4th PAN AMERICAN CONFERENCE ON GEOSYNTHETICS
26-29 APRIL 2020 • RIO DE JANEIRO • BRAZIL

Modular block reinforced structure applied for the highway interchange

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ABSTRACT
The interchange is composed of three-dimensional intersections and several ramps to guide vehicles heading towards different directions. The project is located in a developed country of the Middle East. The main roads are connected to the downtown. In fact, the uneven settlement of the foundation creates difficulties to the road users. To improve this condition, the precompression method is included in the project design. For a period, temporary static load is applied to reduce the soil void ratio and water content. Simultaneously, it increases the shear strength of soil and lateral stress to improve structural stability. The weight of the soil in the reinforced structure provides friction to resist the lateral earth pressure and reduce the lateral deformation, and the precompression method can eliminate the settlement problem after construction. Thus, we can stay that the reinforced structure has the ability to bear settlement.
The two sections of the project are 130m and 205m respectively, and the three ramps of the road are all equipped with a reinforced structural. At the same time, the geogrid Type A (ACEGrid® GG150-I) is laid to wrap-around. The Type B (GG200-I) is reserved for the wall surface to combine with modular block. The modular block reinforced retaining wall is constructed by using the landscape stone (hollow concrete block), which is connected with the geogrid to form a safe structure, and can appeal to the natural ecology and beauty, it is a convenient construction and cost-effective method compared to a traditional concrete wall.

1. BACKGROUND

This paper is introducing a new project for a highway interchange adopting reinforced structure in the Middle East.
Due to the fact that the northern part of the communication road is adjacent to a continuously expanding industrial area, before the construction of this project, the residents in the southern part of the industrial area could only access the industrial area through the surrounding urban roads, which caused traffic congestion in the urban area.
In addition, in order to reduce the population density of the city on the west side of the highway, the government has planned to develop residential areas on the east side of the freeway. Therefore, new connecting roads are needed on the east and west sides of the highway.
As the elevation on the east and west sides of the project site is higher than that of the highway, a large number of retaining structures is necessary to construct an alternating channel system to smoothly connect the elevation to the freeway.

Figure 1. 3D concept diagram

2. GEOLOGICAL CONDITIONS

A total of 23 vertical boreholes were drilled within the site area, and the boreholes were arranged according to the principle of covering the site area.
During the process of drilling, the Standard Penetration Test (SPT) shall be performed every 1.5 meters or at the change of soil layer under the surface, split tube sampling is used for general physical properties test.
Among the 23 boreholes, the design unit selected five drills around the existing channel to perform some in-situ stress and water level pressure measurement, including two drilling numbers K8 and Kr8, then installed a pipe phreatic level reader. Undisturbed soil samples were taken from two boreholes numbered K2 and K6 for Consolidated Undrained Triaxial Compression Test, and one borehole numbered K3 for Pressure meter Test. The positions of these five boreholes are shown in Figure 2.
Figure 3 shows the boring log of representative borehole location K8. It can be seen that the soil layer in this project is within the drilling depth and can be divided into three main layers; silty sand (SM) and poor grade sand (SP) are within 3m below the surface, 3~10m below the surface are low plastic clay (cl-ml) and high plastic clay (CH). The soil strength of this soil layer is to be improved. Below the soft soil layer are sand stone and poor grade sand.
The groundwater level of this base is very high. During the observation period of two and a half months, the water level of K8 borehole was about 3.45~5.4m below the surface, while the water level of Kr8 borehole was about 0.63m~1.2m below the surface, but the location of this borehole was lower than that of K8.

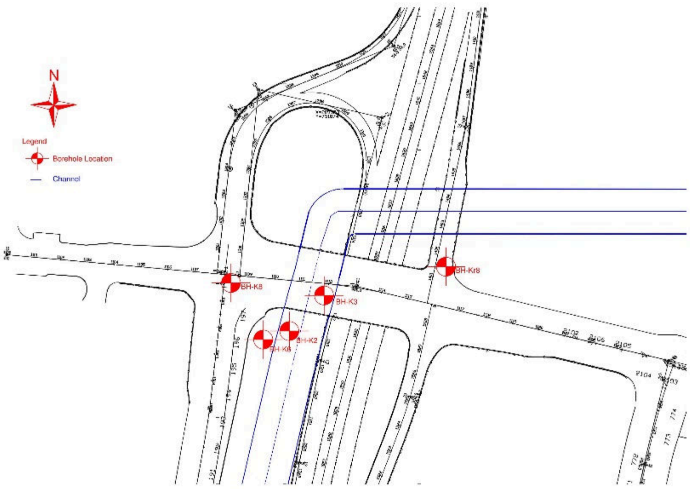


Figure 2. In-situ stress and water pressure measure the borehole position

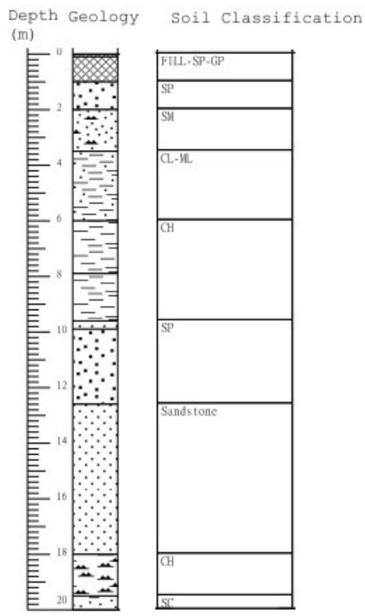


Figure 3. Boring log of No. K8

3. DESIGN AND CONSTRUCTION

3.1 Design Parameters

3.1.1 Soil Parameter

The project designer summarized soil design parameters of this case in-situ according to 23 data, including geological drilling data, test data in the backfilling area, test data of replacement soil in foundation improvement areas after construction, showing in Table 1. In addition, according to monitoring results the groundwater level was set at K8 under the surface of the borehole at 0.6m depth.

Table 1. Soil design parameters

NO.	Soil layer	Unit weight (γ) kN/m3	Internal angle of friction (ϕ) (deg)	Cohesion (c) KPa
1.	Reinforced soil	21	34	0
2.	Retained soil	21	32	0
3.	Replaced soil	21	34	0
4.	Foundation soil	18	18	45

3.1.2 Earthquake Parameter

According to relative standard in Israel (SI 413,2013). "Design Provisions for Earthquake Resistance of Structures", Acceleration coefficient Z=0.2 is adopted for the seismic design.

3.2 Project Design

3.2.1 Configuration of Reinforced Structure

In this case, the ac road system is designed to use a number of solid cross ramps to provide access to the highway. The topography of this case is about 2~8m higher than the existing highway in the middle of the project site. Therefore, in the design of connecting the highway between the ac road and the project site, a large number of fills is necessary to construct the road system. Additionally, due to the limited hinterland, gentle slope cannot be applied, so the design unit adopts a large number of reinforced retaining walls at the filling as a stable road foundation. As shown in Figure 4, there are four reinforced retaining walls (design cross sections no. 1-1, 2-2, 4-4, 7-7) and two reinforced embankments (design cross sections no. 3-3, 6-6). The length of the ramp on the west side of the highway is 1303 on the northbound lane and 1203 on the southbound lane. Because there is an existing channel below the road, is it necessary to construct a bridge deck, the section (reinforced design section 6-6) and the bridge deck junction adopts reinforced abutment design. Typical cross sections 1-1, 3-3, 6-6 reinforced abutments are shown in Figure. 5. The table 2 shows the number of road mileage corresponding to the reinforced structure.

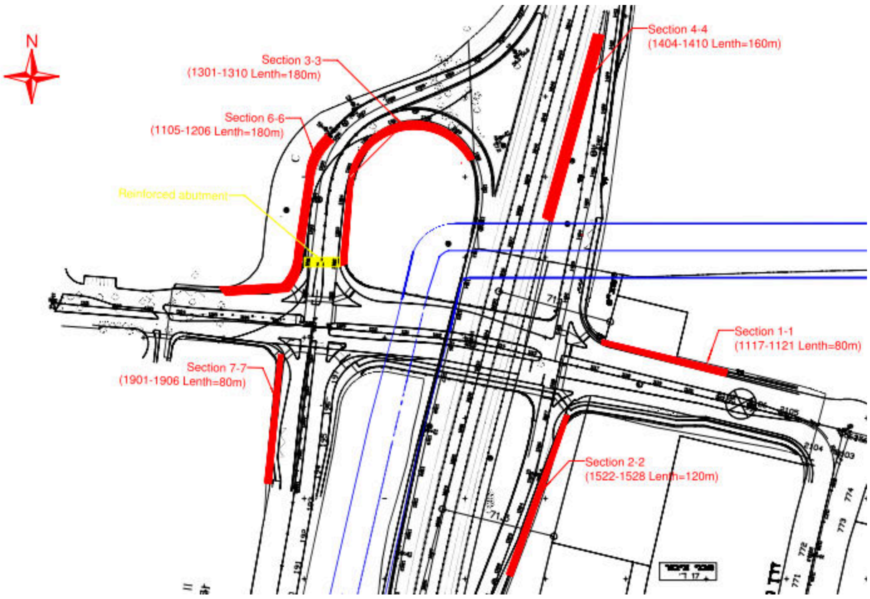
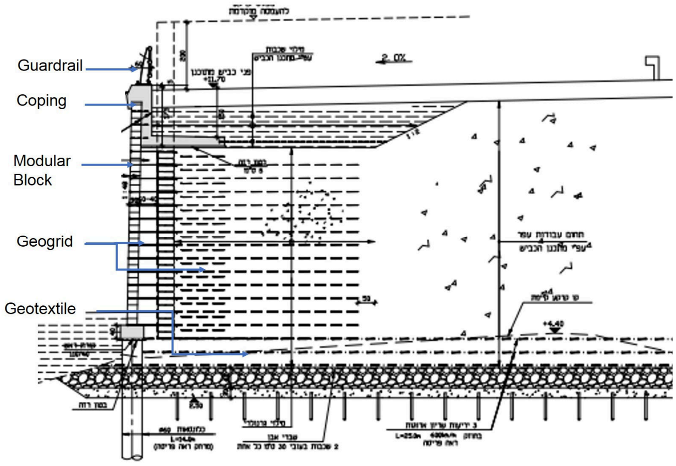


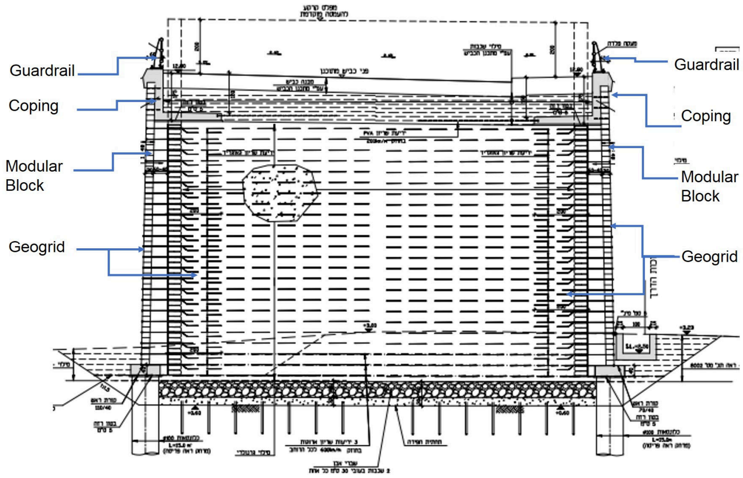
Figure 4. Layout drawing of reinforced structure

Table 2. Mileage location of reinforced structure

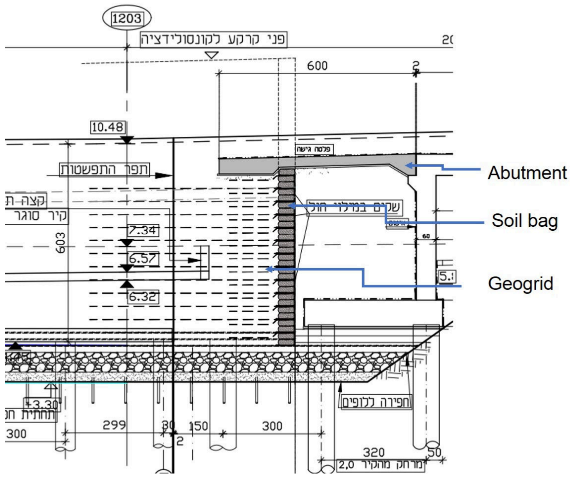
	Mileage		
RW2	1523	1527-1522	1522-1518
RW3A	1410-1404		
RW6	1423-1428	1413-1428	1402-1408
RW7	1303-1309		
RW8	1105-1206		
RW9	1905-1901		
RW10	1117-1121		1403-1401



(a) Design cross section 1 - 1



(b) Design cross section 3 - 3



(c) Design cross section 6 – 6 Abutment

Figure 5. Typical section of reinforce structure

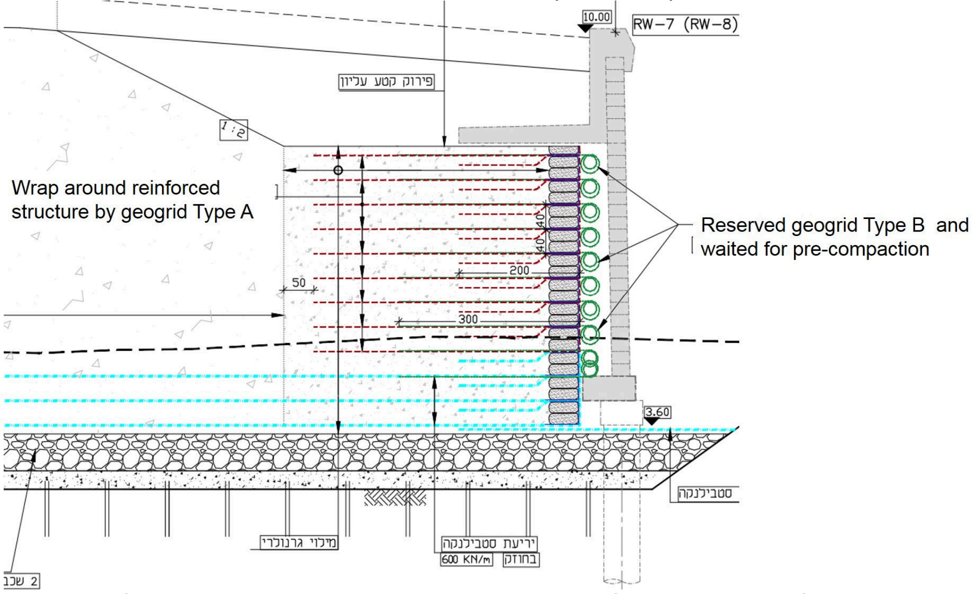
3.2.2 *Cross Section Design*

This case is divided into 3 parts by the standard sectional design of structures, showing in Figure 6. below:

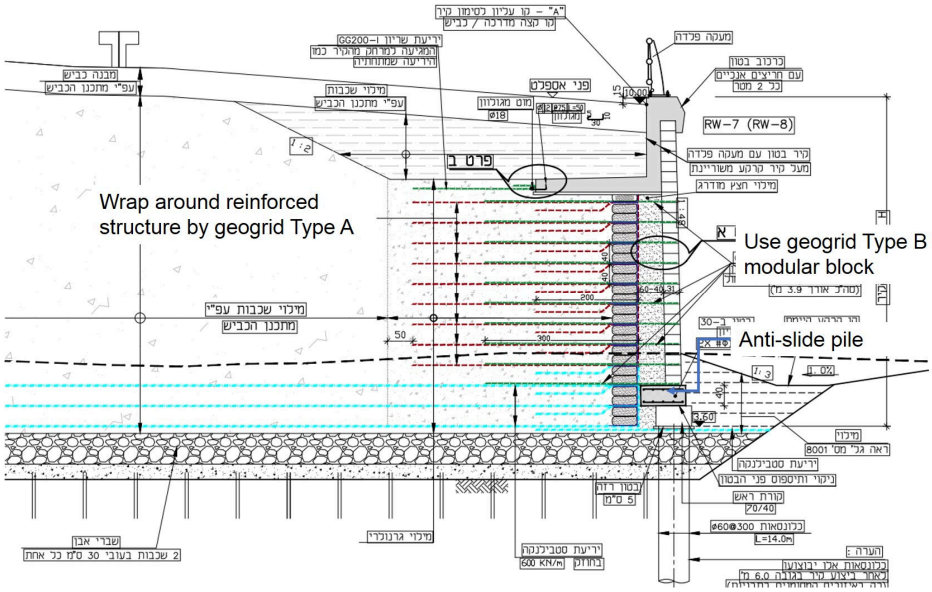
(a) Foundation Improvement: There is low-strength of the clay layer with 7m of thickness under the structures so PVD (Prefabricated Vertical Drains) must be installed in the foundation of reinforced structures to shorten the drainage path in the clay layer. The interval of PVD installation is 1m, and installation depth is 10m for the purpose of getting through the clay layer.
There is 30cm of sand pavement above PVD and the purpose of sand pavement is to evacuate water drainage from PVD. Then 60cm of gravel was paved above the sand pavement for the purpose of replacement by higher strength of soil to increase loading capacity and anti-slide for the foundation of reinforced structures. In addition, reinforced structures were immediately built above the gravel layer. Besides, 2 layers of tone bulk bags with 2m height were stacked on the reinforced structures for surcharge. Then adopting the preloading method accelerated compaction of the clay layer in order to shorten the construction period.

(b) Cast-in-place anti-sliding pile: In order to increase anti-slide stability for the reinforced structures, according to the stability analysis results, a row of cast foundation piles is set below the wall of the reinforced structure. Based on the height of different reinforced structures, two sized of foundation piles are adopted, one of 14m length and 60cm in diameter and another of 15m length and 100cm in diameter respectively. The horizontal spacing between the two sizes of anti-slide piles is 3m. The length of the pile should be set at the bottom of the pile in sand stone to avoid the subsidence of the anti-slide pile.

(c) Reinforced structure: The reinforced structure is above the gravel gradation layer, and only the bottom of the reinforced structure is laid with 600km/N geotextiles of 2~3 layers with a vertical spacing of 40cm, and the buried horizontal length is the same as the width of the driveway. The function of geotextile is to transfer the reinforced structure and the vehicle load evenly to the base soil below like the theory of the membrane action, and at the same time, the lateral deformation of the stiffening structure above the geotextile can be restrained (thereby reducing the vertical deformation of the reinforced structure). In this case, the reinforced structure is a stacked reinforced retaining wall and a reinforced embankment with a wall slope of 88.8 ° nearly vertical, with a maximum height of 9.2m. After stability analysis, a layer of 150kN/m geogrid with a vertical spacing of 40cm is laid to build the reinforced structure. Because the wall of the reinforced structure is located on the anti-slide pile, and because the precast compaction method is applied at the same time, the amount of settlement of the wall and soil in the reinforced area is different.
If the two structures are built at the same time, the grid located on the wall can be fractured due to differential subsidence and shear force. Thus, in this case, the reinforced structure is designed with a special two-stage construction method. In the first stage, the reinforced structure is constructed with wrap around method. However, during the construction in this stage, it is within 2m of the retaining wall. An extra layer of 200kN/m geogrid is laid in advance, and the geogrid with a length of 0.7~0.9m is reserved outside the retaining wall. After the pre-compaction is completed, the second stage is applied as a stop slide pile, and the reserved geogrid is connected with the stacked bricks on the wall above the pile to complete the construction of reinforced structure.



(a) The first stage is pre-compaction and construction of wrap around reinforced structure



(b) The anti-slide pile and wall at second stage
Figure 6. Design section of reinforced structure

3.3 *Subsidence Monitoring Design*

In order to understand the settlement results of pre-compacting method, in this case, an 8m long sinking pillar is embedded at twelve different spots as shown in Figure 7. The bolted screw is used as a fixed measuring point at 2m, 4m, 6m, 8m of the extension tube of the sinking pillar.
Monitoring of subsidence begins after installation (and therefore includes monitoring during construction) until a predetermined amount of subsidence is reached.

Figure 7. Consolidation meter device

3.4 *Construction Sequence*

The construction sequence of the project is first to lay the woven geotextile at the bottom of the foundation for reinforcement, and the construction of the back-filled reinforced retaining wall is carried out from bottom to top.
Nonwoven geotextile is applied to cover backfill material in the wall section of the reinforced structure, and Type A grid is used as the wrap around reinforced material in the wall, while Type B grid is the material for connecting stacked bricks. After waiting for a period of time for pre-compaction, the wall of the wrap around section is connected with the stacked panels. Figure 8. is a photo in construction.

Figure 8. During construction

4. PRELIMINARY RESULTS OF SUBSIDENCE MONITORING

At the time of writing this paper, there are still three wrap around reinforced structures of the first stage under construction. Therefore, the monitoring of the subsidence is only carried out for four months. At present, the monitoring data of nine sinking pillars is shown in Figure. 9. The maximum subsidence amount of 32cm (subsidence rate of about 8cm per month) occurs at the distance of 1212.Note that this is not the distance where the reinforced structure is located, so whether the large subsidence is a geological improvement issue remains to be discussed.

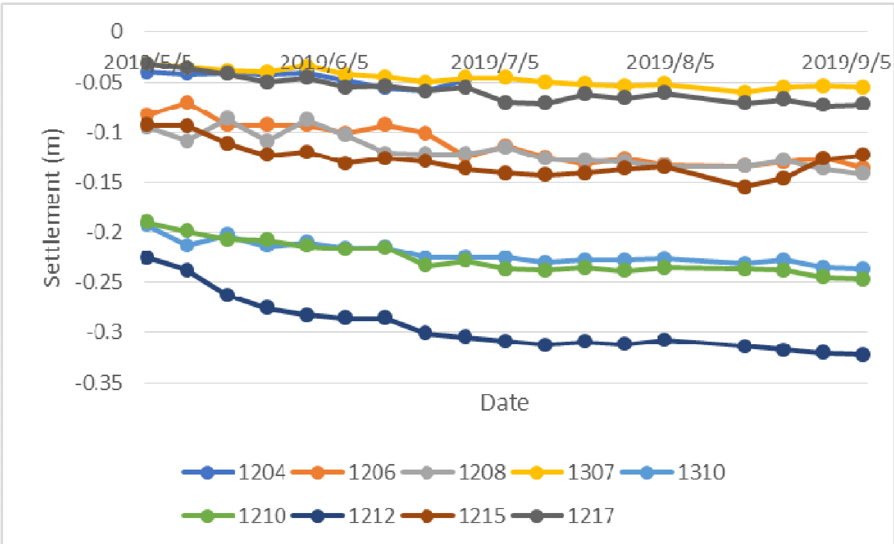


Figure 9. Subsidence monitoring data

5. CONCLUSION

The main reason why the reinforced structure can work is that it has better flexibility, and the reinforced material has strong tensile resistance, uniform distribution of stress, and provides high impedance force. The reinforced structure can withstand the deformation behavior more than the traditional concrete retaining wall, and the lateral deformation and subsidence can occur after any retaining structure is built.

Therefore, after the completion of the main structure, the reinforced method can be placed for a period of time, waiting for the main compaction and lateral deformation to be developed, and then the stacked panel can be connected, so as to effectively control the deformation of the future retaining structure to the minimum value with the concept of the secondary construction method of pre-compaction and pre-deformation. Furthermore, the construction is rapid and the construction cost is low, achieving both economic and safety benefits

REFERENCES

Israeli Standard SI 413. (2013). Design Provisions for Earthquake Resistance of Structures.