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# Structural-Geotechnical Effects of the Foundation of a Medium-Height Structure

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***Abstract*—**The interaction effects between the existing soil and the substructure of a 5-story building with an underground one, were evaluated in such a way that the structural-geotechnical concepts were validated through the method of impedance factors with a program based on the method of the finite elements. The continuous wall-type foundation had a constant thickness and followed inclined and orthogonal directions, while the ground had homogeneous and medium-type characteristics. The soil considered was type C according to the Ecuadorian Construction Standard (NEC) and the corresponding foundation comprised a depth of 4.00 meters and a basement wall thickness of 40 centimeters. This project is part of a mid-rise building in the city of Azogues (Ecuador). The hypotheses raised responded to the objectives in such a way that the model implemented with springs had a variation with respect to the embedded base, obtaining conservative results.

***Keywords*—**Interaction, soil, substructure, springs, effects, modeling, embedment.

## I. Introduction

THE structural analysis of the foundation of a structure has been carried out over time, in such a way that the stresses of this study are those that reach the embedded supports for the foundation, without considering the geotechnical-geophysical effect; that, as generally known, this involves a transfer of loads and displacements to the different strata of the present soil [1]. The general disposition of this analysis is to define, using the impedance functions methodology, proposed by the ASCE [2], some springs with displacements and rotations calculated over an optimal area to effectively distribute the areas of ground stress surrounding.

When it is necessary to select a foundation for a mid-rise building in a seismic risk zone, the engineer will choose a combined shoe to support the loads. However, it may be that they have a different behavior, depending on the project and the causes that affect it, as a result of the interaction of the soil with the substructure; since the geotechnical properties, the type of footing, the dynamic characteristics and the damping, have influence on its seismic response [3]. Subsequently, the foundation walls are also built with respect to the base of the structure, which are often used to resist the different lateral loads, imposed by the design earthquakes that are defined in the design. Precisely, this demand requires considering suitable non-linear factors to know and evaluate the behavior of the substructure, the interaction and the movements of the surrounding terrain [4].

The great limitation of such analysis is the change in the internal stresses and their calculated variation, since generally the soil structure interaction is not considered. Therefore, a modeling is proposed such that the effects of the soil are added to those of the specific substructure by means of the aforementioned supports. These are defined as a set of changes in the response of the flexibility of the terrain, in which the hardness and movements present in it due to the structure are established, and which are presented in such a way that due to the variation of the period, the components and type of foundation; they conclude in other types of results [5].

### A. Objective of the Study

The soil structure interaction effect is modeled in a building approved by the competent entity, using the method of impedance functions to establish the performance guidelines of the established foundation [6]. Likewise, the behavior of the stresses resulting from the foundation is evaluated against the ground in which it is located; by means of analysis of infinitesimal elements, to obtain the structural configuration patterns regarding the type of foundation and its affection according to the type of soil.

As a final point, the periods of vibration and drifts of floors are contrasted, by means of the replacement of the embedments by springs, to get to know the capacity of the substructure with regard to its primary characteristics.

### B. Theoretical Basis

The soil substructure interaction (SSI) is solved in a practical way, incorporating the coefficients for the stiffness of the ground and its strata. The contributions of science regarding this issue are given for the consideration of the foundation and its adjacent or surrounding terrain. These consider bending and displacement vibrations. The different methodologies for calculating foundations also contribute greatly to the development of this type of study, about structural effects [7]. This SSI effect takes place, through dimensionless parametric analyzes that control gravity, one is the stiffness index of the soil and the other is the relation of the structure in its aspect, both of which are correlated. This effect considers a homogeneous elastic space using different models with the cone methodology in different soil circumstances [8].

The concept of interaction requires a modeling that allows to analyze the total structure, focusing on the combined footing type substructure, considering the soil in the range of linear and non-linear behavior [9].

The aforementioned analysis is based on the equations of the

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elastoplastic deformations and the discretization of finite elements by the efforts and pressures produced on the surrounding soil, in which the constitutive laws are evaluated [10]. Due to these pressures and tensions, in a general way, carried out broadly, the structure itself is conceived in such a way that it has certain displacements due to the existing terrain; that is, the weight of the structure settled on it [11]. In this part it refers to the foundation since it is the party of interest in this analysis. After this paragraph is an outline to help understand it better: The stiffness matrices to be obtained from these efforts follow analytical solutions of the displacement of the Soil-Substructure Interaction problem and the modification of its dynamic response; mainly taking into account the effects of the entrance movement in the substructure and its generated vibration waves, demonstrating its effectiveness [12].

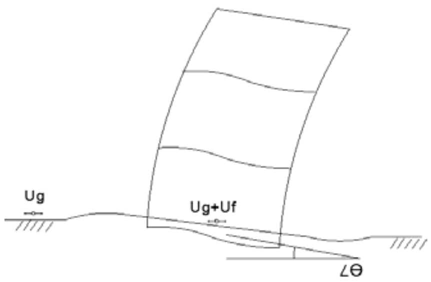



Fig. 1 Displacement scheme

## II. Applied Methodology and Case Study

To present this research, there is a structure of medium height type, of 5 levels with one of them underground with a hybrid type construction, in the city of Azogues in the province of Cañar (Fig. 2). The presented system consists of the two major construction materials as a whole, such as reinforced concrete and A36 steel, taking note in particular that its foundation is a combination of continuous and isolated footing throughout its area.

The substructure covers an area of approximately 15 meters x 23.94 meters of land, with the effective width of the footings being 1.50 meters (Fig. 2). It consists of a foundation system that is chosen due to the complexity of the analysis as it is not an isolated footing in general, but rather ones that comprises a basement wall 4 meters below the ground; so, the analysis of its effects on the ground should provide interesting technical insights.

The methodology adopted in the present study is that of the substructure [13], since springs are proposed based on the footings, obtaining their respective stiffnesses to establish comparisons according to the type of soil and its shear modulus as a function of the pseudo-acceleration obtained by geophysical tests. This ISE analysis is based mainly on the modeling of the substructure with its adjacent terrain in a finite element program, which contains capabilities for structural science on par with geotechnics, through which several parameters of great interest are defined for the study [14].

The method of infinitesimal elements is based on the equivalence of rigid bases to bases with spring elements; in this case, it refers to the chosen foundation which is the one that represents this element. This statement corresponds to a virtual work for the subsequent resolution to the approximate way of equilibrium used in a discretized model of the foundation [15]. Similarly, the impedance functions for the comparison of results are of interest and fundamental for the aforementioned equivalence springs, those are the ones in Fig. 4.

### *A. Description of the Geophysical Test*

For geology, a field trip was carried out where the disposition of the structural characteristics and geological units was verified, proceeding to their corroboration through geophysics (Seismic Refraction Lines). It is evidenced that the area is made up of a geological unit, the Azogues formation, whose behavior is rocky, exposing sandstones on its slopes. Susceptibility is moderate to low since it is a heterogeneous solid soil.

The interest of the wave velocity lies in the requirement of the Soil-Structure Interaction, as shown in Table I, generated by the National Earthquake Hazards Reduction Program (NEHRP), since by determining this parameter, Vs30 using the Multichannel analysis of surface waves (MASW methodology) [16] is based on the type of soil and the area are of interest, according to the local regulations.

The Multichannel Surface Wave Analysis (MASW) method evaluates the elastic condition of the soil for geotechnical engineering purposes using the dispersion of Rayleigh waves, which takes two thirds of the total seismic energy generated by the source, obtaining the profile of speeds of the shear waves, Vs [17].

Considering the succession of geophysical tests, the obtaining of the shear modulus G is corroborated, according to the table found in the regulations depending on the speed parameters and periods.

TABLE I
Classification of Soils According to the NEHRP

| Soil Type | Soil Classification | Vs 30 (m/s) |
|---|---|---|
| A | Hard rock | > 1500 |
| *B* | Rock | 760 - 1500 |
| *C* | Very dense soil or soft rock | 360 - 760 |
| *D* | Hard ground | 180 - 360 |
| *E* | Soft soil | < 180 |
| *F* | Special soils that require site-specific evaluation | - |

The typification of geophysical and geotechnical characteristics is obtained in terms of values of interest for later development of the impedance functions for springs.

Figs. 7 and 8 describe the curve that depicts the variation of the propagation speed of Rayleigh waves [18] (phase velocity) as a function of frequency (or wavelength).

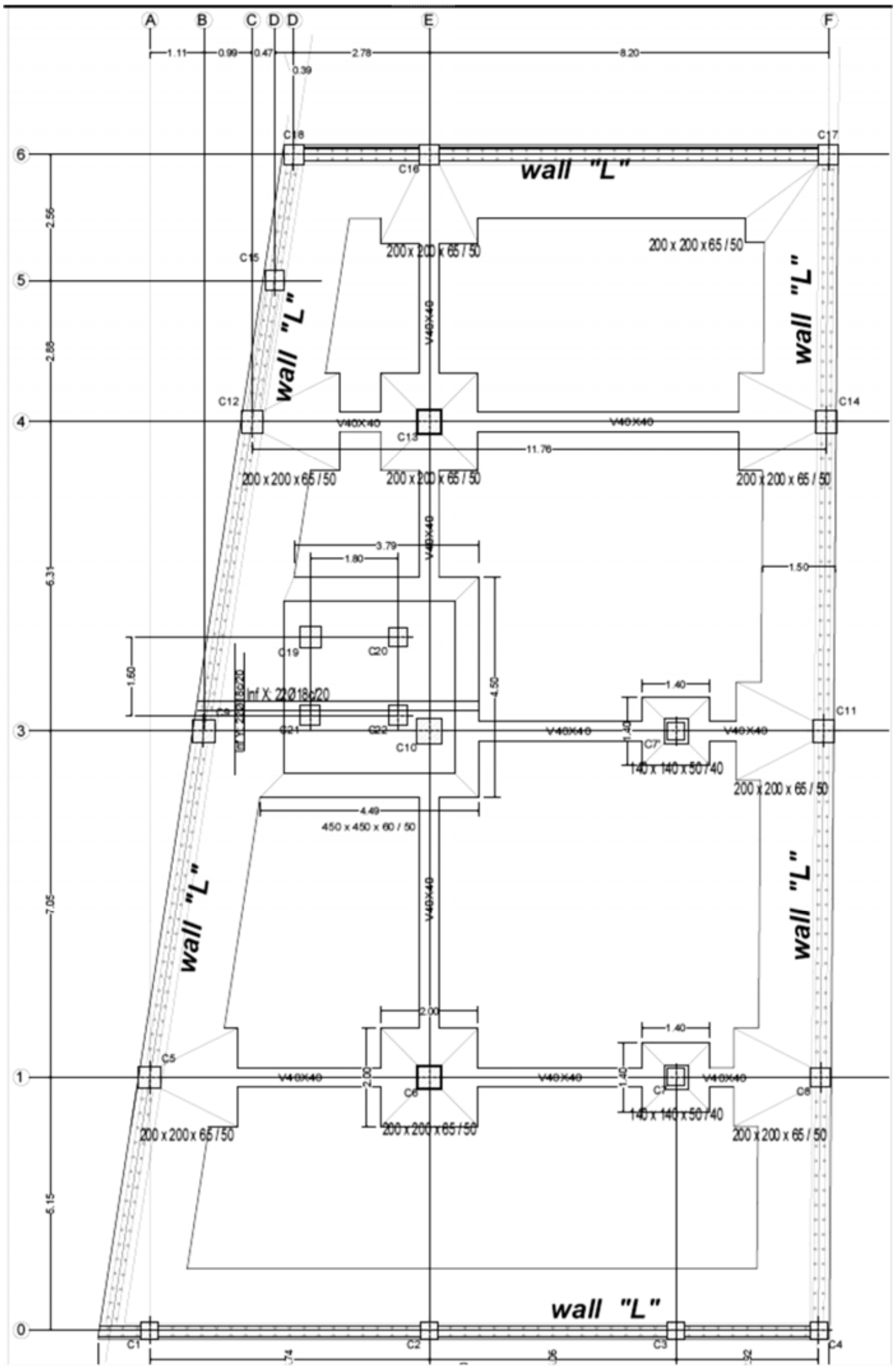



Fig. 2 Foundation plant

*B. Method Development*

The advanced method of impedance functions that involves the characteristics of the soil and existing basements is used, for which the structure is described in a structural analysis program [19].

Basically, to begin with, there is a foundation plant of approximately 15.00 meters x 23.94 meters with five floors and one underground as an addition, consisting of both isolated and continuous footings; which were modeled in a finite element program, as described in Fig. 9.

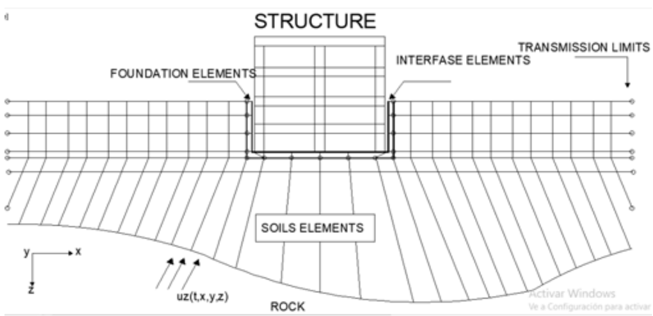
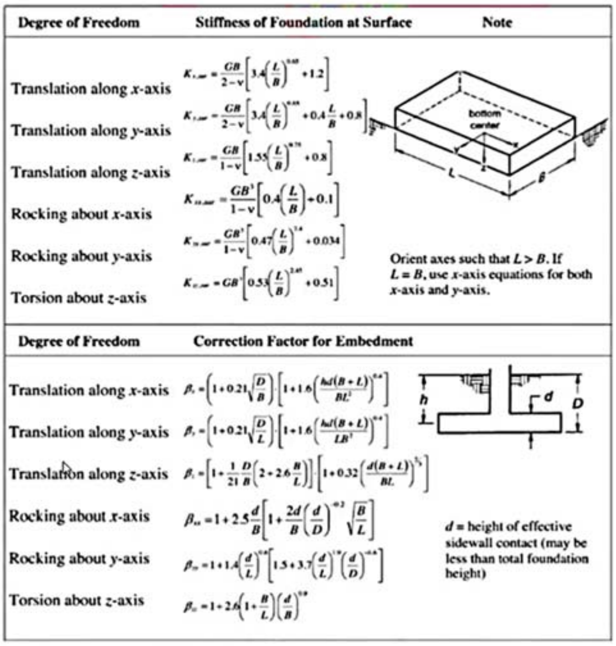



Fig. 3 Discretization method [15]

Structure characteristics: the columns are 300 mm x 300 mm x 10 millimeters and the beams according to plans are mostly made of A36 steel IPE, which vary from # 200 to # 450. The slab has a collaborating plate with a thickness of 25 centimeters and a concrete resistance f'c of 210 kg/cm$^2$.



| Degree of Freedom | Stiffness of Foundation at Surface | Note |
|---|---|---|
| Translation along *x*-axis | $K_{x,sur}=\frac{GB}{2-\nu}\left[3.4\left(\frac{L}{B}\right)^{0.65}+1.2\right]$ | |
| Translation along *y*-axis | $K_{y,sur}=\frac{GB}{2-\nu}\left[3.4\left(\frac{L}{B}\right)^{0.65}+0.4\frac{L}{B}+0.8\right]$ | |
| Translation along *z*-axis | $K_{z,sur}=\frac{GB}{1-\nu}\left[1.55\left(\frac{L}{B}\right)^{0.75}+0.8\right]$ | |
| Rocking about *x*-axis | $K_{xx,sur}=\frac{GB^3}{1-\nu}\left[0.4\left(\frac{L}{B}\right)+0.1\right]$ | |
| Rocking about *y*-axis | $K_{yy,sur}=\frac{GB^3}{1-\nu}\left[0.47\left(\frac{L}{B}\right)^{2.4}+0.034\right]$ | Orient axes such that $L > B$. If $L = B$, use *x*-axis equations for both *x*-axis and *y*-axis. |
| Torsion about *z*-axis | $K_{zz,sur}=GB^3\left[0.53\left(\frac{L}{B}\right)^{2.45}+0.51\right]$ | |

| Degree of Freedom | Correction Factor for Embedment | Note |
|---|---|---|
| Translation along *x*-axis | $\beta_x=\left(1+0.21\sqrt{\frac{D}{B}}\right)\cdot\left[1+1.6\left(\frac{hd(B+L)}{BL^2}\right)^{0.4}\right]$ | |
| Translation along *y*-axis | $\beta_y=\left(1+0.21\sqrt{\frac{D}{L}}\right)\cdot\left[1+1.6\left(\frac{hd(B+L)}{LB^2}\right)^{0.4}\right]$ | |
| Translation along *z*-axis | $\beta_z=\left[1+\frac{1}{21}\frac{D}{B}\left(2+2.6\frac{B}{L}\right)\right]\cdot\left[1+0.32\left(\frac{d(B+L)}{BL}\right)^{2/3}\right]$ | |
| Rocking about *x*-axis | $\beta_{xx}=1+2.5\frac{d}{B}\left[1+\frac{2d}{B}\left(\frac{d}{D}\right)^{-0.2}\sqrt{\frac{B}{L}}\right]$ | *d* = height of effective sidewall contact (may be less than total foundation height) |
| Rocking about *y*-axis | $\beta_{yy}=1+1.4\left(\frac{d}{L}\right)^{0.6}\left[1.5+3.7\left(\frac{d}{L}\right)^{1.9}\left(\frac{d}{D}\right)^{-0.6}\right]$ | |
| Torsion about *z*-axis | $\beta_{zz}=1+2.6\left(1+\frac{B}{L}\right)\left(\frac{d}{B}\right)^{0.9}$ | |

Fig. 4 Impedance functions

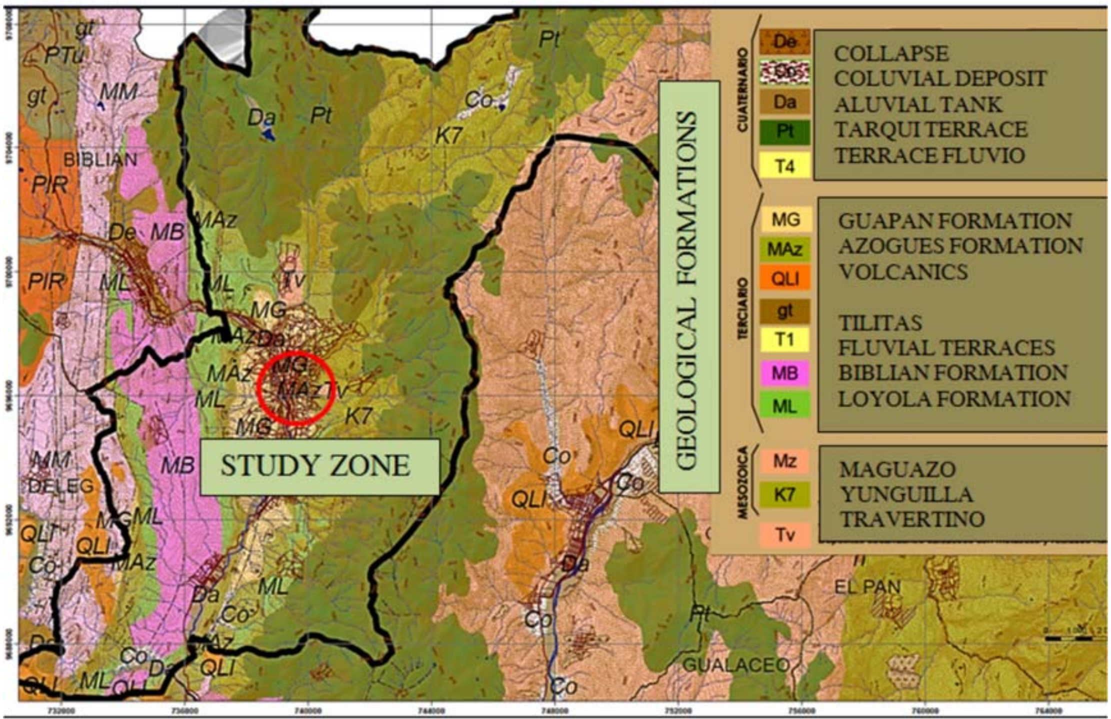



Fig. 5 Classification of soils according to NEHRP [16]

1. Model 1: Recessed Base

The structure is recessed as a structural modeling is normally carried out in accordance with the NEC [20], in which it is stated that the design spectra must have 85% of the basal stress, that is, they must have modal calibration for that requirement. As such, the vibration periods of the rigid base structure are presented in Fig. 9; in the same way, the drifts obtained are in Table IV.

2. Model 2: Spring Base

In the first place, the factors of the impedance functions are calculated, which are equations that allow the calculation of stiffnesses and damping in the main directions of the foundation, taking into account the underground foundation and the flexibility of the existing soil.

| Site Class | Effective Peak Acceleration, $S_{XS}/2.5^a$ $S_{XS}/2.5 = 0$ | $S_{XS}/2.5 = 0.1$ | $S_{XS}/2.5 = 0.4$ | $S_{XS}/2.5 = 0.8$ |
|---|---|---|---|---|
| A | 1.00 | 1.00 | 1.00 | 1.00 |
| B | 1.00 | 1.00 | 0.95 | 0.90 |
| C | 1.00 | 0.95 | 0.75 | 0.60 |
| D | 1.00 | 0.90 | 0.50 | 0.10 |
| E | 1.00 | 0.60 | 0.05 | b |
| F | b | b | b | b |

Fig. 6 Shear modulus as a function of effective acceleration

TABLE II A
FINAL CHARACTERISTIC VALUES: WAVE SPEEDS

| Seismic line executed | Defined strata: number of layers present | stratum variation (m) | stratum power (H) | Wave speeds: Vp (m/s) | Vs (m/s) |
|---|---|---|---|---|---|
| LS -1 | 1 | 0.0-4.5 | 4.5 | 878 | 510 |
| | 2 | 4.5-30 | 25.5 | 1018 | 620 |
| LS -2 | 1 | 0.0-1.0 | 1 | 1288 | 788 |
| | 2 | 1.0-30 | 29 | 1560 | 930 |
| LS -3 | 1 | 0.0-12 | 12 | 1080 | 660 |
| | 2 | 12.0-30 | 18 | 1145 | 700 |

TABLE II B
FINAL CHARACTERISTIC VALUES: CAPACITIES

| Specific weight | Allowable capacity | Cutting module | Poisson's ratio | Young module |
|---|---|---|---|---|
| $KN/^3$ | q (kg/cm$^2$) | G (KN/m$^2$) | v ( - ) | E (KN/m^2) |
| 17.42 | 296.12 | 461843.62 | 0.25 | 1150352.15 |
| 18.08 | 448.27 | 708273.99 | 0.21 | 1707195.81 |
| 19.17 | 604.25 | 1213423.42 | 0.2 | 2914385.87 |
| 20.11 | 935.16 | 1773078.72 | 0.22 | 4341652.31 |
| 18.34 | 403.58 | 814563.19 | 0.2 | 1958161.75 |
| 18.61 | 434.34 | 929776.19 | 0.2 | 2234424.24 |

TABLE II C
FINAL CHARACTERISTIC VALUES: MODULES

| Endometric module | Bulk module | Ballast module | Dominant period |
|---|---|---|---|
| Ec (KN/m$^2$) | kb (KN/m$^2$) | k (KN/m$^3$) | T (s) |
| 348511.17 | 753019.96 | 1224031.38 | 0.16 |
| 562950.08 | 965107.46 | 1782225.69 | |
| 969653.9 | 1623942.75 | 3086952.44 | 0.12 |
| 1375331.29 | 2624869.92 | 4571710.37 | |
| 650045.5 | 1095060.16 | 2041436.14 | 0.1 |
| 742340.27 | 1247971.54 | 2329076.87 | |

Initial data: according to the geophysical study and the structural plan, we have the starting data in Fig. 11 for the calculation of stiffnesses.

The procedure for the values of the impedance factors in terms of stiffnesses and rotations is as follows:

- It begins with the calculation of stiffnesses and rotations, taking into account the units according to the geophysical study.
- Depending on the positioning of the shoes, a correction factor "ß" is calculated.

Fig. 7 Equipment used for the Seismic Refraction test

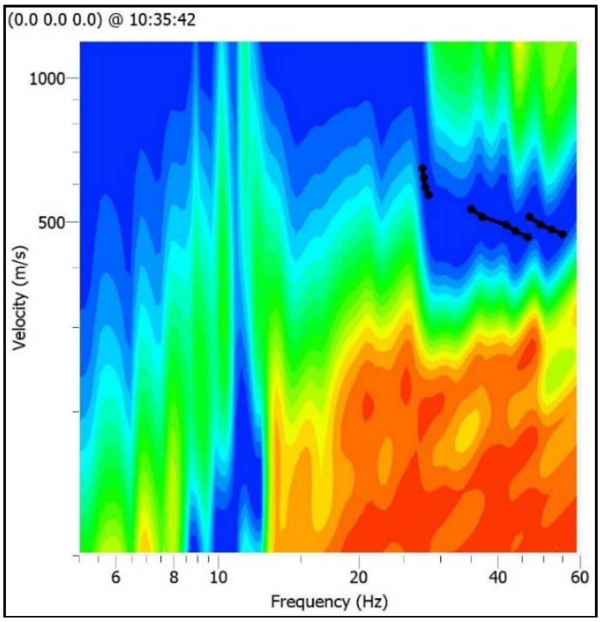



Fig. 8 LS dispersion curve - 1

TABLE III
MODAL PARTICIPATING RATIOS: RECESSED BASE

| Case | No. | Period(s) |
|---|---|---|
| MODAL | 1 | 0.793096 |
| MODAL | 2 | 0.713611 |
| MODAL | 3 | 0.568602 |
| MODAL | 4 | 0.227405 |
| MODAL | 5 | 0.225566 |
| MODAL | 6 | 0.223137 |
| MODAL | 7 | 0.222386 |
| MODAL | 8 | 0.221274 |
| MODAL | 9 | 0.220606 |
| MODAL | 10 | 0.220222 |
| MODAL | 11 | 0.203456 |
| MODAL | 12 | 0.188807 |

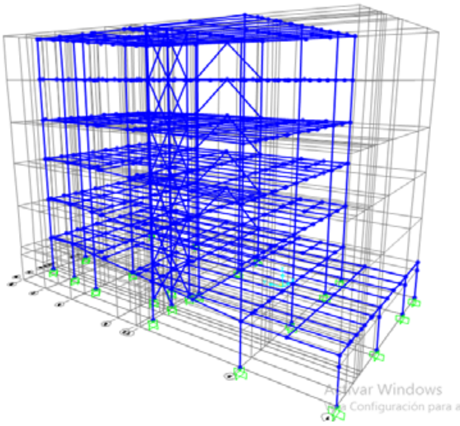


Fig. 9 Recessed base model

The dynamic stiffness components depend on the position of the shoe and also on the existing terrain data. One of the ways to calculate the aforementioned functions is presented, starting with the main "k" rigidities and their corrections. Once all these values have been obtained, the process occurs in each assigned support, by assigning springs with restrictions, depending on whether the footing is isolated or continuous, the initial input data varies, the table of values of one of the columns from the structure.

TABLE IV
DRIFT DUE TO PERMANENT LOAD: RECESSED BASE

| UX | UY | UZ | PISO | Δ (m) | H (m) |
|---|---|---|---|---|---|
| 0.0005 | 0.0004 | 0.0006 | PO | 0.0006 | 2.7 |
| 0.0005 | 0.0004 | 0.0006 | P1 | 0.0005 | 3.24 |
| 0.0005 | 0.0004 | 0.0006 | P2 | 0.0010 | 3.24 |
| 0.0005 | 0.0004 | 0.0006 | P3 | 0.0014 | 3.06 |
| 0.0005 | 0.0004 | 0.0006 | P4 | 0.0019 | 3.06 |
| 0.0005 | 0.0004 | 0.0006 | P5 | 0.0021 | 3 |

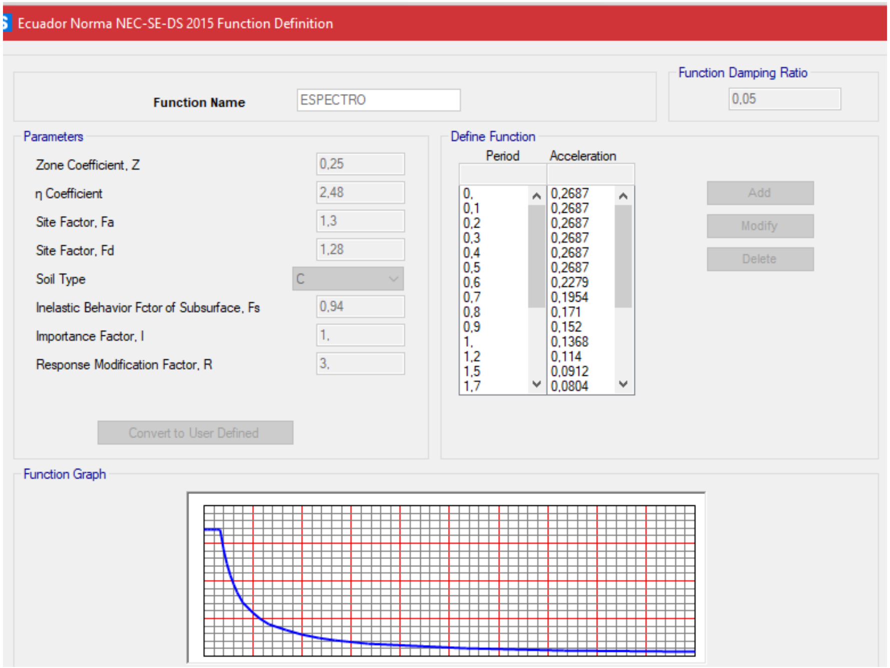
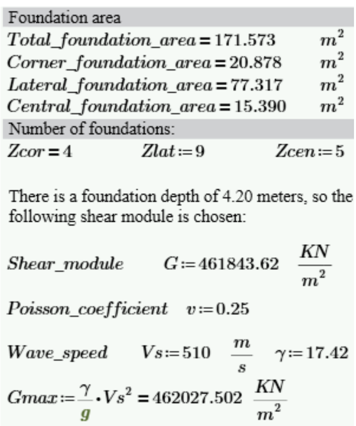



Fig. 10 Spectrum according to NEC



Foundation area

$Total\_foundation\_area = 171.573 \quad m^2$

$Corner\_foundation\_area = 20.878 \quad m^2$

$Lateral\_foundation\_area = 77.317 \quad m^2$

$Central\_foundation\_area = 15.390 \quad m^2$

Number of foundations:

$Zcor = 4 \qquad Zlat := 9 \qquad Zcen := 5$

There is a foundation depth of 4.20 meters, so the following shear module is chosen:

$Shear\_module \quad G := 461843.62 \; \frac{KN}{m^2}$

$Poisson\_coefficient \quad v := 0.25$

$Wave\_speed \quad Vs := 510 \; \frac{m}{s} \quad \gamma := 17.42$

$Gmax := \frac{\gamma}{g} \cdot Vs^2 = 462027.502 \; \frac{KN}{m^2}$

Fig. 11 Foundation area [19]

The model with springs obtained is shown in Fig. 13. Concerning the results in Fig. 13, in regard to the vibration periods, the Summary table, Table VI, is available. The drifts obtained are given in Tables V and VI.

## III. Comparison between a Rigid Base and Base with Springs

The characteristic parameter of a structural model is the period of vibration. In view of that, in this research work, the effects of the soil on the substructure or foundation are considered to contrast the performance guidelines in terms of their drifts and periods.

As a general indicator, it is known that the modes of participation of the structure are the three initial ones, since the participation of the structure is found in those.

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$$G = 461843.62 \ \frac{KN}{m^2}$$

$$v = 0.25$$

$$D := 1.50 \ m$$

$$B := 1.40 \ m$$

$$h := 1.0 \ m$$

$$L := 1.40 \ m$$

$$d := 0.55 \ m$$

$$Kxsur := \frac{G \cdot B}{2 - v} \cdot \left(3.4 \cdot \left(\frac{L}{B}\right)^{0.65} + 1.2\right) = 1699584.522 \ \frac{KN}{m}$$

$$Kysur := \frac{G \cdot B}{2 - v} \cdot \left(3.4 \cdot \left(\frac{L}{B}\right)^{0.65} + 0.4 \cdot \frac{L}{B} + 0.8\right) = 1699584.522 \ \frac{KN}{m}$$

$$Kzsur := \frac{G \cdot B}{1 - v} \cdot \left(1.55 \cdot \left(\frac{L}{B}\right)^{0.75} + 0.8\right) = 2025954.013 \ \frac{KN}{m}$$

$$Kxxsur := \frac{G \cdot B^3}{1 - v} \left(0.4 \cdot \left(\frac{L}{B}\right) + 0.1\right) = 844865.929 \ \frac{KN \cdot m}{rad}$$

$$Kyysur := \frac{G \cdot B^3}{1 - v} \left(0.47 \cdot \left(\frac{L}{B}\right)^{2.4} + 0.034\right) = 851624.856 \ \frac{KN \cdot m}{rad}$$

$$Kzzsur := G \cdot B^3 \left(0.53 \cdot \left(\frac{L}{B}\right)^{2.45} + 0.51\right) = 1317990.849 \ \frac{KN \cdot m}{rad}$$

$$\beta x := \left(1 + 0.21 \cdot \sqrt{\frac{D}{B}}\right) \cdot \left(1 + 1.6 \cdot \left(\frac{h \cdot d \cdot (B + L)}{B \cdot L^2}\right)^{0.4}\right) = 2.763$$

$$\beta y := \left(1 + 0.21 \cdot \sqrt{\frac{D}{B}}\right) \cdot \left(1 + 1.6 \cdot \left(\frac{h \cdot d \cdot (B + L)}{B \cdot L^2}\right)^{0.4}\right) = 2.763$$

$$\beta z := \left(1 + \frac{1}{21} \cdot \frac{D}{B} \cdot \left(2 + 2.6 \cdot \frac{B}{L}\right)\right) \cdot \left(1 + 0.32 \cdot \left(\frac{d \cdot (B + L)}{B \cdot L}\right)^{\frac{2}{3}}\right) = 1.571$$

$$\beta xx := 1 + 2.5 \cdot \frac{d}{B} \cdot \left(1 + \frac{2 \cdot d}{B} \cdot \left(\frac{d}{D}\right)^{-0.2} \cdot \sqrt{\frac{B}{L}}\right) = 2.925$$

$$\beta yy := 1 + 1.4 \cdot \left(\frac{d}{L}\right)^{0.6} \cdot \left(1.5 + 3.7 \cdot \left(\frac{d}{L}\right)^{1.9} \cdot \left(\frac{d}{D}\right)^{-0.6}\right) = 3.114$$

$$\beta zz := 1 + 2.6 \cdot \left(1 + \frac{B}{L}\right) \cdot \left(\frac{d}{B}\right)^{0.9} = 3.243$$

$$Kxe := Kxsur \cdot \beta x \cdot \frac{Corner\_foundation\_area}{Total\_foundation\_area} \cdot \frac{1}{Zcen} = 95372.106$$

$$Kye := Kysur \cdot \beta y \cdot \frac{Corner\_foundation\_area}{Total\_foundation\_area} \cdot \frac{1}{Zcen} = 95372.106$$

$$Kze := Kzsur \cdot \beta z \cdot \frac{Corner\_foundation\_area}{Total\_foundation\_area} \cdot \frac{1}{Zcen} = 64637.46$$

Fig. 12 Stiffnesses and rotations of interest - foundation [19]

When the base is rigid compared to that of springs, a significant difference is obtained in terms of modal share values, so structural and geotechnical effects should be included more often to the foundation.

The indicative of the period of vibration is a very important factor, and the resonance issue of a structure should be evaluated to reach 90% of its behavior [20].

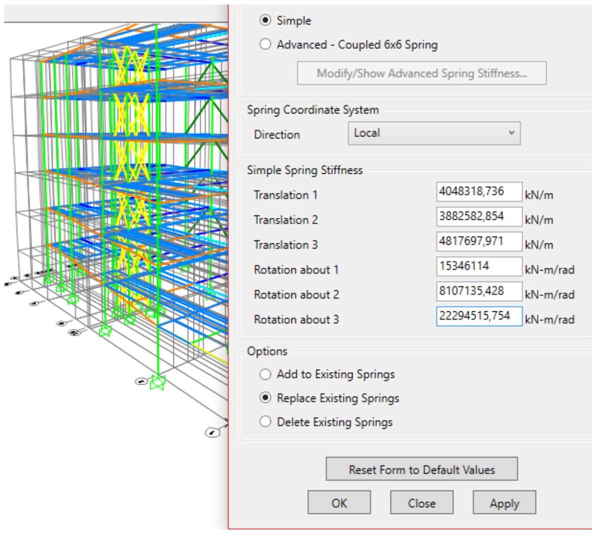


Fig. 13 Introduction of stiffnesses and rotations – foundation

TABLE V
MODAL PARTICIPATING RATIOS: MODEL WITH SPRINGS

| Case | No. | Period(s) |
|---|---|---|
| MODAL | 1 | 0,8735804 |
| MODAL | 2 | 0,7860325 |
| MODAL | 3 | 0,6311943 |
| MODAL | 4 | 0,2504898 |
| MODAL | 5 | 0,2483756 |
| MODAL | 6 | 0,2456399 |
| MODAL | 7 | 0,2446477 |
| MODAL | 8 | 0,2434421 |
| MODAL | 9 | 0,2426743 |
| MODAL | 10 | 0,2423674 |
| MODAL | 11 | 0,2239666 |
| MODAL | 12 | 0,2082817 |

TABLE VI
DRIFT DUE TO PERMANENT LOAD: MODEL WITH SPRINGS

| UX | UY | UZ | PISO | Δ (m) | H (m) |
|---|---|---|---|---|---|
| 0.0001 | 0.0001 | 0.0001 | PO | 0.0004 | 2.7 |
| 0.0003 | 0.0002 | 0.0001 | P1 | 0.0006 | 3.24 |
| 0.0007 | 0.0003 | 0.0002 | P2 | 0.0010 | 3.24 |
| 0.0011 | 0.0005 | 0.0002 | P3 | 0.0014 | 3.06 |
| 0.0015 | 0.0008 | 0.0002 | P4 | 0.0020 | 3.06 |
| 0.0020 | 0.0010 | 0.0002 | P5 | 0.0022 | 3 |

TABLE VII
PERIOD COMPARISON

| Mode | Embedment Base | Spring Base |
|---|---|---|
| First | 0.793096 | 0.8735804 |
| Second | 0.713611 | 0.7860325 |
| Third | 0.568602 | 0.6311943 |

Regarding drifts, it must be verified according to current regulations in the country which specify that certain amounts are not exceeded according to the structure, in this case we take the value for metallic structure.

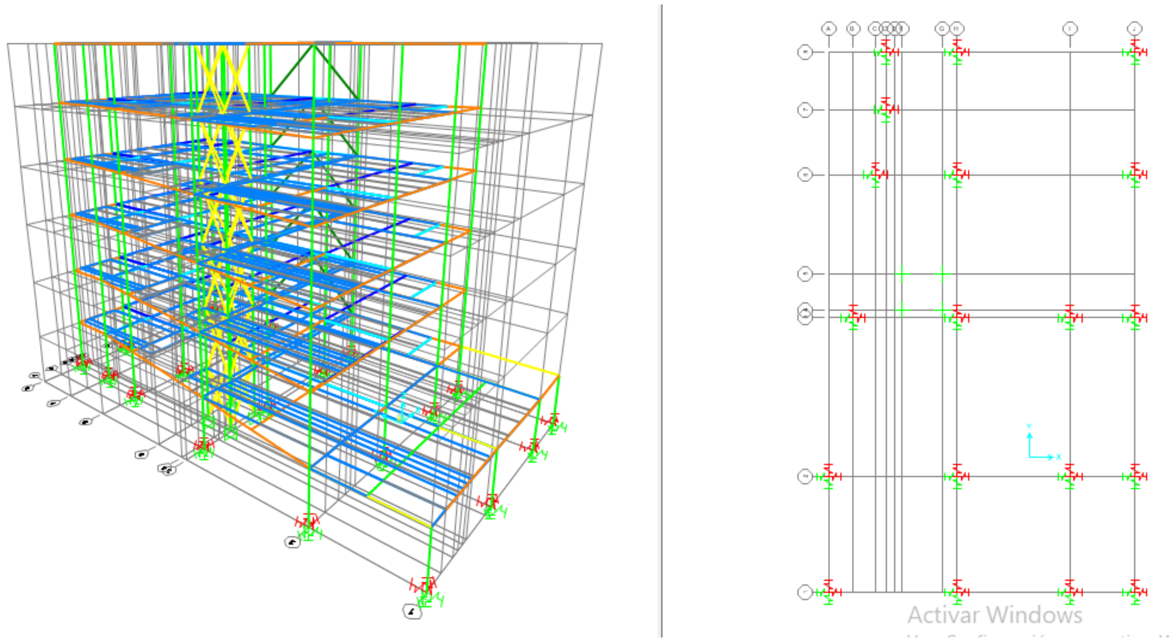


Fig. 14 Model with springs

TABLE VIII
PERMISSIBLE DRIFT ACCORDING TO NEC

| Structures | Maximum Drift (-) |
|---|---|
| Concrete | 0.02 |
| Masonry | 0.01 |

MAXIMUM INELASTIC DRIFT LIMIT = 0.75 * R * Δ
0.0022 * 0.75 * 3 = 0.004995

So, it is below the limit. By the same token, there are drifts obtained in both models.

TABLE IX
DRIFT COMPARISON

| Model | Embedment Base | Spring Base |
|---|---|---|
| Maximum Drift (m) | 0.00214 | 0.00220 |

It is observed that although the structure was approved by the competent entity, it does not effectively satisfy the vertical displacements of the normed Table IX, however, they are acceptable, but not conservative. The model with springs represents similar values, so the geotechnical effect in this sense was similar in terms of their vertical movements.

## IV. CONCLUSIONS

To establish the shear modulus, Poisson's ratio and wave velocity geophysical tests were carried out in the field and also corroborated by the ASCE formulations.

A rigid base represented by embedments assumes that the terrain is not real, therefore it does not represent its different movements demonstrated in the seismic exploration lines. A more realistic result in the analysis of structural-geotechnical effects when modeling a structure is given with the basis in which springs are included through the impedance functions.

The impedance functions include dynamic parameters such as the shear modulus and wave velocity obtained from geophysical tests, which were verified mathematically with the formulations of interest. The wave velocity and its exploration lines were taken at depths of 30 meters according to the regulations; however, for the analysis, the Vs30 is taken at the depth of the study foundation.

When replacing an embedment with springs, different behaviors are obtained in the vibration modes parameters by approximately 8% when it comes to a mid-rise building.

It is concluded that, by not including the structural-geotechnical effect in an infrastructure modeling, several fundamental criteria are omitted that would generate chain errors in the constitutive design.

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