Segmental Retaining Wall Reinforced with Geogrids, in New Hospital Works (Salamanca, Spain)

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ABSTRACT: *The construction of a new hospital, located by the river Tormes in the Spanish city of Salamanca, involved the expansion of roads and the construction of a new way of access to the complex, as well as a large retaining wall to bridge the gap between them and the river level. The project original solution was in situ foundations and precast concrete walls. However, at both ends of the alignment of Transición Española Avenue, there were several construction constraints (such as the existence of rainwater chambers for discharging into the river, a large-diameter drainage pipe at the back of the walls, communications, and gas services). The need to maintain steady access to the old hospital in service during the COVID-19 pandemic was furthermore required. The wall was founded on fills with low bearing capacity in other sections. Finally, a reinforced segmental retaining wall (SRW) was adopted as the optimum choice. It consists of concrete block (segmental) facing with a high-quality fill reinforced backfill, reinforced with polyester (PET) geogrids. The facing required a variable inclination from 80º in the main wall to vertical at the junction with the existing precast structure. The design was constrained by several factors: the limitation of length of the geogrids by existing structures or services, the alignment having a sinuous section to allow for planting, that it was set within a floodable zone and was founded on fills, and traffic overload. The design of the reinforced soil structures required new geotechnical tests and an analysis by analytical and finite element methods. The maximum height of the wall reached 8.9 m and the final measured face area of 2200 m^2. The works were undertaken during the first half of 2020.*

KEYWORDS: wall, blocks, reinforced, geogrids, anthropic, fills.

SITE LOCATION: **Geo-Database**

INTRODUCTION

The construction of the new university hospital in the city of Salamanca, Spain, has been one of the most ambitious investments the city has undertaken in recent decades. Six years of work were carried out to erect this hospital complex, which was completed in 2021. The works have required a complementary project for the development of a new east-west road axis in the city, which regulates traffic and provides access to the new hospital. This new avenue, known as Transición Española Avenue, runs parallel to the banks of the Tormes River, and has been executed by the contractor Ferrovial. The work began in 2019 and finished in January 2021.

The most important feature of the road project was the challenge of erecting a retaining wall more than 600 m long and with an average height of 7 m, to accommodate the differences in elevation between the river and the level of the new road.

The original design solution was large prefabricated concrete walls anchored to large footings built on site. However, it was necessary to study an alternative system that would overcome several important construction constraints located in two areas, as well as speed up the works. A reinforced SRW was adopted, consisting of a concreted block facing reinforced with geogrids The use of SRW systems are becoming increasingly popular due to their relatively low cost and versatility as compared to other retaining solutions (Colt, 2014). Two segmental retaining walls (SRWs) were proposed, one to the east and the other to the west of the main wall body, keeping to the original solution at the central section where there were no constraints.

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The Design for the SRW was undertaken by local municipal technicians, supported by technical services of Ferrovial as the main contractor. The subcontractor, Orbe Técnicas y Medioambiente, who specializes in reinforced soil structures, also participated in the preparation of the alternative design proposal and subsequent execution of the work. Huesker's engineering services were also supported during the design process by specialists geogrid and geotechnical solutions.

There are dozens of segmental block wall marketed worldwide, with a variety of sizes, shapes, textures, and appearances (Bobet, 2002), a lot of them available in Spain. Terraforce blocks were finally chosen as facing system of the options available on the Spanish market. The blocks consist of a hollow core with a textured facing. The blocks are connected to the geogrid by placing a gap graded stone with the hollow of the facing blocks that interlocks in the apertures of the geogrid place at the block interface below. Each proprietary segmental block system will undergo connection testing with the proprietary geogrid to confirm the connection capacity of the system.

Regarding the geogrid supply, an established manufacturer with independently certificated geogrids was required. The capability of provide on-site technical support was also a consideration. Huesker Geosintéticos were chosen, and supplied flexible geogrids, namely Fortrac T, geogrid produced with PET yarns and covered with polymeric coating.

The design was carried out for long term condition using the simplified Bishop and sliding block methods in accordance with (DIN 4084, 2009) for compound stability and also by the (NCMA, 2010) code for internal/external stability. The case study of the construction of both segmental retaining walls (SRW) is presented in the following sections.

SEGMENTAL RETAINING WALL 1

The west wall is located between the abutment of the University Bridge and the central roundabout of the Transición Española Avenue (Figure 1), where it hits the precast concrete structure.

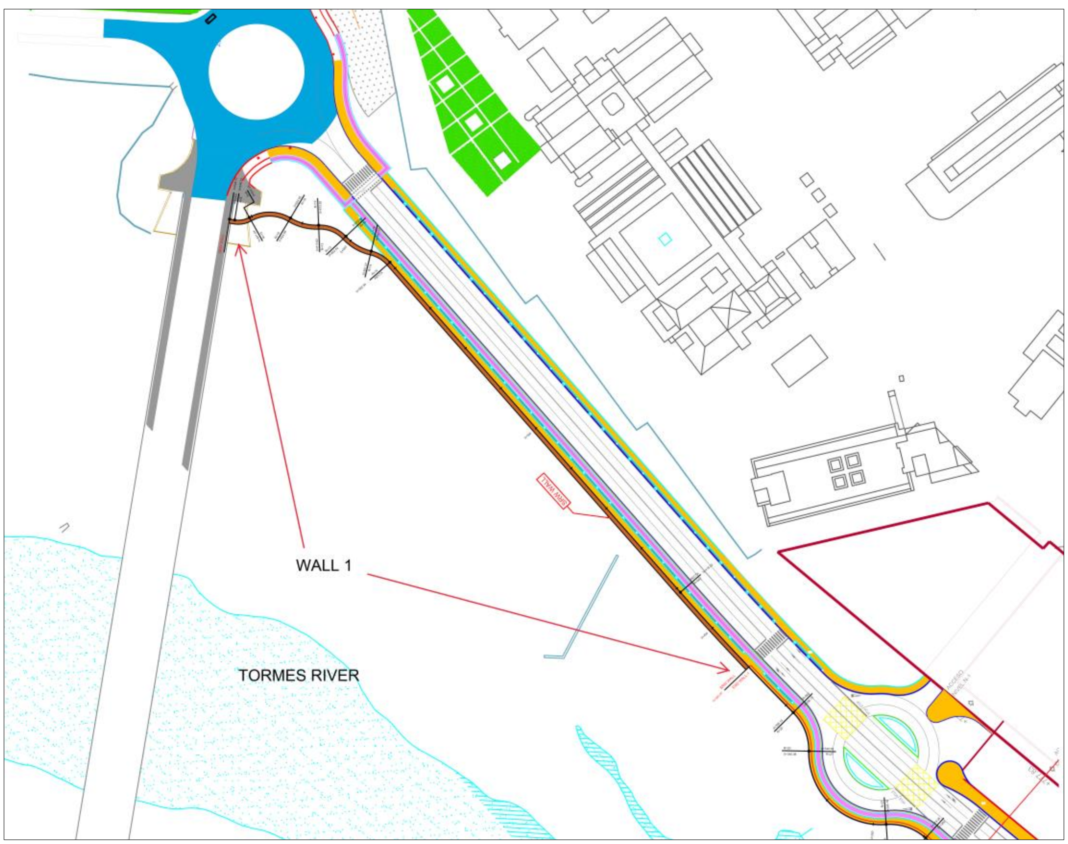

Figure 1. Plan view of wall 1 (Orbe Técnicas y Medioambiente).

The length of this section is about 185 m with a maximum height of 7.67 m (40 blocks of 190 mm high plus the additional coping block) above the foundations and an inclination of the exposed face of 80º. The inclination was achieved by a simple setback of 30 mm at each line of block. Pedestrian and cycle lane areas were planned above the crown and behind them the new road with two lanes in each direction. In front of the wall, a green area was planned, although it is a floodable zone within in the 100 and 500 years of return period.

Geology of the Area

The promoter of the works commissioned a geotechnical report to study the foundations of the retaining walls. Three structurally significant strata have been identified in this area of the site:

- Level of anthropic fills. These are heterogeneous, anthropogenic fills that have been dumped on the riverbank since ancient times. Their maximum thickness is at the western end, about 4 m from the foundation level, and descends in an easterly direction to 0.5 m with an estimated bearing capacity of 0.5 kg/cm^2.

- Level of sand and gravel. Underlying the fills are natural fills of alluvial origin, consisting of angular siliceous gravels in a sandy, slightly clayey matrix with a variable thickness and low strength.

- Level of slate. This is located immediately below the layer of sands and gravels and is made up of completely weathered slates with a degree of weathering V according to (I.S.M.R. 1981), giving rise to an alteration soil of the silty-sandy clay and sandy-clay silt type, being a competent stratum for support according to the values of the DPSH tests.

The water table was located below the planned foundation level of the walls, and it is not expected to rise except in very occasional episodes of flooding. Additionally, Spanish seismic regulations (NCSE-02, 2002) do not apply in this area. As for the infill material, a nearby borrow pit of not slightly weathered rock of slate origin was located, which, once classified as processed and graded, could be used as fill (PG3, 2015). Different laboratory tests were carried out on this soil to characterize its geotechnical parameters, together with the foundation soil and drainage gravel (see Table 1).

Table 1. Soils properties of wall 1 (Orbe Técnicas y Medioambiente).

Soil	Unit weight, γ (kN/m^3)	Friction angle, ϕ (º)	Cohesion, c (kN/m^2)
Infill	20.0	30.0	0.0
Foundation	19.9	28.0	10.0
Gravel	17.0	35.0	0.0

Conditions of Wall 1 Area

As the axis of the wall runs parallel to the banks of the Tormes River, it was to be expected that the structure would intercept hydraulic drainage works. In this section, two large rainwater drainage chambers from the current hospital and adjoining urban development were located. These reinforced concrete chambers limited the planned length of the geogrids in two sections of 5 m and 23.5 m in length and 3.5 m in height from the level of the wall foundations.

There were still more construction challenges to overcome. The first one was the presence, along 139 m, of the 185 m length of a new Ø2500 mm drainpipe parallel to the axis of the wall centered 5.6 m back from the wall face. In addition, there was a concrete manhole, a Ø2300 mm diameter drainpipe behind the wall facing, over its entire height. The second challenge was the joint of the wall facing at 80º against a prefabricated wall at 90º, at a section of the wall where both the bottom and top of the wall had to incorporate steps.

Finally, when designing the reinforced soil structure, what had to be taken into consideration was that this area of the site is in a flood zone for the 100 and 500 years' return floods, with expected water levels of 2.3 and 3.6 m above the formation level of the wall foundations.

Solutions Adopted for Wall 1

To prepare the structure for foreseeable seasonal floods, a riprap was designed at the level of the wall, as scour protection of the foundations. To support the blocks on the facing, a foundation trench of approximately 1 x 1 m was built, filled with gravel, and wrapped in a non-woven geotextile filter. Behind the block face, a generous one m wide backfill of crushed gravel was installed (see Figure 2), as well as the drainpipe collector surround. Both drainage systems were completed with corrugated HDPE drainage pipes passing through the block face towards the river, arranged perpendicular to the line of the wall. Light- and medium-sized compactors were used to minimize the long-term facing deformation to reduce the lateral forces against the wall (Bathurst et al. 2010).

Figure 2. Different phases of the erection of Wall 1

The section was discretized into several representative design sections. The maximum section height was 7.67 m above the foundations. The surcharge loading was 5 kN/m in the first five meters from the facing for the pedestrian zone, and a second of 10 kN/m for traffic thereafter. The length of the first layers of geogrids was limited by the presence of the collector and the two chambers (see Figure 3). It resulted in a trapezoidal section with less geogrid length at the base than at the crest in some sections. The minimum distance found was 2.6 m for a section of 6.5 m in height. The vertical distribution of geogrids was at 380 mm layers (two blocks) approximately up to 60% of the total height in most cases, and 570 mm (three blocks) for the rest of the wall. Furthermore, the transient situation was checked for maximum flooding and rapid drawdown, with favorable results. The geogrids used were flexible PET geogrids with PVC-free coating, with nominal strengths ranging from 35 kN/m to 80 kN/m.

Following the recommendations in the Spanish codes (Guía de cimentaciones en obras de carretera, 2003), the upper layer of the geogrid was extended through the grade of the future avenue to minimize possible cracks in the long term because the potential for different settlement behaviors of simple compacted infill and the reinforced fill.

The last of the challenges was the geometric encounter with the existing prefabricated vertical wall. It was solved thanks to the professionalism and skill on the installers' part, bearing in mind that a face angle of the exposed face is required to make a smooth transition from 80º to 90º with steps at both at the foundation base and at the top of the blocks by varying the horizontal set back of each course. The installation company's engineers carried out a geometric fit using CAD, which was later redefined on site and each course was checked with precision.

Figure 3. Wall 1 under construction (Orbe Técnicas y Medioambiente).

SEGMENTAL RETAINING WALL 2

This section covers the development of the access roundabout to the new emergency area of the hospital and links the new Transición Española Avenue with San Vicente Avenue (see Figure 4). The wall had a length of 35 m with a maximum height of 9.2 m at the joint with the prefabricated wall, decreasing to a height of 2.7 m at the opposite end.

Geology of the Area

The existing slope formed by the placement of anthropogenic material had an average inclination of 1H:1V and was partly supported by two lines of very deteriorated 1 x 1 m gabions. The main contractor decided to carry out a new geotechnical testing campaign on this area. Thus, the grade of the embankment was lowered by about a meter and a half below the level of the variable fill on the avenue and levelled so that the machinery could access it, creating a work platform. A campaign of five dynamic probe super heavy (DPSH) two direct shear test and densities were carried out in May 2020.

The DPSH tests clearly show in all five logs a relatively high strike layer of between 40 and 60 strikes (to advance 20 cm), and two of them show rejection at that level. However, the P-2 and P-3 tests, located in the central third of the wall, show a sharp drop below -2 m with very low blows, below 10 m until reaching rejection suddenly at around -13.5 m depth. This area coincides topographically with the steepest slope of the earth embankment and the one with the most evident signs of instability.

From these tests, a friction angle of 31.1° and a cohesion of 11 kPa were determined. It can be deduced from the tests, as well as from the on-site inspection, that toward the body of the embankment there were better mechanical properties, and the surface layers and the existing embankment were more unstable.

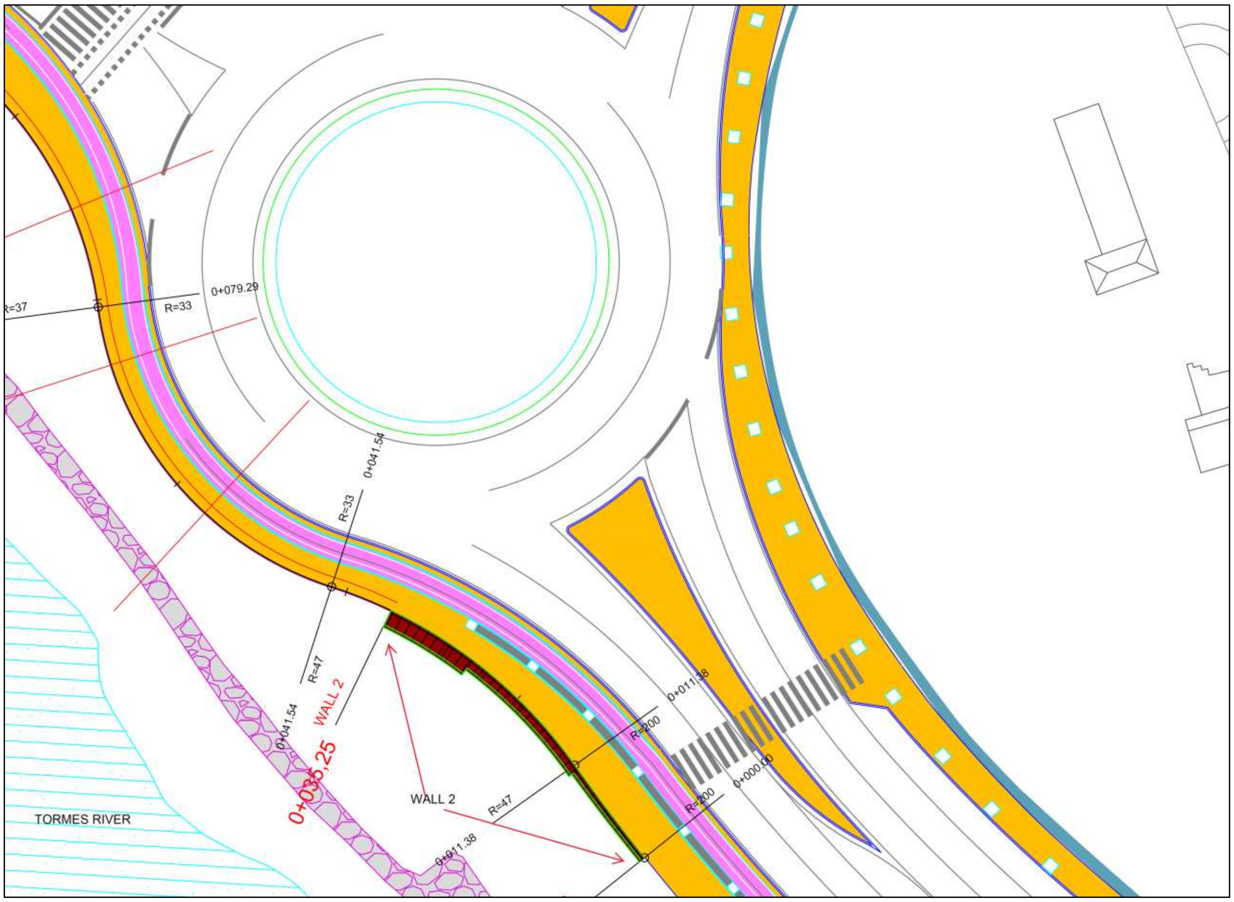

Figure 4. Plan view of Wall 2 (Orbe Técnicas y Medioambiente).

Conditions of the Wall 2 Area

Despite the short length, this section was the most problematic to undertake for various reasons. The wall begins at the joint of the precast wall, from a completely vertical slope and at a floodable level, and continues over an embankment of anthropic upfill from historical dumping on the banks of the Tormes River. Moreover, as it advances in length, closer to the visible face is Avenida de San Vicente, an important service road which provides access to the hospital in service. Parallel to the alignment of the road, there was a zone of affected services that could not be out of service during the works (electricity, gas, telephony). This service area limited both the effective length of geogrids and the foundation excavation of the walls.

Solutions Adopted for Wall 2

From the results of the tests, it was proposed not to excavate below the -2 m level of the working platform on the embankment, taking advantage of the layer detected with greater resistance. In addition, to homogenize as far as possible the response of the ground to the load of the retaining wall (approximately one meter of earth above the current level), it was decided to create reinforced soil foundation between elevations of -2 m and 0 m of the working platform, made up of 500 mm layers of granular soil with high internal friction and geogrids over the full available width of the excavation. The reinforced soil structures are more forgiving to differential foundation settlements and more adaptable to low quality backfill (NCHRP Report 556, 2006). This not only creates a stiffer layer that transmits stresses more efficiently and homogeneously, but also helps from a slope stability point of view to increase the safety factor.

For the design of the geogrids' reinforced soil foundation and the retaining wall, as well as the overall stability of the embankment, the geotechnical characteristics of the ground were first defined (see Table 2), with the help of tests, known data from the geotechnical report of the area, retrospective equilibrium analyses, and technical literature (SE-C, 2006).

Table 2. Soils properties of Wall 2 (Orbe Técnicas y Medioambiente, Huesker geosintéticos).

Soil type	Unit weight, γ (kN/m^3)	Friction angle, ϕ (º)	Cohesion, c (kN/m^2)	Young's modulus, E (kN/m^2)	Poisson's ratio, ν (-)
Anthropic Fill	18.00	31.1	11.0	12000	0.35
Wall Infill	20.00	30.0	0	80000	0.30
Wall Embankment	20.00	35.0	0	100000	0.30
Wall Foundation	19.95	28.0	10.0	140000	0.20
Avenue Subgrade	20.00	32.0	10.0	120000	0.30

Three sections were discretized and analyzed (one every 10 m) with special attention to the most unfavorable section at 0+24 at mid-slope. The stability analysis was carried out by using GGU Stability software following the Simplified Bishop Method. In addition, a simplified model in finite element was checked using Plaxis 2D software (see Figure 5). A 15 Node and Plane Strain Model was used. The soil model was a Mohr-Coulomb type in drained conditions, and an elastoplastic one for geogrids. No interfaces were used around geogrids because of their great interaction with soil particles. The finite element model detected failure surfaces coinciding with those obtained in the ultimate limit state and with factors of safety in the same range. It also confirmed the existence of surfaces susceptible to surface landslides throughout the embankment under the wall. Thus, a reduction in the slope inclination to increase the factor of safety against failure was necessary. Values of less than 10 mm of settlement were estimated in the model, which were assumed to be acceptable for the project.

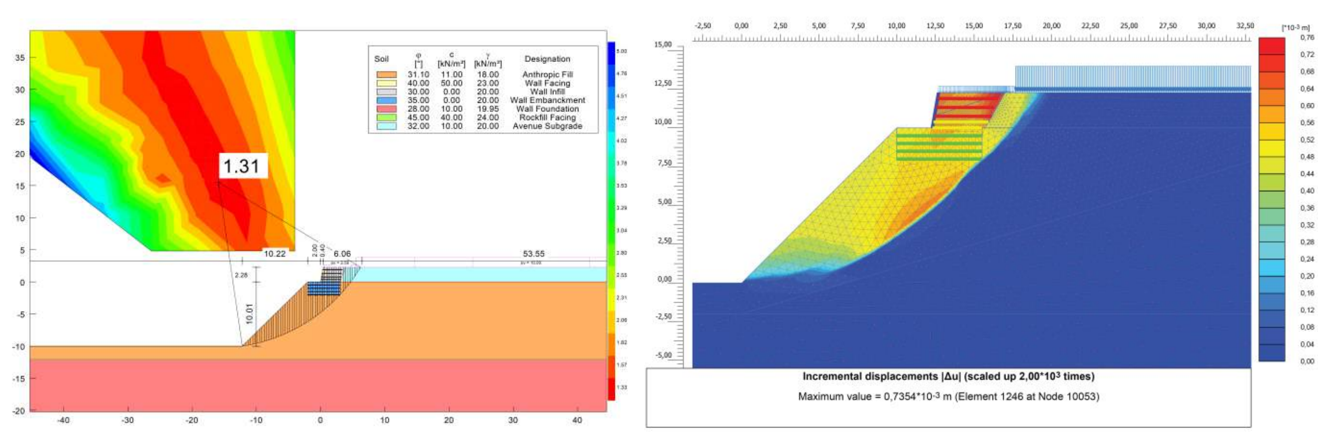

Figure 5. Section 0+24 preliminary analysis of global stability failure: (a) Bishop and (b) FEM (Huesker Geosintéticos, 2020).

In the first approximations of the solution, it was found that the reinforced soil structure had a safety factor above the required minimum (1.5). However, the overall stability, including the embankment at the foot of the wall in its natural state, was very doubtful. The global long-term stability of the embankment and wall was analyzed and a factor of safety of 1.31 was obtained by the Simplified Bishop's Method and 1.23 by a FEM analysis. In observing the deformation of the finite element model, it became clear that the embankment could deform at its footing, which made reinforcement necessary. Finally, the situation was solved by installing a riprap at the foot of the slope and its extension up as a rockfill facing to the platform of the walls. In this case, granite stone was projected instead of the less heavy limestone that had been used in the previous sections. With these actions, the global stability safety factor was raised to 1.57 by the Bishop analysis. This solution also protected the embankment and the walls against floods and surface erosion, so that in the long term there would be no problems of potential slippage (see Figure 6).

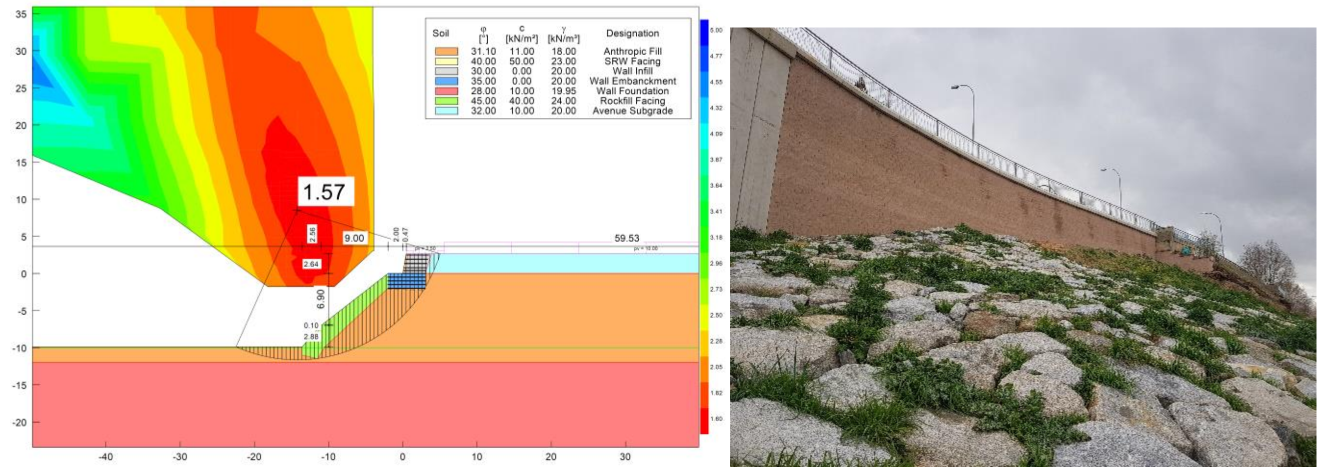

Figure 6. Section 0+24 final analysis of global stability failure: (a) Bishop and (b) real view (Huesker Geosintéticos, 2020).

In the final design, the reinforced embankment was made up of four layers 0.5 m high of granular material and 80 kN/m geogrids of PET type Fortrac 80 T between them. The length of these geogrids was variable in each section and the entire lengths available in the excavation were used: 8 m for the section at km 0+24 as a maximum value, and 5 m in Section 0 as a minimum value.

The retaining walls were designed with geogrids of nominal resistance from 80 kN/m to 35 kN/m of PET with a maximum vertical spacing of two to three blocks (380 mm to 560 mm) and using the entire length available in the excavation, ranging from 4 m for Section 0+24 to 5.45 m of free wall height and 3 m in Section 0+6 as a minimum for a free wall height of 2.64 m. Special mention should be made of s=Section 0+30, which forms the transition between the precast concrete wall and the special sections at mid-slope.

The level of the foot of the wall is 775.14, i.e., 350 mm below the height of the maximum 500-year return flood, coinciding with the base of the precast wall. The maximum clear height in this section was 8.92 m. Several factors made it unsuitable for installation at this level: the foundation of the precast wall was located at a depth of 4.69 m below this level, in the unaltered slate stratum; and, between the two levels, there was a fill of anthropic material that was incompatible with the foundations to allow differential settlement. From experience, it is known that the transition between geogrid-reinforced soil structures and conventional compacted embankments has different behaviors and is often reflected in the form of cracking. This effect could be amplified by laying foundations on materials with different bearing capacities. Finally, it could not be overlooked that the support level is below the maximum flood level and would have to be treated. It was decided to over excavate to the level of the foundations of the precast wall and to fill this gap with a small stone riprap. In addition, it was proposed that the last meter of height of the reinforced soil structure should extend the geogrids by at least 5 m to the backfill of the precast wall, as a “transition slab” between the two backfills. The entire foundation face of both walls was furthermore protected with a big stone riprap. As a geosynthetic reinforcement, PET geogrids of 80 kN/m, 55 kN/m and 35 kN/m were installed from footing to top, with a spacing of two blocks (380 mm up to a height of 6.46 m, after which every third block (570 mm) was installed). The length of reinforcement was constant throughout the 6 m section.

DISCUSSION

It is well known that retaining wall systems consisting of geogrid-reinforced soil and segmental concrete block facing is a highly versatile and efficient construction procedure. Its decades-old implementation, the abundant technical literature and codes for its design, and a history of successful construction cases support it. However, there is one vital point that is not always clear and can lead to undesirable results: the organizational environment; specifically, the distribution of roles and responsibilities.

In this case, the role of manager of all the parties involved in the works was correctly carried out by the civil engineer *in situ* of the main contractor, fully supported by the civil engineer of the subcontractor specialized in SRW and supervised by the owner representative engineer. In addition, a professional team of installers with more than 20 years of experience in the installation of block walls was on site, and the good results are evident (see Figure 7).

Figure 7. Wall 1 at the present time (Huesker geosintéticos).

The choice of manufacturers of quality materials in terms of geogrids and blocks, as well as the engineering support by their professionals also with decades of experience, made the whole process easier while overcoming construction problems during the execution of the work.

It should be noted that the work was carried out during the Covid-19 pandemic and under lockdown, with major logistical problems and limited movement of people. Thanks to new technologies and their effective usage, information on the work was shared amongst the site team and the designers, and enabled virtual coordination meetings between all parties. As result of this, the retaining structure was successfully built within the time limit despite the construction and geotechnical obstacles at the site.

CONCLUSION

In 2020, the construction of a 600 m long and 7 m high (on average) wall was carried out to support a new avenue in Salamanca, Spain. Geometric and geotechnical constraints motivated the replacement of two wall sections from a precast concrete wall system and large foundations to SRWs. Wall 1, at the west end of the development, was over 185 m with a maximum height of 7.67 m above foundations and a face slope of 80º. The length of the geogrids was restricted by the presence of a Ø2300 mm drainpipe at 5.6 m from the wall's face. This implied the choice of selected geogrids with a high soil interaction coefficient. The design included, in addition to the classic checks, a rapid drawdown analysis due it being a floodable area. A permeable gravel foundation was designed to support the exposed face on the most competent soil stratum, as was a riprap to protect against flooding scour issues. A network of drainage pipes was placed through the wall to facilitate drainage in case of flooding.

A second wall at the eastern end was founded on complex variable fills and at mid-slope. The length was 35 m and the maximum height was 8.92 m. A specific geotechnical testing campaign was carried out to characterize and design the reinforced soil structure. In addition, the deformations of the slope-wall assembly were checked by means of a simplified finite element model. All these tools allowed for a satisfactory design consisting of a heavy rock riprap at the base of the slope, a reinforced soil foundation at the above, and finally the SRW on it.

The professionalism and the experience of the installers led to an exceptional finish, even at the 90º joints with the existing wall. Coordination was facilitated between all parties involved, especially under the harsh working conditions caused by the lockdown due to the Covid 19 pandemic, largely thanks to new information technologies and an excellent management of design and construction processes.

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