Recognition and Delineation of a Landslide, Turkey

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SYNOPSIS: Geological mapping, geophysical surveys, test pits, and shallow borings were used to identify and evaluate a site containing a landslide complex. An investigation was performed to characterize the extent and nature of the complex, determine the suseptibility to movement, and the potential for impact on a nearby proposed reservoir and dam.

The methods of investigation established a relationship between the morphology, geology, and hydrology of the slide complex. The surface of the slide was initially identified by a series of scarps, seeps, and slopes. Seismic refraction and resistivity surveys were performed to determine depths to the basal failure surface and to aid in the selection of two borehole locations. The results of the combined investigation activities led to estimation of an areal extent of about 35 ha, a thickness of about 12.5 m. in the drilled area, and a low potential for rapid displacement.

INTRODUCTION

The landslide complex, located in eastern Turkey, was initially identified in 1984 as part of a regional mapping program, by the presence of step-like masses of soil and rock, distorted tree growth, headwall scarps, heterogeneous soil and rock, small tensional ground cracks, steep slopes lacking outcrop, and water seeps. To aid in the present investigation of this slide complex, air-photo interpretation, geological mapping, geophysical surveys, test pits, and borings were performed. The investigation was conducted to determine the extent of the slide complex, its potential for movement, and its potential for impact on a nearby proposed reservoir and dam. Due to limited time, this investigation was confined to the area of most visible disturbance.

The site is located on the west bank of a substantial river drainage (Figure 1). The topography in the region is mountainous with the site situated on a steep hillside. This part of the Anatolian plateau is considered seismically active. The region is very sparsely populated with access provided by one gravel road. This paper will describe the investigation that was carried out to delineate and characterize the slide complex.

MAPPING AND GEOLOGY

A plan of investigation was prepared after a regional mapping program identified the site as a possible landslide. Black and white air-photo coverage at a scale of 1:40,000, was used to interpret the site and site area prior to a detailed field mapping program. The site was then mapped and the landslide features, as well as the locations of all site investigation activities, were plotted at a scale of 1:5000. Due to the imminent onset of winter conditions, only the area of most visible disturbance was evaluated in detail with the results of the study being extrapolated to the remainder of the slide complex.

The slide complex, occupying an area of about 600 m by 800 m, consists of materials derived from the underlying rocks, residual soil, and some glacial debris. These unconsolidated materials are gravel to boulder-size fragments in a sandy to clayey matrix. The fragments are angular to subangular and occasionally display gross downslope dipping stratification.

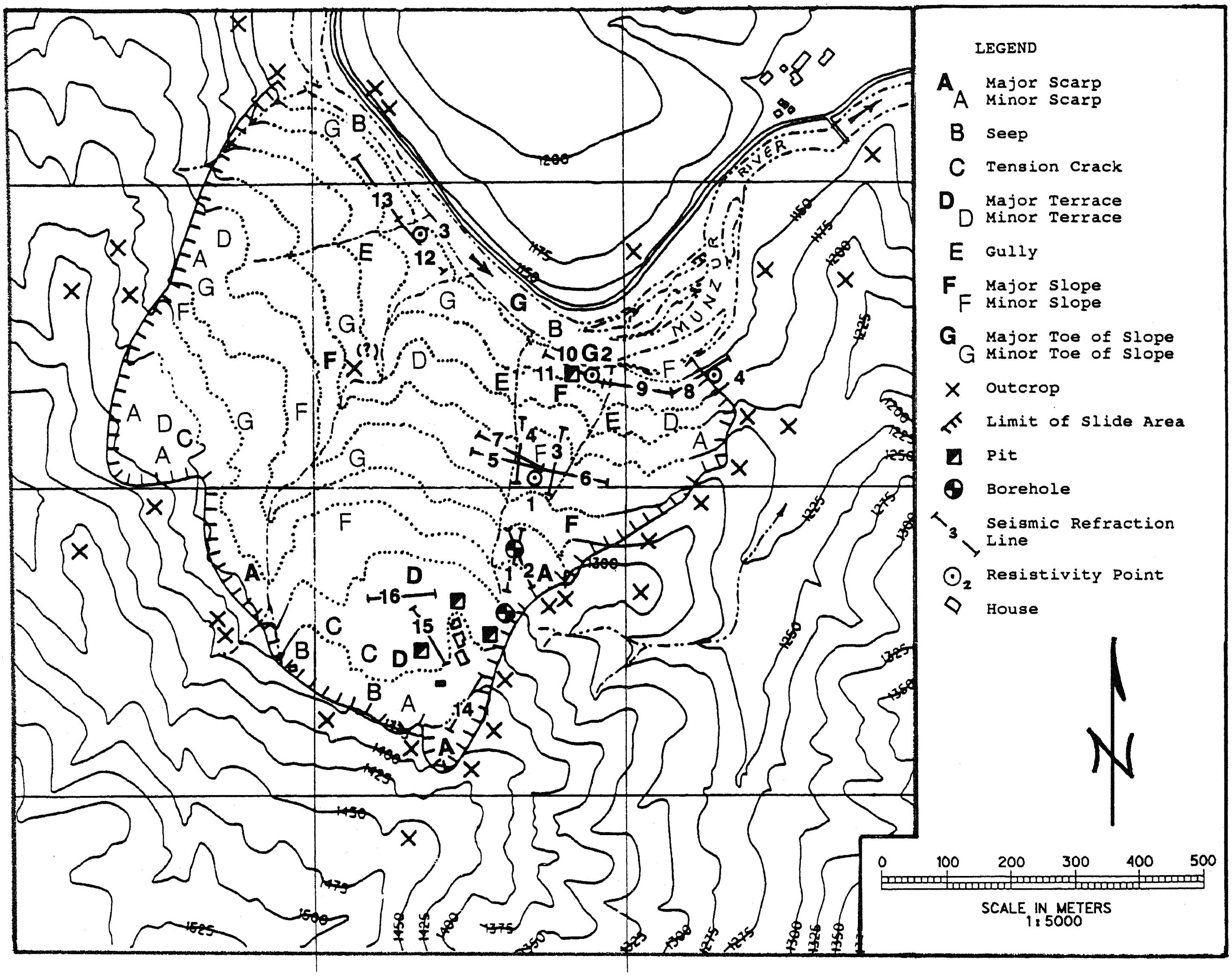
The bedrock underlying the slide area consists of Miocene-age competent sandstone, siltstone, pebble conglomerate, and limestone (Özgul, 1984). The units trend from northwest-southeast to west northwest-east southeast, and dip gently to moderately (10 to 45 degrees) to the north. Stratification parallels the sloping surface of the hillside.

Glaciation during the Pleistocene resulted in accumulation of thin, irregular patches of glacial debris upon the hill. The debris consists of morainal deposits on the slopes and well-compacted deltaic deposits forming river terraces at and very near the base of the slope at the Munzur River. The toe of the slide terminates at the river with the opposite bank composed of stratified very coarse-grained outwash and fluvial deposits. The river valley is essentially devoid of glacial materials downstream of this area.

MORPHOLOGY, VEGETATION, AND EFFECTS ON CULTURAL FEATURES

The slope displays the morphology indicative of a landslide (Krist and McComas, 1977). There are major changes in slope at several locations, there are a number of scarps, portions of the slope are hummocky, tensional cracks are present in the upper parts of the slope, there are

Figure 1. General Map of the slide area, geologic-morphologic features, and locations of exploration activities



discontinuous relatively flat areas, several linear gullies (mudruns ?) have formed due to the more easily erodible nature of the disturbed materials having a distinctly different appearance than the drainages over non-disturbed slopes, and the presence of toes at the base of failed slopes. Altogether, the morphological features are distinct (Schlemon, 1977; Terzaghi, 1960), but subdued.

The vegetation is that of semi-arid mountainous regions, that is, the slopes are intermittently covered with clumps of grass, bushes, and small oaks with much of the slopes barren ground. The vegetation of the slide is indicative of an area of disturbance. Modest tree growth is found on the slide with some of the older trees showing distorted vertical growth, indicating downslope surficial movement. Active seeps are delineated by small concentrations of grasses and more robust tree growth. Additionally, areas around active seeps are frequently indicated by small settlements and villages, such as here, since perennial water is scarce in the region away from the major drainages.

A settlement is located on the flat, terrace-like upper surface of the slide. The settlement is located on the broadest terrace and near the largest seep on the slope. The houses and structures, all composed of rock and hewn trees, have been there for more than forty years. Only during the last ten years have minor cracks developed in one house. It is not known whether the cracks developed due to normal building deterioration, settlement, or local slope movement. Cracks in the soil were observed in several garden plots and groves of walnut trees located near the active seeps. The residents stated that most of these cracks opened and closed seasonally, but some of the cracks have now remained open for several years.

In fact, many of the mountainous settlements are located on or near landslides, since the disturbed ground often takes on a characteristic terrace-like form and have active springs and seeps nearby. Flat ground and perennial water is a scarce combination in this mountainous region of the Anatolian Plateau. Apparently, catastrophic land failures rare here, since some of these villages have been continuously occupied for generations without loss of life and property.

GEOPHYSICAL SURVEY METHODS

As part of the characterization of the slide complex, a decision was made to perform seismic refraction and electrical resistivity surveys to aid in the determination of the depths to the basal failure plane (Cummings and Clark, 1988, Hutchinson, 1983) and selection of the location of two borings to assess the subsurface conditions.

Seismic refraction was chosen since a velocity contrast was expected at the basal failure surface (Carroll et al., 1972). Resistivity was performed since a distinct degree of water saturation could be expected in the disturbed materials versus bedrock (Moore, 1972). Topography over portions of the slide area was determined by measuring elevations to ± 0.1 m using a theodolite and range finder. Due to the irregular surface and steep slopes of the site area, all geophysical survey lines were positioned to minimize significant elevation changes.

Thirteen reversed seismic refraction lines were run in the area using an EG&G Geometrics Model ESS-1225, signal enhancement seismograph with dynamite as the energy source. The spacing of the geophones was 10 m along each of the spreads, which were 120 m long in all cases. Where the topography allowed it, several of the spreads were placed contiguously with no overlap in the positions of the geophones, because seismic events could be traced fairly well from one part of the array to the next. As would be expected, the seismic refraction travel-time pattern on the slide is more complex than away from the slide area (Carroll et al., 1972).

The morphological features of the slide were used to plan line placement in order to investigate the thickness of disturbed materials at different locations (Figure 1). The majority of the survey lines were oriented approximately parallel to the strike of the slope in order to minimize the adverse influence of elevation changes. Where that orientation was not possible and the slope inclination was reasonably constant, the lines were oriented approximately perpendicular to the slope. Refraction and resistivity lines were situated on the scarps, terrace, slopes, and the toe of the slide complex.

Four electrical depth-soundings using a McPhar Geotronic resistivity meter were performed along the seismic lines in order to have coincident data points for the two types of geophysical survey. The Schlumberger electrode array was used for soundings to a depth of about 50 m. The sites were chosen so that the array could be expanded in a straight line as close to parallel to the probable strike direction of the bedrock. The survey was performed at the end of the summer dry season in mid-September.

The geophysical data were interpreted onsite using simple methods. The seismic refraction data were interpreted using the time-intercept method (Griffiths and King, 1965; Milson, 1989) and a processing program for a pocket calculator to yield velocities and depths. The electrical resistivity data were interpreted using curve matching methods (Orellana and Mooney, 1972).

The refraction data indicated a three - or four-layer model. However, given the heterogeneous nature of disturbed materials, it is possible that lower velocity zones exist within the slide debris and may be suggested by the recorded resistivity readings (Cummings and Clark, 1988). The electrical resistivity data indicate three or four layers with the intermediate layers sometimes yielding lower apparent resistivity values than the adjacent layers.

GEOLOGIC INTERPRETATION OF THE GEOPHYSICAL DATA

The range of velocities for each of the layers is generally consistent from line to line. Boring logs, together with the results of a seismic refraction survey performed off the slide complex, but within the site area, provided a calibration of these geophysical data (Palmer and Weisgarber, 1988). The velocities of layer 1 may be of unsaturated, unconsolidated disturbed soil and broken rock; those velocities in layer 2 may be of unsaturated, very slightly consolidated disturbed materials; those velocities in layer 3 may be of slightly to moderately saturated, moderately consolidated materials or fractured bedrock; and those velocities in layer 4 may be of unfractured rock.

Table 1 *Summary of the Site Geophysical Layers*

Layer	Seismic Velocity (m/sec)	Resistivity Value (ohm-m)
1	200-600	36-160
2	400-900	62-168
3	1250-2100	48-530
4	2300-2800	>300

The range of resistivity values for each of the layers is generally consistent from location to location. The apparent resistivity values of layers 1 and 2 may be of unsaturated disturbed materials; those resistivities of layer 3 may be of slightly to moderately saturated disturbed materials; those resistivities of layer 4 may be of unfractured bedrock.

The geological interpretation of the geophysical data, together with other gathered information, were used to construct profiles of the slide complex. The basal failure surface of the slide was considered to be the refraction velocity boundary between layers 3 and 4, with layer 4 taken to be undisturbed bedrock.

BORINGS AND TEST PITS

Two borings, SA-1 and SA-2, were drilled on the slide (see Figure 1) to confirm its nature and extent using N-size equipment, standard split spoon sampling, and diamond coring. Boring locations were chosen on the bases of morphologic features, geophysical interpretation, and physical restrictions imposed by the terrain (Figure 1). Boring SA-1 was sited to determine the depth to the basal failure surface in an area near a scarp, and boring SA-2 was sited to verify the depth to bedrock at the intersection of two crossing refraction lines.

Boring SA-1, close to the houses at Kort, penetrated 13 m of disturbed soil and rock and 6 m of bedrock. Boring SA-2, about 100 m downslope from SA-1 on one of the slope terraces, penetrated 16 m of disturbed materials and 6.5 m of bedrock.

The retrieved samples showed the slide to consist of gravel and larger-sized rock fragments of limestone, sandstone, pebble conglomerate, and siltstone in a clayey sand matrix that became progressively more damp with depth. Rock cored was a slightly weathered to fresh, fractured to unfractured, friable to competent, moderately dipping bedded sandstone. The relatively slow velocities of the lowermost layer along two lines are interpreted to represent highly weathered and fractured bedrock zones.

No conclusions could be made about the nature of the failure surface in either borehole, as no sample was recovered in the split-spoon sampler driven through this interval. Groundwater was not detected in either boring.

Four test pits were dug by hand to supplement the boring data. Unbraced pits were excavated to a depth of about 2.5 m, so only provide information about the surficial aspects of the slope. The locations were chosen to evaluate a scarp, a terrace, a major slope, and a major toe. The material in the scarp pit showed gross, downslope dipping stratification and a buried soil horizon. The terrace pit consisted of randomly oriented cobble to boulder-sized fragments coarsening with depth and the slope pit contained unstratified boulder-size fragments in a damp, sandy clay matrix. The toe pit exposed steeply dipping, coarsely stratified severely weathered boulder-sized fragments of the different bedrock strata from the slope.

EXTENT AND THICKNESS OF THE SLIDE

The average maximum thickness of disturbed materials is 12.5 m., based on the various investigation methods. Surface mapping has indicated that the slide complex occupies an area of approximately 35 ha and extends from about el 1375 m down to the Munzur River at about el 1140 m. Both the ground surface and underlying bedrock have an average slope of about 20 degrees with slope extremes of 10 to 40 degrees.

The perimeter of the slide complex is easily delimited in the field by the presence of many exposures of undisturbed bedrock on the upper and flanking slopes. The disturbed material thickness decreases to zero at one location, as evidenced by an apparent exposure of undisplaced bedrock.

CAUSE

The apparent cause of slope failure was the downcutting and removal of the Pleistocene river terraces by the river and the subsequent southward migration of the river into the west bank. This erosion may have removed a substantial mass of the terrace that had accumulated on the south bank of the river, as evidenced by remnants of terraces on either side of the slide area and across the river. Removal of the terrace material at the toe of the slope, together with erosion of the basal sandstone unit destabilized the slope. The moderate seismicity of the region may have had a significant role in the slope failure. The slope has been adjusting to this unstable condition since that time of destabilization.

CONCLUSIONS

A number of field methods were used to characterize a recently recognized slide complex. Each method - mapping, geophysics, and drilling, added substantively to the delineation of the slide.

Geophysical surveys were used to determine the depths to the basal failure plane to determine its configuration. Picking the depths on the basis of the results of the seismic refraction or resistivity surveys alone was difficult and not always consistent, and is indicative of the complexity of the disturbed materials and degree of saturation. Offsite surveys tied to borehole information allowed interpretation of slide data with a moderate degree of confidence. Onsite (slide) borings greatly improved the initial interpretation.

The factors contributing to the slide appear to be the original dipslope orientation of the sedimentary rocks, the undercutting and removal of the toe of the hill, and the competency of the bedrock. The morphology of the slide is the result of the interaction between geology, hydrology, and vegetation and an understanding of this relationship is necessary to the interpretation of the slide complex.

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