Post Landslide Investigation Procedures – the Cherry Hills Case

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ABSTRACT

The tragic loss of life in the Cherry Hills landslide attracted a lot of media attention and with it a lot of speculations an rumors as to what caused the slide. Several professional organizations and government agencies were also involved in the various studies and investigations to understand what really happened.

The Philippine Institute of Civil Engineers (PICE) and the Association of Structural Engineers of the Philippines (ASEP) banded together through a fusion of its Geotechnical committees to offer the services of volunteer members to investigate, document and come out with a factual report on what happened.

This report summarizes the work of the committee, including the methodologies and tools employed in reconstructing the conditions before and after the landslide, its findings, conclusions and recommendation. Guidelines adapted from numerous sources are also included herein to help the Engineering community and the public in understanding potential hazards.

It is not the intention of this committee to pinpoint responsibility or determine the culpability of any person or organization, public or private. This matter is best left to the courts to decide.

INTRODUCTION

The Investigation of Landslides presents a very interesting yet very difficult Challenge. It involves a more detailed understanding of the facts at hand in order to reconstruct what happened and how it happened.

Unlike standard design projects involving slopes, where, the parameters and geometry are known as well as the anticipated environmental conditions, landslide investigations have to deal with a lot of unknowns and involves the formation of several assumptions of hypotheses which need to be tried out, studied, eliminated, validated and only then can conclusions be made and accepted.

In the meantime, these assumptions need to be compared with the actual slide conditions to ensure that the theory and assumptions agree with each other, likewise be presented.

Findings and conclusions on the results of the study will also be presented.

SLIDE NOMENCLATURE

The diagram illustrates a typical landslide and the components that make up the slide. ***(See Figure 1.0)***

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DATA GATHERING PROCEDURES

General

A slide event needs fast response if we need to ensure that critical evidences and telltales are not obliterated or further idsturbed by rescue operations or by washouts or additional mudflows or debris flows.

Thus it is important to mobilize the investigation team as fast as possible in order to gather as much information as possible before disturbances to the slide affected areas occur.

Field Reconnaissance and Site Interviews

The site reconnaissance is one of the most important field activities if done as soon as possible. A good site reconnaissance could record important data and information which otherwise could have been lost but which would be critical to a proper and adequate understanding of how the slide occurred and the mechanism involved.

Interviews with the locals or residents in the slide affected areas is also very important in determining whether there were any telltale signs of an impending slide and what were the conditions immediately predecing the landslide event.

Aerial and Site Photographs

Particularly for slides of large extent, Aerial and site Photographs would be very valuable in establishing the extent of the slide and whether other slides could have been initiated by the main landslide event. Photographs could permanently record conditions at the site, which may not be readily apparent or could have been missed entirely in the initial walkthrough survey. Such visual records would prove invaluable in looking at several hypotheses.

Mapping of Extent of slide Geometry

The extent of the slide needs to be mapped approximately particularly very important if an aerial survey cannot be done due to limitations in time, budget or availability.

The slide geometry may not be readily apparent in photographs but sketches and notes taken could sometime be very crucial to the understanding of the slide mechanism.

Understanding the slide Geometry could also aid in guiding the analytical and computational approaches or tools that could be used to analyze the slide.

Study of the Geology of the Site and the Nature and Character of the Soil Deposits and Rocks

Understanding the Geology of the area is important in piecing together the various pieces of the puzzle.

The following items need to be considered:

- Orientation and dip of Bedding Planes
- Manner and origin of deposition
- Intensity of Jointing and fracturing in the case of rocks
- Relic slides
- Geochemistry of soils and rocks

Understanding the Environmental factors likely to have influenced the slide

Environmental effects causing destabilization almost always precede landslides. These is due to climatic, hydrogeologic, chemical and other natural environmental effects and changes, in addition to the artificial disturbances caused by man.

A very dominant factor in the initiation of landslides is the sudden rise or lowering of the water table, which could induce the same effects.

An increase in the water content of soils or rocks, leading to saturation could reduce effective stresses and also cause degradation of fine-grrained soils. In addition, the original dry mass becomes heavier due to absorption of water and sliding follows particularly after prolonged heavy rains. Similarly particularly in dam embankments where sudden drawdown occurs, the saturated soil loses the buoyancy support from the water and thus slides downslope of the embankment.

ENGINEERING STUDIES

Reconstruction of Slope Geometry

Engineering plans or records of the preslide slope configuration normally would be available from the owners of the affected property for developed areas. In the case of Mountainsides or Natural terrain, the use of Topographic maps such as the NAMRIA series could be used to recreate the slope prior to the slide.

Of course when developments or interventions by man are not recorded in plans or maps, the task of reconstructing the slope geometry prior to the slide becomes very difficult and would involve a lot of field measurements and surveys.

Subsurface Soil Exploration and Insitu Tests

Most often and particularly if no such investigation have been done in the past, subsurface borings would be needed to define the nature and character of the soil and rock deposits in order to determine with some degree of certainty the strength condition prior to failure. It is also important to know how the environmental factors have affected the original soil and rock condition.

Necessarily, the soil borings need to be performed in the slide zone to determine the vertical extent of the slide from detection of the extent of disturbance and residual strength and also at the unaffected areas to serve as a benchmark comparison.

Shallow test pits are also an inexpensive means to gather more information about the slide. These field tests would have to be supported by Laboratory testing to classify the soils and rocks and also determine their physical as well as Chemical properties.

Geophysical methods such as Electrical resistivity logging and Seismic Refraction surveys could aid in establishing the true vertical extent of the slide by being able to discriminate between disturbed and undisturbed zones.

Analyses Procedures

After all data gathering is nearly complete, trial and preliminary back of the envelope calculations can be done and published nomograph could be used as a "first pass" analysis using simplifying assumptions.

Once a general idea is formed more detailed Slope Stability using back-analyses procedures need to be started. As the name implies, back analysis is the reverse of a conventional Slope stability analysis. Because of the highly interactive procedures and computationally intensive tasks, this is best done using dedicated programs.

The procedure begins by assuming first a homogeneous soil or rock mass and determining the critical failure Surface (Lowest Factor or Safety) by assuming a set of strength parameters (c and phi) and setting the program to search for the most critical failure surface. (The one with the lowest Factor of Safety). Once the critical slip surface or surfaces is/are identified the following **Back Analysis** procedure takes place:

- A set of strength parameters (**c** and **phi**) is assumed and an interactive search is made on the most critical slip surface by setting **c** constant and varying the value

of **phi** until a factor of safety of 1.0 (impending slide) is obtained.

- The value of **c** is then changed (increased or decreased) and a corresponding value of **phi** is solved iteratively to yield a factor of safety of 1.0.
- The Family of paired values of (**c** and **phi**) normally would fit a straight line. This line defines the most probable value sets that could have been present immediately prior to slide initiation.

Of course it must be understood that this exercise has greatly simplified the search routine by assuming a homogeneous mass which would be unrealistic. However, this could also lead to an understanding of the failure mechanism, which could expedite the detailed analyses that follow. Additionally, this leads to a concept known as the *"characteristic strength of the slope"* which for lack of a better description is a grossly simplistic attempt at quantifying the overall strength of the slope material at slide inception. Knowing what this is could lead to a quantification of the other external factors that have more than likely contributed to the slide.

Use of Empirical Methods and Criteria by Studying Records of Landslides in the past

Empirical methods are also available to determine the most probable set of strength parameters at slide inception by comapring this with historial records of known slides where back analyses have been performed. In addition *Bieniawski* has provided an empirical procedure in determining the quality of Highly Fractured rocks by a term known as the Rock Mass Rating (RMR). Several authors have further extended the RMR, notably Hoek in order to quantify the strength of these fractured rocks by relating them to the RMR and other qualitative properties to come out with **"m"** and **"s"** parameters. These are then in turn substituted into the *Hoek-Brown* formulation of a curved Failure envelope using *Mohr's* circle.

Normally, although not always, the two preceding procedures although independent of each other would find fairly acceptable agreement.

Obtaining convergence allows the investigator to go into more detailed analysis by factoring in multilayered slopes with varying strengths, etc.

Factoring in Environmental Influences

The influence of external environmental factors likely to have contributed to the slide to any degree needs to be considered and factored in the detailed Slope stability analyses.

These factors are:

- Groundwater levels at time of slide
- Amount of precipitation
- Possible man-made disturbances

Performing the Detailed Slope Stability Analyses to Identify Candicate Failure Modes

Once the results of the two procedures agree to a fairly acceptable degree, a more detailed analysis can be undertaken factoring in all the factors that are likely to have influenced the slide.

The detailed analysis may or may not probably represent the true conditions at slide inception. Nevertheless, its generation and the detailed and painstaking studies leading to it would invariably gain for the investigator a better understanding of the slide and attain a more solid foundation to rest on, compared to a study that suffers for lack of a detailed methodology and procedure and the absence of realistic and factual data.

Comparison of Results with Actual Post Slide Geometry

As the saying goes, the "*proof of the pudding is in the eating*". Nowhere is this saying more evident than in this stage when the theoretical failure geometry is arrived at and compared or matched with the actual Failure geometry. It goes without saying that these two should match otherwise failure geometries and perhaps revised strength parameters need to be restudied.

CONCLUDING THE POST SLIDE INVESTIGATION

The post slide investigation does not end with the Preparation of Report on Findings and explaining what happened and how it happened.

The real value of the investigation is when it adds to the body of knowledge and contributes to the welfare of society by recommending steps to prevent future similar landslides.

Identifying, the need for corrective works and remediation procedures is a critical component of any investigation report n order to prevent the initiation of future landslide from the unstable and weak geometry of the Relic of the slide. Means should be provided in order to stabilize the slide and prevent the formation of other slides in the disturbed areas.