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A CASE STUDY ON THE USE OF FLEXIBLE EARTH RETAINING STRUCTURE IN INSTABLE SLOPES

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ABSTRACT

Recently new highway, motorway and railway projects take place in many developing countries within the aggressive infrastructure investment programme of governments. In rugged topography, engineers face the challenging problems of designing safe and cost effective cuts and fills for these projects especially under seismic loading and marginal stability conditions. Overall stability mechanism and safety of the cut generally controls the design decisions for the relevant section. In addition, because of the construction width limitations, in some mechanically stabilized earth wall projects sufficient width to accommodate the strip lengths of the retaining system cannot be provided. To eliminate all these problems, to minimize cut and backfill volumes and provide an innovative solution in such difficult terrains, soil nailing is implemented in the cut side together with the mechanically stabilized earth wall in the fill side together both are being flexible earth retaining structures. In addition, soil nails could be designed in such configuration and length that nails will also contribute to overall stability conditions of the cut slope. Furthermore, implementation of the system brings the advantage of reduction of both cut and fills volumes, therefore more cost effective and safer design. This paper presents application of this system in a recent case study, in Baku, Azerbaijan.

INTRODUCTION

Reinforced Earth (Mechanically Stabilized Earth) wall systems were successfully used for many years in highway and railway projects which require relatively large quantities of excavation and/or fill during the construction, Sankey and Hutchinson (2011), Freitag et al (2011). Especially, their applications in mountainous regions may bring further special stability problems. To overcome these disadvantages, a new system in the form of combination of both soil nailing and the reinforced earth systems have been developed as seen in Figure1. , Freitag, et al(2005), Morrison, et al(2006).

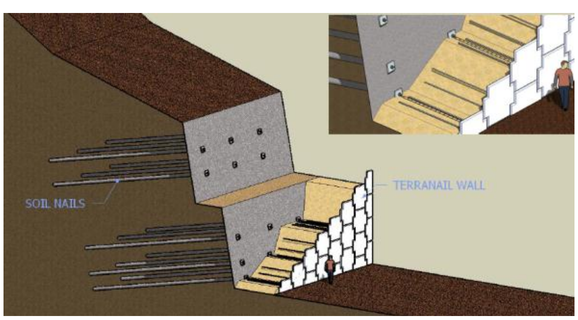

Fig. 1. Soil nailing linked to reinforced earth

With this combined system, required strip length for a regular reinforced earth wall can be significantly reduced. The reinforced earth system has been widely implemented in highway and railway construction projects especially for forming a new platform on a different level from its surroundings. In addition, the system is also used for adding new lanes or tracks to the existing highway or railway respectively, (Freitag, 2012).

Further, both soil nailing and Reinforced Earth are flexible retaining structures, as a result their behavior under major earthquakes have been very favorable in comparison to various rigid retaining structures, Mitchell et al (2000).

When highway route passes through a steep terrain, required excavation quantity increases dramatically, as the reinforced earth wall base should be placed on the slope having a required base width of about 70 percent of the height. The earth-movement quantity also increases by the required minimum embedment depth of the reinforced earth wall. With the linked system the required strip lengths and base width of the reinforced earth wall could be reduced as a result more economical design could be implemented, Figure 2, (Durgunoglu, 2012).

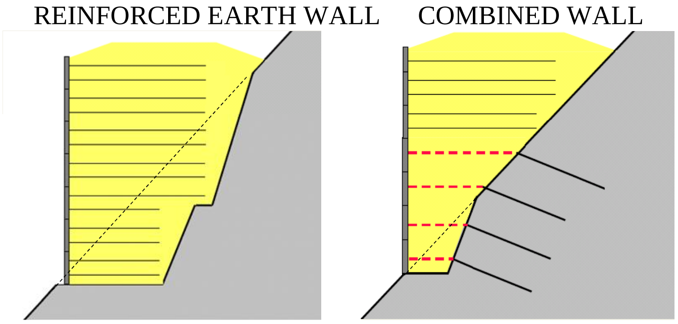

Fig. 2. Reinforced Earth and its combination with soil nailing

Overall stability problem is one of the serious problems of reinforced earth and as well as rigid retaining walls when they are implemented in sloping areas. Further to achieve stability of the toe of the wall sufficient embedment depth should be considered as a function of slope angle. For this reason deeper excavations are required on steep slopes. With implementing combined systems of RE and Soil Nailing in these areas, there is a possibility to reduce the base width down to 30 percent of the wall height in order to reduce the earth volume required (Freitag, 2012), (Durgunoglu, 2012), Figure 2.

COMBINED RE-SOIL NAILING SYSTEM

To evaluate performance of combined wall system the Federal Highway Department FHWA, has tested the system using large scale site test and a centrifuge model. These tests have shown that base width reduced to 0.3H is sufficient for reinforced earth wall strip lengths to provide the stability requirements, Morrison et al (2006).

The combined system is obtained by linking reinforced earth wall and soil nailing which are both known as flexible earth retaining systems. Obviously in the cut side, although they are in rigid form other supporting systems than nailing could also be implemented such as, sheet pile wall, diaphragm wall, intersecting or tangent piled wall or soldier piles as proposed by FHWA, 2006. Therefore recently the system has been also named as Terra Link, (Freitag, 2012).

In soil nailing shoring system nails are located at a certain angle to horizontal and tensile forces will be developed by limited lateral displacements during excavations. Nails are placed into predrilled holes and are grouted through their complete lengths. Nails are connected to steel wire mesh and shotcrete lining at the face of the slope. In the combined system first the temporary excavation is done implementing nailing system and then reinforced earth wall is constructed in front.

Soil nailing construction consists either temporary or permanent nail preparation, drilling, installation, grouting, placement of steel wire mesh and connection of nail with the facing and finally shotcreting of the slope face. Drilling up to a specified length can be achieved with drill rigs at the site and soil nails are installed in the holes with injection tubes and protection sleeves prior to grouting. Recently pressurized grouting in order to increase the friction between the nails and the soil has also been implemented, (Seo et al, 2012). Facing is generally consist of shotcrete and wire mesh. Generally shotcrete is applied in two stages. Two layers of wire mesh are applied both back and front sides of the facing. After implementing the first layer of shotcrete and wire mesh, head plate and nut for the soil nail are installed and application is finalized with implementing last layer of shotcrete and wire mesh. Later, reinforced earth wall is constructed in front of the soil nailed wall using standard construction procedures.

In addition, in permanent soil nailing, the followings should be fulfilled. (Morrison et al, 2006);

- Aggressive soil condition that causes the corrosion of nails must be protected with epoxy coating or polyethylene tubes.
- To avoid hydrostatic pressure, permanent drainage measures must be taken.
- Protection of the steel elements, such as nails, plates and nuts that is used should be covered with shotcrete

Soil nailed wall will be designed based on internal stability and the global stability of the cut slope. The pullout resistance determined by the nail length and tensile resistance determined based on nail cross section both are considered in internal stability.

The linked system could also provide advantage on long term overall stability of the slope. The wall design is performed in four-stages. In the first stage, reinforced earth wall internal stability, pullout capacity in selected backfill using width of the wall must be examined. To ensure the internal stability reinforced earth wall strip lengths are designed separately considering the minimum design requirements. In addition proper choice of strip sections are implemented in order to have sufficient factor of safety against tensile forces at various levels. At the second stage, external stability must be checked along the reinforced earth wall and soil nail interface. At the third stage, bearing capacity and settlement of backfill is checked and required replacement depth is determined. At the fourth stage, overall stability analysis of the combined system must be performed, (Morrison et al, 2006).

In the design of the linked system, the most important factor is to provide the friction link between reinforced earth and soil nail walls. This could be achieved in two ways; one being the direct connection using synthetic extensible strips as in Figure 3, or using inextensible galvanized steel rod as in Figure 4. The second way is to employ the friction connection by using special galvanized steel ladder strips as in Figure 5. (Freitag, 2012), (Durgunoglu, 2012).

Fig. 3. Direct Connections with Synthetic strips

Fig. 4. Direct Connection with Steel Rods

Fig. 5. Friction Connection with Galvanized Steel Ladder Strips

CASE STUDY

One of the challenging implications of this linked system as combination of flexible earth retaining structures has been achieved recently in Baku, Azerbaijan on the new periphery highway that is located on a very steep topography, Figure 6. Originally, classical reinforced earth retaining wall was considered however, it is known that the width of such walls are at least 70 percent of their heights; as a result, large amount of excavation will be required at the hillside prior to construction of RE walls. In fact, this will also hinder existing highway operation located at the top of the slope and it is likely to be detrimental to the overall stability of this section which is known to be problematic and marginal. In order to overcome these problems, the linked system is proposed to be constructed for a stretch of 540 m which will allow smaller amount of excavation and RE wall could be constructed with a smaller base width. This is achieved by means of combination of soil nail wall at the cut side and RE wall at the fill side employing additional special galvanized steel ladder friction members.

Main lithological unit of siltstones at the site are very sensitive to erosion and getting wet in the presence of surface and subsurface water. Even without the presence of the planned retaining structure on the slope, the overall stability of the slope was critical and marginal. The stability of the slope at the cut side was achieved by implementing long permanent soil nails at various elevations together with strict surface and subsurface drainage measures, Figures 6a and 6b.

Fig. 6a. Cut Slopes-Drainage and nailing

Fig. 6b. Cut slopes-Existing Highway Lanes

At the lower part of the slope however, there was a necessity to construct a retaining structure on the existing slope in order to have required platform width for the new highway. Due to the special problems of the site given above, the linked system was proposed to be implemented, Figure 7.

Fig. 7. Linked System Under Construction

The design requirements were to place a reinforced earth structure having minimum excavation and once the wall is placed, the factor of safety against marginal overall stability should not be reduced. Typical siltstone formation with drained shear strength parameters of c'=20 kPa and Ø'=26° were considered in the early stage design calculations based on the reported values in previous studies in similar formations. Consequently, it was shown that, under this condition implementation of two rows of long soil nails at the toe of the structure having 38 mm diameter and 24.0 m length with s_h=1.5 m horizontal spacing is compulsory in order to achieve overall factor of safety of FS=1.50 under static and FS>1.0 under earthquake loading conditions. Systematic subhorizontal drains are considered in order to prevent pore pressure build up behind the wall.

In the meanwhile, a supplementary soil investigation program is submitted to be implemented at this specific section in order to verify the assumed soil conditions and drained shear strength parameters. In this respect, in-situ block samples of siltstone were taken and tested in the laboratory in a large displacement direct shear test in order to verify drained shear strength parameters. It is determined that residual strength parameters of saturated samples were very close to the values used at early stage of design. On the other hand, considering that no previous slope failure has occurred at this part of the slope (i.e. lower elevations) at this location peak values of fully saturated samples are adopted for the final design for further cost optimization. These values are measured as c'_p=30 kPa, and $Ø'_p$=35°. In such condition toe nails horizontal spacing were increased from original value of s_h=1.50 m to s_h=2.15 m to achieve required minimum safety factors for the global stability. In addition, some of the upper nail lengths were also decreased to 6.0 m. The typical implemented design cross-section for the linked wall system is given in Figure 8. It is seen that some of the soil nails in the cut side is long, in order to intersect the potential critical slip surface. Further in order to place the wall with a minimum base excavation on a sloping terrain at the reinforced earth part, toe of the wall was also tied back to original slope by means of long nails.

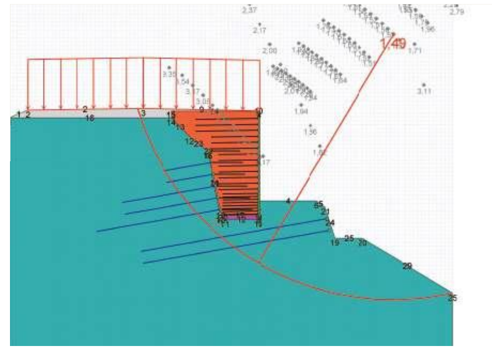

Fig. 8. Typical Design Cross-Section

The total surface area of the implemented retaining structure is 3650 m² having a maximum height of 12.5 m. The construction has been completed in four months with a great success. As seen in Figure 9, specially designed galvanized steel ladders are used as friction connection. Two ladders are connected to each soil nail in V shape in order to achieve the required frictional resistance. Additional photographs of construction phases of the wall are given in Figures 10 and 11. The wall is monitored by means of inclinometers after completion for a period of one year due to the critical overall stability concerns. It is determined that the resulting maximum lateral displacements were limited to few millimeters. As a result, this case study could be classified as one of the successful application of flexible linked system using both soil nailing and reinforced earth on a very difficult topographical, lithological, and drainage conditions.

Fig. 9. Construction Phases – Galvanised Steel Ladders

Fig. 10. Construction Phases –Panels and RE Wall

Fig. 11. Construction Phases – Drainage Measures

CONCLUSIONS

The linked system of soil nailing and reinforced earth satisfies the significant need of highway and railway construction with its advantages in reducing the earthwork and providing the possibility of increasing global stability of sloped terrain. In conventional reinforced earth wall road widening at steep terrain brings the need of large amount of excavation which in some cases may lead to failure in global stability. Besides, the excavation works significantly increase the cost and decrease in speed of construction. With the application of the combined system, all the disadvantages of the classical reinforced earth wall on steep sloping terrain could be eliminated. Both design and construction of a flexible linked system is presented in the case study, and based on the results of observations, it was proved to be successful and this is further verified by the results of subsequent monitoring programme employing inclinometers.

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