Numerous landslides and landslide restorations – an example

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Numerous landslides appeared in a smaller area of north-western Croatia during a short span of time; in a large number of cases these landslides infringed upon local roads, public objects and other landscape. As is well known, the phenomenon of multiple landslides is connected to specific hydrometeorological features of the period, but also with geotechnical sensibilities of the terrain, which has a bearing on destabilizing factors. As this high number of landslides was previously unheard of, the action of preparing documentation for their restorations was also quick and arduous. A high level of systematization and a plan involving the approach to solving the problem as a whole and in phases is necessary for any mass-restoration/reconstruction approach. The paper deals with the characteristics of landslides in the examined area, with cause(s) of appearance of these numerous landslides, with investigations and restorations of landslides, and with additional notes to keep in mind when examining the problem and constructing the solution. Geometry, geological content, frequent geotechnical characteristics, etc. will be described as landslide characteristics. These hydrometeorological causes will be examined more closely through time. Familiarizing with multi-landslide locations, i.e. making the correct diagnosis is then followed by mass restoration. In order for restoration to be successful, one must set a good concept of effectiveness - which is arrived at through correct analysis of area characteristics. The paper also describes the chosen ways of restoration/reconstruction, emphasizing that these were solutions minimizing possibilities of errors in mass restoration.

Key words: *landslides, infiltration, site investigations, construction, restoration concepts.*

Introduction

Natural disaster and the approach to strategies of handling mass landslides

A natural disaster hit north-western Croatia in the spring of 2006, manifesting itself as a large number of landslides within a small area and in a relatively short time span. Over 50 individual landslides appeared within approx. 150 km^2, or more precisely, in the predominately hilly Bednja area. Mass landslides can, in most cases, be connected to specific weather characteristics of the period, but also with the geotechnical sensitivity of the terrain, which can cause destabilizing factors.

This area, with respect to sloping, is comprised of plains, gentle slopes, sloped terrain, significantly sloped terrain and steep terrain (according to degrees of slope as shown below), (Soldo B., et. al., 2006.-2007., Soldo B., et. al., 2008.).

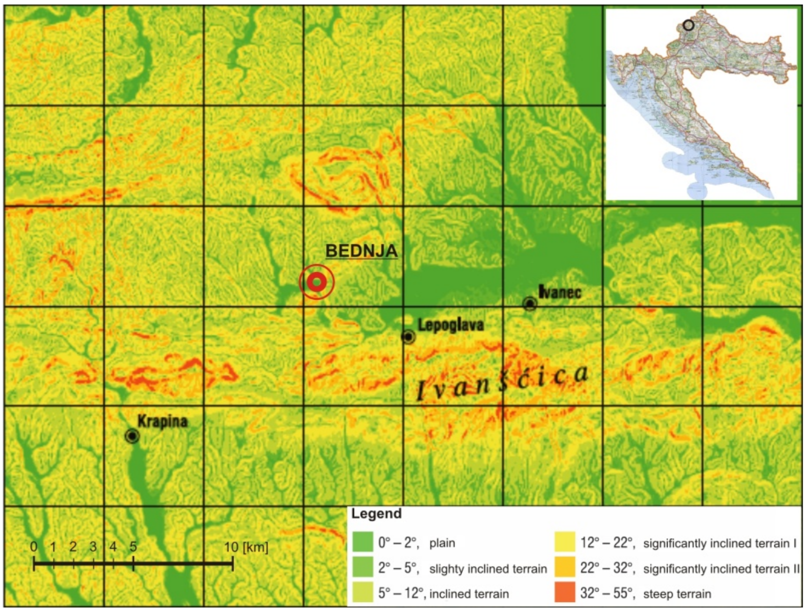

Fig. 1. Map of various degrees of slope in the examined area.

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The size of the landslide by the road is most often approx. 50m wide and 70m long. This caused sagging in the road, sometimes slight, sometimes more significant, but often the flow of traffic had to be stopped altogether. In a short time more than 50 landslides were registered (Soldo, et al 2007.). A map of these slopes was made, telling us that landslides most frequently happened at slopes of 15-20 degrees, virtually all between 12-30 degrees (Soldo, et al 2004.).

Fig. 2. Typical landslides in the Bednja area:
2A) Most frequent appearances at road bends; 2B) Often landslides will happen beneath houses.

Due to this mass appearance of landslides, it was necessary to search for a strategic approach to handling and solving this problem with a high degree of systematization. The starting point was the local self-government, whose main task was to make a list of (i.e. register) the landslides and supplement the list with basic data. The next step called for a mixed team comprised of local government representatives and competent experts (geotechnicians) specially engaged for this purpose to go into the field armed with this data (Soldo, et al 2009.). The list/register would then be filled with relevant geotechnical data and various statistical weight numbers in order to reach the decision on the urgency of restoration. In the next step, the experts took over the task, performing investigations (with surveying) and engaging an architect in order to draft technical documentation necessary for landslide repair. The final step was the restoration/repair itself, with obligatory geotechnical oversight (Soldo, et al 2009.).

Constant and persistent procurement of financial assets for all operations was necessary from the beginning of the project, i.e. from the first registration of landslides.

Appearance and characteristics of numerous landslides

Numerous landslides originated within a very short time period, which was unheard of before, both in number and speed of landslides. They were spotted in various locations, but most often (and causing the largest damages) on roads. Case-by-case investigations were initiated immediately after visual inspection of noted landslides; the investigations were to find out why all these landslides appeared in such a short period of time and why at the end of May 2006 (last two days of May). The first suspect was rain; therefore, precipitation in the past few years was checked in local meteorological stations. Investigations bore fruit, and the following was concluded: precipitation was continuous all through winter and spring, in significant increases with respect to previous years. This precipitation was mainly in the guise of seeping rain which slowly irrigated the soil, leading to maximum saturation after the winter and to slow thawing of snow. It was therefore logical that during this period the evaporation of water from the soil was minimal. As the final nail in the coffin, in May precipitation reached approx. 150mm, and over 35 mm only on the last day of heavy rains (Croatian Meteorological and Hydrological Service, 2006.-2009.). Diagram of precipitations during the year is shown Fig. 3, and precipitation during the months of April and May on Fig. 4. During precipitation (heavy rains) at the end of May, quicker sliding was noticed, reaching up to 1 m/h (landslide). Roads saw shifts of more than 1m, and in extreme cases, even several dozen metres.

Calculation of the average precipitation through 8 months of winter and spring (i.e. the period of lesser vaporization), up until the end of May, led to the following results: in 2003 the average precipitation was ≈40 mm, in 2004 ≈58 mm, in 2005 ≈55 mm, in 2006 ≈91 mm, in 2007 ≈67 mm, in 2008 ≈57 mm and for 2009 ≈75 mm. The same numbers told us that the highest precipitation happened in 2006 during the season of lesser vaporization (winter-spring).

Road landslides most often occurred on road bends. In fact, the starting point of the slide was at the most curved point of the road, where the surface water from the slopes above the road flowed into the lower slopes (slopes beneath the road).

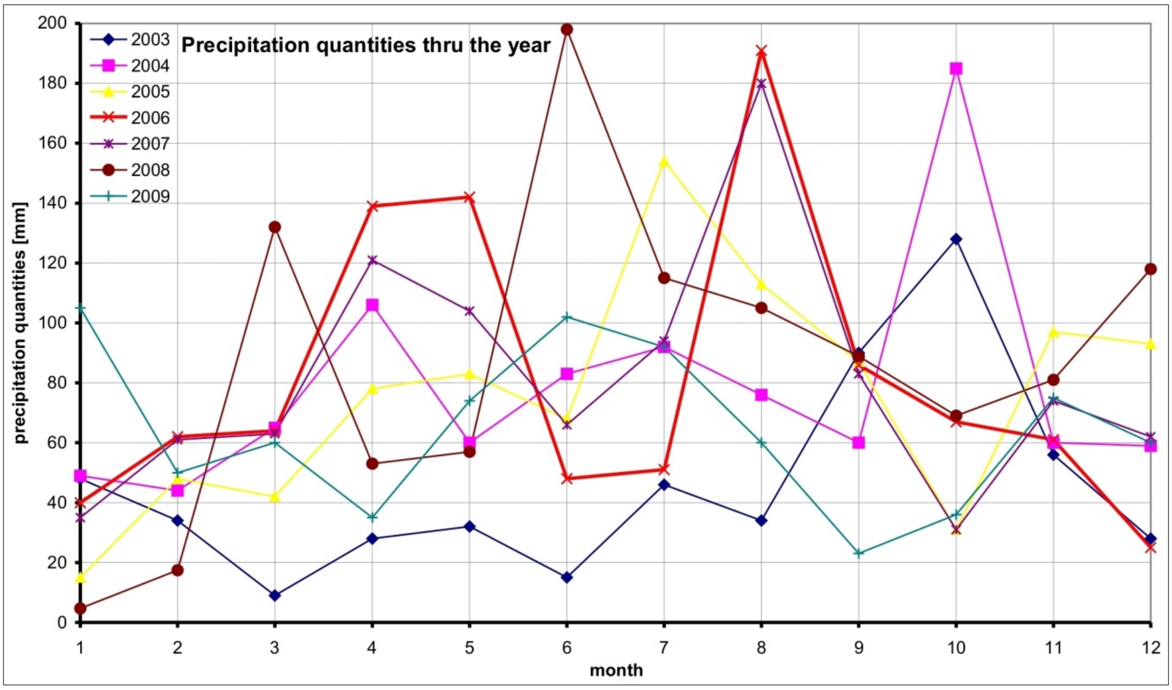

Fig. 3. Precipitation during 2003-2009.

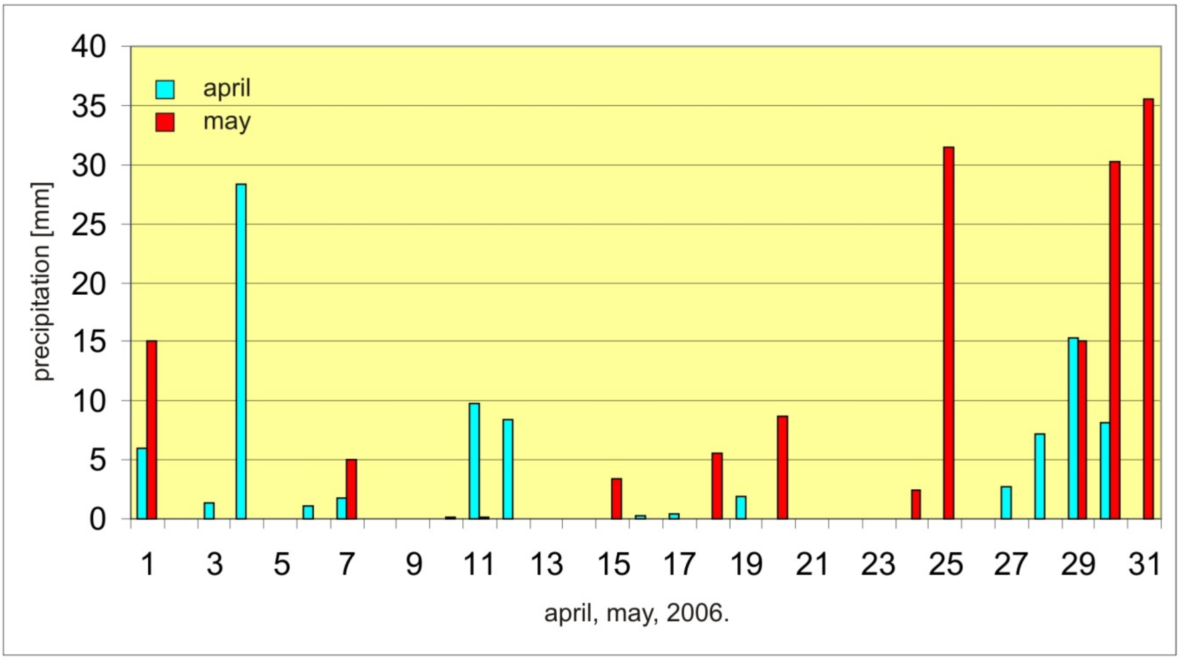

Fig. 4. Precipitation during April and May 2006.

After 2006 and before the restorations started in 2009, some old landslides expanded even with less damaging hydro-meteorological characteristics, since they were already "hurt" (shear rigidity was lower, and there were cracks through which water reached the sliding plateau).

Geotechnical investigations

Visual inspection of the initiation and size of landslides was bolstered by geotechnical investigations. They were performed within a short time period on 20-odd landslides, those must urgently in need of attention. As the first step, some 4 boreholes were made to satisfactory depths (beneath the sliding layer) at each landslide. A common geotechnical characteristic of these landslides is that hard marl is found beneath the sliding layer, usually at the depth of 3m (Soldo, et al. 2004). One of the profiles characteristic for the area is shown on Fig. 1.

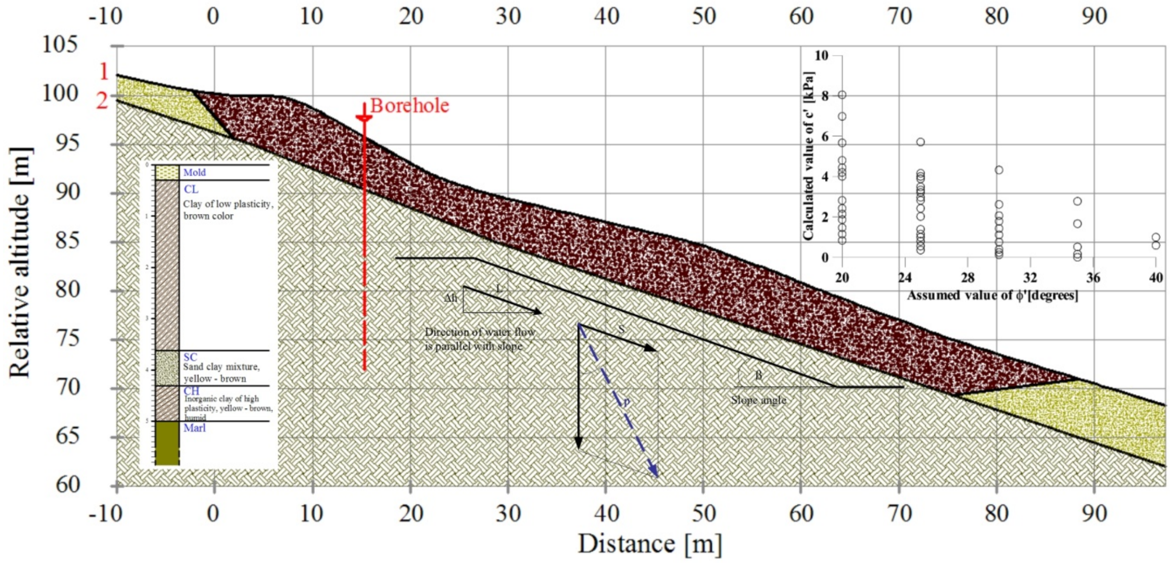

Fig. 5. Geotechnical profile of typical landslide in the examined region.

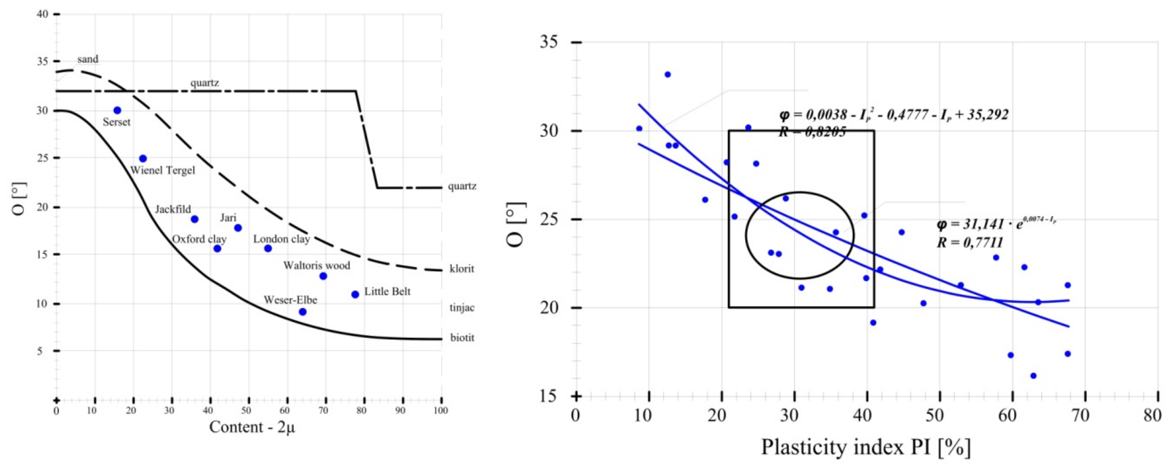

Fig. 6. Certain important correlations of geotechnical parameters.

The so-called return analysis of slope stability was proven to be a steadfast method when dealing with this quantity of calculations. The average cohesion value gained through said return analysis for the angles of friction of these landslides is relatively low, as shown on Fig. 2B. The areas of most frequent landslides are shown on figures presenting the relation of the plasticity index (PI) and the percentage of clay particles smaller than 2 μm with the angle of friction. The plasticity index (PI) and the percentage of particles smaller than 2 μm (colloidal particles) is around 30 %, meaning the clay activity is close to 1 (according to the diagram showing the relation of the plasticity index and colloidal particles). Good results were also shown by the analysis of the effect of current pressure (Fig. 2C), providing there is no cohesion in sliding. When water is flowing in the soil due to the difference in potentials, this water must work through the friction with the soil particles, where one portion of potential energy is transformed into friction itself. Additional frictional force acts on the sunken soil volume and turns the resulting force in the direction of the water flowing through the soil. The figure shows an example using a fully saturated case, i.e. water flowing parallel to the slope as the most critical case for slope stability. The angle of deviation of resultant p from the vertical γ' may be calculated from the following polygon: $\delta = arctg((S \cdot \cos\beta)/(\gamma' + S \cdot \sin\beta))$. If we assume that at the moment of the beginning of the mass movement (crawl) cohesion c=0, then the angle of the slope incline increased for the angle of the deviation may, in a borderline case, be equal to the angle of internal friction of the material in question ($\beta+\delta=\varphi$). $F_s = tg\varphi / tg(\beta + \delta) = 1$.

Most frequent restoration concepts

The choice of the restoration/repair concept for landslides is extremely important; it is, in fact, essential for the effectiveness, and thereby the success of the restoration itself. General situation found in the examined area (area of Bednja, in Croatian Zagorje) where numerous landslides occurred generally favoured the restoration concept comprised of the following operations (Soldo, B., et al 2006.-2007., Soldo, B., et al 2008.):

- digging a number of drainage points (the bottom of these drainage points must be below the sliding layer),
- partial (and in some cases, full) substitution of damp or slid soil materials from the road and the contact area,
- micro-pile security of endangered structures, and if necessary, building micro-pile foundations for the gabion wall,
- construction of a flexible gabion wall on points of higher terrain denivelation, (gabion walls are most often built parallel to road axes),
- installation of special materials (geo-textiles etc.) in certain areas, if necessary,
- ballast relocation of soil masses (unburdening the frontal and adding weight to base zones of landslides),
- constructing the system of surface drainage, with controlled drainage flow to the appropriate recipient,
- arranging/beautification of the restored/repaired terrain, including planting appropriate plant life (for solidifying the soil and increasing evapotranspiration),
- setting up the monitoring system,
- maintaining and putting finishing touches on the restored area.

Fig. 7. Example of restoration solution for the landslide:
7A) Ground plan of restoration, 7B) Typical most frequent cross-section of restoration

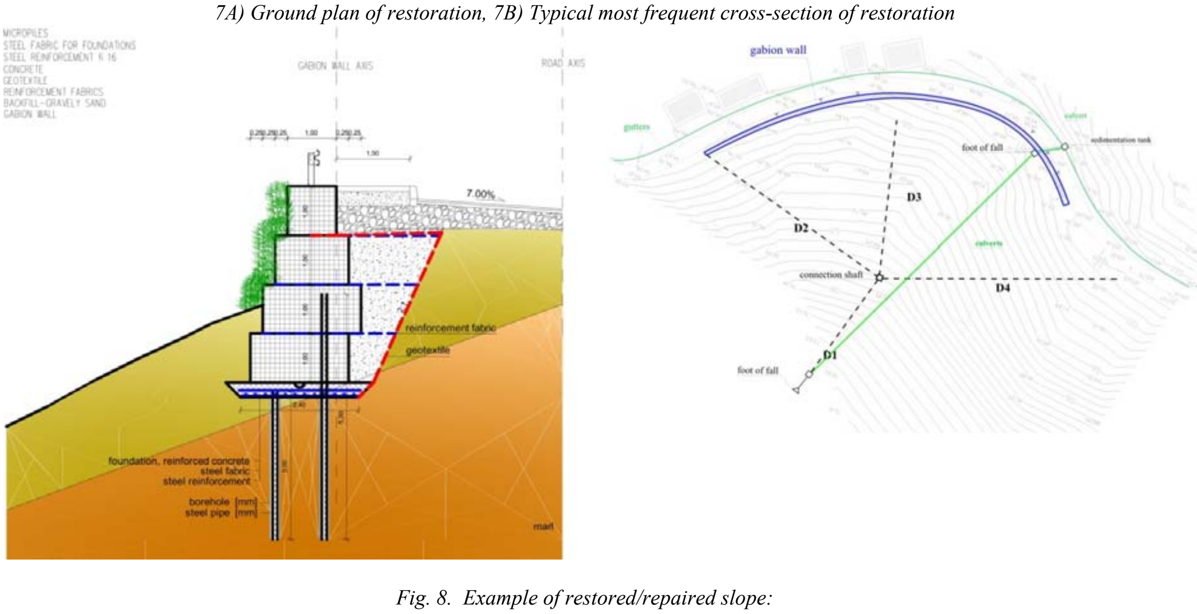

Fig. 8. Example of restored/repaired slope:
8A) After sliding and before restoration; 8B) Slope after restoration.

Conclusion

Hilly terrain configuration and specific geological and technical characteristics of the soil in the area, as well as meteorological and hydrological characteristics are the main causes of mass landslides. To this we can also add certain secondary causes, such as human interventions (larger mortises, unfavorable directing of groundwater, etc). After natural disasters/heavy precipitation and the emergence of numerous landslides, restoration and repair of these landslides must be varied and carried decisively - which is the topic this paper dealt with. It is important that the approach, i.e. solution to this problem be strategically thought-through and systematic. The choice of technical restoration solutions is especially important, while the solutions should be optimally balanced throughout the restoration project. One of the points to take into consideration is that restoration solutions fit in well with the landscape/scenery. The character of restoration solution should be such that said solutions are able to, as much as possible, be adjusted to the actual situation in the field. In that sense, a high quality contractor for the performance of the works is of great importance, as is competent oversight of works.

References

Croatian Meteorological and Hydrological Service: Količine padalina u Bednji, Zagreb, http://meteo.hr/ , *2006.-2009*

Duncan, J.M. and Stark, T.D.: Soil strengths from back analysis of slope failures, *Proc. Of Specialty Conf. Stability and Performance of Slopes and Embankments-II, ASCE, Berkeley, CA, Vol.1, pp.890-904., June 1992.*

Jian-Hua Y.: Properties and behaviour of Hong Kong marine deposits with different clay contents, *Canadian Geotechnical Journal, Volume 36, Number 6, 1085-1095., 1999.*

Ortolan, Z., Mihalinec, Z.: Plasticity indeks – Indicator of shear strength and a major axis of geotechnical modelling, *Geotechnical Hazards, balkema, Rotterdam, 743-750., 1998*.

Soldo, B. 27-28 Characteristics of road landslides in cohesive soils, *I. BH Kongres o cestama, Sarajevo, September 2007.*

Soldo, B., et al.: Projektna dokumentacija: Geotehnički elaborati o istražnim radovima na klizištima u općini Bednji; *Faculty of Geotechnical Engineering in Varaždin, University of Zagreb., 2006-2007*.

Soldo, B., et al.: Projektna dokumentacija: Projekti sanacije klizišta u općini Bednji; *Faculty of Geotechnical Engineering in Varaždin, University of Zagreb., 2008*.

Soldo, B., Ivandić, K.: The Analysis of the Illite - Clays Natural Landslides, *IX International Symposium on Landslides, Rio de Janeiro, Brazil., from 28 June to 2 July 2004*.

Soldo, B., Orešković M,.: Mass appearance and rehabilitation of landslides in northwest Croatia, *International scientific conference, People, buildings and environmental, Conference proceedings No.10, 119-123, Czech Republic, Brno., November 26-27, 2009*

Soldo, B., Orešković, M., November: Road slopes – securing and stabilization at road reconstruction, *International scientific conference, People, buildings and environmental, Conference proceedings No.10, 115-118, Czech Republic, Brno., 26-27, 2009*

Wilson, H.Tang, Timothy D.Stark and Maurico Angulo.: Reliability in back analysis of slope failures, *Japanese Geotechnical Society, Soil and Foundations, Vol.39, No.5, 73-80., 1999.*