VOL. 15, NO. 18, SEPTEMBER 2020 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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TECHNICAL FEASIBILITY OF EARTH RETAINING SYSTEMS BUILT FROM STEEL PIPESINJECTED WITH GROUT

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ABSTRACT

The construction systems of the retention structures usually used for stabilizing excavations have technical restrictions in areas with the presence of large rock blocks. A similar situation is experienced in projects where the slope of the terrain makes access and location of large mechanical equipment difficult. Therefore, the most widely used system in the construction of these structures is restricted to manual excavation methods. Such methods, in addition to being expensive, require long execution times and considerable uncertainty within the construction schedule. Based on the construction limitations presented by traditional earth retaining systems (RS), this research proposes to carry out a technical evaluation of an alternative retaining system. This alternative consists of a wall constructed from steel pipes injected with grout and strutted with prestressed anchors (RS-2). For this evaluation, it is proposed to elaborate a numerical modeling of the RS-2 for different vertical separations between elements, and to compare these results with the behavior registered in the field during the construction of a typical earth retaining system in the Valle de Aburrá (Medellín, Colombia); where a reinforced concrete wall strutted with active anchors (RS-1) was employed. This research establishes the technical feasibility of a retaining system built from steel pipes as an alternative earth retaining system. Its feasibility was sustained after verifying that the safety factor found for RS-2 retaining systems was greater than the required safety factor; in addition, the RS-2 retaining system presented deformations similar to those registered in the field, during the construction of a traditional retaining systemRS-1.

Keywords: earth retaining structure, injected pipes, numerical modeling.

1. INTRODUCTION

Due to the continuous urban development in the metropolitan area of Valle de Aburrá (Medellín, Colombia); most of the areas with low slopes are urbanized. This phenomenon has generated a growth towards the slopes of the valley in search of new spaces, and with this, the use of earth retaining systems has become a common practice to guarantee the stability of structures adjacent to engineering projects [1]

The construction systems used in stabilizing the excavations for expansion areas of the Valle de Aburrá usually present construction restrictions due to the presence of large rock clasts, or to zones with a high slope that limit the use of large drilling equipment. Contemplating these limitations, this research raised the possibility of adapting a pre-support system used in tunnel construction, as anearth retaining system for horizontal thrust conditions.

The proposed pre-support method is made up of steel pipes injected with grout ("forepoling"). This system is used in the conventional construction of tunnels to cross areas of highly fractured rock or soils; and avoid detachment into the excavation [2, 3]. This methodology provides a substantial increase in safety, and given the good results obtained, its use has become widespread in recent years [4, 5].

This system has great advantages such as the maneuverability of the equipment necessary for its implementation, since these have such dimensions that they are easy to access and locate. Furthermore, this system is highly adaptable to the real conditions found in the subsoil. The forepoling has been developed in a pseudo-horizontal way and thus, given the good results obtained, this research proposes evaluating the technical feasibility of retaining systems built from steel pipes injected with grout, as an alternative to traditional earth retaining systems [3, 6, 7]. To fulfill this purpose, a comparison was made between the deformations registered in the field by a retaining system, consisting of a reinforced concrete wall with prestressed anchors (RS-1); and the deformations generated from a numerical model that contemplates a system of injected steel pipes with grout installed vertically with prestressed anchors (RS-2).

2. MATERIALS AND METHODS

To carry out this investigation, it was necessary to generate a numerical model and perform its calibration, with the help of information recorded during the construction of a RS-1 earth retaining system, typically used in hillside areas in the city of Medellín. The calibration of the model was carried out comparing the deformations registered during the construction of a RS-1 retaining system, and those obtained in the finite element method (FEM). The modeling of both structures (RS-1 and RS-2) was carried out by means of a 2D plane deformation analysis using the Phase2 software. This type of analysis was adopted for the critical section of the wall (greater height), since the length of the containment system (L) islarge enough to prevent the ends of the retaining system from having an impact on the registered deformations [8].

VOL. 15, NO. 18, SEPTEMBER 2020 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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2.1 Characteristics and Requirements of the Project

The project selected for the calibration of the numerical model corresponds to a typical earth retaining structure used on the slopes of the Valle de Aburrá (Medellín, Colombia). This structure corresponds to a 21 MPa concrete wall with a thickness of 0.3 m, and reinforced by eight (8) rows of active anchors of different lengths [9] (see Figure-1 and Table-1).

Table-1. Parameters of the RS-1 earth retaining system in the referenced project.

Max. high (m)	**20,3**	
Concrete compressive strength (MPa)	**21,0**	
Anchor length (m)	Rows 1 y 2	30,0
	Rows 3 y 4	30,0
	Rows 5	25,0
	Rows 6, 7 y 8	15,0
Bulb length (m)	Rows 1 y 2	20,0
	Rows 3 y 4	15,0
	Rows 5	12,5
	Rows 6, 7 y 8	10,0
Tilt angle on horizontal (◦)	-15,0	
Drilling diameter(mm)	101,6 - 4,0’’	
Anchoring diameter(mm)	51	
Allowable anchor strength (kN)	660,0	
Young's module (GPa)	200	
Pretensioning (kN)	Rows 1 y 2	400
	Rows 3 y 4	400
	Row 5	300
	Rows 6, 7 y 8	300
Vertical separation (m)	1,5	
Horizontal separation (m)	2,0	

Figure-1. Earth retaining system in the reference project RS-1.

2.2 Geological Characterization of the Subsoil

The excavation area is made up of aflow of sludge and rubble (Qfl), with an approximate thickness of 15 m. This material is made up of heterometric rock blocks, with variability in their weathering state, embedded in a soil matrix with a saprolite structure. Underlying the flow, amphibolite (IC) saprolite-like material was found, consisting of a dense clayey silt matrix, characterized by the preservation of the parental structure and its low oxidation (see Figure-2) [9].

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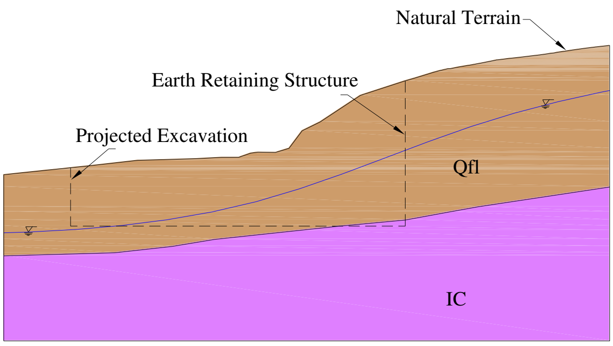

Figure-2. Predominant geological profile.

2.3 Calibration and Validation of the Numerical Model

To carry out the calibration of the numerical model, it was necessary to define the resistance and stiffness parameters, which represent the behavior of each of the soil strata. The geotechnical parameters entered into the numerical model were taken according to the results of laboratory resistance to shear tests during the field explorations; and for the calibration of the model, it was necessary to compare the deformations recorded in the field using inclinometers and those obtained in the numerical model (see Figure-3) [10]. During the comparison of deformations registered in the field vs. the deformations provided by the model, four stages were considered within the construction process of the earth retaining system. The stages considered in the analysis process are observed in Table-2, and the parameters that represent the behavior of the analyzed geotechnical profile are shown in Table-3.

Table-2. Stages of analysis in the construction process.

Stage	Construction activity
Stage 1	Installation of plates and pretensioning of the third anchorage level
Stage 2	Excavation up to 0.75 m below the level of the sixth anchorage level
Stage 3	Installation of plates and pretensioning of the seventh level of anchorage
Stage 4	Installation of plates and pretensioning of the eighth level of anchorage

Table-3. Stages of analysis in the construction process.

Material	Unit weight (kN/m3)	C (kPa)	ϕ (°)	Elasticity module (kPa)	Poisson ratio
Flow of sludge and rubble	20	19,5	25	33.000	0,35
Amphibolite saprolite	22	32,0	35	850.000	0,25

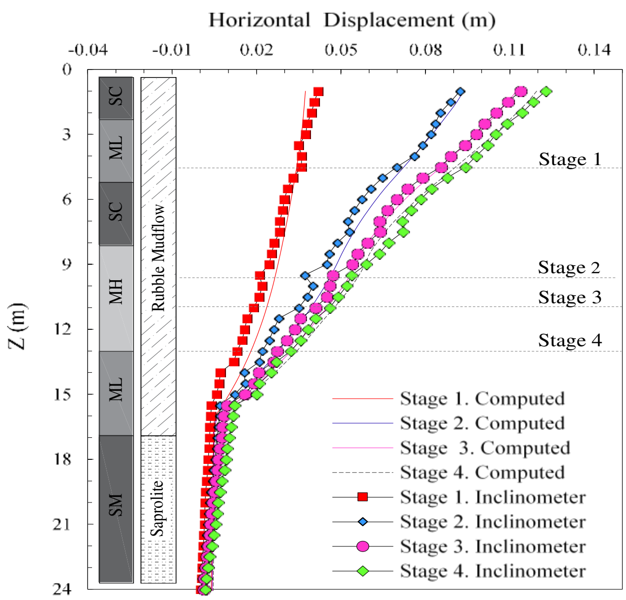

Figure-3. Superposition of deformations calculated from the calibrated numerical model and deformations registered in the field by the RS-1 system.

2.4 Characteristics and FEM Modeling of the Proposed Earth Retaining System

During the modeling of the RS-2 retaining system, a 5” diameter Schedule 40 steel pipe was used. This type of pipe is commonly used in the forepoling pre-support system implemented in tunnels. The technical specifications of the type of pipe selected can be seen in Table-4.

Table-4. Technical specifications of the type of pipe selected.

Description	Schedule 40–5”
External diameter (mm)	141
Internal diameter (mm)	128
Nominal thickness (mm)	6,6
External cross-sectional area (mm^2)	15677
Internal cross-sectional area (mm^2)	12903
Steel area (mm^2)	2774
Weight (kg/m)	21,74

VOL. 15, NO. 18, SEPTEMBER 2020 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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For the construction of the numerical model, the stiffness provided by the section composed of steel tube and grout was considered. In this way, the stiffness and resistance parameters of the vertical elements were estimated. The specifications of the composite section can be seen in Table-5, and the section of the element is presented in Figure-4.

Table-5. Technical specifications of composite cross section.

Description	TI_SC40-5”
Diameter (m)	0,2
Area (m^2)	0,031
Weight (kg/m)	90,48
Moment of inertia (x106 mm^4)	78,54
Young'smodule (GPa)	35,89
Poisson’s module	0,21
Compressive strength (kPa)	49.465
Tensile strength (kPa)	45.900
Axis separation between elements	1D

TI: Grout Injected Steel Pipe; SC: Schedule type

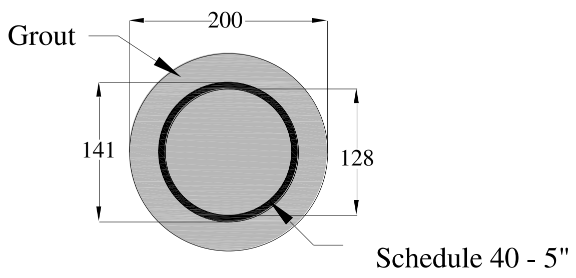

Figure-4. Cross section composed of steel pipes and grout.

3. RESULTS AND DISCUSSIONS

3.1 Moment and Shear Capacity Analysis of Vertical Elements in the Retaining structurers-2

To verify the viability of the RS-2 earth retaining system, it was necessary to perform an analysis of the safety factor in terms of capacity at moment and shear of the vertical elements that make up the retaining structure. The analysis of the safety factor was proposed for elements that are separated at different distances between vertical axes, the analyzed separations were 20cm (S=1D), 30cm (S=1.5D) and 40cm (S=2D) (see Figure-5).

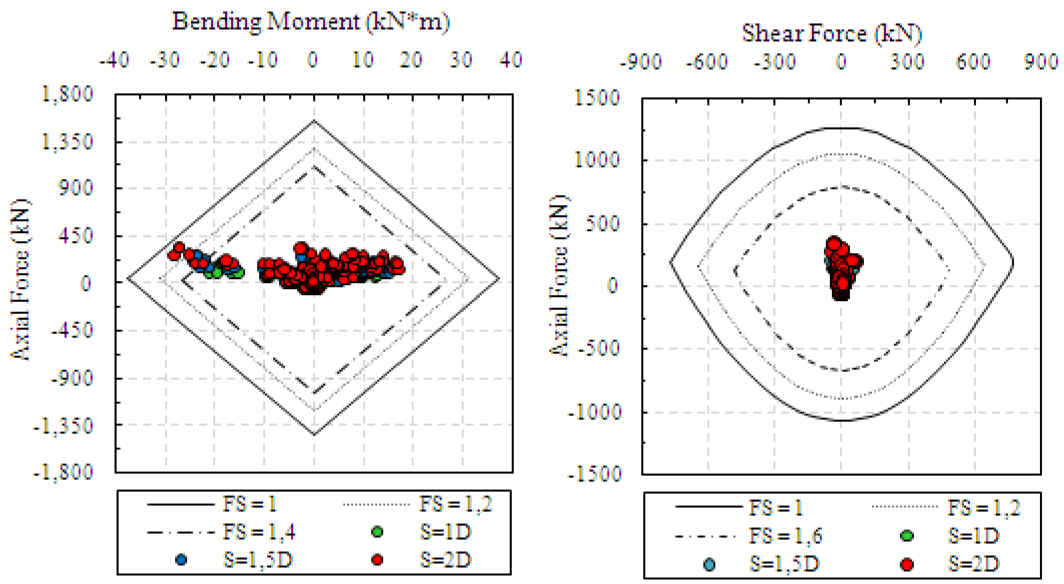

Figure-5. Moment and shear capacity of the vertical elements that make up the RS-2 type earth retaining structures for 5” (S40-5”) Schedule 40 steel tubes.

By comparing the safety factor of the proposed RS-2 retaining structure for different separations with the required safety factor (FS = 1.2), it can be concluded that the retaining structures built from Schedule 40 type steel pipes 5”, with spacings less than 1.5 diameters from center to center (S<1.5D) are technically feasible for the referenced case. For these structures, the safety factor is higher than the required safety factor.

3.2 Allowable Lateral Movements

To validate the behavior of the RS-2 earth retaining system in terms of allowable deformations, the lateral displacement in stage 4 of the RS-2 retaining system was compared for a separation between elements of 30 cm (S=1.5D) (Condition unfavorable, which complies with the required FS), with the field deformations registered of the retaining system (RS-1). Figure-6 shows the estimated lateral movements of the

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retaining structure built from 5” Schedule 40 steel tubes with a 30 cm (S=1.5D) separation between elements.

Based on Figure-6, it is clearly evidenced that the lateral movements estimated using the numerical model of the RS-2 type earth retaining system are significantly less than those presented by the RS-1 type retaining structure for a separation of 30cm (S=1.5D).

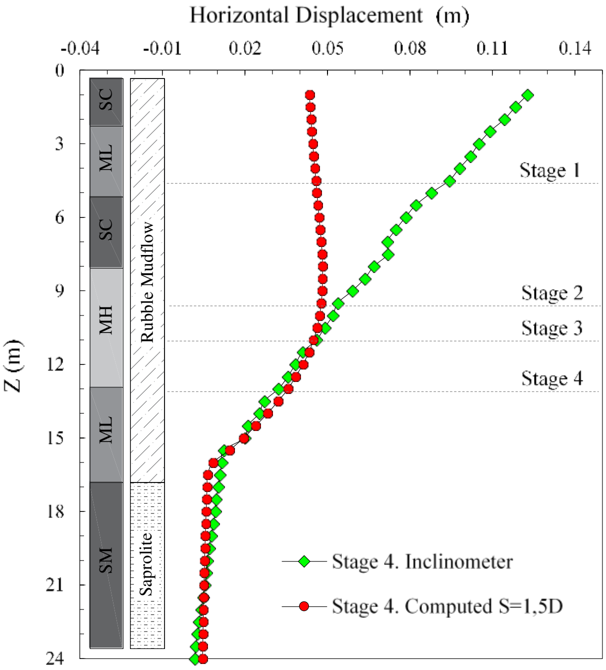

Figure-6. Lateral movements of the earth retaining structure built from 5” Schedule 40 steel tubes. 30cm separation (S=1,5D) between elements.

CONCLUSIONS

The earth retaining system constructed from grout-injected steel pipes and strutted with prestressed anchors (RS-2) is technically feasible as an alternative in the construction of retaining structures. Its feasibility was sustained after verifying that the safety factor is higher than the required. In addition, the RS-2 alternative retaining system presented deformations similar to those registered in the field during the construction of the traditional RS-1 retaining system.

Due to the low rigidity of individual 5” Schedule 40 elements, the critical condition of RS-2 type retaining systems is the moment capacity. To guarantee the minimum safety factor required for such condition, the earth retaining system must be constructed using elements with a separation equal to or less than 30 cm (S=1.5D).

The shear capacity of the RS-2 type earth retaining system complies with the required safety factor (FS=1.2) when using individual 5” Schedule 40 type elements with separations from 1D to 2D.

The horizontal deformations found for the RS-2 earth retaining system are less than those registered by the traditional RS-1 retaining system. This happens due to the individual elements of the RS-2 retaining system have a level of embedment that allows the control of deformations in each of the stages of the excavation.

The construction of RS-2 type earth retaining structures has great advantages due to its adaptability to soils with large rock blocks, and that the equipment necessary for its implementation has such dimensions that they are easily accessible and located.

ACKNOWLEDGEMENTS

The authors thank Surcolombiana University, National University of Colombia and EAFIT University for their collaboration during the development of this study.

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VOL. 15, NO. 18, SEPTEMBER 2020 ISSN 1819-6608
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