Foundation Design Alternatives for Residential Building Near Natural Slope

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Abstract. This study presents the global stability analysis of the slope developed in the design phase of the foundation of a 12-level building of the ALZATI Apartments project, allowing to select the alternative of foundation that presented the best structural behavior and the best distribution of stresses to the land without putting in risk the natural slope contiguous to the project, which will support the loads of the building and parking area. The evaluated alternatives correspond to independent foundations to isolate the stresses from the 210 kN/m^2 towers area of the slope, leaving only the stresses from the 10 KN/m2 parking area on it (option 1), or a single foundation slab for each tower and parking area with a uniformly distributed stress throughout the foundation slab in both the tower and parking area of 54 KN/m^2 (option 2). It is concluded that although option 2 represents 5 times more loads on the natural slope than option 1, option 2 is also safe, it meets the minimum slope stability factors suggested by the Colombian Seismic Resistant Standard (NSR-2010) and generates greater technical benefits for the project.

Keywords: slope · foundation · stability

1 Introduction

In the preliminary geotechnical study of the ALZATI Apartments project [1], the total and maximum differential settlements with shallow footings for apartment towers were estimated at 12,9 mm and 5,4 mm, respectively, complying with the maximum total settlement of 150 mm[1], but not with the maximum differential settlement of 4 mm[2].

According to the above, the preliminary design is modified, deepen 3.5 m the foundation slabs of the buildings by building a level of basements, reducing differential settlement to 2 mm.

Additionally, to improve the behavior of the structure against earthquakes, the structural engineer recommended that the foundation slab should cover the area of the building

[1] NSR-2010 numeral H.4.9.2 - TOTAL SETTLEMENT LIMITS, literal b.
[2] Estimated for a light between supports of 4 m, according to the NSR-2010 numeral H.4.9.3 - LIMITS OF DIFFERENTIAL SETTLEMENTS,

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and its surrounding areas, roads and visitor parking, transferring the stresses of tower 2 and other elements to the natural slope area, a condition that would affect the overall stability of the project.

As a result of the new condition of loads, levels, and the extension of the tower 2 foundation at the crown of the slope, a more detailed geotechnical analysis is carried out on it, proceeding to the in-situ location of the new design of the foundation slab to verify the most critical design profile, the exploration of the subsoil is complemented and simulations are carried out to verify the stability condition of the slope.

Verification of the stability condition of the slope adjacent to tower 2 was ensured in the design phase and is described below in the present study.

2 Project Description

2.1 General

The residential project called ALZATI Apartments is located in the east of Neiva and consists of building 2 towers of 11 floors, designed for a total of 154 apartments, a basement for residents' parking, social areas and visitor parking.

The exploration of the subsoil consisted of borings carried out with mechanical percussion and rotation equipment with washing, with recovery of samples and performing the Standard Penetration Tests (SPT), taken for this study as the main direct measure of on-site shear resistance and determination of geotechnical parameters by correlations for the estimates of bearing capacity, settlements and acting and resistant forces of the soil under study.

Figure 1 shows the masterplan, identifying the location of tower 2, parking area, borings which was performed subsurface exploration program and the natural slope.

The topography where the towers will be located corresponds to a flat terrain with slope less than 5%, however, towards the parking area the slope begins to increase until the end of the terrace, which has a slope of 56%. Figure 2 shows identifying the area of towers and natural slope.

2.2 Geotechnical Exploration, Geology and Stratigraphic Profile

The substrate of foundation of the project belongs to the aluvio-torrential formed of sand-sized sediments, typically loamy to clay, grey, with yellow and reddish veins because of the weathering of the clayey minerals of its fine matrix.

According to Colombian Resistant Seismic Standard (NSR-2010), the building unit category and seismic hazard are high [2].

The exploration of the subsoil for the ALZATI Apartments project was made through perforations with mechanical percussion and rotation equipment with washing, the Standard Penetration Tests (SPT) were carried out to determine the bearing capacity.

Table 1 lists the number of blows to penetrate 12 inches in the development of the standard penetration test (SPT) in borings. Cells with value (-) in Table 1 corresponds to rejection during penetration of the SPT, between 11 and 25 m depth was rejected.

After analyzing the altered samples recovered from of tower 2, slope and related areas, concludes that there are mainly layers of clayey or silty sand between loose to very

Fig. 1. Masterplan, identifying the location of the tower 2, borings, parking, and natural slope.

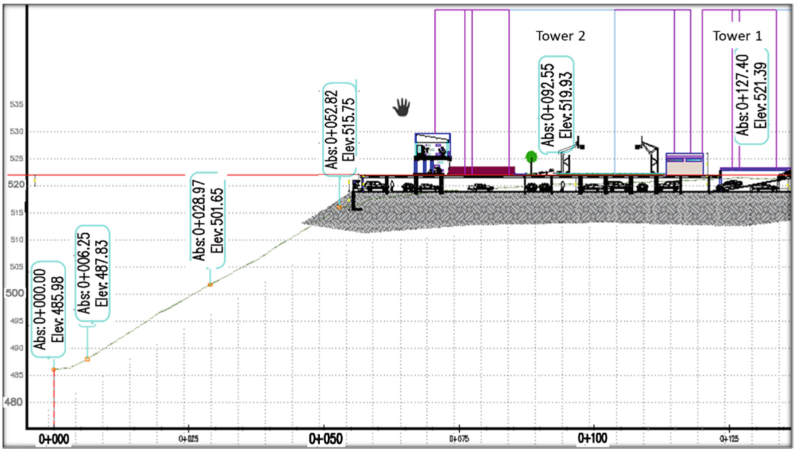

Fig. 2. Topographic and architectural profile of the project.

dense, reddish in color with isolated gravel, and low-compressibility clay of consistency very firm, or intercalations of these in the 25 m of exploration.

No water table was found during the geotechnical exploration.

The geotechnical soils strength parameters internal friction angle and cohesion (c´ y φ´) are estimated according to the results of the cut resistance test - direct cut method - consolidated drained according to Colombian standard of the national institute of roads INV E-154, with soil samples extracted in complementary exploration for slope stability analysis, shown in Table 2:

Table 1. Number of blows to penetrate 12 inches in the development of the standard penetration test (SPT) in borings

Depth (m)	B1T	B2 T	B3 T	B4 T	B1 P	B2 P	B3P	B4 P	B Slope
0,50	19	17	17	8	10	3	33	13	15
1,00	14	14	14	11	15	11	18	15	15
1,50	21	11	11	9	26	14	36	33	21
2,00	19	22	22	42	24	11	58	42	19
2,50	27	24	24	21	24	24	49	50	27
3,00	38	28	28	26	36	25	57	58	38
3,50	55	33	23	26	24	50	43	45	55
4,00	51	33	23	26	30	46	40	56	53
4,50	55	33	23	26	67	21	29	31	55
5,00	37	33	23	54	62	35	69	73	57
5,50	37	33	23	51	70	57	85	73	37
6,00	27	33	19	51	70	90	85	73	65
7,00	27	19	34	51					70
9,00	27	34	34	51					73
9,50	27	34	66	70					69
10,50	-	-	-	-					72
11,00	-	-	-	-					-
25,00	-	-	-	-					-

Table 2. Lists of direct cutting results on altered samples.

Depth (m)	Cohesion (kN/m2)	Internal friction angle (°)
3	45	36
11	106	45
18	55	55

3 Statement of the Problem

In the preliminary design of the project, the load transferred to the slope crown is 10 kN/m^2, corresponding to the loads imposed by the parking area and the load of Tower 2 with a foundation slab adjusted to the area of the tower of 1,050 m^2 without any impact on the slope, as shown in Fig. 3(a), the perimeter of the foundations represented by the polygons in red, called option 1.

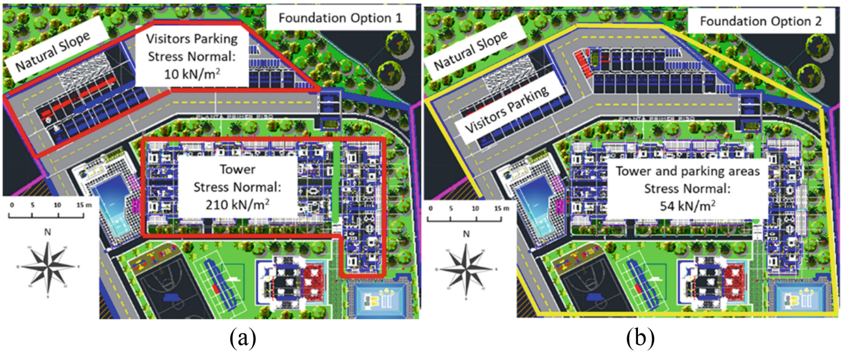

Fig. 3. Project location by google earth average slope magnitude in project areas.

Extending of the foundation slab from 1,050 m^2 to 4,165 m^2: this change consists of making a single foundation slab for Tower 2 and its connected areas such as parking and roads, extending the slab to the limit of the platform at the crown of the slope under study, as shown in the yellow polygon in Fig. 3(b), uniformly distributing the load of these elements estimated at 54 kN/m^2, called option 2.

The new distribution of stresses that would be transferred on the ground with the change in foundation design and considering that the terrace area where the tower would be founded would have fewer stresses, bearing capacity and settlement failure mechanisms would already be secured, making the main challenge from the geotechnical point of view the verification of the stability of the slope, although increased the load on the crown of the slope by 5 times, from 10 kN/m^2 to 54 kN/m^2.

4 Methodology

To determine the stability of the slope, an absolute analysis is performed according to the relationship between the resistant and acting forces. The modeling is carried out in the stability analysis software for the study slope, SLIDE 6.005 from Rocscience®, based on the methods of limit equilibrium, specifically the technique of the doves of Bishop simplified (1956); under the protection of the criterion of resistance of Mohr-Coulomb and consistent with the most likely failure mechanisms.

The stability analysis is performed using the limit equilibrium method for static and pseudo-static slope conditions without the presence of groundwater.

In addition to the above, the stability analysis in pseudo-static condition is sensitized by the simplified Janbu method which considers a different distribution of stresses and deformations in the fault zone than the simplified Bishop method.

The acceleration to consider the possibility of seism and its maximum horizontal acceleration magnitude is Kst/a max = 0.25g[3].

[3] Value Aa assigned to Neiva according to the NSR-2010 Table A.2.3-2 Value of Aa and Av for departmental capital cities.

Table 3. Factors of safety for each simulated slope condition and the minima suggested by the Table H.2.4-1 NSR-2010.

Scenario	Condition	Factor of Safety	NSR-10	Observation
1	Slope option 1 static (Bishop)	1.75	1.5	Complies NSR-10
2	Option 1 Pseudostatic (Bishop)	1.14	1.05	Complies NSR-10
3	Option 1 Pseudostatic (Janbu)	1.07	1.05	Complies NSR-10
4	Option 2 Pseudostatic (Bishop)	1.16	1.05	Complies NSR-10
5	Option 2 Pseudostatic (Janbu)	1.06	1.05	Complies NSR-10

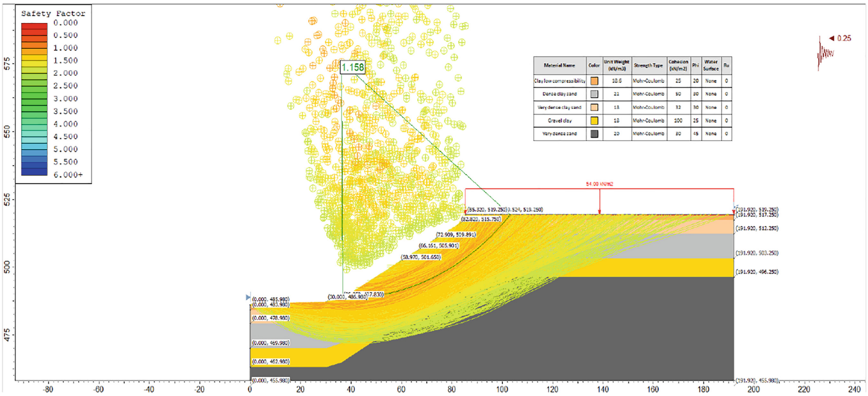

Fig. 4. Stability option 2 slope in pseudostatic condition FS = 1.158, sensitivity FS less than 2.

4.1 Results

The results of the modelling of each slope condition are presented in Table 3 to verify compliance with the minimum factors of safety (FS) suggested by the NSR-10 Table H.2.4-1.

Figure 4 shows the simulation results in the SLIDE 6.005 software for scenario 4, which corresponds to the natural slope of option 2, sensitizing FS less than 2.

5 Conclusions

Expanding the foundation area of Tower 2 to improve the performance of the structure against earthquakes affected the stability of a slope adjacent to the project, increasing 5 times more loads on the slope, however, it was possible to demonstrate that this alternative, called option 2, is also safe and complies with the minimum factors of safety suggested by the (NSR-2010).

References

1. Cuéllar, A.: Geotechnical study project ALZATI Apartments. Neiva (2021).
2. Asociación Colombiana de Ingeniería Sísmica, Reglamento Colombiano de Construcción Sismo-resistente NSR-10, Bogotá (2010).