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EMBANKMENT FOUNDATION OF THE SAN MARTÍN RAILWAY VIADUCT

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ABSTRACT
In the San Martín Railway Viaduct, one of the most important railway project carried out in the Autonomous City of Buenos Aires, it was planned the construction of steel strip reinforced soil walls (up to 6 m high), placed over about 6 m of thick soft clay, underlined by a stiff soil. In order to reduce the settlement of the reinforced soil walls and of the track structure, the work started with the construction of controlled density fill piles 50 cm in diameter, founded in the stiff soil layer. Nano-polymeric geocells were used in order to evenly distribute the embankment weight and the railway load to the piles. As the aforementioned solution was failing to meet the project deadline, an alternative solution was studied: the partial replacement of the compressive layer (3 m in depth) and the lay down of two layers of nano-polymeric geocells. A finite element analysis was carried out, and the results showed that the proposed solution did not cause any issues in terms of deformations and settlement of the walls and track structure. Moreover, besides from distributing evenly the load onto the piles, the geocells increased the safety factor related to the global stability analysis; at the same time, the solution allowed the construction company to meet the project deadline.

Keywords: embankment, railway, geocell, settlement, consolidation

1. INTRODUCTION

1.1 Project location and description

The San Martín Viaduct project is part of the Plan RER (Regional Express Network), whose main objectives are, among others, to improve the connectivity and quality of the public transport service throughout the Metropolitan Region and activate the 100 km network of trains of the City of Buenos Aires, improving its connectivity and doubling its frequency.
This five-kilometer-long section spans over the neighborhoods of Palermo and Paternal. It is entirely composed of an elevated railway viaduct structure, hovering above the existing San Martín railway track, thanks to which 11 level crossings were eliminated.

Figure 1. Project location and railway track.

Part of the new elevated railway tracks is supported by embankments and steel strip reinforced soil walls, up to 6 m high. Figure 2 shows a typical 3D section of the embankment, which has been considered to carry out the settlement analysis and the global stability verification.

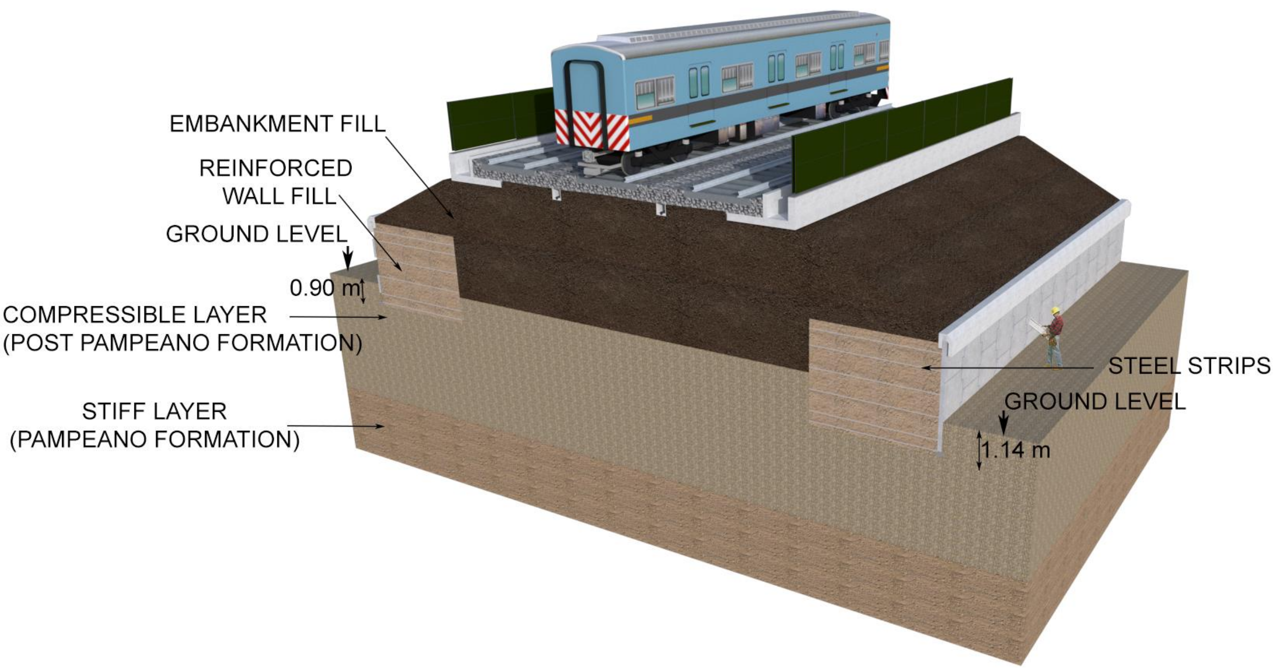


Figure 2. Typical 3D section.

1.2 Embankment foundation

The subsoil consists of a soft clay layer, of which the thickness varies along the embankment between 4,00 m and 6,00 m approximately (Figure 2). In order to overcome the typical problems related to the construction of embankments on soft soils caused by low shear strength, low permeability, high compressibility and high water content, conventional methods have been considered for the construction of the foundation:

- Total replacement of the compressible layer by compacted silty soil fill.
- Partial replacement by controlled density fill trenches, throughout the embankment length.
- Foundation on piles, micropiles, gravel columns, arranged in staggered rows.
- Construction of the embankment in stages, with or without vertical drains

The aforementioned methods were considered to be time consuming, so a different solution was proposed (Alternative 1) and the works started with the construction of a foundation made by controlled density fill (CDF) piles 50 cm in diameter, beneath both reinforced soil walls (Figure 3). The length of the piles varies between 4,00 m and 5,00 m. Two layers of nano-polymeric geocells have been used (one at the pile cut-off level and the other one just beneath the leveling pad of the reinforced soil walls) in order to evenly distribute to the plies the surcharge imposed by the embankment weight and the railway. Additionally, woven geotextiles have been employed to separate the embankment fill from the natural soil.

As the Alternative 1 was also failing to meet the project deadline, another solution (Alternative 2) was studied in order to accelerate the construction process. The proposal consisted in a partial replacement of the compressive layer (3 m in depth), just beneath one of the reinforced soil walls and the lay down of two layers of nano-polymeric geocells, one placed just beneath the reinforced soil walls leveling pad, and the other one placed at the base of the excavation, 3.00 m below the ground level, acting as separator between the embankment fill and the natural soil (see Figure 4). Similarly, in Alternative 2, woven geotextiles have been used to separate the embankment fill from the natural soil.

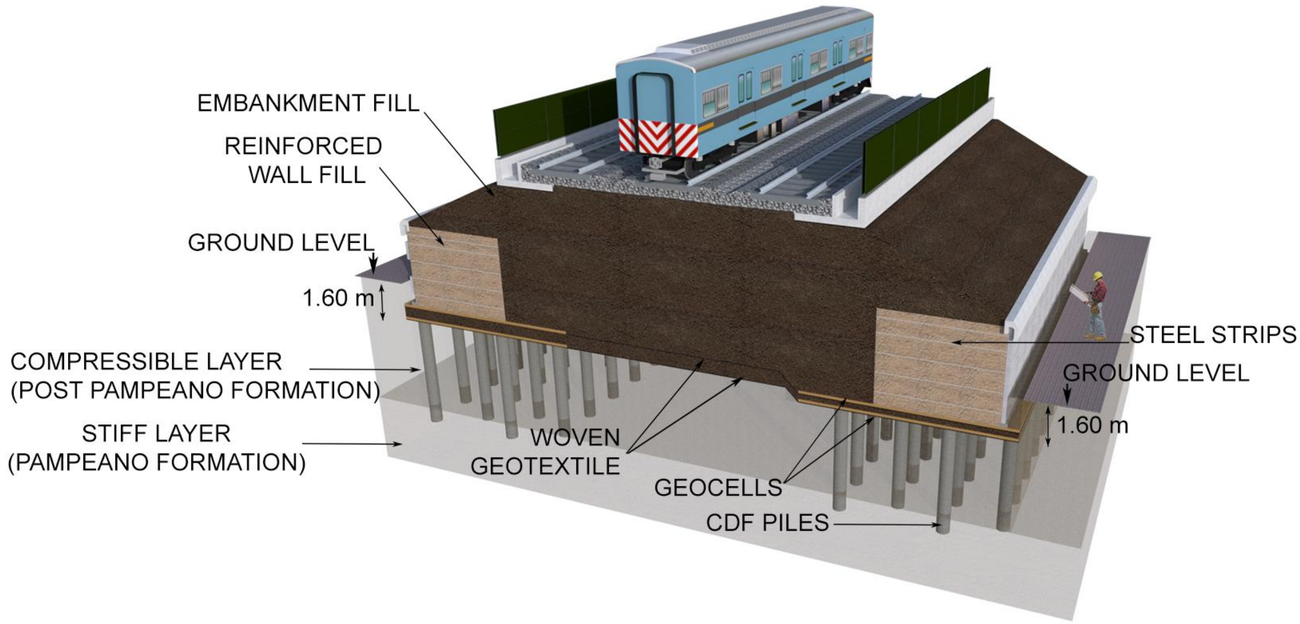


Figure 3. Embankment foundation – Alternative 1.

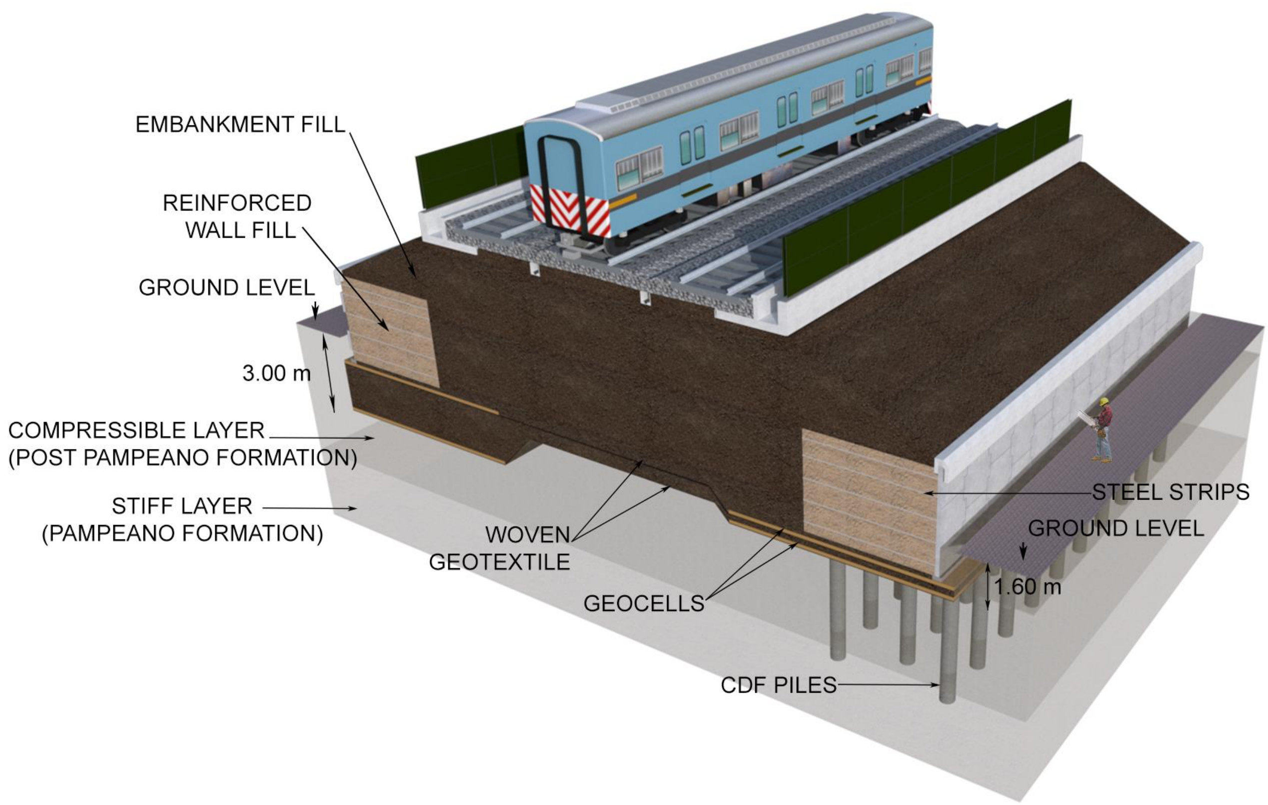
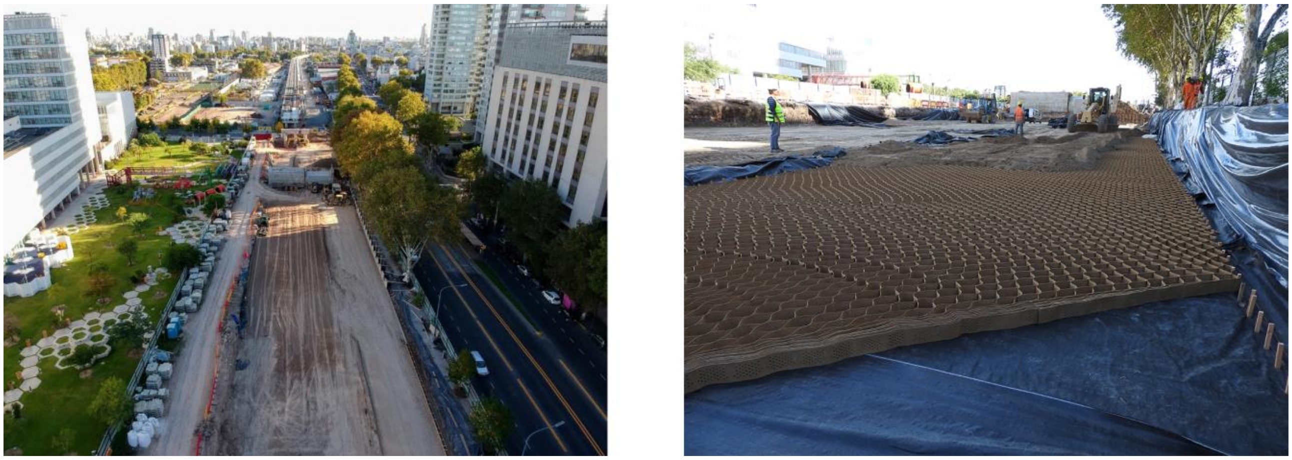


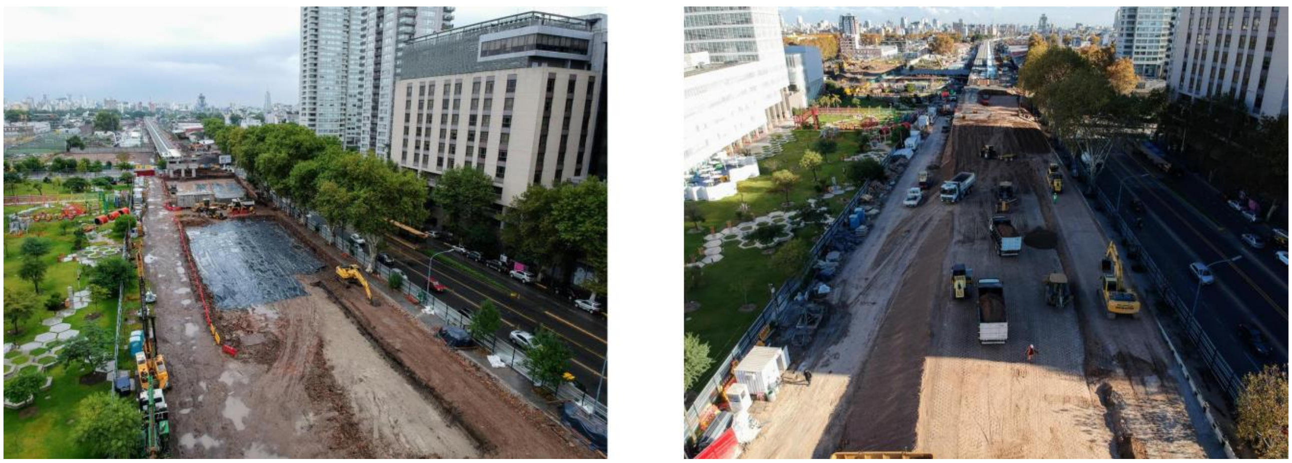
Figure 4. Embankment foundation – Alternative 2.

Figures 5 to 7, show different phases of the construction of the embankment.



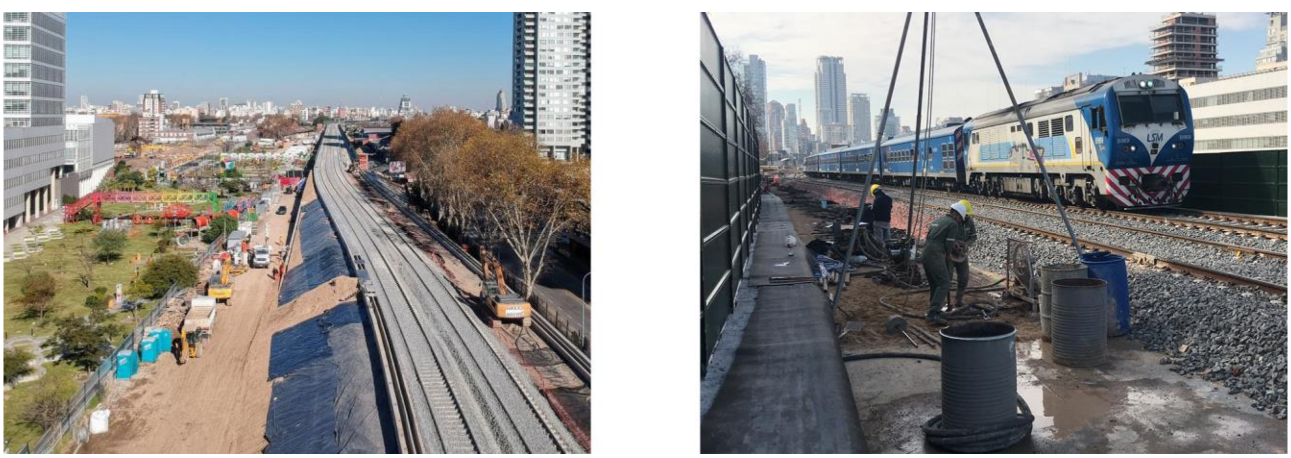
a) Embankment construction area b) Lay down of geotextiles and geocells

Figure 5. Embankment construction process.



a) Foundation construction phase b) Embankment construction Phase

Figure 6. Embankment construction.



a) Track structure lay down b) San Martín train in service

Figure 7. Embankment construction.

2. SUBSOIL PROPERTIES

The subsoil consists of a soft compressible clay layer (Postpampeano Formation), which varies from 4 to 6 m along the embankment, underlayered by stiff and very stiff silts of the Pampeano Formation.
The following design parameters were assumed to represent the behavior of the aforementioned soils and to perform the calculations.

Table 1. Soft clays (Below the ground level and until -6,00 m).

Parameter	Symbol	Value	Unit
Unit weight above the water table	γ_{hum}	17.50-18.00	kN/m³
Unit weight below the water table	γ_{sat}	18.00-18.50	kN/m³
Horizontal permeability	K_h	0.0000864/0.0000432	m/d
Vertical permeability	K_v	0.0000864/0.0000432	m/d
Modulus of elasticity (tangent)	E_0	4500-5000	kN/m²
Oedometric modulus	E_{oed}	9500-10500	kN/m²
Poisson's ratio	ν	0.45 – 0.50	-
Undrained cohesion	c_u	20 - 30	kN/m²
Undrained friction angle	ϕ_u	4 - 6	°
Drained cohesion	c´	0	kN/m²
Drained friction angle	ϕ´	24 - 26	°
Angle of dilatation	ψ	0	°
Interface strength	$R_{interf.}$	0.50	-
Failure ratio	R_f	0.85	-

Table 2. Stiff and very stiff silts (between -6,00 m. and -15,00 m).

Parameter	Symbol	Value	Unit
Unit weight above the water table	γ_{hum}	18,00/18.50	kN/m³
Unit weight below the water table	γ_{sat}	18,50/19,00	kN/m³
Horizontal permeability	K_h	0.00864/0.00432	m/d
Vertical permeability	K_v	0.00864/0.00432	m/d
Modulus of elasticity (tangent)	E_0	8000-10000	kN/m²
Oedometric modulus	E_{oed}	10000 - 12500	kN/m²
Poisson's ratio	ν	0.28 - 0.30	-
Undrained cohesion	c_u	50 - 60	kN/m²
Undrained friction angle	ϕ_u	10 - 12	°
Drained cohesion	c´	15 - 20	kN/m²
Drained friction angle	ϕ´	30 -32	°
Angle of dilatation	ψ	0	°
Interface strength	$R_{interf.}$	0.67	-
Failure ratio	R_f	0.85	-

3. GEOSYNTHETICS PROPERTIES

As mentioned earlier, geosynthetic materials have been employed in the foundations of the embankments, at different positions, either to evenly distribute the surcharge to the piles (geocells) or to separate the natural soil from the embankment fill (geotextiles and geocells). PRS Neoloy® geocells Category-C and Pavco T2400 woven geotextiles have been used.
The geocells which were used are lightweight and flexible three-dimensional expandable panels made of nano-polymeric alloy material strips. The strips are welded together into an extremely strong net-like configuration. Each cell composing this honeycomb structure is 120 mm high and the maximum distance between the welded joints is 330 mm; the maximum tensile strength is 19 kN/m.
On the other hand, the geotextiles that were used are 0,10 cm thick and display a tensile strength in transverse and longitudinal direction respectively of $T_{serv\ t}$ = 6,40 kN/m and $T_{serv\ l}$ = 4,10 kN/m. These values are related to a 2% strain value, at service state.

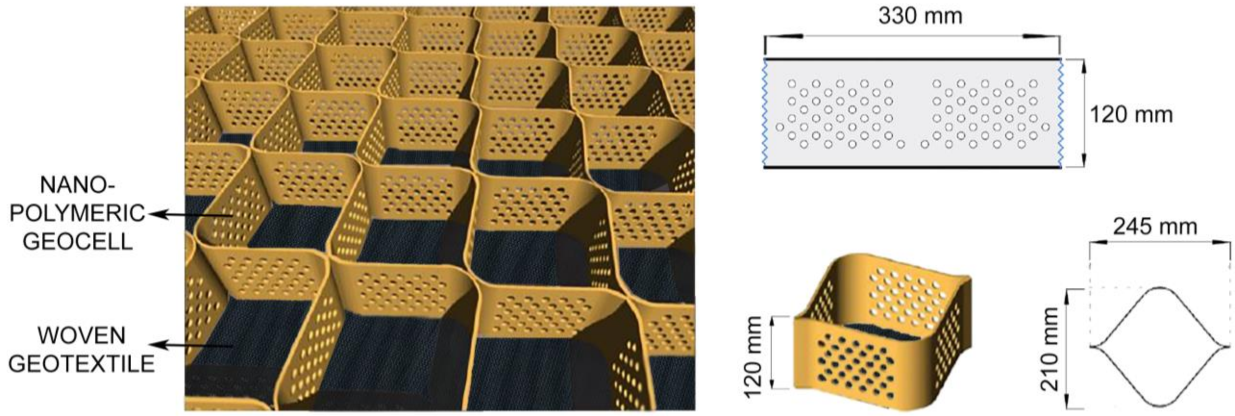


Figure 8. Nano-polymeric geocells and woven geotextiles

4. NUMERICAL ANALYSES

In order to evaluate the elastic settlement of the embankment and of the soil reinforced wall, as well as the safety factor related to the global stability, two numerical analyses were performed, using the commercial three-dimensional finite element software PLAXIS 3D, which takes into account the soil-structure interaction. Furthermore, through an analysis which allows the excess pore water pressure dissipation, consolidation settlements (and the related consolidation time) were calculated. Moreover, stresses on piles and geosynthetics (geocells and geotextiles) were determined. The model geometry is 50 m wide and 10 m long; the embankment is placed in the center of the geometry. According to chapter 2, the subsoil consists of two horizontal layers, and, according to the results of the geotechnical investigations, the water table is set at -4,00 m below the ground level. The Geocells, the geotextiles and the steel strips (of the soil reinforced wall) were modeled using the structural element “geogrid”, while the pile were modeled as an “embedded beam” element. These two models, corresponding to the two alternatives of foundation proposed, are showed in Figure 9 and Figure 10.

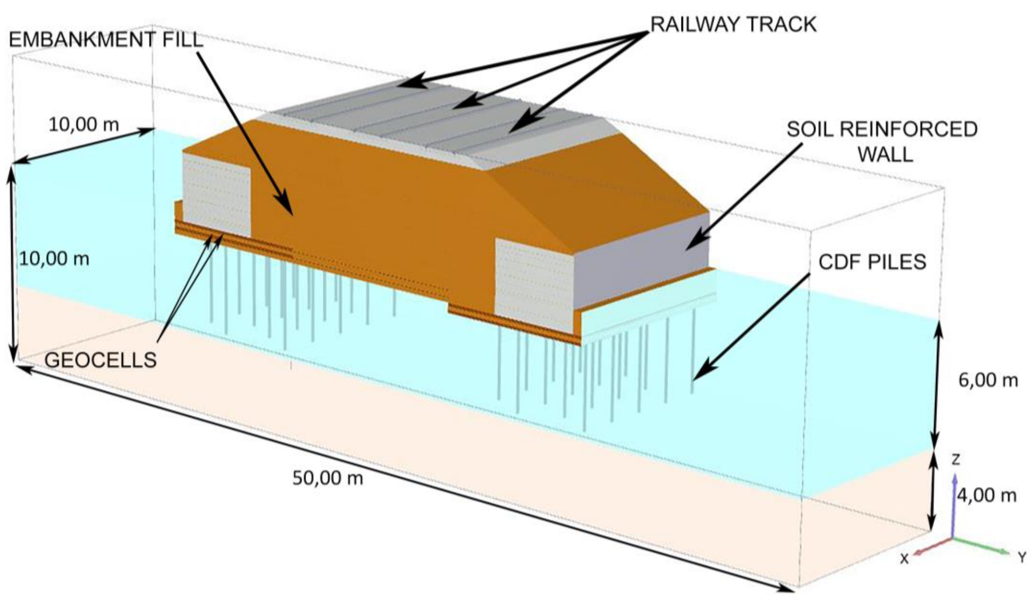


Figure 9. Model corresponding to Alternative 1

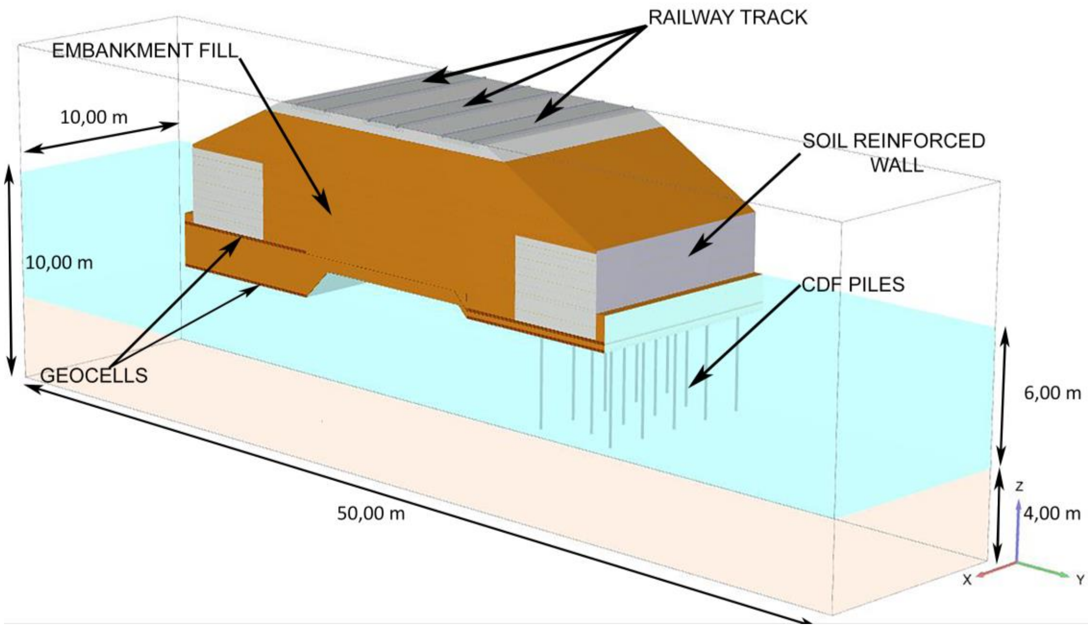
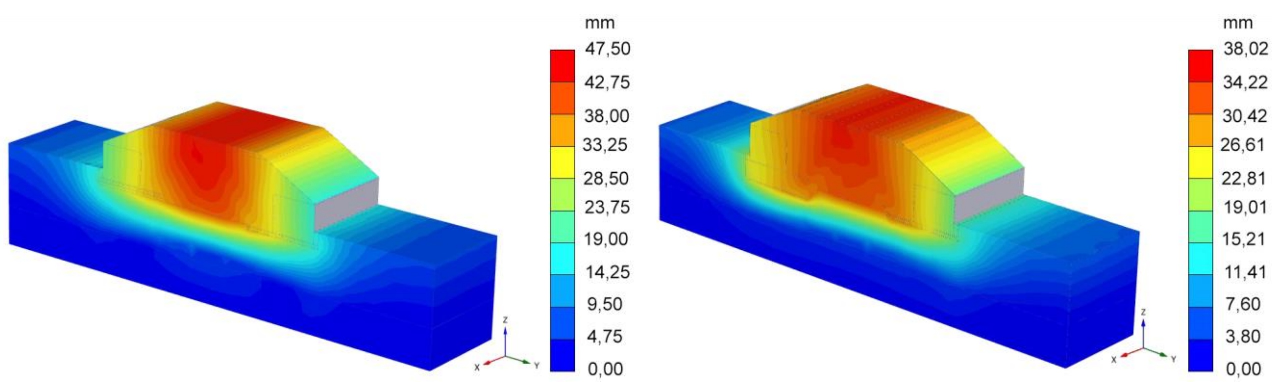


Figure 10. Model corresponding to Alternative 2

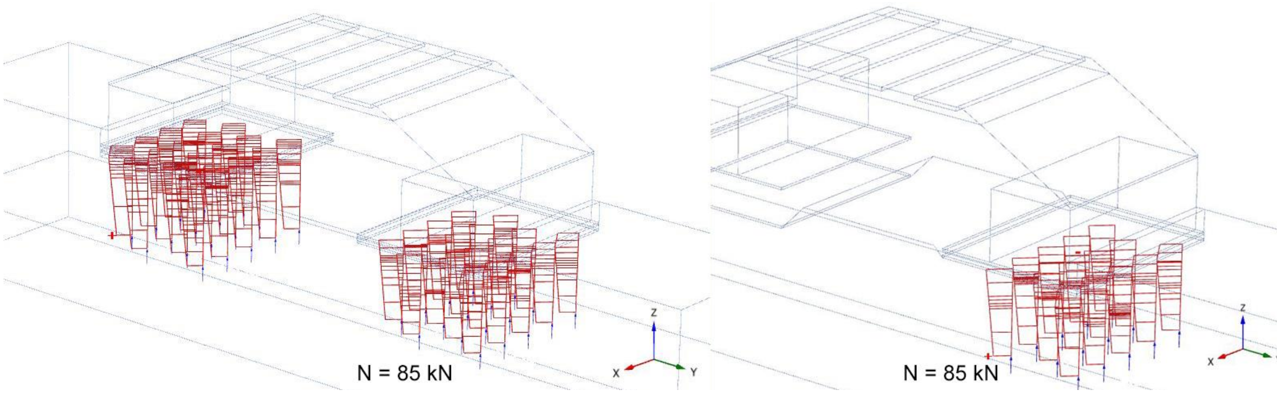
5. ANALYSES RESULTS

The numerical simulations, performed according to Chapter 4, revealed that the consolidation settlement, at the base of the embankment and the soil reinforced wall reaches the maximum values of 2.50-3.00 cm; the railway traffic dynamic load was not considered, as it is, in nature, a fast occurring load that does not generate long term settlements. On the other hand, the differential settlements at the base of the soil reinforced walls do not exceed the value of 0.50 - 1.00 cm; in other words, they are small enough to prevent any damage to the reinforcement elements (steel strips) and to the facing units (precast concrete panels). Moreover, as expected, it can be seen that the overburden stress imposed by the embankment weight and the railway is evenly distributed to the piles, by means of the geocells layers. Finally, it should be noted that the use of geosynthetics has increased the safety factor related to the global stability analysis, besides being employed as a separator between the natural soil and the embankment fill and/or the load transfer platform, without exceeding the limit values of tensile strength and elongation defined in Chapter 4. The safety factor calculation in PLAXIS, consists in successively reducing the shear strength parameters tanφ and c of the soil, until failure of the structure occurs. It should also be noted that the safety factor is higher than 1,65, for both Alternative 1 and Alternative 2. Figure 11 to 15 shows the results in terms of consolidation settlements, axial forces on piles, displacement of the geosynthetics and safety calculation.



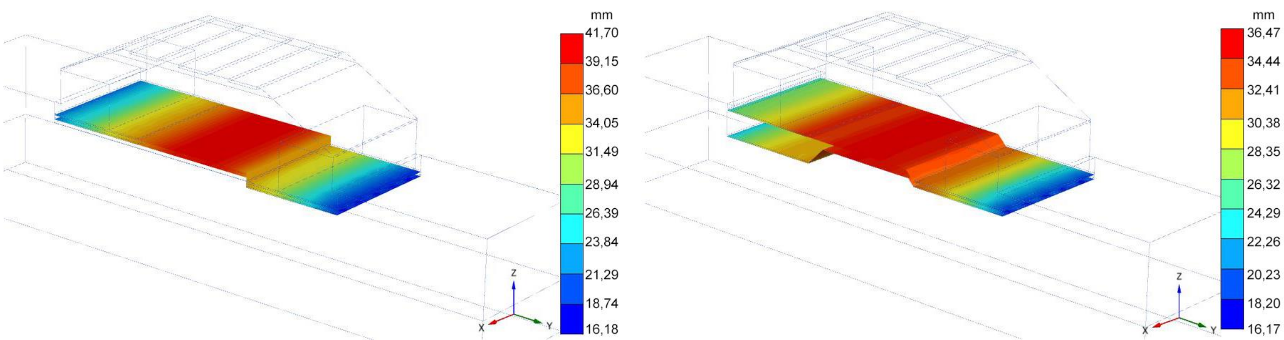
a) Alternative 1 b) Alternative 2

Figure 11. Consolidation settlements



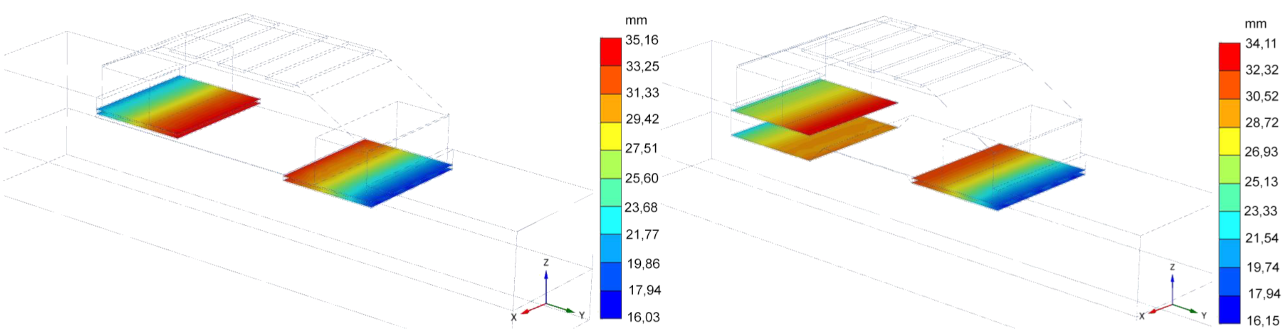
a) Alternative 1 b) Alternative 2

Figure 12. Axial load on piles



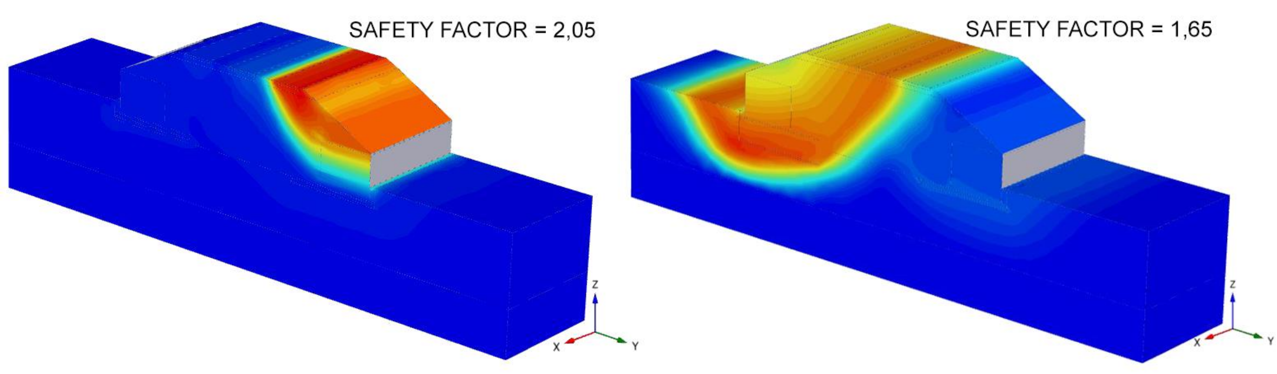
a) Alternative 1 b) Alternative 2

Figure 13. Displacement of geotextiles



a) Alternative 1 b) Alternative 2

Figure 14. Displacement of geocells



a) Alternative 1 b) Alternative 2

Figure 15. Safety Calculation

6. CONCLUSIONS

The use of nano-polymeric geocells as a mean of reinforcement of foundation soils in railway projects has been developing successfully in numerous countries worldwide, and its first applications were carried out in the High Speed Passenger Rail Operations, Amtrak, USA. In the case of the San Martín railway viaduct, the first argentine attempt of nano-polymeric geocells practical application as an element of foundation reinforcement of railway embankments, the elastic deformation in the construction phases and the consolidation of the compressive soft soil layer (a typical geological formation of our region, called Postpampeano) have been controlled successfully. Furthermore, the construction process proved to be efficient, time saving and easy to implement, guaranteeing the proper degree of serviceability required for this particular type of project.

7. REFERENCES

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