Revista Ingenio, vol 21, n°1, January – December, 2024, pp.1-8, ISSN: 2011-642X - E-ISSN: 2389-864X

Revista Ingenio
UFPS Ocaña
"Journal of Engineering Sciences"

Original Article DOI: https://doi.org/10.22463/2011642X.3588

Geotechnical and dynamic design of the foundation for a marble block cutting machine in Puebla City, Mexico.

Diseño geotécnico y dinámico de la cimentación para una máquina laminadora de mármol en la ciudad de Puebla, México

PhD. Oscar Andrés Cuanalo-Campos[1], Ing. (c) Reyna Ayala-Aranda[2], MSc (c). Leidy Joana Quintero-Lemus[3]

[1] Profesor investigador de la Facultad de Ingeniería Civil, Universidad Popular Autónoma del Estado de Puebla, México, Orcid: https://orcid.org/0000-0002-8031-6958, Email: oscarandres.cuanalo@upaep.mx
[2] Estudiante de la Facultad de Ingeniería Civil, Universidad Popular Autónoma del Estado de Puebla, México, Orcid: https://orcid.org/0000-0002-8084-5817, Email: reyna.ayala@upaep.edu.mx
[3] Estudiante de maestría, Universidad Santo Tomas, Colombia, Orcid: https://orcid.org/0000- 0001-6356-1575, Email: leidyquintero@usantotomas.edu.co

Cite this article as: O. A. Cuanalo-Campos, R. Ayala Aranda & L.J. Quintero-Lemus, "Diseño geotécnico de la cementación para una maquina laminadora de mármol en la ciudad de Puebla,México ", Rev. Ingenio, vol. 21, n°1, pp. 1-8, 2024, doi: https://doi.org/10.22463/2011642X.3588

Received Date: 15 de marzo, 2023
Approval Date: 29 de agosto de 2023

ABSTRACT

Keywords:

Swelling clays, Foundation block, Geotechnical and dynamic design, Construction specifications, Rolling machine.

This paper presents the geotechnical and dynamic design of the foundation of a marble block cutting machine in Puebla, Mexico, approached from the geotechnical construction point of view, since foundation engineering is a fundamental part of this discipline, especially the design of machine foundations with rotating parts that generate dynamic stresses in the foundation and its supporting soil. The foundation consists of a block of reinforced concrete, the superficial ground where the foundation was to be placed consists of expansive clays, located mainly in the south of the city of Puebla, including the neighborhoods of Agua Santa, San Ramón and the communities located on the periphery of the Valsequillo Dam, including San Francisco Totimehuacán, San Pedro Zacachimalpa and Los Ángeles Tetela. A detailed description of the characteristics of the Italian marble cutting machine, the foundation block and the characteristics that the foundation soil must meet, as specified in the plans provided by the manufacturer, are included. It also describes the exploration and sampling work, the laboratory tests, the results of the geotechnical and dynamic design of the foundation, the construction specifications, and the supervision and quality control of the work.

RESUMEN

Palabras clave:

Arcillas expansivas, Bloque de cimentación, Diseño geotécnico y dinámico, Especificaciones constructivas, Máquina laminadora.

Se presenta el diseño geotécnico y dinámico de la cimentación para una laminadora de mármol en Puebla, México, abordado desde el punto de vista geotécnico-constructivo ya que la ingeniería de cimentaciones es parte fundamental de esta disciplina, y especial el diseño de cimentaciones para maquinaria con partes giratorias que producen esfuerzos dinámicos en la cimentación y su terreno de apoyo. La cimentación consiste en un bloque de concreto armado cuyo terreno de cimentación superficial donde se pretendía desplantar la cimentación está constituido por arcillas expansivas, ubicadas principalmente al sur de la ciudad Puebla, abarcando las colonias de Agua Santa, San Ramón y las comunidades ubicadas en la periferia de la presa de Valsequillo, incluyendo San Francisco Totimehuacán, San Pedro Zacachimalpa y los Ángeles Tetela. Se incluye una descripción detallada de las características de la máquina laminadora de origen italiano, del bloque de cimentación y de las propiedades que debe cumplir el terreno de cimentación especificadas en los planos del fabricante; además, se indican los trabajos de exploración y muestreo, las pruebas de laboratorio, los resultados del diseño geotécnico y dinámico de la cimentación, las especificaciones constructivas, la supervisión y el control de calidad para la ejecución de la obra.

1. Problem Statement

The company "Transformación Artística del Mármol" has scheduled the installation of an Italian marble cutting machine at a property in Valsequillo Puebla. This machine will exert a dynamic load of 415 kN on the foundation soil and has spinning components operating at a speed of 90 cycles per minute. Typically, the base for vibrating machines is a sturdy block of reinforced concrete built on high-quality ground to effectively bear the weights without experiencing shear or punching failure. Also, to prevent the occurrence of unbalanced forces and torques during operation, as well as to avoid resonance, the center of gravity of the machine must align with the one of the foundation. As a result, the structural design of this foundation block differs significantly

Corresponding Author
Email: oscarandres.cuanalo@upaep.mx (Oscar Andrés Cuanalo Campos)

from the design of common shallow foundations like spread footings or in terms of shear and flexural design [1, 2]. The specifications provided by the Italian manufacturer contain detailed descriptions of the structural and geotechnical technical parameters.

The details can be found in sections 2.1.1 a 2.1.4 of this paper; as far as the geotechnical aspect, it is necessary to have uniformly distributed and densely packed soil that can support the foundation up to a depth of 15 m, which should be able to bear a static pressure of at least 100 kN/m2 and have an average response modulus of 50,000 kN/m3. As in our particular case, the soil foundation is composed of volcanic ash stemming from the eruptions of nearby volcanoes in Puebla, i.e. Popocatepetl and Iztaccihuatl; on the surface, there is a layer of dark brown expansive volcanic clay with high plasticity, classified as type CH, which is 3.6 meters thick, which is completely unsuitable for placing the foundation block of the rolling machine and led to propose the complete removal of this layer and make adjustments to the geotechnical and dynamic design of the foundation as recommended by the manufacturer of the vibrating machine. The expansive clays of volcanic origin found in Puebla can generate pressures of up to 20 kPa. Even, these have the potential to lift a 2-story building due to the changes in volume caused by variations in consistency throughout the year. For instance, the clay contracts during the dry season and expands during the rainy season.

2. Argument-based Explanation

2.1 Features of machinery

2.1.1 Overall Information. The following information was gathered from the catalog of a machine manufactured by an Italian company:

- Max. Length = 12.35 m
- Height = 3.35 m
- Width = 4.60 m
- Total weight = 400 kN
- Number of blades = 40
- Length of the blades = 4.2 m
- Strokes per minute = 90
- Main Engine Power = 75 kW

The following data were extracted from the drawings furnished by the manufacturer.

2.1.2 Machine-related data.

- Static load per column = 75 kN
- Dynamic load per column = 70 kN
- Moving Mass = 140 kN
- Dynamic Load on Battery = 415 kN
- Static Load on each Support = 50 kN

2.1.3 Reinforced concrete block foundation.

- Length= 11.74 m; width = 5.50 m; depth =1.50 and 2.50 m.
- Concrete's strength f'c = 30 000 kN/m2
- Reinforcing Steel with 3/8" y 5/8" diameter

2.1.4 Foundation ground.

- It is uniformly distributed and densely packed up to a depth of 15 meters below the foundation.
- The soil beneath the foundation must have a high bearing capacity to support a static pressure of over100 kN/m2
- The average modulus of the reaction of the soil should be equal to 50,000 kN/m3

3. Methodology

The review of the geotechnical and dynamic of the foundation of the marble cutting machine was conducted by performing the following activities:

3.1 Field work and sampling

To ascertain the site's stratigraphy and obtain accurate samples of the soil layers, intact cubic samples were collected from the foundation slump level and the expansive clay stratum. Furthermore, conventional penetration testing was conducted at a depth of 14.4 meters.

3.2 Laboratory Tests

The collected samples underwent the laboratory tests listed in (Table 1)

3.2.1 Index Tests. The identification of various soil types is determined using the SUCS classification system, in which each soil type is assigned a descriptive name or symbol based on its index qualities [3], which were determined through laboratory tests as listed below:

- Granulometry
- Natural Water Content
- Atterberg Limits
- Volumetric Weight
- Solid Density

3.2.2 Mechanical tests. The shear strength of a soil mass refers to its ability to withstand shear stress and prevent failure or slide along any internal plane [4].

For this research, simple compression in addition to unconsolidated and undrained triaxial compression tests were conducted [5].

Table 1. Index and mechanical testing of the foundation soil of marble cutting machine

Sample	1 Inalt.	2 Inalt.	3 Barrel Denison	4 Barrel Denison
Prof. (m)	2	3	5	12
Y_m (Kn/m^3)	17.1	16.8	15	17
W (%)	33.5	30.4	20.6	37.2
Granulometry				
G %	0	0	3	0
S %	12	16	18	14
F %	88	84	79	86
Limits A.				
LL %	66.2	57.3	47	72
LP %	232	24.2	27	28
IP %	43.2	33.1	20	44
SUCS	CH	CH	CL	CH
qu (kPa)	47	---	---	191.3
Triaxial UU				
C (kPa)	---	---	100	---
Φ (°)	---	---	15	---

Table nomenclature and abbreviations
Inalt. → Unaltered
Prof. → Depth
Limits A. → Atteberg limits
CH → High plasticity clay
CL → Low plasticity clay
Y_m → Specific gravity
W → Water content
G → Gravels
S → Sands
F → Fines
LL → Liquid Limit
LP → Plastic Limit
IP → Plasticity Index
qu → Simple compressive strength
c → Cohesion
Φ → Angle of friction

3.3 Standard Penetration Test SPT

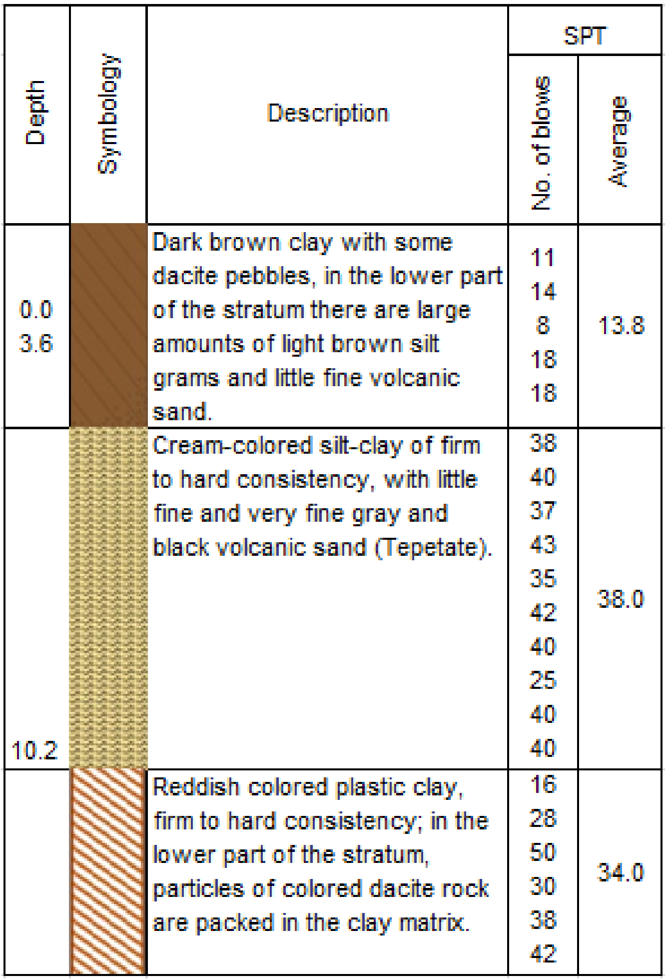
To determine the stratigraphic profile of the soil, a standard penetration boring was conducted at a depth of 14.4 m, in which three distinct types of material were revealed (Figure 1). The top layer, which extends to an average depth of 3.60 m, consists of dark brown CH clay with high expansivity [6], which has a firm to hard consistency, with a sand content of 12% and fines comprising the remaining 88%. The natural water content is measured at 33.5%, while the liquid and plastic limits are 66% and 23% respectively. The SPT test yielded 8 to 18 strokes within this layer, with an average of 13.8 (Figure 1).

The unconfined compression test was conducted on an intact sample collected at a depth of 2 m, resulting in a cohesiveness value of 47 Kpa (Table 1).

Below the previous layer, as deep as 10.2 m, there is a light brown "volcanic ash" called tepetate, composed of a hard CL clay. It has a water content of 20.6% and liquid limits of 47% and plastic limits of 27%. The SPT test showed that the number of strokes ranged from 25 to 43, with an average of 38 blows in this layer (Figure 1).

The unconsolidated undrained triaxial "UU" tests produced volumetric weight measurements of 15 kN/m3, a cohesiveness value of 100 kPa, and an angle of internal friction of 15 degrees.

The two anterior layers, originating from volcanic activity, are placed on top of a reddish dacite rock, which in their first two meters have undergone complete alteration, resulting in the formation of a CH plastic clay with a firm to hard texture. During testing, the number of strokes ranged from 16 to 50, with an average of 34 blows (Figure 1); At depths over 14.4 m, rock-type particles can be seen, specifically gravel-sized and sandstone-sized, densely packed inside a clayey matrix. Also, it can be deduced that the deeper the rock is placed, the better the condition will be.



Depth	Symbology	Description	SPT No. of blows	SPT Average
0.0 3.6	🟫	Dark brown clay with some dacite pebbles, in the lower part of the stratum there are large amounts of light brown silt grams and little fine volcanic sand.	11 14 8 18 18	13.8
10.2	▒	Cream-colored silt-clay of firm to hard consistency, with little fine and very fine gray and black volcanic sand (Tepetate).	38 40 37 43 35 42 40 25 40 40	38.0
	▨	Reddish colored plastic clay, firm to hard consistency; in the lower part of the stratum, particles of colored dacite rock are packed in the clay matrix.	16 28 50 30 38 42	34.0

Figure 1. Stratigraphic terrain profile in the marble cutting machine (Valsequillo, Puebla).

4. Geotechnical review of the foundation

The bearing capacity of the soil under study was determined using the stratigraphic profile from standard penetration tests and the results of laboratory tests (soil classification and strength parameters).

As the superficial clay stratum is completely unsuitable for providing a stable foundation for any structure due to the significant volumetric changes when its water content fluctuates (expanding when wet and contracting when dry), Therefore, it was determined that the tepetate stratum, located between 3.6 and 10.2 meters deep and characterized by a solid and firm composition, should serve as the support.

By utilizing Vesic's formula for shallow foundations (Equation 1) [7], it was determined a permissible soil carrying capacity "qadm" of 481 kPa with a safety factor of 3.

$$q_{adm} = \frac{CNc\ \delta c + ym\ Df\ Nq\ \delta q + 0.5\ y\ B\ Ny\ \delta y}{3} \qquad (1)$$

In which:

C = cohesión = 100 kPa

$\gamma_m = 17.1$ kN/m3 $(Peso\ especifico)$

$Df = 2$m (profundidad de desplante)

$Nc, Nq, N\gamma =$ $Factores\ de\ capacidad\ de\ carga$

$\delta c, \delta q, \delta\gamma = Factores\ de\ forma\ de\ Vesic$

$B = 5.5$ m $(ancho\ de\ la\ cimentación)$

$y = 15 \frac{kN}{m3}$ $(peso\ especifico\ estrato\ de\ apoyo)$

The soil response modulus, derived by considering the allowed bearing capacity, was determined to be 57,720 kPa (Equation 2) [8].

$$Ks = 120\ q_{adm} \qquad (2)$$

The soil's elastic characteristics, determined by correlations with the modulus of response, were found to be a modulus of elasticity (E) of 40,000 kPa and a Poisson's ratio (μ) of 0.4 [8].

$$E = \frac{(1-\mu^2)}{1.13} \sqrt{A} * Ks \qquad (3)$$

In which , A = the area of the plate is 1.20 m by side

It was noticeable that the values obtained for the permissible carrying capacity and reaction modulus were often greater than the machine manufacturer's specified values of 100 kPa and 50,000 kN/m3 for each parameter, respectively.

5. Dynamic foundation design

The subsequent values were considered in the dynamic foundation design:

- Total weight of machine = 400 kN
- Weight of rotating parts= 240 kN*
- Operating speed = 102 cpm =1.7 cps
- Height of the shaft = 1.20 m
- Height of the center of mass 1.31 m
- Floor-plan dimensions = 11.74 m and width = 5.5 m
- unbalance forces and torques
- Fx = 13.4 kN*
- Fz = 37.4 kN*
- My = 49.6 kN-m*

Note * values provided are derived from the machine's dimensions. [9,10].

The following data regarding the foundation block were collected:

- Dimensions: length =11.74 m, width = 5.5 m Depth = 1.5 a 2.5 m.
- Volume = 151 m3
- Weight = 3624 kN

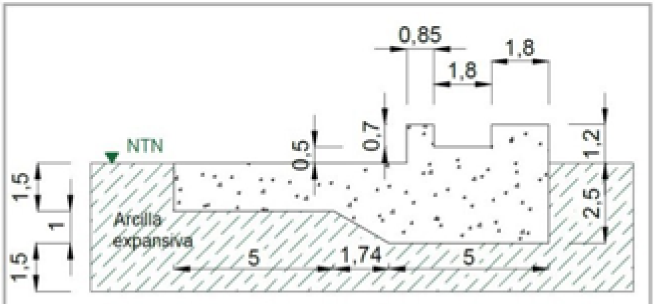
5.2 Revision of center of gravity

a) Machine's center of gravity. Derived from the manufacturer's drawings, it is placed at the given coordinates as follows: y = 7.05 m (in the longitudinal direction), x = 1.31 m (in the transverse direction), and z = 1.31 m (in the vertical direction).
b) Center of gravity of the foundation. Derived from the manufacturer's drawings, it is placed at the given coordinates as follows: y = 4.70 m (longitudinal direction) x =2.75 m (transverse direction) z = 1.68 m (vertical direction
c) Common machine-foundation center of gravity y= 4.93 m

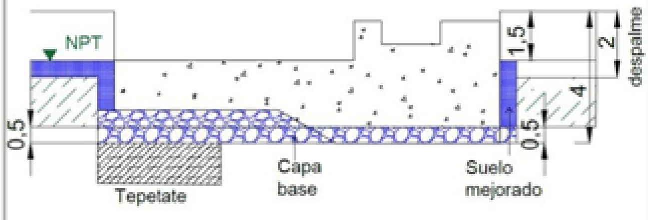
The machine's common center of gravity and its foundation is located 4.93 m from the outside edge where the revolving flywheel is positioned. The center of gravity of the contact region between the foundation block and the soil is 5.87 m from the same edge.

In this particular case, there is a 94 cm difference in eccentricity between the centers of gravity. However, according to the technical literature referenced [11], it is advised to align the common center of gravity of the machine and its foundation with the center of gravity of the contact area to prevent differential settlements and torsional vibration.

To resolve this issue, multiple trial-and-error were used on the dimensions of the foundation block until the desired alignment was attained (Figure 2).



a) Original foundation



b) Proposed foundation

Figure 2. Foundation based on a reinforced concrete block

5.3 Dynamic pressure.

A dynamic impact factor of 1.5 was considered, resulting in a dynamic pressure of 66 kPa, whose value is below the permissible load capacity of 481 kPa. (Equation 4).

$$\sigma_{d}= \frac{W_m\, FI + W_{bc}}{Ac} \qquad (4)$$

In which:

$\sigma_d = Presión\ dinámica$
$W_m = Peso\ total\ de\ la\ máquina$
$FI = Factor\ de\ impacto$
$W_{bc} = Peso\ del\ bloque\ de\ cimentación$
$A_c = Área\ de\ contacto\ de\ la\ cimentación$

5.4 Natural operating frequency

The soil-foundation-machine system has a natural frequency of 6.4 cycles per second (cps) (Equation 5) [12, 13], which is 3.8 times higher than the machine's natural operating frequency of 1.7 cps. According to the technical literature, it is recommended to have a minimum frequency of 1.5 times.

$$f_n = \frac{f_{nr}}{\sqrt{\sigma e}} \qquad (5)$$

In which:

$f_n = frecuencia\ natural\ de\ operación$
$f_{nr} = frecuencia\ natural\ reducida = 16$
$\sigma_e = esfuerzo\ estático\ o\ presión\ estática = 62.4\ kPa$

5.5 Displacement Amplitudes

The displacement amplitudes yielded during machine operation were calculated to be 0.114 mm for the vertical component "Av" and 0.07 mm for the horizontal component "Ah", (as per Equations 6 and 7), which categorize the vibration as ranging from noticeable to barely noticeable, with no detrimental impact on the machine itself or adjacent buildings or structures.

$$A_v = \sqrt{(A_z)^2 + (A_{v\emptyset})^2} \qquad (6)$$
$$A_h = \sqrt{(A_x)^2 + (A_{h\emptyset})^2} \qquad (7)$$

In which:

$A_h = componente\ de\ desplazamiento\ horizontal$
$A_x = amplitud\ de\ desplazamiento\ en\ función\ de\ la\ fuerza\ horizontal\ fx$
$A_v = componente\ de\ desplazamiento\ vertical$
$A_z = amplitud\ de\ desplazamiento\ en\ función\ de\ la\ fuerza\ vertical\ fz$
$A_{v\emptyset} = amplitud\ de\ desplazamiento\ en\ función\ del\ momento\ vertical$
$A_{h\emptyset} = amplitud\ de\ desplazamiento\ en\ función\ de\ la\ profundidad\ de\ desplante\ Df$

6. Settlement calculation

When it comes to designing foundations for machinery with vibrating elements, the deformations in the ground caused by the machinery's operation are assessed in terms of vertical and horizontal displacement amplitudes. In this case, the values are Av = 0.114 mm and Ah = 0.07 mm, (as stated in section 5.1.4.) which classify the vibration as ranging from noticeable to barely noticeable, with no adverse impact on the machine or the surrounding buildings or structures.

Yet, the settlements that occurred in the support layer made of well-compacted sandy gravel with thicknesses between 1.5 and

2.5 m during the construction of the foundation block were only 1.8 mm, whose value is significantly lower than the maximum tolerable settlement of 80 mm. These settlements were assessed using the following formula:

$$\delta i = \sigma * B \left(\frac{1-\mu^2}{E}\right) * Iw \qquad (8)$$

In which:

$A_x = amplitud\ de\ desplazamiento\ en\ función\ de\ la\ fuerza\ horizontal\ fx$
$A_v = componente\ de\ desplazamiento\ vertical$
$A_z = amplitud\ de\ desplazamiento\ en\ función\ de\ la\ fuerza\ vertical\ fz$

7. Project outcomes

After completing the various stages outlined in the previous paragraphs, the building specifications for the machinery's placement could be incorporated, as shown in the details below:

- Carry out the dig to a depth of 4 m to eliminate the expansive clay layer (Figure 3).

Figure 3. CH expansive clay layer

- An additional 50 cm will be dug around the perimeter of the area to install granular material, which will help minimize vibrations while the machine is operating.
- At the lower end of the excavation, a base layer, that is 50 cm thick, should be placed on the deeper side and 1 m thick on the shallower side. The base layer will consist of compacted gravel-sand to 95% of the modified Proctor density, specifically, in layers that are 10 cm thick, using a smooth manual vibratory roller (Figure 4).

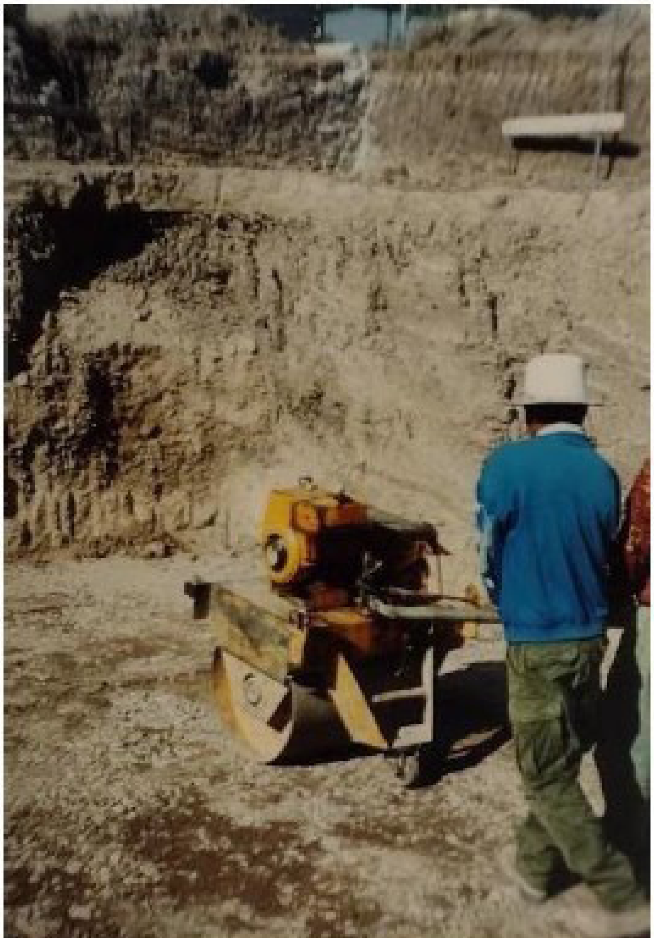


Figure 4. Compaction of the base layer (gravel - sand)

A concrete base of 5 cm thick is placed on the base layer, which will serve as a foundation for the concrete of the foundation block [14].

- After the reinforcing steel has been placed and the foundation block has been formed when the concrete has reached 85% of its strength, a layer of sand will be applied around the perimeter of the block and it will be compacted to a density of 95% and will have a width of 50 cm and a thickness of 10 cm (Figure 5) [15].

Figure 5. Reinforcing Steel in the foundation block

- The compaction of the gravel-sand base layer and the perimeter sandy material will be performed using manual vibratory compactors, for which the process should be supervised and quality control will be ensured by using volumetric trial pits to reach the specified level of compaction.
- During the process of casting the foundation block, it is important to monitor and ensure the quality of the concrete by conducting slump tests and acquiring cylindrical specimens for compressive strength testing at specific intervals of 7, 14, and 28 days (Figure 6).

Figure 6. Casting of the foundation block

- To prevent direct support on the poor-quality expansive clay, it is recommended to place a 50 cm thick layer of enhanced soil across the entire work area and vehicular circulation.
- The construction of any further structures on the site shall be limited to the tepetate layer, which is found at a depth of 3.60 meters (10 feet).
- Create a drainage system that enables the efficient removal of surface runoff water, including water used during machine operation and rainwater, which would prevent the infiltration of it into the ground in areas where critical structures are located (Figure 7).

Figurae7. Marble cutting machine

8. Conclusions

A typical foundation for machines with rotating components, which generate both static and dynamic loads on the earth, typically comprises a robust reinforced concrete block. To ensure the stability of the vibrating machine and its foundation block, it is necessary to have high-quality soil that can bear the weight and minimize deformation, which should have sufficient load capacity and minimal deformability, extending to a depth where the stresses caused by the loads may be dispersed.

If the surface soil is of inadequate quality, that is, characterized by low shear strength and/or high compressibility, there are various alternative options that might be considered:

a) To avoid or substitute low-grade surface soils.
b) Support the structure using a deep foundation on a high-quality layer of soil.
c) Relocate the emplacement of machinery

In our specific scenario, the entire upper layer of expansive clay was removed whereas the foundation was supported on a lower layer of enhanced soil (gravel-sand), which was to be placed on a deposit of volcanic ash, which is classed as CL clay with high shear strength and is not prone to compression. This enabled us to fulfill the load capacity and modulus of response requirements specified by the block cutting machine manufacturer.

Furthermore, it was essential to adjust the size of the foundation block to align the collective center of gravity of the machine and its foundation with the center of gravity of the contact area. This was crucial in preventing differential settlement and torsional vibration.

What is more, the machine-foundation-soil system met the specifications for the natural frequency of the machine system, as well as the allowed displacement amplitudes.

8. References

[1] Freitas de Almeida, I., Castelo Branco de Noronha Campos, M., y Almeida de Oliveira, R. A comparative study in flexure and shear design of spread footings. Rev. Ingenio, vol. 16,n°1, pp.23–29, 2019,doi: https://doi.org/10.22463/2011642X.2364

[2] Pérez-Giraldo, M., y Yepes-Tumay, J. D. Diseño geométrico de una zapata doble para cimentación aplicada en torres de transmisión eléctrica. Rev. Ingenio, vol.18, n°1, pp.17–24, 2021,doi: https://doi.org/10.22463/2011642X.2385

[3] L. J. Quintero, and R. J.Gallardo. Caracterización mineralógica de arcillas expansivas con fines de estabilización. Geotécnica. Acapulco Guerrero, México. 2010. Vol. 1 pag. 295-301, 2015.

[4] C. Castrillón and J. D. Quintero. Guía de instrumentación en taludes intervenidos por un proyecto vial (Bachelor's thesis, Universidad de Medellín). 2012.

[5] N. E. Matos. Diseño de cimentación superficial de tanque séptico para almacenamiento de agua residual utilizando métodos: Hansen-Vesic- Comunidad Maravillas-Cusco, 2021.

[6] O. Linares, O. Flores, A. Hernández and A. Aguilar. "Caracterización de arcillas expansivas de San Francisco Totimehuacán". XXV Reunión Nacional de Mecánica de Suelos e Ingeniería

[7] B. Das. Principles of Foundation Engineering. 7th Edition. Cengage Learning. USA, 2011.

[8] J. Bowles "Foundation Analysis and Design". 5th Edition. McGraw Hill. USA, 1997.

[9] J. Marujo da Silva, Structures & Foundations Supporting for Vibration Machines, 2019.

[10] R. Kameswara. Foundation Design. Theory and Practice. John Wiley & Sons. Asia, 2011.

[11] J. Nieto and D. Reséndiz. Criterios de Diseño para Cimentaciones de Maquinaria. Instituto de Ingeniería. Universidad Nacional Autónoma de México, 1967.

[12] B. Das. and G. Ramana, Principles of Soil Dynamics. 2nd Edition. Cengage Learning. USA, 2011.

[13] S. Giorgetti, A. Giogetti, R. Tavafoghi andG. Arcidiacono. "Machinery Foundations Dynamical Analysis:ACaseStudyonReciprocatingCompressor", vol. .9 (10), 2021. Foundation, Machines. Doi: https://doi.org/10.3390/machines9100228

[14] E. Sahar. Practical Design and Construction of Machine Foundations Subjected to Impact Loads. Practice Periodical on Structural Design and Construction. 25, 2020. 04020008. 10.1061/(ASCE)SC.1943-5576.0000491.

[15] ACI. Foundations for Dynamic Equipment, 2004. [Online] Available: https://www.academia.edu/25648225/ACI_351_3R_04_Foundations_for_Dynamic_ Equipment