hydraulic heads at depth as illustrated in Figure 2. The nature of this movement has been described as “forward pulsing” (Bonzanigo et al. 2007), making it an ideal case for this study.

4 COMPUTER MODELLING

The modelling presented here focuses on the pre-drainage/pre-stabilized behaviour of the landslide to study its response to fatigue in the form of seasonal fluctuations in the modelled water table. In this sense, the Campo Vallemaggia case history serves as a more generalized example of a large slow-moving landslide affected by cyclic loading and progressive localized strength degradation and shearing.

The commercial distinct-element program UDEC was used (Itasca 2004), in which the problem geometry was represented as an assemblage of deformable interacting blocks. The discontinuity network was generated based on that by Eberhardt et al. (2007) to portray a strong horizontal anisotropy within the slide body and vertical anisotropy below it as mapped during construction of the drainage adit used to stabilize the landslide. Permeability and fluid flow in the UDEC formulation are controlled by the input for fracture aperture based on the cubic law relationship (Priest 1993). The modelling performed involved a multi-stage cycling procedure. Once an initial model equilibrium had been established, a simulated water table was raised and lowered for 1000 time-steps each, representing a period of 1 year. The 1000 timestep limit was selected based on calibration testing as to the number of timesteps required to reproduce the velocity trend of 2-5 cm/year established for the landslide through long-term monitoring. Various versions of the model were tested for durations of up to 800 “years”. The basic model, and the two water tables representing annual lows and highs, can be seen in Figure 6. Table 1 provides the discontinuity and block properties used in the model.

4.1 Compound Sliding and Fatigue

The model was first run with only the basal sliding surface and the representation of the meso-scale joint network explicitly presented. Major faults mapped across the landslide body were not included. The most prominent of these, in the 2-D cross-section (Fig. 5), form upper and lower scarps in the upper half of the slide body below the Piano dei Pii and Piano delle Rose. A parallel set of models with these features included (Fig. 6) were also tested in order to examine their influence on the landslide behaviour and its evolution.

The initial non-faulted model was examined at multiple stages of cyclic loading in order to observe the development of plastic yielding in the form of shear and tensile damage indicators. These damage indicators and their progression with each load cycle (i.e. raising and lowering of the water table) were interpreted as representing rock mass damage and fatigue. In particular, it was noticed that yielding tended to localize around the regions of the modelled slide where the major fault and scarp features previously noted coincide. Although these concentrations can be partly attributed to the characteristics of the uneven basal sliding surface, which in turn are partially interpreted based on the presence of these faults (Bonzanigo et al. 2007), the model results suggest that sliding could not occur as modelled without some internal yielding and shearing at these points. Figure 7 shows the progression of yielding over 800 modelled years, or fatigue cycles, of raising and lowering the groundwater table. The results show that after only 10 years of displacement, stress and strain concentrations already begin to focus around these areas.

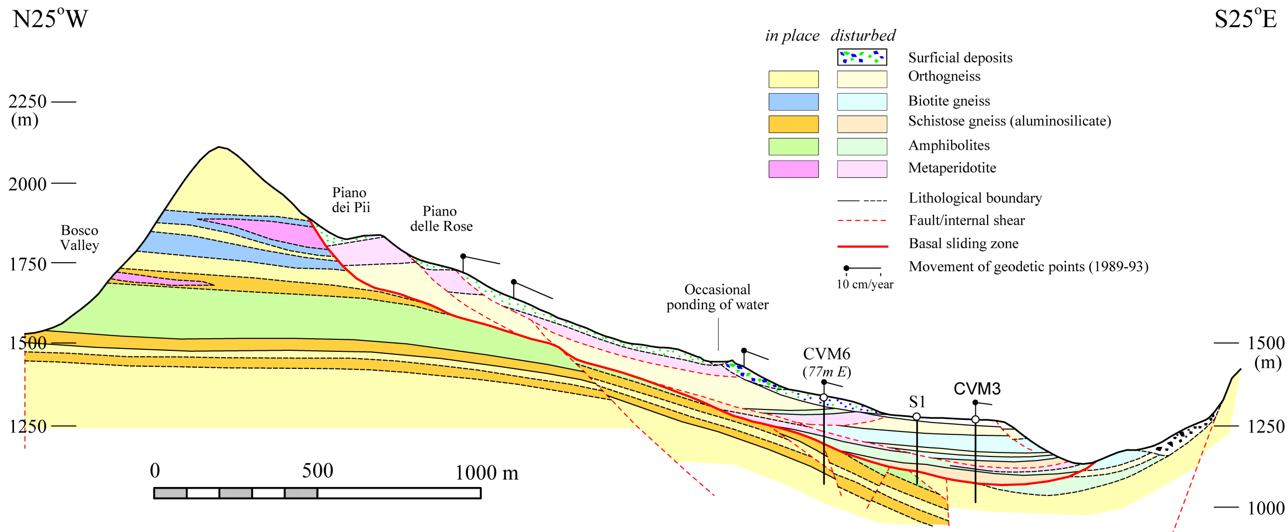

Figure 5. Geological cross-section taken longitudinally through the Campo Vallemaggia landslide (after Bonzanigo et al. 2007).

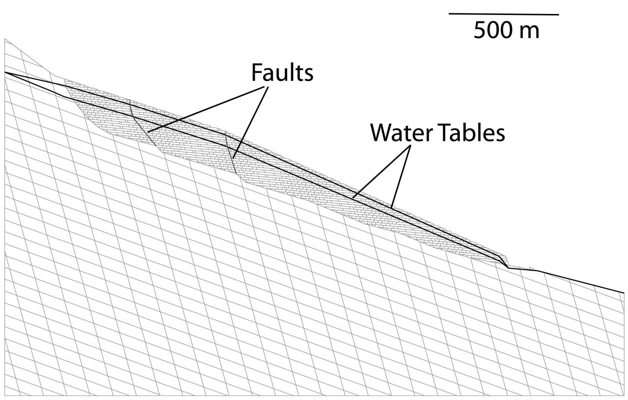

Figure 6. Model of the Campo Vallemaggia slide geometry, showing locations of water tables and faults.

After 200 years (Fig. 7b), there are fewer yielded elements localized around the upper fault due to the redistribution of stresses enabled through the previous yielding of elements and accommodation of slip along the discontinuities. However, throughout the model there are increasing numbers of yielded elements localizing down slope of the lower fault. A scattering of yielded elements can also be seen throughout the lower part of the slope. These represent the more general trend of fatigue within the slope, and the need for internal rearrangement and/or yielding of the rock mass in order to kinematically enable downslope movement. The 400 and 800 year yielding patterns (Fig. 7c,d) continue to follow this trend of increased overall yield.

The above noted model results confirm the development and position of major faulting leading to compound sliding for the problem geometry. Subsequent sets of models were then constructed to explicitly include these faults, as they represent dominant features in the surface morphology of the landslide. The models were then solved for 800 years and examined to assess the continued evolution of internal yielding and fatigue, and the characteristics of the downslope deformation patterns.

Table 1. Rock mass properties used for modelling, taken from Bonzanigo et al. (2007).

Property	Below Slide	Upper Sliding Body	Lower Sliding Body
Density (kg/m^3)	2600	2300	2250
Young's Modulus (GPa)	30	20	5
Poisson's ratio	0.25	0.3	0.35
Block cohesion (MPa)	n/a	1	0.2
Block internal friction angle (°)	n/a	45	30
Block tensile strength (MPa)	n/a	0.5	1
Joint friction angle (°)	45	40	35
Joint cohesion (MPa)	0	0	0
Zero joint aperture (mm)	2	1	1
Residual joint aperture (mm)	1	0.5	0.5
Sliding surface friction angle (°)	25		

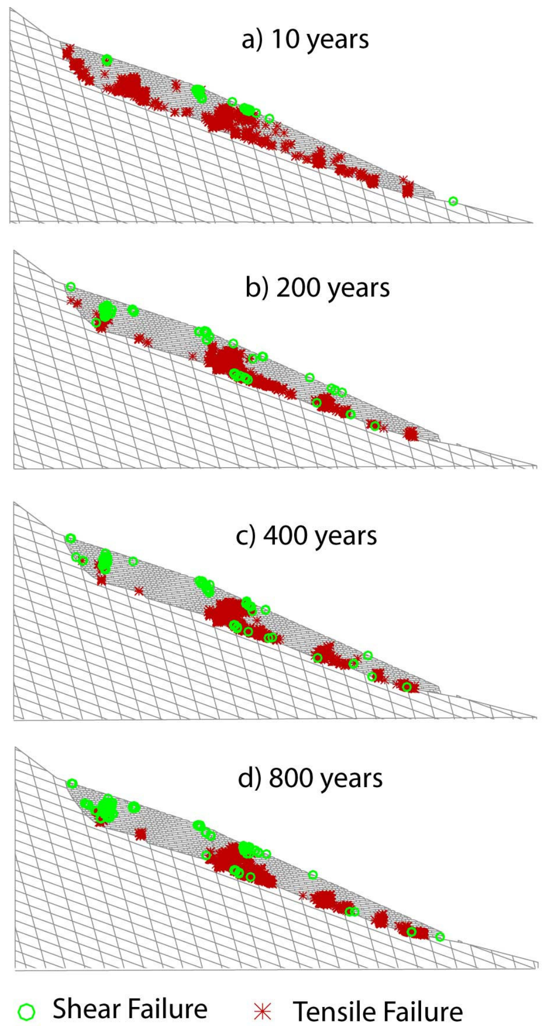

Figure 7. Progression of yielded elements with increasing number of model years.

Figure 8 shows the tendency of the lower half of the model to move more than the upper half. This difference in displacement accommodates some of the internal rearrangement seen in the yielding within the model. Figure 8b shows how this is still true, but to a greater extent in the faulted version of the model than the non-faulted. This indicates that the presence of these faults give the lower part of the slope increased kinematic freedom to move at different rates than the upper half of the slide. Otherwise, the only key difference between the two sets of models is that the velocity difference between the upper and lower halves of the slide body is more abrupt when the faults are explicitly included.

4.2 Analogies with Monitoring Techniques

To further evaluate the model results, a series of history points were added to the model to simulate surface geodetic and borehole inclinometer measurements in the modelled slope. These provided a means to compare the models' response to fatigue cycling to the actual monitored temporal response observed at Campo Vallemaggia.

A typical example of the modelled movement pattern is shown in Figure 10. Figures 10a and c show the horizontal displacement of the toe for the first 10 and 800 years, respectively. Figures 10b and d show the same time intervals, but for a surface point approximately halfway up the slope (i.e. representing the behaviour of the landslide above the secondary slide scarp fault).

The repeating stick-slip trend seen in these graphs corresponds to one model year. The steep portion of each step corresponds to a period of increased precipitation and groundwater level, while the flattened portion represents the dry season and lowered groundwater table. The amount of displacement, seen mainly in the slip period, is on the order of 2-4 cm/year, similar to displacements recorded at Campo Vallemaggia (Eberhardt et al. 2007).

It can be clearly seen that the displacements measured at the toe have a very regular pattern, while those in the upper part of the slide show more variation with each cycle. This is logical given that the toe is unconstrained and would be free to move in response to the changing effective stress conditions along the basal sliding surface. Downslope displacements in the upper part of the slope would also be promoted by the changing pore pressures, but would be constrained in part by the buttressing effect of the lower half of the slide. This can be clearly seen in Figure 8

This difference illustrates why it is often difficult to interpret periodic accelerations in geodetic monitoring data. A perfectly placed measurement point may pick-up the stick-slip stepped velocity pattern seen in the model results, and over time, the more generalized continuous behaviour (i.e. constant velocity) with repeated cycles. However, it is often the case that a measurement point depicts a more localized response of complex movements and is therefore not necessarily representative of the global landslide behaviour.

The presence of faults and internal shears may lead surface reflectors to not simply record the overall movement of the slide along the basal sliding surface, but internal deformations related to blocks shifting and rotating in place as well. Accordingly, the interpretation of geodetic monitoring data and the development of an early warning alarm threshold should be based on several reflectors spatially distributed across the slope. The presence of numerous reflectors also allows for the relative movements of the various blocks to be measured within the landslide as discussed by Bonzanigo et al. (2007).

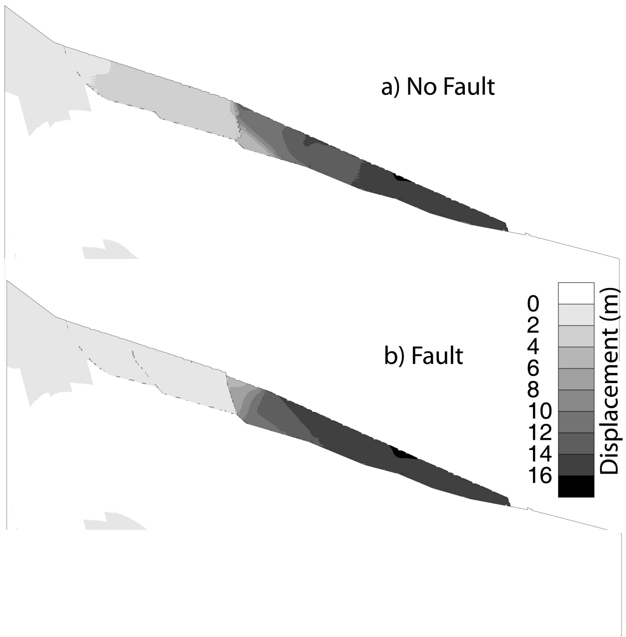

Figure 8. Horizontal displacements are shown for both the faulted and non-faulted versions of the model. Both show fairly distinct upper and lower block movements, with the faulted model shows a more abrupt transition between these blocks compared to the non-faulted model. The displacements shown are those after 800 modelled years.

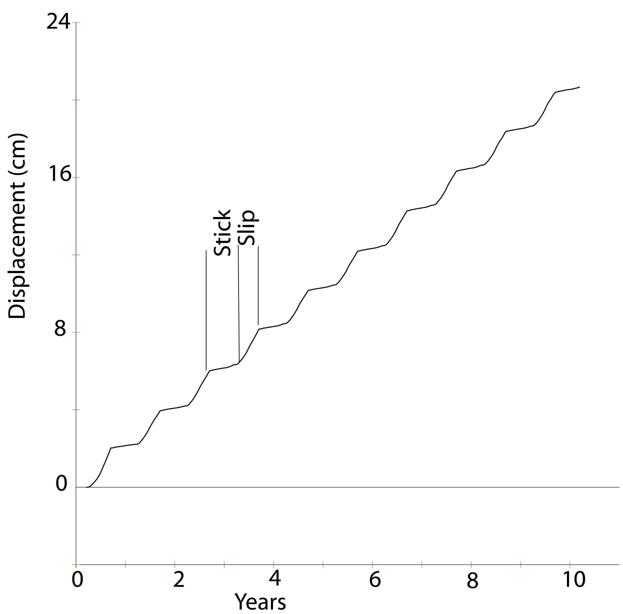

Figure 9. Displacement *vs.* time graph for the first 10 years. The stick and slip portions of the motion are identified.

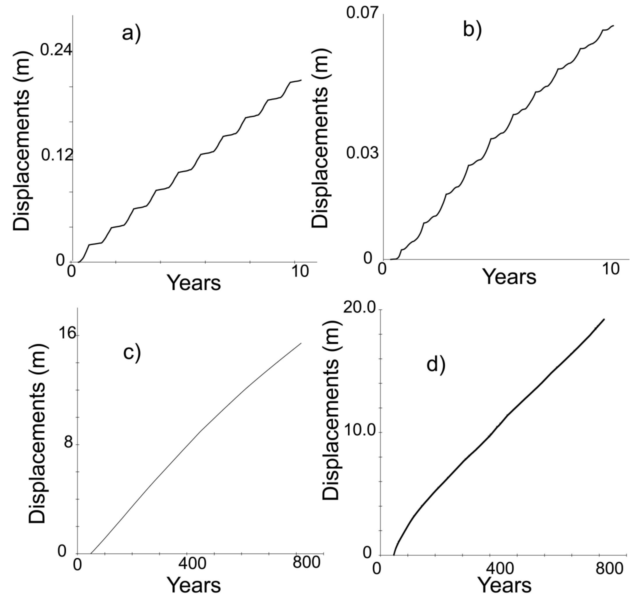

Figure 10. Displacement *vs*. modelled years: a) at the toe after 10 years; b) on surface behind the lower fault scarp after 10 years; c) at the toe after 800 years; and d) on surface behind the lower fault scarp 800 years at the surface.

5 CONCLUSIONS AND CONTINUED RESEARCH

Results from a series of distinct-element models, based on a conceptualized representation of the Campo Vallemaggia landslide, have shown that procedures developed to simulate cyclic loading due to seasonal changes in groundwater levels were able to reproduce the stick-slip movements commonly observed in monitoring data of deep-seated landslides moving on well-developed basal detachment surfaces. The results indicate that incremental plastic yielding, in both shear and tension, lead to localization, fatigue and internal shearing in combination with slip along already existing discontinuities to produce intermittent downslope displacements.

Modelled monitoring points designed to represent surface geodetic measurements, as used for early warning, illustrated a general weakness of this monitoring technique when stick-slip behaviour is involved. Only an ideally placed monitoring point is likely to pick up a clear stick-slip trend that can be used to establish expected thresholds used to differentiate typical phases of acceleration from those that may precede catastrophic failure. If incorrectly placed, the monitoring point will record either highly localized block movements or a more generalized movement pattern due to the common compound nature of these slides.

Future work will include a more rigorous comparison to monitoring data from this site, both with respect to model calibration and the interpretation of model results. In addition, model runs will be continued for several thousands of years, in order to test for the potential for accelerating behaviour to develop after significantly longer periods of time.

ACKNOWLEDGEMENTS

The writers would like to acknowledge the collaborative contributions of Luca Bonzanigo, Geolog.ch, Switzerland. Funding in support of this research was provided through an NSERC Discovery Grant.

REFERENCES

Agliardi, F., Crosta, G.B. and Zanchi, A. 2001. Structural constraints on deep-seated slope deformation kinematics. *Engineering Geology*, 59(1-2): 83-102.

Bagde, M.N. and Petros, V. 2005. Fatigue properties of intact sandstone samples subjected to dynamic uniaxial cyclical loading. *International Journal of Rock Mechanics and Mining Sciences*, 42: 237-250.

Bonzanigo, L., Eberhardt, E. and Loew, S. 2007. Long-term investigation of a deep-seated creeping landslide in crystalline rock; Part I, Geological and hydromechanical factors controlling the Campo Vallemaggia landslide. *Canadian Geotechnical Journal*, 44(10): 1157.

Cronin, V.S. 1992. Compound landslides; nature and hazard potential of secondary landslides within host landslides. *Reviews in Engineering Geology*, 9: 1-9.

Crosta, G.B. and Agliardi, F. 2003. Failure forecast for large rock slides by surface displacement measurements. *Canadian Geotechnical Journal*, 40(1): 176-191.

Eberhardt, E., Bonzanigo, L. and Loew, S. 2007. Long-term investigation of a deep-seated creeping landslide in crystalline rock; Part II, Mitigation measures and numerical modelling of deep drainage at Campo Vallemaggia. *Canadian Geotechnical Journal*, 44(10): 1181-1199.

Franklin, J. 1990. *Mine Monitoring Manual*. Harpell's Press Cooperative, Ste-Anne-de-Bellevue.

Fukuzono, T. 1985. A new method for predicting failure time of a slope. *IVth International Conference Field Workshop on Landslides*, Tokyo, Japan. 1, 145-150.

Furuya, G., Sassa, K., Hiura, H. and Fukuoka, H. 1999. Mechanism of creep movement caused by landslide activity and underground erosion in crystalline schist, Shikoku Island, southwestern Japan. *Engineering Geology*, 53: 3-4.

Glawe, U. and Lotter, M. 1996. Time prediction of rock slope failures based on monitoring results. *Seventh International Symposium on Landslides*, Trondheim, Balkema. 3, 1551-1555.

Goodman, R.E. 1980. *Introduction to Rock Mechanics*. John Wiley and Sons, New York.

Hall, K. 1999. The role of thermal stress fatigue in the breakdown of rock in cold regions. *Geomorphology*, 31(1-4): 47-63.

Halsey, D.P., Mitchell, D.J., Dews, S.J. and Anonymous 1998. Influence of climatically induced cycles in physical weathering. *Engineering Geology*, 31(4): 359-367.

Itasca 2004. *UDEC 4.0*. Itasca Consulting Group, Inc., Minneapolis.

Jaeger, J.C. 1979. *Fundamentals of Rock Mechanics*. Fletcher and Son Ltd., Norwich.

Leroueil, S., Vaunat, J., Picarelli, L., Locat, J., Lee, H.J. and Faure, R.M. 1996. Geotechnical characterization of slope movements. *Seventh International Symposium on Landslides*, Trondheim, Balkema. 1, 53-74.

Priest, S. 1993. *Discontinuity Analysis for Rock Engineering*. Chapman & Hall, USA.

Rose, N.D. and Hungr, O. 2007. Forecasting potential rock slope failure in open pit mines using the inverse-velocity method. *International Journal of Rock Mechanics and Mining Sciences*, 44(2): 308-320.

Saito, M. 1965. Forecasting the time of occurrence of a slope failure. *6th International Conference on Soil Mechanics and Foundation Engineering*, Montreal, University of Toronto Press, Montreal, Canada. 2, 537-541.

Sitar, N., MacLaughlin, M.M. and Doolin, D.M. 2005. Influence of Kinematics on Landslide Mobility and Failure Mode. *Journal of Geotechnical and Geoenvironmental Engineering*, 131(6): 716-728.

Terzaghi, K. 1950. *Mechanism of landslides*. *Application of Geology to Engineering Practice (Berkey Volume)*, Geological Society of America, 83-123.

Voight, B. 1989. A relation to describe rate-dependant material failure. *Science*(243): 200-203.

Watson, A.D., Martin, C.D., Moore, D.P., Stewart, T.W.G. and Lorig, L.J. 2006. Integration of geology, monitoring and modelling to assess rockslide risk. *Felsbau*, 24(3): 50-58.

Zangerl, C., Eberhardt, E., Schonlaub, H. and Anegg, J. 2007. Deformation behaviour of deep-seated rockslides in crystalline rock. *1st Canada-US Rock Mechanics Symposium*, Vancouver. Taylor & Francis, Vancouver, Canada. 2, 901-908.