Design of Idemli Bridges in Landslide Areas

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ABSTRACT: In this paper, design of a highway viaduct located in a landslide area is studied. The depth of landslide is expected to be up to 20 meters from the surface. At the time of construction, since retrospective inclinometer data was not available, movement rate of the mobilized soil was unknown during harsh climatic conditions etc. One alternative is to design a foundation system capable of resisting all forces and displacements resulting from mobilized soil for even the greatest movement rate that could be expected. Another alternative is to keep span lengths of the structure as large as possible with a foundation system having technically feasible small dimensions in order to not to be affected by the mobilized soil as much as possible. The second alternative was adopted with165 cm diameter composite piles having a thick steel tube and steel fiber reinforced concrete in the foundation system.

1 INTRODUCTION

A new highway connects city of Samsun to town of Gerze in northern part of Turkey. Old highway is a narrow one crossing mountainous region with a curved profile. Increases in tourism revenues necessitated a new modern highway.

The new highway is 40 km long including many bridges, viaducts and tunnels due to topography of the site. The route of the site mainly follows the narrow area between the mountains and North Sea due to economical reasons.

Unfortunately, deep and massive landslides are expected at some parts of the route up to 20 meters deep from the surface. The view of the Idemli bridge site is presented in Figure 1.

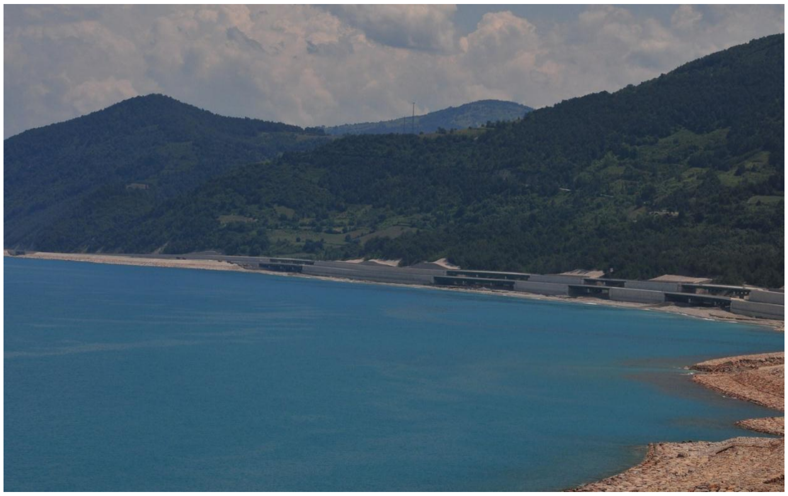

Figure 1. General View of the Site-Idemli Viaducts

2 LITERATURE REVIEW ON DESIGN OF BRIDGES ON LANDSLIDE AREAS

The number of bridges designed and built on landslide regions is quite small since routes are normally designed to eliminate destructive effects of landslides. Therefore, in literature, solutions and design guidelines for bridges on landslide areas are scarce.

In Croatia (Nossan et. al,2009), a viaduct on landslide area is designed and constructed utilizing a foundation system consisting of diaphragm walls under a pile cap. The diaphragm walls are positively connected to the pile cap, forming a typical pile foundation system. The diaphragm walls are socketed into the firm ground below movable soil. Soil layers that are prone to landslide consist of medium to highly plastic clay. The main idea of designing such a laterally rigid foundation system is to resist full thrust resulting from a possible landslide. The diaphragm walls are designed to sustain the lateral thrust of the sliding soil mass approximately equal to three times the theoretical passive earth force. The view of this system is presented in Figure 2.

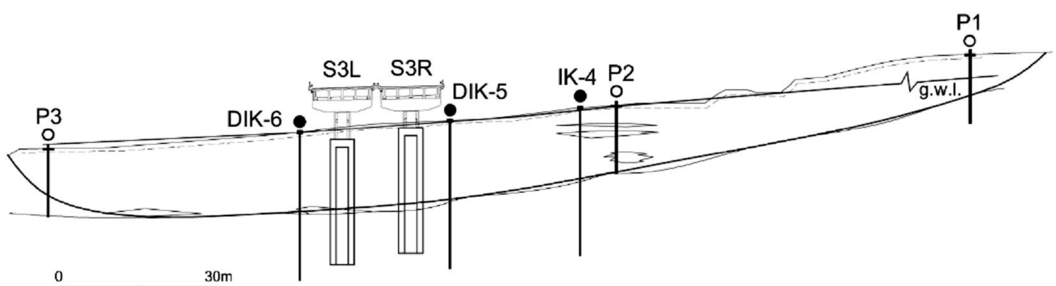

Figure 2. An Application for Design of a Bridge Foundation In a Landslide Area- (P1, P2, P3, DIK5,DIK6, IK4 indicates inclinometer positions) (Nossan et.al, 2009)

Inclinometer readings taken at various positions near the bridge indicates stabilization of the mobilized soil after completion of the diaphragm wall construction. The initial yearly movement of 15-20 mm reduced to 1-7 mm after construction of the diaphragm walls (Nossan et. al, 2009).

3 GEOTECHNICAL PROPERTIES AND SEISMICITY OF THE IDEMLI SITE

Seismicity of the site is quite low and peak ground acceleration for 475 year return period earthquake is assumed as 0.1g. Therefore, seismically induced landslide is not a major issue for the bridge site.

At the time of structural design, inclinometer readings were available for a 3 month time, indicating 1-3 mm horizontal movement. On the other hand, the data was collected during autumn, without heavy rainfall. It is well known in engineering community that heavy rainfall triggers landslides. For this reason, foresight was necessary during structural design in order to find out optimum solution. Structural design processed in parallel with construction due to tight schedule.

At Idemli Site, inclinometer data implied horizontal soil movement up to 20 meters from free-field. There are some underground water streams as indicated by Figure 3. There are two threats in landslide areas: (1) Whole ground can slip and move as one. (2) Debris may roll down the surface and therefore hit the deck, which is above ground level. In scope of this project, only the first threat is taken into account.

Figure 3. View of the Movable Soil and an Underground Stream

The nature of the movable soil ranges from loose sand to rock particles. As shown in Figure 1, over the bridge, a steep valley is present indicating a major risk for the bridge, due to huge amount of potentially movable soil.

4 ADOPTED SOLUTION

There are two alternatives for foundation design of bridges located on landslides. First solution as adopted by Nossan et. al is to design a laterally rigid system capable of resisting full lateral thrust applied by moving soil. According to authors, this solution requires well documentation of site and geotechnical features. Moreover, soil movement rates should be known for a long period of time.

Second solution implies minimal interference of the foundations with movable soil. This solution necessitates long span bridges with piles that are founded at a level below the possible landslide depth, and strong enough to resist the force arising during a landslide. Instead of diaphragm walls, piles with circular cross-section are preferable in this solution since circular cross-sections exhibit Omni-directional properties, being independent of the direction of the landslide, at least in a cross-sectional basis without considering pile group effect. In case of diaphragm walls, the direction of the landslide should be known exactly in order to place short dimension of the wall perpendicular to landslide so as to reduce total lateral thrust applied by the moving soil and to increase lateral rigidity of the foundation system. In Idemli bridges, second alternative is adopted due to uncertainties in character and extent of the landslide expected at the bridge. The foundations of the bridges are located on relatively shallow landslide prone regions, as presented in Figure 4. The piles are embedded into firm ground although not presented in Figure 4. Embedment lengths are in the range of 7-10 meters. The symmetrical arrangement of the span lengths necessitated some foundations to be located on relatively deeper movable soils as compared to others.

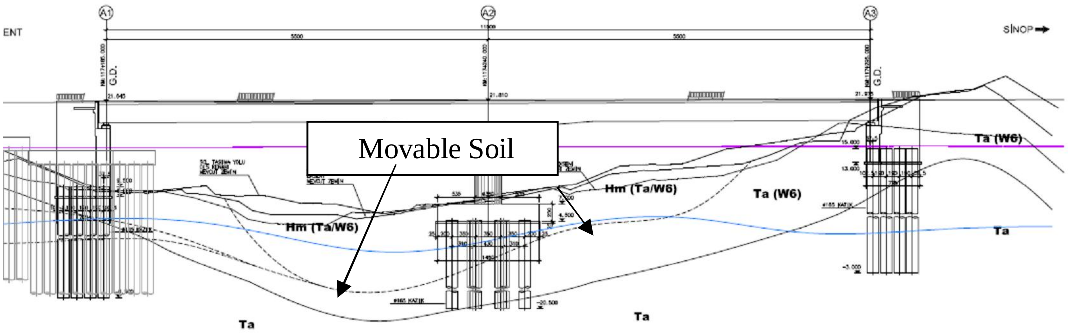

Figure 4. Foundations of the Idemli-2 Viaduct are Located on Relatively Shallow Landslide Prone Regions

At Idemli Viaducts, a composite superstructure consisting of four steel I girders and cast in situ R/C slab with a maximum span length of 75 meters is selected. The superstructure is continuous to be able to absorb lateral movements resulting from mobilized soil without unseating of girders, if occurs. The span length is limited by girder height since profile of the bridge is low. The girder height should be kept optimum/minimum so as to provide a free flow path for the mobilized soil. Accumulation of soil at the bridge level may lead to sweeping of the superstructure toward sea. The uphill soil as well as soil at the bridge site consists of moveable soil, whereas difference in movement rates and restraints provided by bridge etc. may result in accumulation of soil debris. The cost of constructing a barrier to inhibit movement of uphill soils is prohibitively high, implying many rows of piles with large diameter.

In foundation system CFT (Concrete Filled Steel Tubes) piles with a diameter of 165 cm are selected. The outer steel shell is 20 mm thick and it is made up of S355JR steel. At the inner periphery of the pile, eight steel T profiles are used as longitudinal reinforcement. The concrete inside of the steel tube is steel fiber reinforced concrete with steel fiber density of 30 kg/m^3.

The steel fiber is utilized so as to increase ductility of the concrete. The depth of pile ranges from 20 meters to 30 meters. The piles are embedded in base rock about 8 to 10 meters. There are 16 piles in a pier foundation.

The views of the bridge, a pile and pile system are presented in Figure 5, Figure 6 and Figure 7, respectively.

Figure 5. View of Idemli Viaduct

Figure 6. View of a CFT Pile

Figure 7. View of a Pile System

The pile system is capable of resisting thrusts applied by mobilized soil within its elastic range. The expected thrust at a pile system is presented in Figure 8.

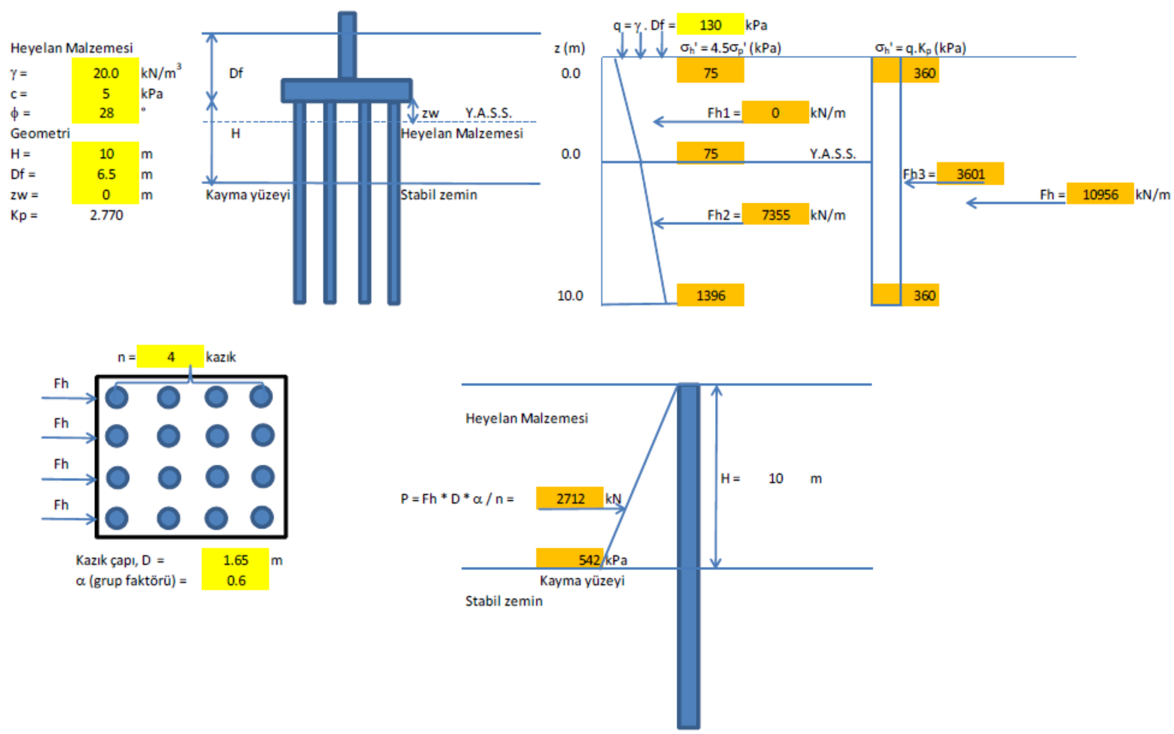

Figure 8. Representation of the Thrusts Applied By the Movable Soils to the Pile System

The construction of the viaducts has been completed and they are in use since November 2012. Up to now, no problem is observed due to lateral soil movement. Unfournately, inclinometers were removed following completion of the construction hindering a quantative verification of this application.

5 CONCLUSIONS

Design of bridges located on movable soils is a special task due to uncertainties associated with rate of movement and lateral thrust applied by mobilized soil.

At the site of Idemli Viaducts, depth of landslide can reach up to 20 meters and character of movable soil ranges from loose soil to rock particles. In design of these viaducts, maximum span length of 75 meters was adopted which minimizes the risk of soil accumulation due to very high girder depths and also minimizes number of piers in movable soils. In the foundation system, concrete filled steel tubes (CFT) are utilized so as to minimize dimension of the system prone to lateral soil movement, while maximizing resistance of the cross-section. Sixteen steel CFT piles are utilized at each pier foundation.

REFERENCES

Nossan, S.A., Nossan, S.V., Stanic, B., Mihaljevic, I. 2009. A Bridge Foundation Resisting Sliding Soil Mass. Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering.