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Glassfiber reinforced polymer consolidation for enlargement of a railway underpass in Brandizzo, Italy

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ABSTRACT: The paper describes the enlargement of an existing railway underpass in Brandizzo, Turin, Italy. Variable geometry of consolidation and reinforcement of Glassfiber Reinforced Polymer, with definition of the geotechnical parameters of the soil and the embankment, allowed to perform the complex excavation, with constant verification of design assumptions and operational control of the executive phases. Lateral to the existing underpass on both sides, on the body of the railway embankment, cemented forepoling were performed, defining as a discrete volume of soil improved, like an earth retaining wall. A series of subhorizontal nails made from inside the existing underpass, has represented a tie for the underpass. During jacking phase of new reinforced concrete element, bigger than the existing underpass, demolition has involved at the same time the old underpass, and the excavation of two lateral parts of embankment.

1 INTRODUCTION

The underpass, as part of the work of "Soppressione del passaggio a livello al km 22 + 871 e 23 + 114 of the Turin - Milan railway line", in the municipality of Brandizzo, Turin, Italy, was affected by a widening of the roadway. The existing underpass, with a net section of dimensions 4.00mx3.70m (Figure. 1) has been replaced by a new box-shaped underpass, formed outside the railway embankment, and subsequently driven by jacks under the railway line, with simultaneous demolition of the existing one.

The enlargement of the underpass required the construction of a new box in reinforced concrete (called "monolith") with net internal dimensions B x H = 8.5 x 4.9 m (Figure 1). The realization of the new structure was preliminarily accompanied by the execution of temporary support works for the excavation and the construction of the thrust area of the "monolith".

In order to avoid the interruption of the railway line, the new r.c. building was positioned under the tracks by means of a progressive thrust system, hydraulically applied with a battery of jacks.

The positioning of the "monolith" in its final order took place by means of excavation sequences from the inside of the work, demolition of the portions of the old sub-area, which are included in the new one, and its drive into the ground. At the end of every single advancement in the ground the system has stopped because of two reasons: the first one to reposition the cylinders of the jacks, and the second one to affix the extension elements, between the thrust structure and the jacks themselves, with the aim of creating the thickness sufficient to start a new step of advancement.

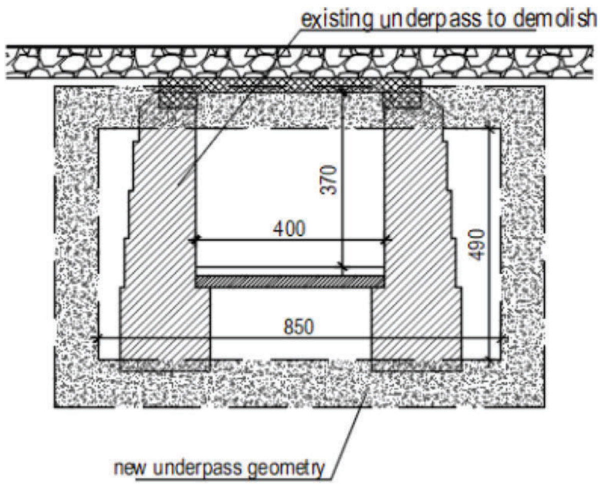

Figure 1. Geometry and dimensions of the existing underpass and of the new project monolith.

The original project based on the tender, contemplated the push of the project “monolith” and the complete demolition of the existing walls of underpass, during the pushing phase, after filling with concrete (with low percentage of cement) the volume of the vacuum constituting the existing underpass. The modification of construction design was necessary in order to adapt the lateral support works for the changes to the relative secondary municipal road network, but above all for the modification of the construction phases, in order to optimize and simplify the execution times of the thrust. The variant consisted in the consolidation of the railway embankment affected by the excavation, on the two sides of the new monolith shape, in addition to the use of horizontal anchors connecting the two portions of the existing underpass and the consolidated soil volumes behind the original walls of underpass.

The advancement of the new “monolith”, for each single step of pushing, was preceded by the demolition of discrete portions of concrete, constituting the underpass to be demolished: portions of masonry/concrete and arched upper structure. Both the lateral consolidation at the embankment and the horizontal lateral anchors, perpendicular to the axis of the manufactured artefact, have been realized through a wide use of tubular elements in GRP, after drilling and casing, and have been cemented with a sequence of injections. Two subhorizontal coring were preliminarily executed to verify the geotechnical characteristics of soil and the railway embankment.

2 GEOLOGICAL, HYDROGEOLOGICAL AND GEOTECHNICAL CONTEXT

The geotechnical characterization of soil was referred to the original tender design documentation. This is stratigraphic and geotechnical information obtained from different series of geognostic surveys, carried out at other sub-areas within the same contract, and located at a certain distance. The underpass in question, except for a depth of about 130cm compared to the current shares, does not affect the ground level at great depth, according to a railway line above ground. This is the reason why, according to the detail design, a stratigraphy and a definition of geotechnical parameters were used, deriving from neighboring works within the same contract, during the “Variante Project”, in order to characterize the natural soil geotechnic and the soil constituting the embankment, two horizontal coring were performed inside it. In general, the geology of the site consists of alluvial deposits characterized by the presence of gravelly-sandy materials, given the proximity to the torrent Malone. On the basis of the available data, the stratigraphic situation of the site has been defined as follows: from ground level and up to a maximum depth of about 12m there is a layer of gravels in a sandy matrix (formation A); from the base of this formation up to the maximum investigated depths there are well

Table 1. Geotechnical design parameters of soil (from Tender).

n.	Desc.	Depth (m)	γs (kN/m^3)	E (MPa)	c' (kPa)	Φ (°)
A	GW	0 - 12	19.0	50	0	34
B	GM	12 – 19.5	20.0	70	0	35

Figure 2. Sub-horizontal coring execution S1 on embankment.

Table 2. Geotechnical parameters of embankment.

n.	Desc.	H emb. (m)	γs (kN/m^3)	E (MPa)	c' (kPa)	Φ (°)
R	GM	4.0	20.0	30	0	34

thickened sand deposits (formation B). The design stratigraphy described below was then defined (Table 1), as derived from the original project based on the contract.

The water table is assumed at the altitude of + 180.50m, about 4 meters from the ground medium level, set at + 184.50. As regards the two sub-horizontal surveys carried out inside the railway embankment, S1 and S2, respectively on the West side shoulder and on the East side shoulder of the existing underpass (Figure 2), the geotechnical parameters used are reported (Table 2). The overall height of the embankment on ground level is about 4 m.

3 THE METHOD OF DRIVEN UNDERPASSES

The construction of railway underpasses represents something extremely complex due to the delicate nature of the intervention context. Over the years the need to realize underpass works at railway lines in operation has grown exponentially, so the need to reduce all types of interference with railway traffic has progressively been highlighted and, at the same time, to reduce time of implementation of the interventions. Important is the effort of the proprietary companies of the railway lines (in this case "Rete Ferroviaria Italiana") in order to modernize the infrastructures, also eliminating level crossings, replacing them with these artefacts.

The works are carried out with modern techniques and are prevalently inserted in strongly urbanized areas, for which special measures are necessary. Since it is easy to understand how the lines to be upgraded are the busiest ones, it is evident that the search for less penalizing solutions for circulation is one of the first working hypotheses of any design. In addition to railway works, a considerable package of interventions to the urban mobility system that should allow the substantial improvement of urban traffic problems is added; there are also many road works in progress that intersect the railway lines, thus making necessary to solve the mutual interference.

In this context, the box-like sections underpass railway lines are inserted, whose main target is the elimination of level crossings and, in general, the improvement of urban traffic conditions. The technique widely used today for the construction and implementation of such structures is that of the "push box", which consists in the construction of an underpass by prefabrication (the entire r.c. underpass called "monolith"), in a special building site on the side of the embankment, and the subsequent placement of this, with hydraulic system, inside the embankment road or rail. During the execution of the work the track is stiffened by a set of beams parallel and connected to each other by crosspieces placed at a limited distance between centers for supporting the rail; this longitudinal stiffening structure rests transversely on steel beams having the function of supporting the whole by sliding on the extrados of the same "monolith" during the launching step. This technique has the following advantages:

- maintenance of the operation of the communication route affected by the underground crossing;
- significant reduction in the support structures of the communication line;
- operational speed;
- minimum site risks;
- installation of the tunnel simultaneously with the construction of the excavation;
- reduction of the environmental impact;
- lower costs than those that characterize traditional executive technology.

The need to guarantee rail traffic, to limit the failure of the infrastructure within very narrow limits, with particular regard to the skew of the rails, to support the side embankment under the tracks and sideways to the axis of the new building, to ensure the impermeability excavation and work during their development are very stringent requirements for designers and contractors.

One of the key elements to solve the problem of supporting the tracks is to adopt an adequate beam system. The Essen system, used here incorporates the concepts underlying the traditional method of rail bundles (stiffening beams in correspondence of the rails and maneuvering beams), and creates a system of constraints able to allow the transit of trains up to 80 km/h. A series of wooden piles, appropriately fixed in the body of the railway embankment, allows the support of the maneuvering beams placed orthogonally to the track. This system supports the Essen bridges, placed longitudinally to the rails throughout the area affected by the thrust works. The maneuvering beams are also constrained to particular beams called "bracing" which balance the frictions during the thrust phase.

The real problem to be solved in the design and execution of an underpass with pushed monoliths, however, is the support of the embankment which is lateral to the monolith itself. From a theoretical point of view, the infixation of the monolith is in close contact with the surrounding ground, with continuous thrust, digging from the front the ground penetrated and protected by the monolith itself, whose front structure is configured with a beak, with inclined spokes.

In reality, due to the sub-roofs made on plain ground, especially under the water table, the intimate connection between side walls and ground to penetrate is rather rare, and the excavation face, especially in the presence of scarcely cohesive soils, tends to collapse inside the monoliths thus involving the ground on the back of the rostrums. Consolidating the ground in which it is necessary to excavate, above all to the side of the rostra, under the rails and for the whole section to be excavated, from the stalls to the arrival of the monolith, is the most complicated challenge. This is because consolidations must be performed from outside the railway line, and often during night hours to eliminate interferences with rail traffic.

Moreover, in the presence of groundwater, these works must guarantee characteristics of absolute impermeability. In general, these are delicate processes, with limited productivity, which can induce lowerings (micropiles) or elevations of the railway tracks (jet-grouting, low pressure injections), which is why these are usually performed with constant topographic monitoring of the tracks.

4 PROJECT DESCRIPTION AND ON SITE ACTIVITIES

The solution proposed to Brandizzo, and then realized, foresees the preventive consolidation of the body of the embankment with threading (nailing) in GRP 60/10mm bars, of variable length from 12 to 17 meters and diameter of perforation equal to 180mm.

The nailing is made sideways to the axis of the future monolith on both sides, along two orthogonal directions, in order to create a grid of reinforcing elements that consolidate the loose material of the embankment.

The first direction is parallel to the axis of the railway line: the nails are made almost horizontal, with the drilling point placed inside the existing underpass, below the railway line; the nails are executed at different heights orders, in numbers of 5/6 nails for each order. They are obviously executed on both sides of the underpass.

The second direction is transversal to the axis of the line; the nails are made from points of perforation which are lateral to the embankment: the rivets are then guided by injection points, two on one side of the embankment and two on the other side, straddling the existing underpass. For each drilling point, 4 nail umbrellas with variable inclination are carried out inside the embankment under the railway line. In this way, a volume of surveyed ground is created, placed immediately behind the walls of the existing underpass. Therefore, there have been no instability phenomena towards the monolith front, nor disturbances to the sediment of the railway line. Some pictures of the intervention are shown in the previous pages. Specifically, Figure 4 shows the view of the heads of the bars in GRP at the exit of the embankment, for the direction of injections orthogonal to the railway axis; it is evident how the nailing point is external to the embankment, therefore without any disturbance for the railway line; the grooves are placed on the back of the wing walls of the existing subbase, thus consolidating the portion of soil which will be subjected to excavation when the monolith is pushed. Figure 5 shows a view from inside the monolith in the pushing phase, with simultaneous

Figure 3. Details of GRP reinforcement during monolith driving.

Figure 4. Demolition of existing underpass during the driving phase of the new one.

Figure 5. The end of the driving phase of the new underpass, and the old one pulled out.

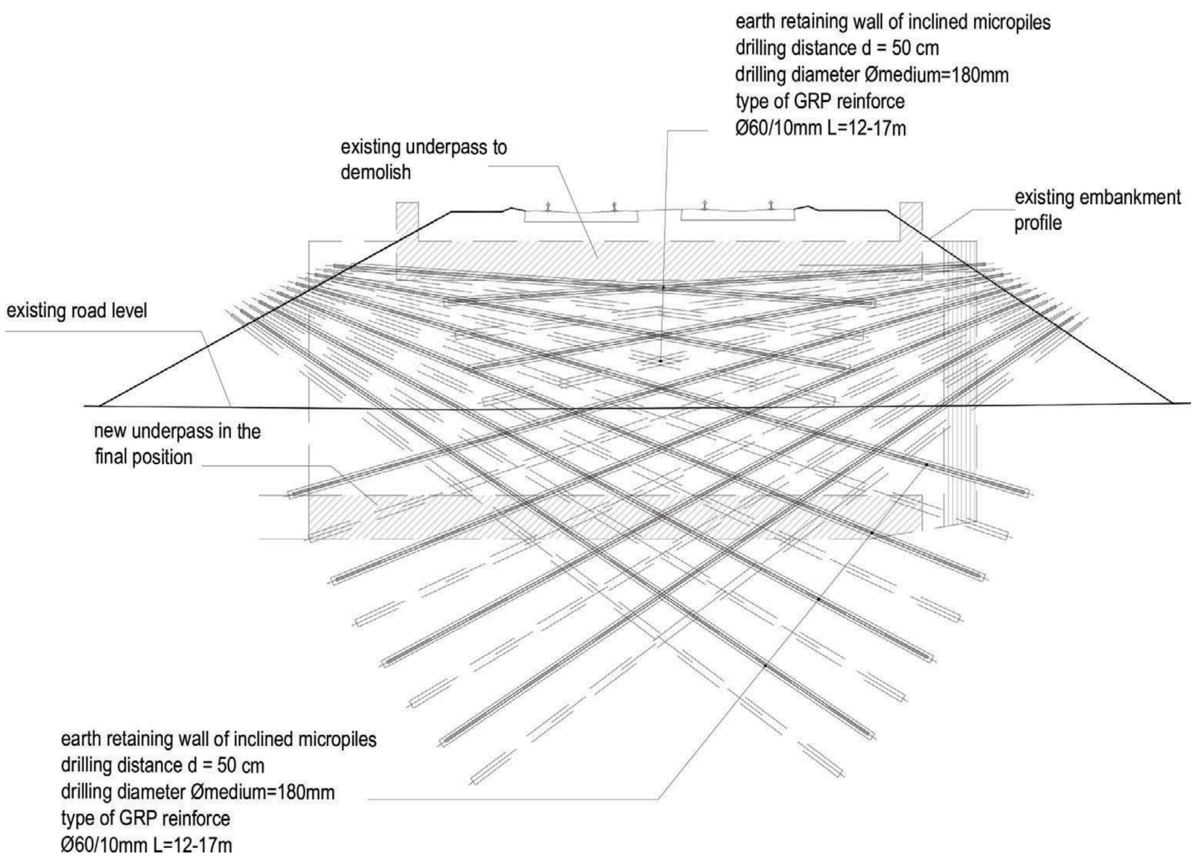

Figure 6. Front view of the GRP consolidation project, parallel to the railway line.

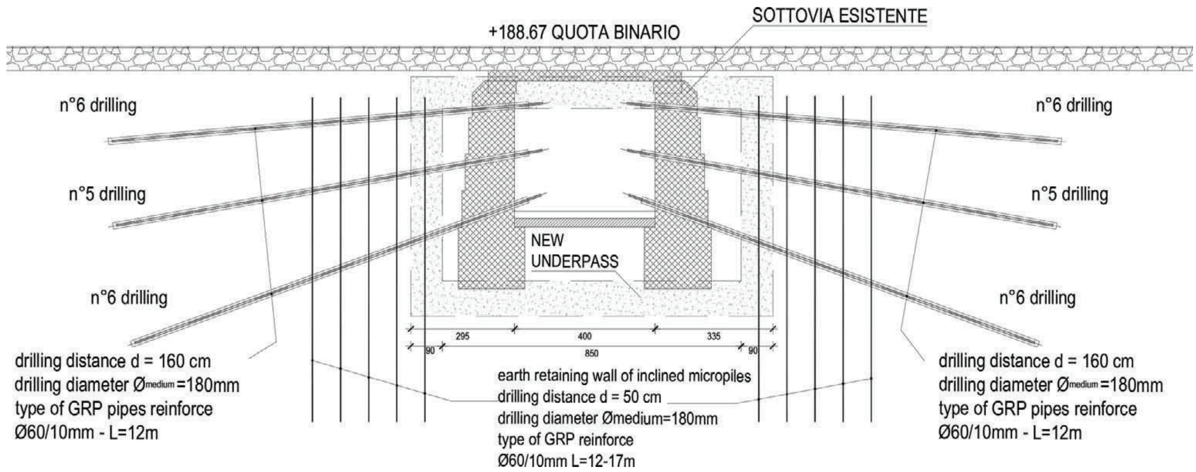

Figure 7. Front view of the GRP consolidation project, perpendicular to the railway line.

demolition of the existing underpass. The ground on the back of the old wall in r. c. is clearly visible, a terrain that presents an almost vertical excavation wall thus avoiding instability of the body of the embankment, which could have an impact on the operation of the above railway line.

5 NUMERICAL ANALYSIS

For the design of the steps work a calculation model was implemented under conditions of plane state, relative to the plane parallel to the railway axis of the embankment. The analyzes were conducted with the PLAXIS 2D calculation code (Brinkgreve and Broere, 2008), schematizing the soil with an elastoplastic model with a hyperbolic hardening (Hardening Soil Model, HSM). The various phases of construction of the building were modeled, starting from the existing initial state: positioning of the Essen bridge, execution of the nailings, progressive thrust of the monolith inside the embankment, removal of the Essen bridge. The excavation of the embankment for the positioning of the new monolith was simulated by decreasing the initial stiffness of the consolidated survey, with descending steps of 20% for each phase, and the simultaneous activation of the clusters relative to the transversal section of the monolith in reinforced concrete, with increasing stiffness steps of 20%, for each phase.

In Table 3 calculation parameters assigned to the land are presented.

For nailing perpendicular to the axis of the embankment, an increase in cohesion and stiffness has been associated with the equivalent soil. In detail, the value of cohesion increase is equal to

$$\Delta c = \frac{\Delta \sigma_3}{2} \cdot \sqrt{K_p} \tag{1}$$

Table 3. Geotechnical parameters used for FEM code PLAXIS.

Desc.	γs (kN/m^3)	E_{50ref} (MPa)	E_{5oedef} (MPa)	E_{urref} (MPa)	c' (kPa)	Φ (°)
R	20.0	30	30	90	0	34
Rcons*	20.0	50	50	150	100	34
A	19.0	50	50	150	0	34
B	20.0	70	70	210	0	35

* Rcons=embankment reinforced with FRP

where $\Delta\sigma_3$ = confinement pressure acting on the excavation front and Kp = $\tan^2(45 + \phi/2)$ = passive earth pressure coefficient. The value of $\Delta\sigma_3$ to be used is the lower value between the yield strength of GRP elements (pipes) and the resistance to lateral skin friction of the injected and cemented pipes.

$$\Delta\sigma_3 = \left(\Delta\sigma\frac{1}{3} = \frac{Avtr \cdot \sigma d}{A}; \Delta\sigma\frac{2}{3} = \frac{\pi \cdot D \cdot L \cdot \tau}{A}\right). \tag{2}$$

where Avtr = fiberglass pipe area, σd = fiberglass pipe design strength (600MPa), A = area of competence of a single pipe, D = diameter of drilling, L = anchorage length, τ = tangential tension of adhesion mortar/soil (50kPa). In terms of safety, cohesion values have been used, equal to 100 kPa, while for the stiffness of the consolidated soil, whose increase is proportional to the area of the fiberglass elements, on the area of competence of each individual nail, a value of E50ref = 50 MPa was chosen. Fiberglass nails parallel to the railway embankment, in the FEM calculation, were considered as linear beam behavior with linear elastic behavior, with the following calculation stiffness values EA = 30 x 103kN/m and EJ = 10 kNm^2/m. A beam-type element was also considered for the Essen track-supporting bridge in the FEM calculation, with linear elastic behavior, with calculation stiffness values EA = 1 x 106kN/m and EJ = 3 x 105kNm^2/m. The following is a view of the geometrical calculation model at the intermediate excavation and final phase (Figures 8-9).

Some views of the results are shown in terms of displacements calculated in the model, in the two phases shown above. The results in terms of displacement were compatible with the work in progress: rail traffic weighed on supporting bridges of the Essen-type platforms, while in addition to being guaranteed the stability of the detections, the movements were limited and confirmed by the continuous topographic monitoring of the trains. These have undergone only and exclusively the movements induced by the passage of the train convoys, however, their load is not directly acting on the survey. Also the displacement value shown in Figure 11,

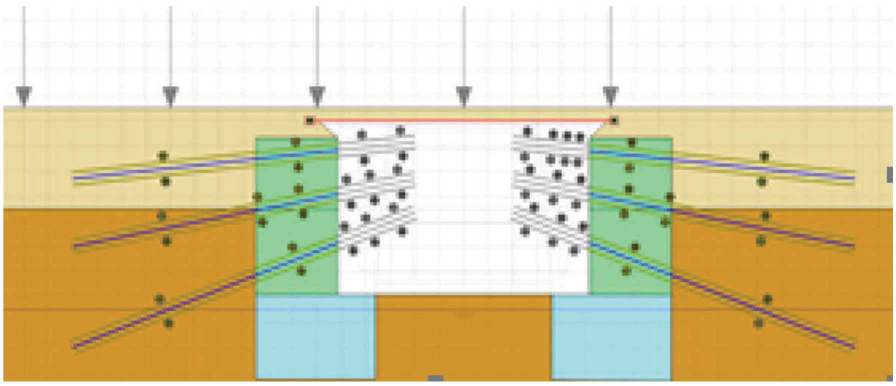

Figure 8. FEM Geometry: excavation and demolition simulation reducing rigidity of excavated elements.

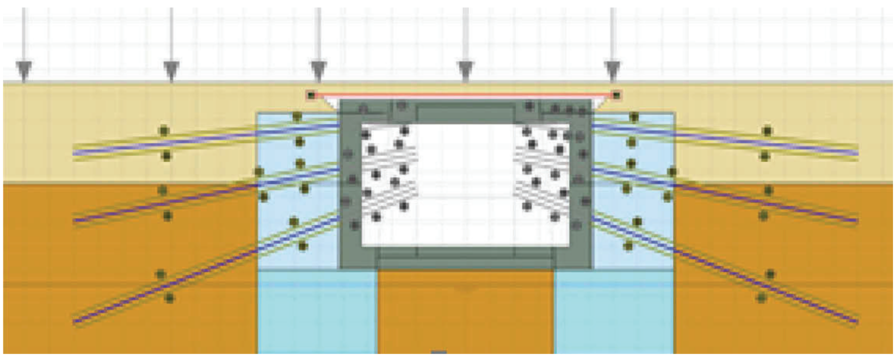

Figure 9. Model FEM: excavation ultimated and underpass driven in a definitive position.

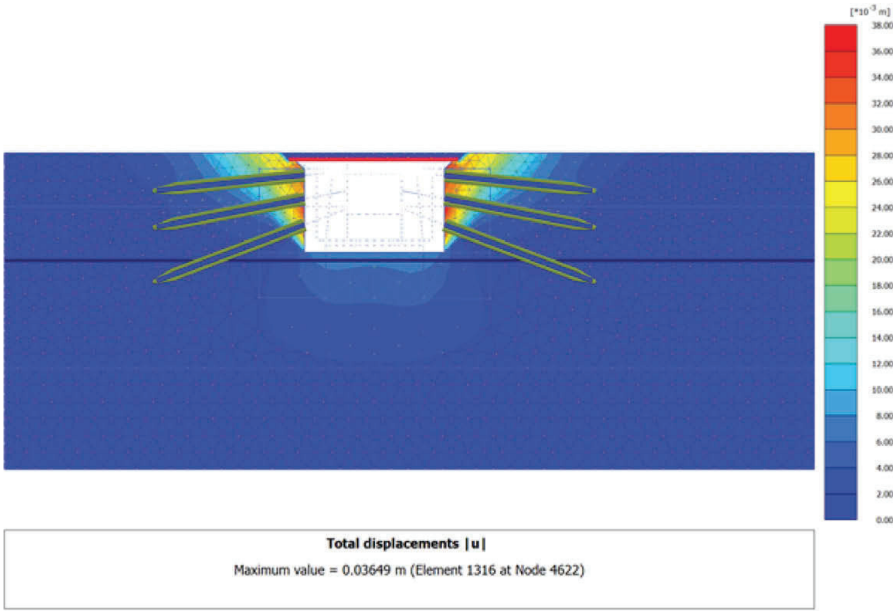

Figure 10. Displacements resulting from the FEM model: excavation and demolition simulation with reduction in rigidity of excavated elements: maximum total displacement 3.7cm.

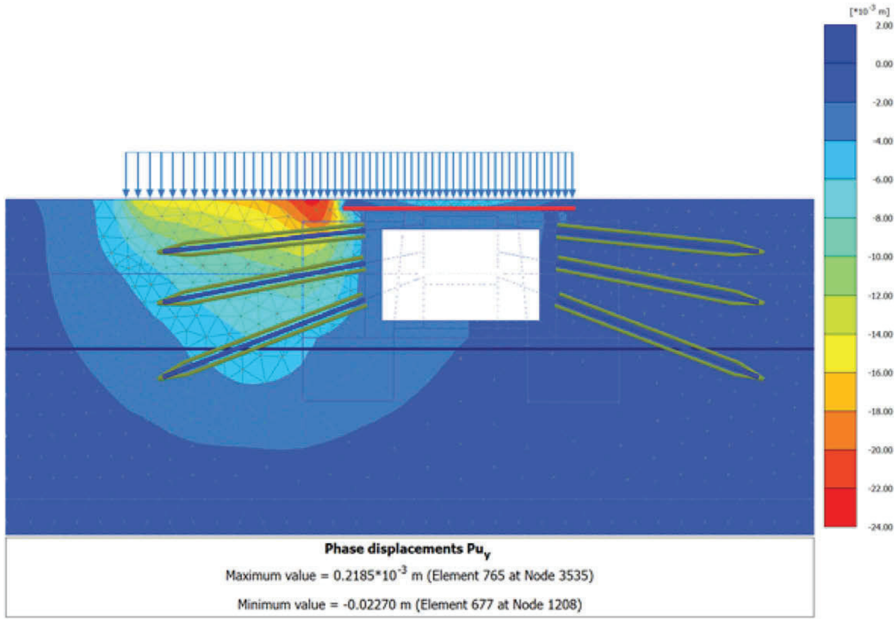

Figure 11. Displacements resulting from the FEM model: excavation occurred and monolith in final position, with railway overhead presence: increase in vertical displacement Puy = 2.3cm.

due to the railway load acting directly on when the work is completed, is compatible with the displacements of the ballast in operation.

6 NEW MATERIAL FOR GRP PIPE: BASALT FIBER

Basalt fiber is a material made from extremely fine fibers of basalt, which is composed of the minerals plagioclase, pyroxene and olivine. It is similar to carbon fiber and fiberglass, having better physic/mechanical properties than fiberglass (Table 4), but being significantly cheaper than carbon fiber (Manuele, Bringiotti, Laganà and Fumagalli, 2019). Basalt fibers are 100%

Table 4. Comparison between basalt rebar and fiber glass rebar.

Properties	Glass Rebar	Basalt Rebar	Unit
Elastic modulus	>30000	>50000	N/mm^2
Elongation at break	>2	>2.5	%
Fiber content	>60	>70	%
Shear strength	>16	>20	Ksi

natural and inert. Tested and proven to be non-carcinogenic and non-toxic and easy to handle. In contrary, fiberglass is made from a mixture of many materials, some of which are not environmentally friendly. Since basalt is the product of volcanic activity, the fiberization process is more environmentally safe than glass fiber process. Basalt continuous filament is a green product, abundant in nature so it can never deplete the supply of basalt rock. This kind of new product, under investigation and test by Maplad Srl, engineered also by Sogen Srl, could really be the material of the future in the field of the composite materials.

7 CONCLUSION

The present paper describes the expansion of an existing railway underpass in Brandizzo, Turin, Italy, on the Turin-Milan historic railway line. The push insertion of the new structure in r.c. ("Monolith"), the demolition of the existing structure, the need to combine the support of the tracks avoiding landslides and collapses for the railway embankment itself, in order not to jeopardize the railway operation, required a careful design of detail, with use of "intelligent" building technologies and sequences. In particular, variable geometries of consolidations and reinforcement in GRP, together with a correct and in-depth knowledge of the geotechnical parameters of the affected terrain, has allowed the delicate interventions to be carried out in safety, with constant verification of the project hypothesis and operational control of the executive phases. On both sides of the existing underpass, on the body of the railway embankment, a succession of VTR insertions were carried out, on perforations then sealed with a cementitious mixture, in form of sub-horizontal micropiles reinforced with VTR pipes. In the body of the embankment this geometry has defined a discrete volume of improved terrain, with supporting wall behavior. A series of nails perpendicular to it, subhorizontal and realized from within the existing sub-line, represented a constraint for them. During the push of the new monolith, having a shape with greater encumbrance compared to the existing underpass, there have been demolition phases of the old structure and demolition phases of part of the consolidated renovation, within which the monolith has found space. The close collaboration between the Works Management, with a daily presence on site, and the Company's Designers, in constant contact with each other, was fundamental for verifying the goodness of the project hypotheses and the on-site compliance of what was previously planned, as well as to solve every single unexpected or contingent problem.

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