DISASTER SCIENCE AND ENGINEERING p. 19-24, 2(1), 2016

Utilization of Optical Fiber System for Mass Movement Monitoring

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Received: 10.04.2016 Accepted: 21.04.2016

Abstract: Geomorphologic parameters, precipitation characteristics, groundwater level changes, daily temperature changes, snow melt and loss of stability due to these elements and seismic effect are the primary factors causing mass movement of landslides. When the landslides and their effects in Turkey are considered, it is almost certain that landslide monitoring can minimize the risk of life and property loss. The purpose of this study is to develop an in-situ monitoring system by using optical fibers in order to decrease the risk caused from mass movements. Optical fibers are preferred to the other available monitoring systems due to their ease of implementation and high sensitivity properties. The optical fiber system used in this study is composed of fiber optic cables and a device that sends laser signals and collects back scattered light; referred to as BOTDA (Brillouin Optical Time Domain Analyzer). The proposed system has a 1 m spatial resolution and it can detect strain with a 0.1με resolution along a 3 km cable. Due to its high sensitivity and continuous data gathering properties, the suitability of the system in relating the strain measurements on the cable with displacement has been demonstrated for landslide monitoring this study. In addition, the system can be suitable for monitoring of other strain based displacements of critical structures such as, roads, tunnels, dams, bridges, etc.

Index Terms**—Landslide monitoring system, Early warning system, Optical fiber, BOTDA, Mass movement.**

I. INTRODUCTION

Mass movements are one of the most destructive natural hazards that occur both in Turkey and in the world. Recently, awareness about landslides and the importance given to the risk management concept has increased dramatically. As a result, early warning systems have gained interest [1]. Today, many different instrumentation techniques, such as inclinometers, tiltmeters, extensometers, LIDAR(Laser Imaging Detection and Ranging) systems are present in order to monitor potential mass movement areas [1, 2]. Although all of these techniques have their own advantages and may be used to detect deformations, neither of them can achieve simultaneous monitoring for an early warning system. Optical fibers are superior than the other methods due to their easy and fast data transfer capability, small diameter and low weight, sensitivity to strain and temperature changes, immunity to environmental and electromagnetic effects, low cost and simultaneous monitoring properties [3&4]. Optical fiber based technology will pioneer similar studies by the advantage of its continuous data transfer which is crucial for early warning systems.

A. Purpose of the study

Landslides cause loss of lives and economical problems in Turkey and in the world, and create risk, especially for crowded cities. Human related activities may trigger slope instability and increase material and vital risk in addition to natural causes such as precipitation, instability of slopes and earthquakes. Landslides rank first with a percentage of 34.18 among the natural hazards that have occurred in Turkey between 1950 and 2005 in terms of the distribution of the affected settlement areas [5]. The aim of this study is to observe mass movement quantitatively in hazard prone areas before the occurrence of a landslide and to develop a continuous monitoring system.

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In addition, the purpose of the study is to develop a monitoring system that can be applicable for all potential mass movements independent from lithology, failure mechanism, and triggering mechanism. The system relates mass movement with strain measured by optical fiber cables. The system was applied to the field in a hazard prone area located in the Bahçecik District of Kocaeli, which is an important city for Turkey's economy that was affected from one of the most destructive earthquakes that took place along the North Anatolian Fault System (NAFS) in northern Turkey in 1999.

B. *Study Area*

Kocaeli has a high risk in terms of landslide as it is an industrialized and crowded city. By considering its economic importance, population density and geographical location, Kocaeli was selected as a pilot area. The study area is located within the borders of the City of Kocaeli, Başiskele Municipality, Bahçecik District. The location map of the study area is given in Fig. 1.

Apart from the importance of Kocaeli, the study area was selected due to its critical location in terms of landslide risk. In 2010, a landslide occurred and the region was announced as a hazard prone area by the Disaster and Emergency Management Authority of Turkey (AFAD) because the landslide was threatening a building complex that was located in the crown area of the landslide.

Fig. 1. Location map of the study area (Google Inc., 2015).

When the precipitation characteristics of the area were examined, it was observed that in 2010, the precipitation was drastically higher than the average precipitation of the region. Due to intense precipitation, the water level in the Sarılık Stream that is passing from the toe of the landslide had increased and by affecting its toe it caused a landslide. For this reason, the most effective landslide triggering factor was attributed to intense precipitation. Fig. 2 shows the landslide and the area affected.

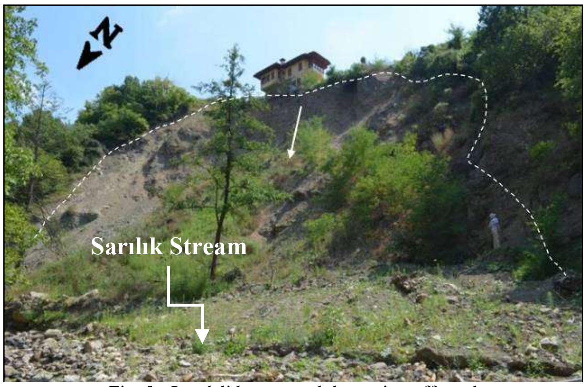

Fig. 2. Landslide area and the region affected.

II. GEOLOGICAL AND SEISMOTECTONIC PROPERTIES OF THE STUDY AREA

A. *Regional Geology and Seismotectonic Properties*

The units that outcrop in the Kocaeli Peninsula are composed of Paleozoic and Permian-Triassic aged allochthonous units, Late Cretaceous-Eocene aged semi-autochthonous units, and Oligocene-Miocene and Pliocene-Quaternary aged autochthonous units [6]. The study area is located in the Armutlu Peninsula that composes the western part of the Pontides and is bordered with two main branches of the NAFS. The units that outcrop in and around the study area belong to the Sarısu and İncebel formations. Eocene aged Sarısu formation is a volcano-sedimentary sequence and generally starts with a 5-10 m thick sedimentary level onto metamorphic rocks. This level is composed of conglomerate, mudstone, sandstone and limestone. Some levels of the sequence contain huge andesite blocks and pebbles of epiclastic deposits. The sequence is cut by basalt dykes that are observed especially in the upper levels.

The İncebel formation is a Paleocene-Eocene aged formation that unconformably covers the metamorphic units and dips towards northwest. The İncebel formation starts with a basal conglomerate layer composed of a flysch sequence of sandstone, mudstone, marl, and conglomerate. However, it can contain volcanic lithologies, namely light colored tuffs and andesitic agglomerate in the upper parts of the sequence [7]. The generalized geological map of the area is given in Fig. 3.

Kocaeli is located in a region that is tectonically active and according to the study made by the Earthquake Research Center study of the Ministry of Public Works and Settlement in 1996, the study area is located in a first degree earthquake zone.

The NAFS which is a right lateral strike-slip fault system is one of the major tectonic structures of Turkey and the study region. NAFS disconnects the Eurasia Plate that is located to the north of the Anatolian Plate and has a length of 1500 km. This fault system has created a 125-145 km long surface rupture as the result of the August 17, 1999 Kocaeli earthquake with a moment magnitude of 7.4 [8&9]. This surface rupture continues into the Marmara Sea [8, 10 & 11]. Another seismic source around Kocaeli is the fault zone created on November 12, 1999, namely, the Düzce earthquake with a moment magnitude of 7.2. This fault zone has a length of 30 to 45 km [12]. In addition, there is another seismic source created by the Abant (May 26, 1957, Ms=7.0) and the Mudurnu (June 22, 1967, Ms=7.1) earthquake fault zones and their continuation in the west [13].

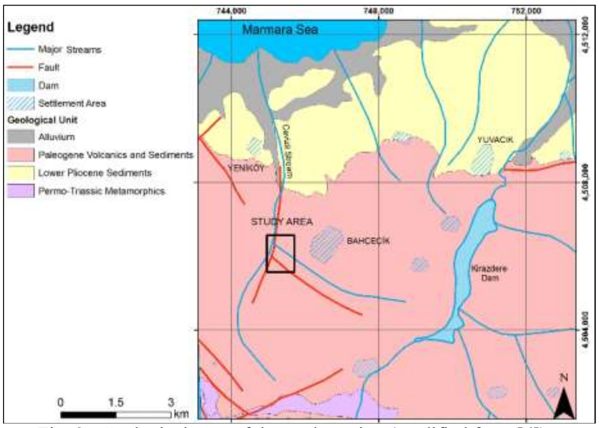

Fig. 3. Geological map of the study region (modified from [6]).

B. Engineering Geological Properties

The study area is located within a valley that lies within the stream bed of the Sarılık Stream. As the result of the field study that was conducted to understand the general geology and to determine the engineering geological properties, the lithology was defined as a sandstone-siltstone alternation. Fig. 4 gives the appearance of the formation in the field.

Fig. 4. A view of the rock mass of the İncebel formation.

According to the field observations, the unit correlates with the Paleocene-Eocene aged İncebel formation. This sequence contains scattered and non-persistent discontinuity sets and small scale folds. According to the engineering geological characterization of the study area conducted by using the borehole data for the study area, there is a 1-2 m thick soil cover on the upper levels of the İncebel formation and this soil cover is underlain by a sandstone siltstone marl sequence. The groundwater was encountered at a depth that generally varyied from 3 to 4 m from the ground surface.

A sequence made up of sandstone and siltstone alternation occurs within the boundaries of the landslide. The sequence is generally tectonically deformed and disintegrated although in several locations of the landslide it outcrops as detached blocks. The sandstone has a yellowish brown color while the siltstone is greenish grey. They possess weak to very weak strength and are moderately to highly weathered [14]. The siltstone is weaker and more weathered than the sandstone layers. Scattered discontinuity sets are present in the area. Discontinuity surfaces are slickensided with clay infilling and possess low persistence according to ISRM (1981). From the boring data, the solid core recovery (SCR) value ranges between 13% and 40% and the rock quality designation (RQD) is between 0% and 10%. Accordingly, the unit was classified as very poor rock (disintegrated/decomposed rock). Since the project site is located in a tectonically deformed zone and since the pole plot distribution of the discontinuity data shows scattering, the rock mass could be treated as an irregularly jointed, highly foliated and very deformable soil-like material, from an engineering geological point of view [15].

III. METHODOLOGY

The system utilized was made up of optical fiber cables and a device called Optical Time Domain Analyzer (BOTDA). The BOTDA working principle is based on Brillouin scattering and the device is responsible for both sending light to cables and collecting backscattered light. This device is named as a time domain analyzer as it uses the time between sent and backscattered light to detect changes that occur on the cable [16]. When the Brillouin frequencies of the sent and backscattered lights are equal, a peak forms on the measurement graph [17]. The location of this peak point shifts by any change on the cables. As a result, strain changes on the cables are detected quantitatively. The strain-mass movement relation of the system attained by sensitivity analyses can be seen in Fig. 5.

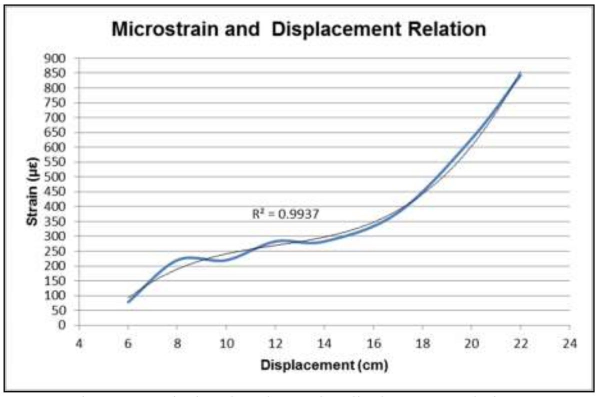

Fig. 5. Graph showing the strain- displacement relation.

The system was implemented in the landslide region located in the City of Kocaeli, Başiskele Municipality, Bahçecik District after the sensitivity analyses were completed. In order to monitor this landslide, a fiber cable network starting from behind the crown of the landslide was utilized. The cable network was embedded to the landslide and turned back to the container where the starting point was located (Fig. 6). For monitoring the deformations that occurred in the landslide, metal poles having a height of 2 m were fixed to the ground in the landslide region and its close vicinity. The fiber cables were then coiled around these fixing poles.

The potential locations of the fixing poles were estimated by a consequence of deformation analyses performed by using the finite element method (FEM) prior to actual installation of these poles. In the FEM study, the required shear strength and elastic deformation parameters for the rock mass were determined from the geomechanical characterization of the rock mass (i.e., field study, scan-line survey, etc.), geotechnical boring and laboratory test results along with the back analysis performed in the landslide area. The back analysis led to a cohesion and internal friction angle along the failure surface of 18 kPa and 26°, respectively, by utilizing the Morgenstern-Price method.

Fig. 6. a) The container's location behind the crown of the landslide b) An inside view of the container and the optical fiber system components.

To check the reliability and accuracy of the field monitoring study, the deformation analyses results from the FEM study and the deformation results from the critical mass movement locations obtained from the fiber monitoring study have been correlated along the landslide region.

In this correlation study, the testing measurements of the temporary poles were initially obtained and then, were examined and compared with the FEM results. Dark colored rods in Fig. 7 represent the test locations of the fixing poles from the field monitoring study. These studies were used for cable implementation along the four different line segments. Following this, the deformation results of the FEM analysis at these fixing poles were compared with the field monitoring results where these compared test results gave satisfactory outputs to implement the final fiber cables position correctly with a reasonable configuration (Fig. 7).

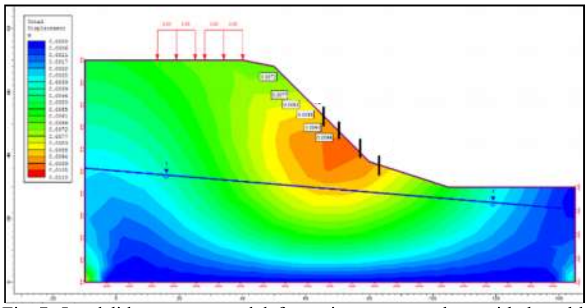
Fig. 7. Landslide geometry and deformation contours along with the cable fixing points.

In addition, a comparison of the field monitoring results obtained from the four cable line segments in the field and FEM modeling of the deformation analysis results are also plotted in Fig. 8. From this figure it can be seen that apart from the differences, the results are relatively consistent. The differences might have have been due to initial testing and modeling configuration and/or temporary poles that were fixed near the surface.

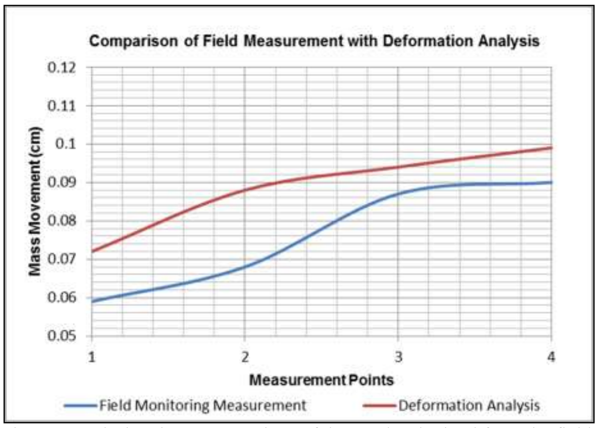

Fig. 8. Graph showing a comparison of the results obtained from the field monitoring measurements and the deformation analysis obtained from FEM.

After the preliminary studies were checked and corrected, finally, the metal fixing poles were buried in a reliable depth at suitable locations determined by the controlling study to collect continuous deformation data from monitoring. The cable fixing points of the optical fiber network can be seen in Fig. 9. After the optical fiber cable network system was implemented to the landslides, sensitivity analyses compatible to field conditions were conducted and simultaneous deformation measurements were started to be collected continuously. In the study area, the deformation data obtained from the monitoring system has been collected continuously since 4 months. Additionally, seismic activity obtained from the AFAD strong motion station and precipitation data obtained from the meteorological stations of Kocaeli have been gathered and then integrated into this system to control the primary factors that might cause movement of landslides. In particular, the effects of intense precipitation and water level increase in the stream that could directly affect the relative movement of a landslide (i.e., deformation changes) have also been directly detected in the monitoring system. These results also demonstrate the reliability and accuracy of the monitoring system.

Fig. 9. a) A close up view (during the installation phase) and b) A general view of the cable fixing points (upon installation) within the landslide footprint area.

For the reliability of these studies and the system's applicability to different mass movement areas, the long-term sensitivity analyses will be continued and simultaneous measurements will be obtained in a certain time interval. This landslide monitoring system is also controlled remotely by the aid of a GPRS system and the data can be evaluated in the office other than in the field. Briefly, the system has been working as a station capable of transferring the data to enable interpretion and processing in another location.

IV. DISCUSSION AND CONCLUSIONS

This study showed that optical fiber technology is a method that may be used for monitoring mass movements with its simultaneous measurement capability. Optical fibers are preferable among other methods due to their advantages and superiorities in field conditions. In the current stage of the project, the system was set in the study area and has been measuring deformation continuously not only in the field but also in the main office by using a GPRS system. In addition, by adapting the suitable application or modification in the software that will be integrated in the field monitoring system, it will be converted to an early warning system in later stages.

In order to control the system's reliability, other testing systems such as a piezometer will be implemented in the landslide area for the monitoring of water level fluctuations. By this way, more reliable data about the most important triggering factor of this landslide will be evaluated accurately. After all these studies, the improvement techniques suitable for landslide mechanism will be proposed and the region may be rehabilitated in order to be used in a safe manner.

Apart from this scientific study, one of the most important point is that the developed system will serve our community by minimizing the loss of life and property or the damage caused by the natural and man-made structures subjected to mass movements.

ACKNOWLEDGEMENT

This study has been supported by the Disaster and Emergency Management Authority of Turkey (AFAD) with the project number UDAP-Ç-14-02. Due to their contributions to the project, the authors would like to thank Dr. Murat Nurlu, Mr. Ahmet Temiz and Mr. Cenk Erkmen from AFAD and Mr. M. Maruf Yaman and Ms. Ceren Deveci from the Department of Planning and Mitigation. Authors would like to thank Dr. Arif Mert Eker from SDS Energy and Mr. Mehmet Abdullah Kelam from HAMA Engineering for their support. In addition, authors owe a debt of gratitude to the directors and personnel from the Kocaeli Disaster and Emergency Directorate and Başiskele Municipality for their help and support on logistics.

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