LEGAL ASPECTS OF A LANDSLIDE CASE

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ABSTRACT: This case history illustrates some of the legal issues encountered in a landslide case including conveying complex and technical causation information to a jury, the possibility for jury confusion, the liability associated with taking over a project from another geotechnical engineer, and the conflicts of interest when defending your own geotechnical design. This case history also discusses some of the ramifications of fill placement on natural slopes surrounded by urban development such as, the importance of stress distribution analyses for determining the depth of influence of surface activities and the potential for overstressing weak materials below the depth of the subsurface investigation.

INTRODUCTION

Between 1988 and 1989, a housing development with about 50 units (the Knolls) was completed on an undeveloped hillside in California (Figure 1). An 11 unit housing development was subsequently constructed upslope of the Knolls (the Vista development) (Figure 1). Neither housing development experienced any complaints from the residents until September 1996. In June 1996, a large fill was started by development upslope of the Vista development. The main purpose of the large fill was to create a visual barrier between the BC Development and the Vista development (Figure 1) and is referred to as the landscape screen herein. Fill placement for the landscape screen ceased in late December 1996 even though the fill had not reached full height because of the onset of homeowner's complaints of damage to their homes. The surface area of the landscape screen in December 1996 was approximately 61,000 square meters, with a height of over 21 m and an estimated volume of 76,600 cubic meters.

There was no significant change in the slope geometry after completion of the Knolls housing development and the construction to date in the Vista development until the BC Development commenced in late 1995. In particular, there was no significant fill placement on the hillside until the BC Development started construction of the landscape screen in June 1996.

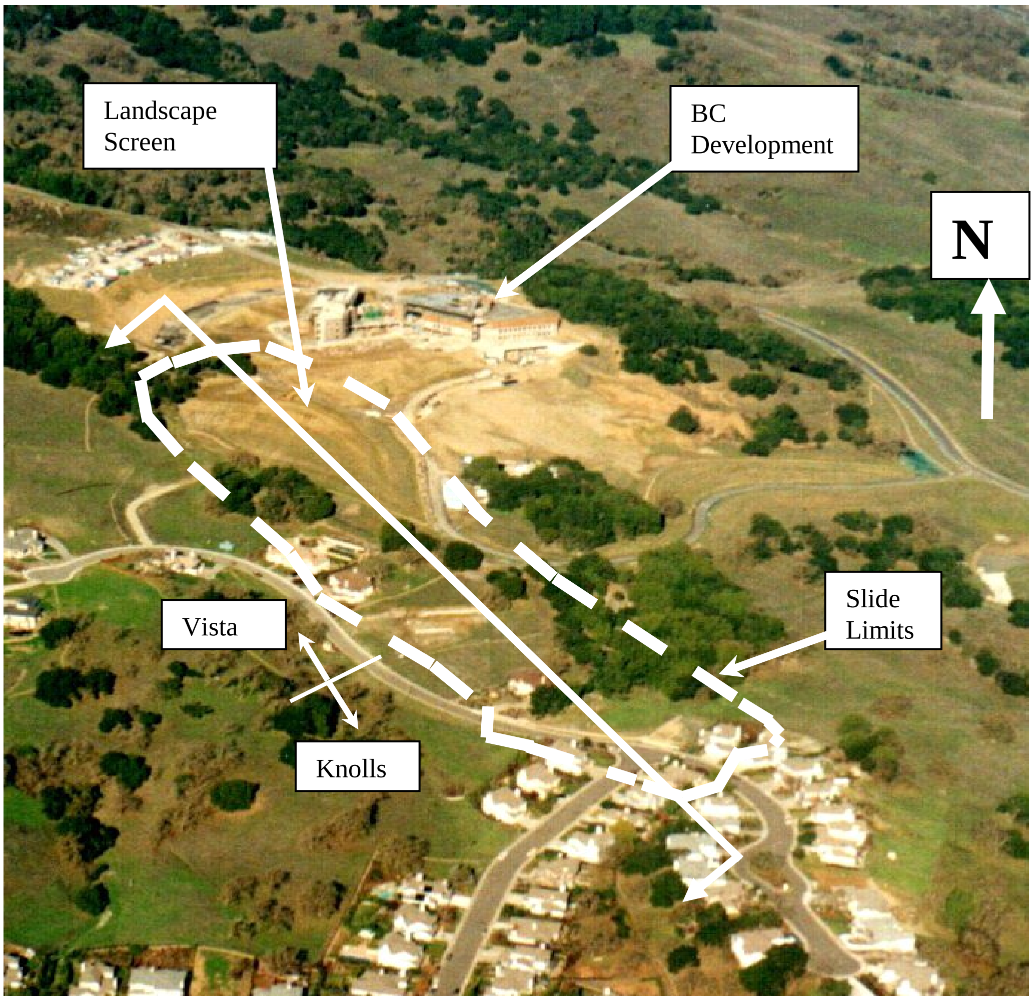

Figure 1. Aerial view of BC Development, downslope housing developments, cross-section location, and an outline of the slide mass (photograph by Cotton, Shires & Associates, Incorporated.)

FORENSIC INVESTIGATION

The main steps in the forensic investigation used to determine the causation of the 1996 landslide are:

(1) develop a number of cross-sections to understand the variability and geometry of the subsurface materials,
(2) determine the failure mechanism, i.e., failure surface, from surface observations and slope inclinometer results,
(3) develop material properties for the materials involved and appropriate groundwater levels,
(4) perform a back-analysis to locate the critical cross-section,
(5) use the back-analysis to estimate the shear strength of the weak layer comprising the majority of the failure surface,
(6) compare the back-calculated shear strength with laboratory test results and empirical correlations to ensure agreement, and
(7) conduct stability analyses to determine the effect of surficial grading in the Knolls development and placement of the landscape screen on the hillside stability.

Cross-Sections

The estimated volume of the landslide is twomillion cubic meters and the slide is underlain by the highly variable Franciscan Complex. The Franciscan Complex is frequently referred to as a mélange, or mixture, because the deposit was formed near the forward edge of a subduction plate boundary (Goodman 1993) and is highly variable. Six cross-sections were drawn to gain an understanding of the materials present, the variability of the materials, and the presence of unusual and varying subsurface features. Four of the cross-sections extend the length of the slide mass and two traverse the slide mass to determine material variability and distribution of the weak layer. The transverse cross-sections revealed the presence of a buried sandstone ridge that increases from a depth of about 40 m on the western portion of the slide mass to a depth of about 18 m on the eastern portion of the slide mass.

Failure Mechanism

The appearance of continuous and substantial tension cracks along the top of the slide limits, i.e., upslope of and around the landscape screen, the approximately 500 m length of the slide mass, the non-circular nature of the failure surface, and the 5 to 40 m depth of sliding indicated a translational failure mechanism rather than a rotational failure mechanism (Cruden and Varnes 1996). In addition, no vertical offset was associated with the tension cracks along the top of the slide limits, which reflects a translational slide that has undergone about 20 to 25 cm of deep-seated movement. The tension cracks upslope of the landscape screen continued to widen until the landscape screen was completely removed in April 1997 and indicate that the slide mass was pulling away from the natural materials upslope of the fill area.

Fifteen slope inclinometers were installed after the initial reports of distress. Nine of the fifteen slope inclinometers provide useful information but the other six are either too shallow or outside the slide limits shown in Figure 1. Each of the nine useful inclinometers show a distinct slide plane at depths ranging from 5 m near the landslide toe to 40 m near the middle of the slide mass. The depth of movement from eight of the inclinometers is plotted on the cross-section in Figure 2. The location of the cross-section is shown in Figure 1.

The fully shaded circles in Figure 2 correspond to inclinometers that show a distinct shear movement and are within 30 m of the cross-section. Thus, the estimated failure surface passes through these dots. The partially shaded symbols correspond to inclinometers that are greater than a horizontal distance of 30 m from the cross-section. Partially-shaded circles correspond to the depth of movement in inclinometers installed deep enough to experience movement while the partially-shaded squares in Figure 2 correspond to the maximum depth of inclinometers that are too shallow to record movement. The failure surface is shown in Figure 2 by the dashed line and was estimated from the surficial movements and the inclinometer data.

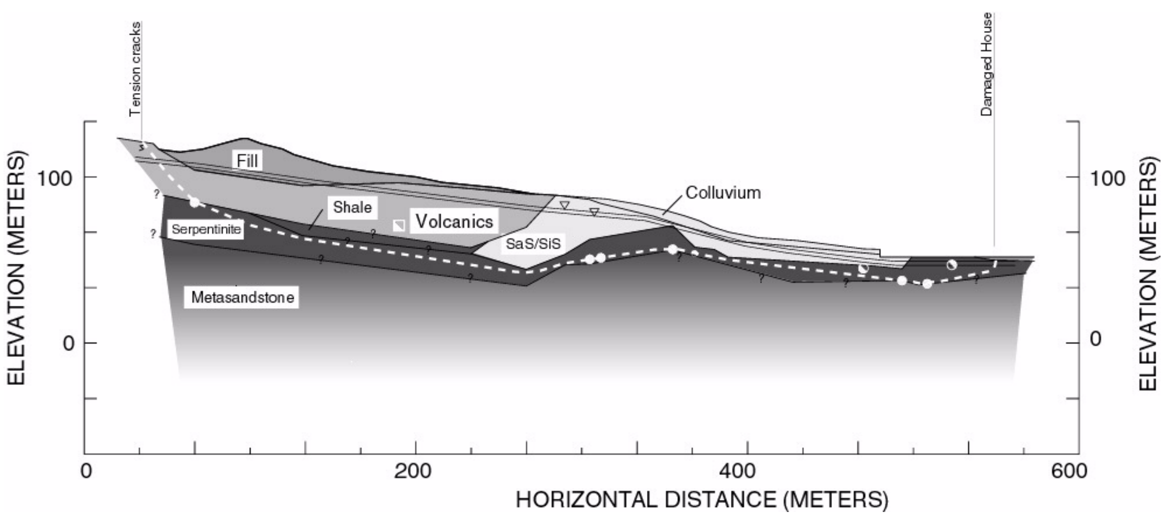

Figure 2: Cross-section through the western portion of the landslide after surficial grading and placement of the landscape screen

Figure 2 shows the estimated failure surface passes through the Tertiary Volcanics upslope of the landscape screen at a steep inclination to the underlying weak and saturated serpentinite. The failure surface continues along the serpentinite layer until the depth of overburden allows it to daylight in the Knolls housing development. The landslide also damaged the homes in the Vista development that are at or near the western edge of the slide mass.

Material Properties and Groundwater Levels

One of the two main uncertainties in the stability analyses for this case was the shear strength of the serpentinite. A back-analysis was conducted to estimate and/or confirm the shear strength of this material because of the variable nature of serpentinite. The groundwater level acting on the failure surface at the time of the initial movement in October to December 1996 was also not known. As a result, a range of groundwater level was used in the analysis with the high level corresponding to the rainy season and the low level corresponding to the dry season as shown in Figure 2. These two groundwater levels were developed from water levels observed in small and large diameter borings, monitoring wells installed as part of the remedial measures, and water levels used by other experts.

Back-Analysis of the Landslide

One of the two main uncertainties in the stability analysis for this slide is the location of the critical cross-section and the shear strength of the serpentinite. A two-dimensional limit-equilibrium back-analysis of the landslide was conducted to locate the critical cross-section and estimate the shear strength of the serpentinite. In each back-analysis, the friction angle of the serpentinite was varied until a factor of safety of 0.99, i.e., slope failure, was obtained.

The back-analysis of each cross-section utilized the failure surface estimated from the slope inclinometers and surface expressions of the landslide. For example, the back-analysis of the cross-section in Figure 2 utilized the failure surface in Figure 2. For each cross-section, a search was conducted between known points on the failure surface, i.e., cracks at the top of the slide mass, shear displacement observed in the inclinometers, and distress at the toe of the slide mass, to ensure the minimum friction angle was back calculated. The opposing experts searched for a failure surface that yielded the lowest friction angle even though the failure surface did not match the surface and subsurface observations. Searching for a failure surface is inappropriate in a back-analysis because the new failure surface has not undergone failure. The new failure surface has not undergone failure because the surface and subsurface movements do not correspond to the new failure surface. Thus, the back-calculated friction angle for the new failure surface is not representative of the mobilized friction angle of the serpentinite involved in the landslide. This mis-use of a back-analysis in landslide investigations should be recognized and discontinued.

Back-analysis of the four cross-sections that extend the length of the slide mass was conducted to locate the weakest portion of the hill or the area most susceptible to sliding. The largest back-calculated friction angle was obtained for the cross-section shown in Figure 2, which indicates that this cross-section is the critical cross-section or the weakest portion of the hillside. The two cross-sections in the eastern portion of the slide mass yielded lower back-calculated friction angles, 7.3 to 7.9 degrees, than the two cross-sections in the western portion, 9.5 to 9.9 degrees. Thus, failure did not initiate in the eastern portion of the slide. The cross-section in Figure 2 yielded the highest back-calculated friction angle of 9.9 degrees and thus is the critical cross-section. This is in agreement with distress being first reported in the homes in the western portion of the landslide toe and the western portion of the Vista development. Therefore, it was concluded that shear movement started along the western portion of the slide mass, which induced movement along the eastern portion to create the slide limits shown in Figure 1.

Comparison of Back-Calculated Friction Angle with Other Data

It is important to compare the back-calculated friction angles with the results of laboratory shear test results and empirical correlations to ensure the back-analysis yields reasonable values of friction angle. The effective stress cohesion is assumed to be zero because of the highly sheared and deformed nature of the serpentinite (Stark and Choi 2004). The fully softened and residual failure envelopes estimated from torsional ring shear tests conducted on samples of serpentinite obtained from a 0.6 m diameter boring on the BC Development property are in agreement with the back-calculated values. The back-calculated friction is between the fully softened and residual failure envelopes, which was expected given the sheared nature of the serpentinite.

Finally, the back-calculated friction angles are also be compared with empirical correlations derived from field case histories to ensure the back-analysis yielded reasonable values of friction angle. Using a liquid limit of 83 to 95%, a clay-size fraction (% < 0.002 mm) of 55 to 60%, and the fully softened and residual friction angle correlations presented by Stark and Eid (1997 and 1994), respectively, the back-calculated friction angles are in agreement with these empirical correlations that have been verified using other field case histories.

In summary, the back-analysis identified the critical cross-section (Figure 2) as being located along the western portion of the slide mass (Figure 1) and the mobilized friction angle of the serpentinite to be 9.9 degrees.

Effect of Surficial Grading and Landscape Screen

Using the cross-section in Figure 2, representative material properties, a range of water levels, and a friction angle of 9.9 degrees for the serpentinite, the impact of surficial grading in the Knolls and placement of the landscape screen in the BC Development on the stability of the hillside was investigated. The cross-section in Figure 2 was modified to reflect the four conditions shown in Table 1 because the cross-section shown in Figure 2 represents the slope geometry after surficial grading and after placement of the landscape screen. The cross-section was modified using the topography before surficial grading and before placement of the landscape screen that is available from the grading plans for the Knolls development and the BC Development, respectively.

Table 1 shows that the slide mass exhibits a factor of safety between 1.10 and 1.15 before any surficial grading or fill placement occurred. After the minor surficial grading in the Knolls, the factor of safety was still a between 1.10 and 1.14 indicating a stable condition and in agreement with no homeowner complaints even though three years of heavy rainfall occurred before placement of the landscape screen. After surficial grading and placement of the landscape screen, the factor of safety decreased to between 0.99 and 1.03 indicating the slope was unstable regardless of the water level. This is in agreement with homeowner distress in September 1996 and the observation of tension cracks occurring in the access road that intersects the slide limits near the structures in the BC Development in October 1996 (Figure 1). Only 2.5 cm of the 63.8 cm of annual rainfall had fallen at the time the access road cracking was observed in October 1996. In December 1996 and January 1997, 27.4 and 22.0 cm, respectively, of the 63.8 cm of rainfall that occurred during the 1996 and 1997 rainy season had occurred. The majority of homeowner complaints started in late December, which is in agreement with the December and January rainfall.

Thus, it was concluded that the landscape screen triggered the slide movement along the western portion of the slide mass and the surficial grading did not significantly reduce the stability of the slope. The jury agreed with this conclusion and the case settled shortly thereafter.

Table 1. Effect of surficial grading and landscape screen on the factor of safety for TDS5 using a serpentinite back-calculated friction angle of 9.9 degrees

Condition	High water	Low water
Before surficial grading	1.10	1.15
After surficial grading	1.10	1.14
After surficial grading and landscape screen	0.99	1.03
Landscape screen and no surficial grading	0.99	1.03

CONVEYING COMPLEX INFORMATION TO A JURY

In a technical case there is a great possibility for jury confusion because the jury has little, if any, geotechnical or geologic background. Thus, the presentation must be simplistic but informative. A major problem in this case was explaining the seven step forensic analysis described above to a lay jury and convincing the jury that the author's analysis was better or more accurate than that of the opposing side. For example, a significant difference of opinions between the experts was the location of the critical cross-section. The opposing experts selected their critical cross-section down "the guts", i.e., the middle, of the landslide. Because their slide mass is much wider than the slide mass in Figure 1, their critical cross-section is located on the eastern potion of the slide mass shown in Figure 1. Conversely, the authors' critical cross-section is located near the western side of the slide mass in Figure 1 based on the back-analysis and timing of homeowner distress. Therefore, the jury had to determine which cross-section was the best representation. This was an important factor in deciding the case because both sets of experts agreed that if the wrong cross-section was analyzed the entire analysis was flawed.

The authors swayed the necessary number of jurors that their cross-section was correct by bringing the site to the jury. This was accomplished using PowerPoint and many field photographs to illustrate the effects of the landslide. This helped convey the slide limits to the jury. Once the jury understood how the authors developed the slide limits from field observations, the jury concurred with the authors' location of the critical cross-section.

The critical cross-section was further complicated by the opposing side providing different interpretations of the descriptions in the boring logs and the geologic formations. Thus, the opposition attacked the material layering shown in Figure 2. This technically oriented discussion was poorly understood by the jury but significantly extended the duration of the trial and may have caused jury confusion.

The opposing side also claimed that only a geologist could draw/develop the cross-section, not a geotechnical engineer. The primary author believes that geologists may be able to develop meaningful cross-sections, but a geotechnical engineer is clearly qualified to develop cross-sections. In fact, a geotechnical engineer may be in a better position than a geologist to develop cross-sections for slope stability analyses because of their knowledge of the stability calculations involved. At the University of Illinois, geotechnical engineering students are trained to develop cross-sections and routinely perform this task in practice.

It is extremely important to convey the location of the critical cross-section to the jury and have the jury agree with your location. The authors were successful in this task by relating all of the cross-section decisions to field observations, such as material types and depths in the borings, movement in the slope inclinometers, timing of surface damage and movement, shape of the slide mass, and agreement with depths of other serpentinite slides from the open literature. However, there is a great potential to confuse a "lay" jury in a technical topic such as cross-section location and development.

DEFENDING YOUR OWN INVESTIGATION AND DESIGN

In this case, the opposing experts were also the engineer of record for the BC Development. Defending their design created an inherent conflict of interest that the jury and other participants probably struggled with. The authors recommend that the engineer of record not serve as the expert and defend his/her design. This situation can lead to questions concerning even simple matters such as interpretation of boring logs and test results. The potential conflicts of interest can adversely affect more significant matters such as developing cross-sections, selecting material properties, performing stability analyses, and reporting factors of safety.

ASSUMING A PROJECT FROM ANOTHER ENGINEER

The engineer of record for the BC Development assumed the project from another geotechnical engineer. The landscape screen initially appeared on construction plans during the tenure of the preceding engineer. However, this engineer left the project and the engineer of record assumed the position of geotechnical engineer. Fortunately, the preceding engineer wrote a letter stating the critical nature and juncture of the project and that he would not assume any liability after his departure. Unfortunately, the succeeding engineer did not conduct stress distribution analyses to determine the depth of influence of the landscape screen, additional subsurface investigation based on the stress distribution analysis, or stability analyses for the landscape screen and simply relied on the prior engineer's work. The prior engineer also did not conduct stress distribution or stability analyses for the landscape screen. Because the preceding engineer limited his liability via a letter, the succeeding firm shared in the liability for the landscape screen and the resulting landslide.

In summary, if an engineer succeeds another engineer, the authors recommend that the new engineer perform a thorough review of the entire project, especially features that are likely to adversely impact adjoining areas, such as the landscape screen in this case.

FORESEEABILITY OF FUTURE DEVELOPMENT

Finally, the design engineer for a downslope housing development must be concerned about the level of foreseeability that is required for their design. For example, the engineer should be concerned with the type of structures that might be constructed upslope of their development, such as a large landscape screen. Typically, the size of structures usually decreases as development progresses up natural hillsides. Thus, it may not be foreseeable that a much larger and heavier development, i.e., a large landscape screen, would be constructed above the single-family housing development. If it was foreseeable or the engineer knew of the future development, the downslope housing development may have to be designed with slope stabilization techniques to ensure stability during or after construction of the upslope development.

In this case the downslope design engineer did not know that the BC Development would occur and thus did not design stabilization techniques to resist the large landscape screen. It is recommended that design engineers clearly state their assumptions in their design and stability analyses in regards to future upslope development so the engineers for future upslope development can identify the prior assumptions and perform stability analyses to assess the impact, if any, of the upslope development on the existing downslope development.

CONCLUSIONS

This case history illustrates some of the legal issues encountered in bringing and defending a landslide case, including conveying complex and technical causation information to a jury, liability associated with taking over a project from another geotechnical engineer, conflicts of interest when defending your own geotechnical investigation, and the possibility of jury confusion.

This case history also illustrates some of the ramifications of constructing a large fill on a natural hillside upslope of housing developments, such as the importance of understanding the depth of influence of the development via a stress distribution analysis, conducting a subsurface investigation that extends through the depth of influence of the development, and performing slope stability analyses to ensure stability of underlying weak layers.

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