Geogrid wall construction using blast furnace slag on a failing slope

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ABSTRACT: A case study of 300 m long, 3000 square meter face area, with one million dollar cost geogrid wall is presented. The wall is located in first degree earthquake zone in a valley with existing slope stability problems. The alternative of the geogrid wall was installation of bored piles costing 3.2 million US dollars. Mobilization of the heavy piling equipment was also of concern due to failing slope. For the construction of the geogrid wall the existing instability created some questions about the constructability of the wall without causing a major collapse. It was decided to build the wall in narrow alternating sections. To cut down the cost of the huge fill volume, steel slag from a nearby plant has been used. Modified compaction tests and large size direct shear tests (0.3 m x 0.3 m) were conducted to obtain maximum dry unit weight , optimum moisture content and shear strength parameters of the slag respectively. Shaking table tests were conducted to observe the compatibility of the geogrid and the slag. X Ray diffraction tests were conducted to obtain the mineralogy of the slag and underlying soils. Dynamic cone penetrometer was calibrated in the laboratory to control the compaction of slag and was used in the field for compaction control. The geogrids were placed every 0.4 meter. An effective drainage system was designed to minimize water percolation. Stability analysis were carried out for static and earthquake loads. The wall is completed and is in service for more than one year.

1 INTRODUCTION

The construction site is located in Karabük, a city located in Black Sea region of Turkey, in a valley oriented in the north-south direction with slope stability problems at the steep west side . The plan view of the construction site is given in Figure 1. At the north section the parking lot is seen. Six blocks are located from north to south in the construction area. The wall is constructed at the west section of the valley.

Sedimentary rocks are present at the slopes of the valley. Under a colluvium layer of up to 3 meters, highly weathered claystone is present with a thickness of 10 to 15 meters. Weathered claystone is present under these layers. Water seeping into the slope from failed pipes was the main reason for instability problems existed in the site. A roadway exists at the top and another roadway exists at the bottom of the slope. A picture of the failing slope is seen in Figure 2. The blast furnace slag geogrid wall is constructed at the site between these two road elevations (up to 25 m of elevation difference).

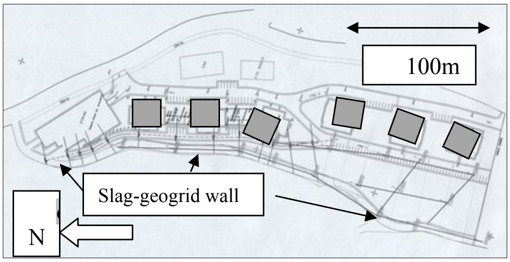

Figure 1. The plan view of the site (The slag-geogrid wall is located at the W side of the valley)

Two contractors work in the construction site, one is constructing 432 apartment units and the other contractor is building 384 apartment units. The contractors are responsible for landscaping and construction of social units also. One contractor has worked with a pile contractor to solve the landslide problem affecting the apartments located at the south section of the valley.. The second contractor found the cost of piles as 3,2 millon dollars and began to search for alternatives. We have proposed this geogrid wall to retain the slope. Although the proposed geogrid wall with 3000 square meter face is a huge one, considering the high cost of pile construction it became the major alternative. The area is also located at first degree earthquake zone. The wall should withstand earthquake forces of 0.4 g according to the Turkish Earthquake code. The unit weight of the wall fill becomes very important because there is an existing slope movement at the site and there is a major

Figure 2. A section of the failing slope seen from upper road elevation

earthquake risk. Located very close to Kardemir Iron and Steel Ltd company (three kilometers to the construction site) the leftover blast slag from granulating process became a good candidate. The engineering properties of the air cooled slag is presented and the details are given in materials section. The final cost of the geogrid-slag wall amounted to 1 million US dollar. The wall is successfully completed resulting in savings of 2.2 million US dollars also utilizing 35000 cubic meters (83000 tons) of unused blast furnace slag. Considering the fact that annual production of leftover blast furnace slag amounts to 42000 tons, the wall consumed nearly two years of waste otherwise which has to be disposed.

2 STEEL SLAG AS FILL MATERIAL

Karabük city is one of the major steel producers in Turkey. Blast furnace slag is a byproduct of the blast furnace industry. Most of the blast furnace slag is deposited in storage areas and these results in serious environmental problems (Ozerinc, 2000). The blast furnace slag was already in the storage area for some years and the company could not find a way to get rid of it (Altun et al 2002).

In order to produce pig iron, iron ore, coke and limestone are heated in the blast furnace. Blast furnace slag is produced as a byproduct of this process. It is defined as "the nonmetallic by-product consisting essentially of silicates and aluminosilicates of lime and other bases" (Das et al, 2007). Selective cooling of the liquid slag results in four distinct types of blast furnace slag:

- Air cooled (solidification under ambient conditions) which finds extensive use as conventional aggregate applications
- Expanded or foamed (solidified with controlled quantities of water, sometimes with air or steam), which is mainly used as lightweight aggregate
- Granulated (solidified by quick water quenching to a vitrified state), which is mainly used in cement manufacture
- Pelletized (solidified by water and air-quenching in conjunction with a spinning drum), which is used both as a lightweight aggregate and in slag cement manufacture.

Kardemir Iron and Steel Ltd company produces more than one million tons of steel product annually. The blast furnace slag is granulated and mostly sold to cement industry at a price of 12 USD per ton (annual granulated slag sale amounts to 276.000 tons). During granulation process some of the blast furnace slag cannot be economically granulated amounting to 42.000 tons per year (Topkaya et al, 2004). This amount is send to a disposal site close to the factory (Kardemir 2006). The factory is located in the municipal area which makes disposal expensive and hard. For the last four decades a lot of untreated blast furnace slag has been accumulated. There is a rapid growth rate in the Karabuk municipal area and new residential development is underway.

3 MATERIALS

Moisture content-dry density tests and large size direct shear tests were carried on at Boğaziçi University Karl Terzaghi Soil Mechanics and Geotechnical Engineering Laboratory. The moisture content-dry density relationship of blast furnace slag and underlying soil was determined as described in ASTM D1557-07. The optimum water content and maximum dry density of blast furnace slag are 10.00% and 23.09 kN/m^3 (2,35gf/cm^3), respectively. The optimum water content and maximum dry density of the underlying soil are 11.50% and 19.13kN/m^3 .

4 TEST RESULTS

Samples were prepared at optimum moisture content for the large size direct shear tests. A specially produced large size direct shear test device was used for obtaining the shear strength parameters (Baykal and Doven, 2000). Shear box dimensions were 30 x 30 x 30 cm. The samples are compacted into the shear box with modified effort to apply modified compaction energy (2700kN m/m^3). The samples were placed into the shear box in five layers.

The results of large size direct shear test of compacted blast furnace slag are presented in Figure 3. The internal friction angle corresponding to peak values is 49 degrees. The direct internal friction angle of the compacted underlying soil is 53 degrees.

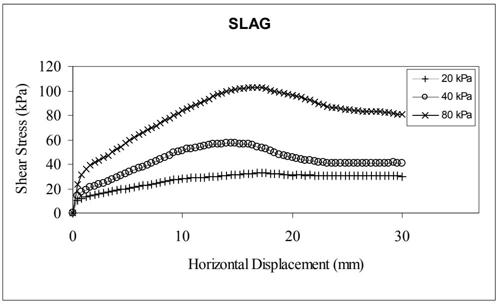

Figure 3 Large size direct shear test results of blast furnace slag

5 DESIGN AND ANALYSIS

Four critical sections have been analyzed using MSEW software as recommended by AASHTO. The minimum factor of safety for static analysis is taken as 1.5 and for earthquake analysis as 1.13. A design acceleration of 0.29 g is adapted as recommended by AASHTO for flexible retaining structures. No water pressure is taken into account because a 0.50 m drainage layer composed of crushed stone has been placed at the back side of the wall. A 160 mm diameter pipe has been placed to collect the drained water which is transferred to the front side of the wall every 20 meters using 1 m wide and 0.5 m deep drainage layers. The water collected at the front side of the wall has been directed to the lowest elevation at the south section of the wall. A surcharge load of 10 kPa is considered at the top of the wall to allow for the traffic loads.

A typical cross-section of the geogrid-slag wall is presented in Figure 4. At this location the maximum elevation difference is 25 meters. The horizontal length of slope is 25 meters. Two geogrid walls of 8.40 m. height x 15.40 m. length at the bottom and 8.00 m. height x 10.00 m. length at the top is designed and constructed. Geogrids of tensile strengths (Tenax 45, 60, 90 kN/m) are used at 0.4 m spacing.

Figure 4. A typical cross section of the geogrid wall

The construction of the geogrid wall is done by wrapping the geogrid in the front face using a steel mesh. The construction phase of the wall is presented in Figure 5.

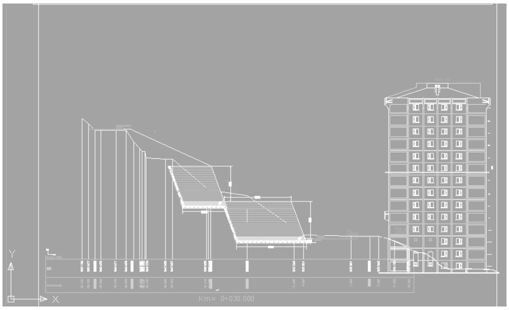

Figure 4. A typical cross section of the geogrid wall

The wall is completed and is in service ,Figure 6.

Figure 5. A typical seen from the construction of the geogrid wall

Figure 6. The completed slag-geogrid wall

6 CONCLUSION

The use of geogrid slag wall decreased the costs by 2.2 million USD when compared to the cost of pile installation. Although the cost was so low as compared to that of pile construction, it was very hard to convince the owners of the project on the constructability of the wall on a failing slope.

- Being in an existing failure zone the construction of the wall was challenging. Using narrow alternating sections proved to be an efficient technique for the construction fulfilling safety, workability and construction time considerations.
- The high compacted unit weight of the slag of 23 kN/m^3 is an advantage to hold the failing slope.
- The stability of the wall under earthquake loads is the most critical issue. The required factor of safety values have been achieved. The legendary performance of flexible retaining structures is well known from the experience gained from past earthquakes. When a new material is used for fill the compatibility of the geogrid openings and the fill material must be tested under earthquake loads. This is done by conducting shaking table tests at Bogazici University.
- The successful completion of the project has demonstrated the fact that byproducts or waste materials can be used safely in many civil engineering applications. Geotechnical engineering applications are especially good because they offer areas with large volume utilization.
- The major consideration in waste utilization is the transportation costs. Whenever possible locally produced wastes should be utilizied by local municipalities and companies. This way while large amounts of waste is discarded, need for natural resources is minimized helping ecological conservation.
- Locally available fill materials cut the cost of geogrid walls considerably. Their utilization is a must provided that necessary environmental concerns are taken into account.
- The percolation of water in the wall is prevented by using an integrated drainage system.

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