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STABILITY ANALYSIS FOR AN AIRPORT EMBANKMENT, EVALUATING SHORT AND LONG TERM TECHNIQUES

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ABSTRACT: This article discusses the stability analysis corresponding to the construction project of a runway embankment over the soft clay, to reach the subgrade level, that confirm the foundation of the runway No. 16/34, for the project Aeropuerto International de Chincheros Cusco - Peru (AICC). The safety analysis consists in evaluating the strength reduction of the foundation, considering the effect of the consolidation, for the short-term and long-term construction techniques considering the soil improvement with preloading, vertical geo-drains and stone columns techniques. The numerical analysis is developed with the Plaxis 2D v8.6 software, considering a typical section corresponding to a critical sector, located on the km 1+180 progressive of the landing strip. According to the results of the definitive geotechnical study, the foundation soil, corresponding to the analysis section, is a saturated soft clay, until a depth of 35 m; then to model its mechanical behavior was used the Soft Soil Model; and for the embankment, that will be constructed of compacted soil obtained from the ground cutting process, was considered the Mohr-Coulomb model. The physical and mechanical parameters were established based on the results of field and laboratory test, correlations and referential values established in the specialized bibliography. From the comparative results based on the calculated safety factors, the stone columns technique presents a higher factor of safety compared to the preloading and vertical geo-drains techniques; while considering the short-term construction, the foundation soil fails due to loss of strength before reaching the total embankment height.

Keywords: Stability of Embankment, Numerical Analysis, Stone Columns, Vertical Geodrains.

1. INTRODUCTION

The construction of the embankment for the runway of the project Aeropuerto Internacional de Chincheros Cusco - Perú (AICC) will allow to reach the level of subgrade, which will form the ground of foundation for the subsequent construction of the runway No. 16/34 (Fig. 1), whose heights vary from 7 m to 13 m according to the site topography [1].

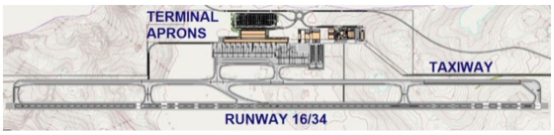

Fig.1 Location of runway No. 16/34 and Taxiways of the AICC project.

The subsurface exploration (trial pits, borings, drillings) and in-situ testing [5] allowed to identify the type and the geological formation of the soils in the zone, standing out its origin of lakebed (central zone), being this zone an old lake that over time was filled with sediments.

In the longitudinal ground profile corresponding to runway No. 16/34 (Fig. 2), are shown the cut zones (S1, S3) and fill areas (S2, S4). The zone of the central sector (S2) on which the embankment will be constructed, is considered like a quaternary deposit of lake origin compound for a sequence of fine soils, shaped for silts and organic clays of medium to high plasticity and typical inorganic soils of elevated zones [5].

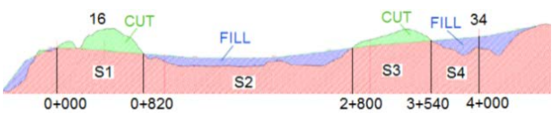

Fig.2 Longitudinal ground profile corresponding to the runway shaft No. 16/34.

Posterior studies executed [1], concluded that the zone of the central sector of sedimentary origin is composed of fine soft soil permanently saturated due to the accumulation of pluvial water, and mostly correspond to gypsum in a saturated state, which gives a whitish color to the surface. According to the USCS, soils are classified as CL, ML and MH.

In the definitive study [8] the longitudinal soil profile of the runway No. 16/34 is presented (Fig. 3), and indicates that the soft soils composed of clays and silts, located between the progressive Km 1+100 to 1+860, with a power of 35m, have weak compressive strengths lower than 0.25 kg/cm^2.

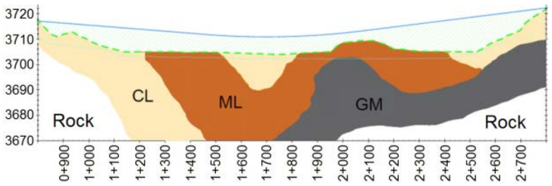

Fig.3 Longitudinal soil profile of the runway No. 16/34.

In the present paper, the stability analysis corresponding to the construction of the runway embankment No. 16/34 on soft clay is developed, in a representative critical section located at Km 1+180 [7], onto the soft soil zone described in the definitive study.

The stability analysis comprises the evaluation of the embankment construction without ground improvement compared with improvement techniques such as preloading, vertical geo-drains and stone columns [2]. The analysis is developed numerically using the finite element method, with the Plaxis 8.6 software, considering a 2D analysis with a plane strain model [6]. The numerical analysis provides the results of settlements, consolidation times, a factor of safety (FS) expressed in graphs, corresponding to the process of embankment construction, comparing indicated techniques.

2. METHODOLOGY

The geotechnical parameters of the materials were established based on the results of the field and laboratory tests, correlations and reference values established in the specialized bibliography related to the subject. The results of the site investigation performed in the zone close to the critical section (Fig. 4) allowed defining the soft soil geotechnical parameters to define the constitutive model for the numerical analysis.

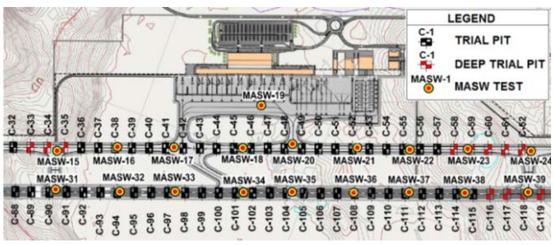

Fig.4 MASW test and trial pits location plan, in the central zone of the runway No. 16/34

The definitive study of the project consisted of the execution of field and laboratory tests, as shown in Table 1.

Table 1 Most relevant field and laboratory tests performed to characterize the soil for the AICC.

Test	Geotechnical parameters
Ground Investigation	
Trial pits	LL, IP, G_s
Compaction test	γ_{nat}
DPL	N_{10}
SPT	N_{SPT}
Drilling	sampling
Lefranc Test	k_x
Piezometers	h_p
Geophysical Investigation	
Seismic Refraction	V_p
MASW Test	V_s
MAM Test	V_s
ERT Test	Ohm-meter
Laboratory Investigation	
Sieve analysis	C_u, C_c
Atterberg limits	LL, IP
Unconfined compression test	S_u
Consolidation	e_o, C_c, C_r, P_c, C_v
Proctor Compaction Test and CBR Test	γ_{dmax}, CBR
Triaxial UU	S_u
Permeability (flexible-wall permeameter)	k_y

In the lakebed zones of the profile, the embankment will be formed by filling, with the cutting materials of the elevated zones, as shown in the longitudinal profile (Fig. 2), and mainly the soils correspond to clays with the presence of sand, evaluated with the Proctor Compaction and CBR test.

The stability and consolidation analysis for the construction of the embankment were executed with the Plaxis 8.6 software. The method for the safety calculation at each stage of the embankment construction was the phi-c reduction, using the total multiplier factor ΣMsf, which represents the factor of safety [6]. For stability analysis, it was considered as a minimum factor of safety FS = 1.3, which allows evaluating the maximum stable elevation of embankment construction.

The consolidation analysis was developed to evaluate soil improvement techniques. For this analysis, the application of load was considered through the option minimum excess pore pressure [6], with a value of 5 KN/m^2, which is a criterion to finish the analysis of consolidation, then the calculation stops when the absolute maximum excess pore pressure is less than the prescribed value of |P-stop| [6].

For modeling the embankment construction, it was considered the application of the load by means of the option staged construction [3], which allows specifying a new state for each increase of embankment elevation, to be reached at the end of the calculation phase [6]. To each stage was specified a time interval of the calculation phase of 5 days, considering the effect of the consolidation, for each increase of load established by the embankment elevation. The results corresponding to the settlements were evaluated at a point located in the central zone of the base of the embankment, at the ground surface.

The stability analysis of the embankment construction comprises two periods; the first consisted in determining the maximum elevation of embankment construction without considering improvement techniques, evaluating the stability of the embankment by means of the established minimum factor of safety; for this period an embankment elevation of 4.5 m was reached. For the second period of the analysis, the improved techniques of the soft soil were evaluated, applying the improvement techniques elements to the geometry established by the maximum embankment elevation stable without improvement techniques (evaluated in the first period). For this latest geometry, the period of consolidation for the clay was considered, until a minimum excess pore pressure of 5 KN/m^2 was reached; and later the embankment elevation was gradually increased every 1 m, controlling the minimum factor of safety, until reaching the elevation established by the project of 9.5 m. The results corresponding to the settlements and duration times for each construction technique are compared, and allow establishing the advantages of the improvement techniques.

For the geometric model of the embankment (Fig. 5) it was considered to analyze half of its geometry for reasons of symmetry. A length of 60 m at the base, a slope of 1:2 (V:H) and a height of 9.5 m specified in the project were considered.

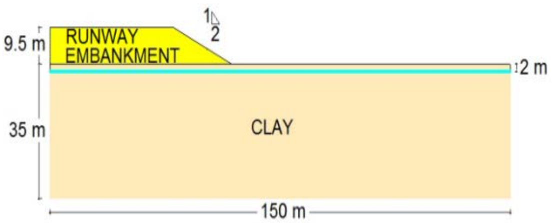

Fig.5 Geometric model considered for the analysis of section Km 1+180.

The stone columns technique has a distribution of square grid, with columns diameter of 1 m, separated 3 m and an area of influence of 8 m^2 per column. For its modeling was considered the transformation of its geometry using an equivalent geometry to perform the plane strain analysis [4], considering each row of stone columns as an equivalent longitudinal trenches with the same area [9], resulting for the numerical modeling, the diameter columns of 0.30 m and the separation between axes of 2.70 m.

For vertical geo-drains, a triangular distribution with a separation of 1.5 m and an area of influence of 2 m^2 for each vertical geo-drain were adopted. In the consolidation analysis, drain elements were used, considering a null value of excess pore pressure at all nodes (finite element mesh) along the lines representing the drains in the model [6].

To model the behavior of the materials, constitutive models available in the program Plaxis 8.6 were used. For the embankment, stone columns and drainage layer the linear elastic-perfectly plastic Mohr-Coulomb model was used. For the soft clay, the Soft Soil model was used, which provides adequate results in situations of primary consolidation; these parameters are shown in Table 2

Table 2 Geotechnical Properties

Material		Clay	Embankment	Stone column, Drainage layer
Model		Soft Soil	Mohr-Coulomb	Mohr-Coulomb
Behavior		Undrained	Drained	Drained
		General Parameters		
γ_{unsat}	kN/m^3	15.7	19.5	19.0
γ_{sat}	kN/m^3	16.0	20.0	20.0
k_x	m/day	4.41×10^{-5}	$2.94\text{x}10^{-5}$	10.022
k_y	m/day	2.94×10^{-5}	$2.94\text{x}10^{-5}$	10.022
		Model Parameters		
E'	kN/m^2		24769	30000
ν'	-		0.3	0.3
c'	kN/m^2	11.0	32.0	1.0
ϕ'	°	2.0	10.0	42.0
Ψ	°	0.0	0.0	0.0
e_o	-	1.403		
C_c	-	0.207		
C_s	-	0.026		
Interface				
R_{inter}	-	1.0	1.0	1.0

3. DISCUSSION OF RESULT

The embankment construction on the soft clay was considered in stages, with increases of the embankment elevation in layers of 1 m, beginning with a drainage layer of 0.5 m covered by a geotextile at the base of the embankment to allow a better distribution of loads and drainage. Fig. 6 shows the finite element mesh corresponding to the geometric model for the embankment construction without any soil improvement technique

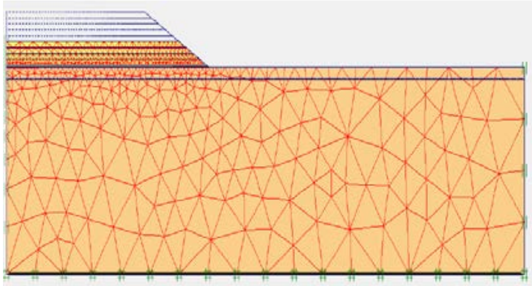

Fig.6 Finite element mesh for analysis without improvement technique.

Figure 7 shows the result of safety analysis for different embankment elevations and Fig. 8 shows the diagram of settlement increase in function of the elevation of embankment construction and the period of time for each calculation phase, for the construction without improvement technique, reaching a factor of safety of 1.32 and a settlement of 11.1cm, in a period of time of 25 days, for an elevation of 4.5 m. This calculated elevation was the reference for the beginning of the consolidation period for the posterior improvement techniques analyzed.

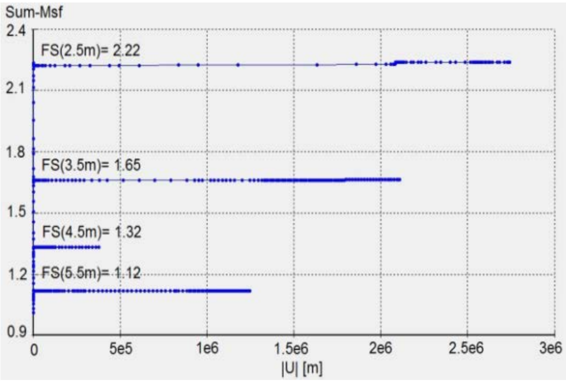

Fig.7 Factors of safety as a function of construction elevations, for construction without improvement techniques.

Figure 9 shows the finite element mesh constructed for this analysis.

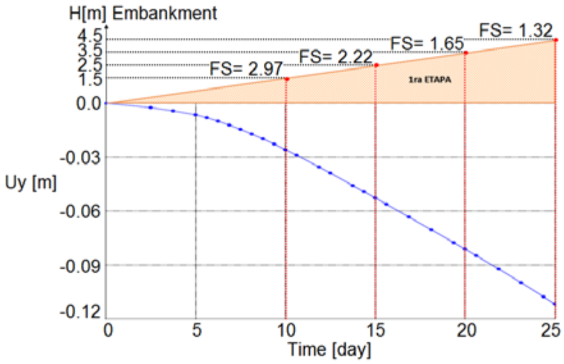

Fig.8 Settlements vs. embankment elevation with the time, for construction without improvement techniques.

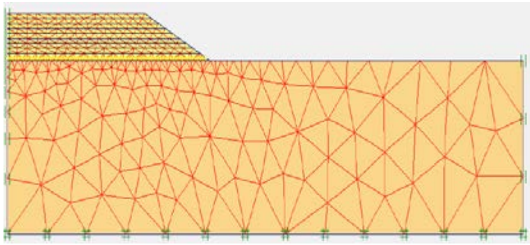

Fig.9 Finite element mesh for analysis of preloading technique.

Figure 10 shows the result of safety analysis for different embankment elevations and Fig. 11 shows the diagram of settlement increase in function of the elevation of embankment construction and the period of time for each calculation phase, for the construction with preloading technique, reaching a factor of safety of 1.32 and a settlement of 87.5 cm, in a period of time of 31.77 years, for an elevation of 5.5 m.

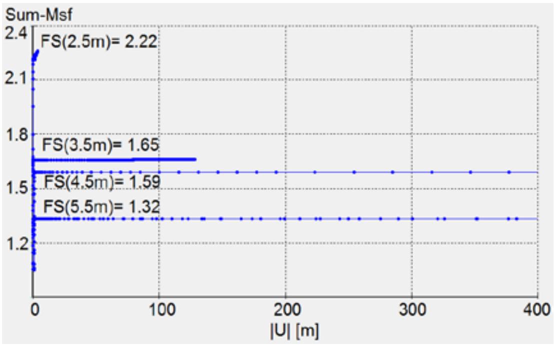

Fig.10 Factors of safety as a function of construction elevations, for construction with preloading technique.

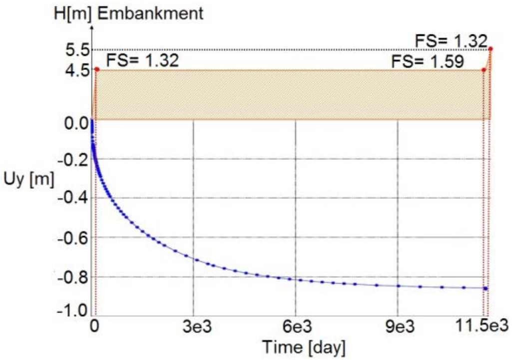

Fig.11 Settlements vs. embankment elevation with the time, for construction with preloading technique.

In order to accelerate the consolidation and reduce the preloading time, the soil permeability is improved by installing vertical geo-drains. Fig. 12 shows the finite element mesh for this analysis considering the drain elements with geometric lines.

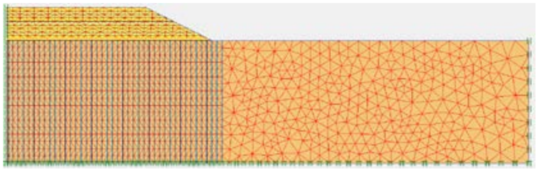

Fig.12 Finite element mesh for analysis of vertical geo-drains technique.

Figure 13 shows the results of the safety analysis for different embankment elevations and Fig. 14 shows the diagram of settlement increase in function of the elevation of embankment construction and the period of time for each calculation phase, for construction with vertical geo-drains technique, reaching a factor of safety of 1.34 and a settlement of 96.6 cm, in a period of time of 220 days, for an elevation of 5.5 m.

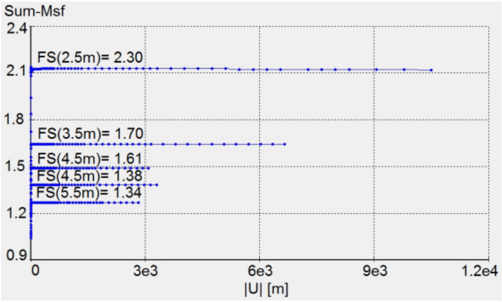

Fig.13 Factors of safety as a function of construction elevations, for construction with vertical geo-drains technique.

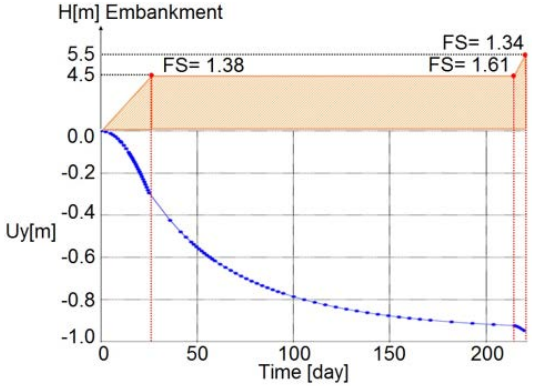

Fig.14 Settlements vs. embankment elevation with the time, for construction with geo-drains technique.

The technique of stone columns improves the soil strength due to the rigidization, decreasing the settlement and improves the drainage. Fig. 15 shows the finite element mesh for this analysis.

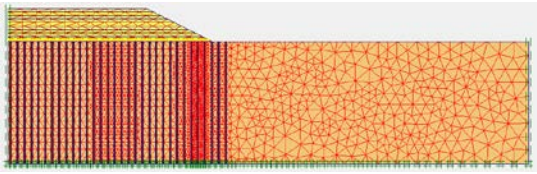

Fig.15 Finite element mesh for analysis of stone columns technique.

Figure 16 shows the results of the safety analysis for different embankment elevations and Fig. 17 shows the diagram of settlement increase in function of the elevation of embankment construction and the period of time for each calculation phase, for construction with stone columns technique, reaching a factor of safety of 1.39 and a settlement of 47.1 cm, in a period of time of 315 days, for the projected elevation of 9.5 m

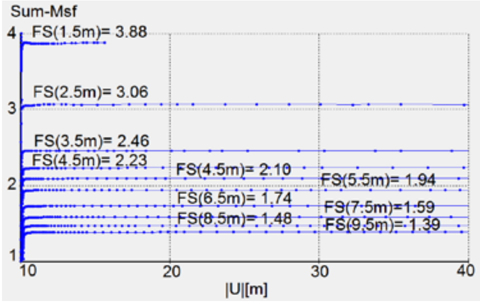

Fig.16 Factors of safety as a function of construction elevations, for construction with stone columns technique

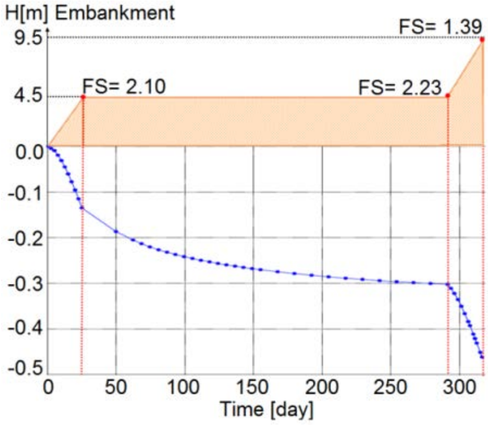

Fig.17 Settlements vs. embankment elevation with the time, for construction with stone columns technique.

4. CONCLUSIONS

The construction in stages of the runway No. 16/34 embankment over soft clay, for the section Km 1+180, was modeled with Plaxis 8.6 software, evaluating the stability, settlements and periods of time for each stage; these results were evaluated to compare the benefits of construction techniques without improvement, preloading, vertical geo-drains and stone columns.

The analysis for the embankment construction without improvement technique attained a maximum stable elevation of 4.5 m, with a factor of safety of 1.32, in a period of time of 25 days, with 11.1 cm of settlement in the point of evaluation, located in the central zone of the base of the embankment. This calculated elevation was the reference for the beginning of the consolidation period for the posterior improvement techniques analyzed.

The construction of the runway embankment considering the preloading technique attained a maximum stable elevation of 5.5 m, with a factor of safety of 1.32, in a period of time of 31.77 years, with 87.5cm of settlement in the point of evaluation. The necessary time required to dissipate the excess pore pressure makes the technique inadequate for the construction.

The construction of the runway embankment considering the vertical geo-drains attained a maximum stable elevation of 5.5m, with a factor of safety of 1.34, in a period of time of 220 days, with 96.6cm of settlement in the point of evaluation. This technique reduced the consolidation time making it most effective than the preloading technique.

The construction of the runway embankment considering the stone columns was the only technique that attains the project elevation of 9.5m, with a factor of safety of 1.39, in a period of time of 315 days, with 47.1 cm of settlement in the point of evaluation.

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