

Acceleration in the Building Floors Using the Seismo-Geodynamic Theory

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Abstract

The experience has indicated the importance in the seismic behavior of buildings and in the structural problems taking place in the upper floors of tall buildings, during destructive earthquakes. The interest has aroused in the application of the "Seismo-geodynamics Theory" to solve the seismic problems of the subsoil and foundations, and the method to calculate the acceleration in the floors of buildings because of the seismic effect of the vertical and horizontal rotations of the foundation, and to verify if the structure of the building can take safe the seismic forces. An important seismic observation was made by the author in 1962, from the recorded pseudo-acceleration response spectrums, obtained at the ground surface of the Central Park and those obtained at the base of the rigid foundation of the Tower Latino Americana in Mexico City. The author found that the ratio of the accelerations for 10.0% critical damping between these two places, less than one hundred meters apart, showed that the rigid box type foundation of the "Tower Latino" suffered only on the order of 50% to 60% of the acceleration with respect to the spectral acceleration at the ground surface in the Central Park. The above observation was verified theoretically by the author.

Keywords: *Seismo-geodynamics, application, subsoil, foundation, building floors.*

Resumen

La experiencia ha indicado la importancia que tiene el comportamiento sísmico de los edificios y los problemas estructurales que se ocasionan en los pisos altos durante sismos destructivos. Se ha despertado interés en la aplicación de la "Teoría de la sismo-geodinámica" para resolver problemas sísmicos del subsuelo y cimentaciones, además del método para calcular la aceleración en los pisos de los edificios, debido a la acción sísmica que produce la rotación vertical y horizontal de la cimentación, y así verificar si la estructura del edificio puede tomar con seguridad las fuerzas sísmicas. Una observación importante fue hecha por el autor en el año de 1962, en registros de los espectros de respuesta de pseudo-aceleración, obtenidos en la superficie del suelo en la "Alameda Central" y los obtenidos en la base de la cimentación rígida de la Torre Latino Americana en la Ciudad de México. El autor encontró que la relación de las aceleraciones para el 10.0% de amortiguamiento crítico entre estos dos lugares distanciados menos de 100 metros, mostraron que la cimentación rígida de tipo cajón de la "Torre Latino" sufrió solo del orden de 50% a 60%, con respecto a la aceleración correspondiente a la superficie de la "Alameda Central". La observación descrita fue verificada teóricamente por el autor.

Descriptores: Sismo-geodinámica, aplicación, subsuelo, cimentación, pisos de los edificios.

I. Introduction

Because of the interest that has aroused in the application of the Seismo-Geodynamics theory to solve seismic problems in the sub soil and foundations, the author has revised and enlarged the original version of this work "Sgedfalt" published in December 1999, now the author presents here again the method to calculate the acceleration in the floors of buildings by means of the seismo-dynamic theory.

It is very important to foresee the dynamic force to which the objects on the floors of buildings may be subjected and to verify if the structure of the building can take the seismic forces.

The experience has indicated the importance in the seismic behavior of buildings, and the structural problems in the upper floors of tall buildings, during destructive earthquakes. The acceleration in the top floors is much higher than the acceleration assigned at the ground surface, "Because of the effect of the vertical and horizontal seismic rotations of the foundation".

Knowing the acceleration to each floor of the building and the individual mass of the objects. The seismic force in each one of them may be calculated by means of the following dynamic law $Force = Mass \times Acceleration$, (Newton), thus being able to fix on the floor the objects with sufficient strength to avoid displacement or overturning. In the same way knowing the acceleration and the floor mass, the dynamic force acting in each floor level can be calculated and the structural resistance and lateral displacements verified.

Furthermore, the knowledge of the relative displacement between the floors are required to foresee the gap to be given in the construction to the floating walls, windows and stairways between floors, and to take into account the dynamic distortion induced in them as well as in other architectural elements.

An important seismic observation was made by the author in 1962, from the recorded pseudo-acceleration response spectrums, obtained at the ground surface at the Alameda Central and those obtained at the base of the rigid foundation of the Tower Latino Americana in Mexico City (Figure 1).

Notice in figure 1, that the ratio of the accelerations for 5.0% critical damping between these two places, one hundred meters apart, show at the rigid box type foundation of the L.A. Tower to a total depth of 16 meters of the "Sheet Piles", that the L.A. Tower shows only on the order of 50% pseudo-acceleration with respect to the spectral acceleration at the ground surface in the Alameda Park (Figure 1).

The above observation was verified theoretically by the author, by means of an analysis he developed and named "The Seismo-Geodynamic Theory", using the soil dynamics physical information of the site. The result of the calculation is shown in figure 2. Where the stratigraphy of the sub-soil is reported, also the quantitative dynamic parameters corresponding to the site in question. The analysis in numerical and graphical form shows that the acceleration at the depth of the foundation grade elevation is on the order of 59% of the value given by the response acceleration spectrum at the ground surface, hence, the theoretical calculation is coincident with the response of the acceleration spectrums, shown in figure 1.

The phenomenon herein reported has been observed in other places. Therefore, the conclusion is that the acceleration imposed to the buildings correspond to that one the seismic wave induces at the foundation grade elevation. Therefore this value is a function of the foundation depth.

On account of this unexpected important seismic phenomenon, the author was motivated to continue investigating the seismic effects in buildings and other seismic problems of ground displacements, distortions. Stresses and accelerations, that is to improve as much as possible the practical use of "The Seismo-Geodynamic Theory".

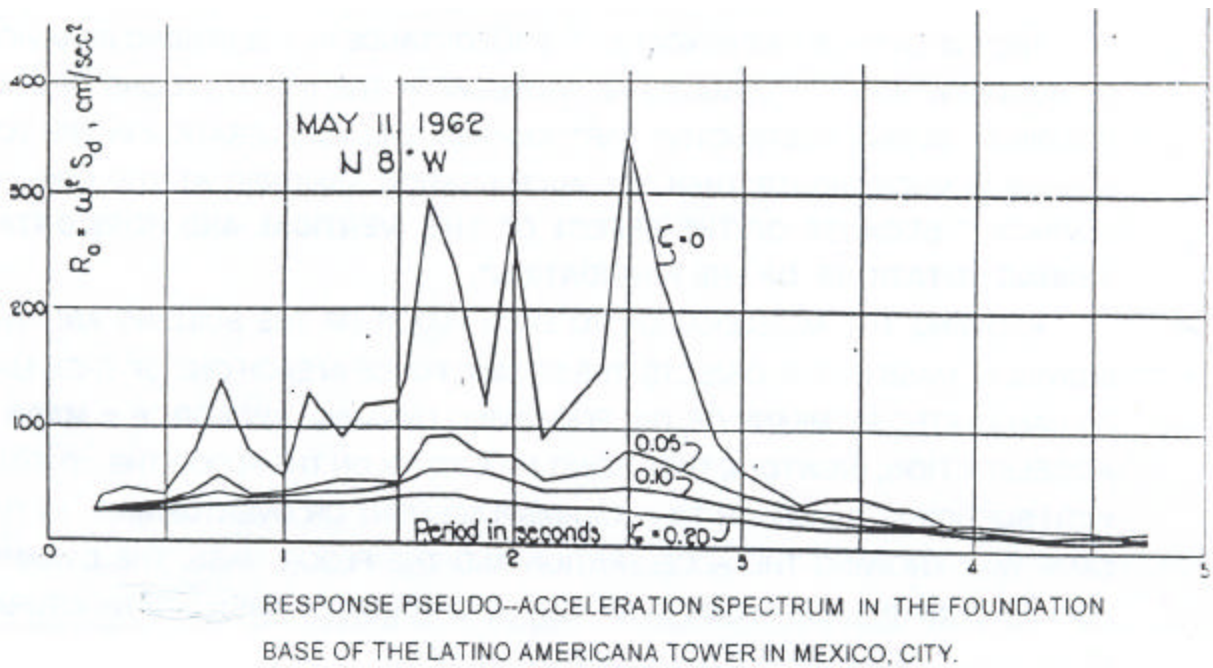
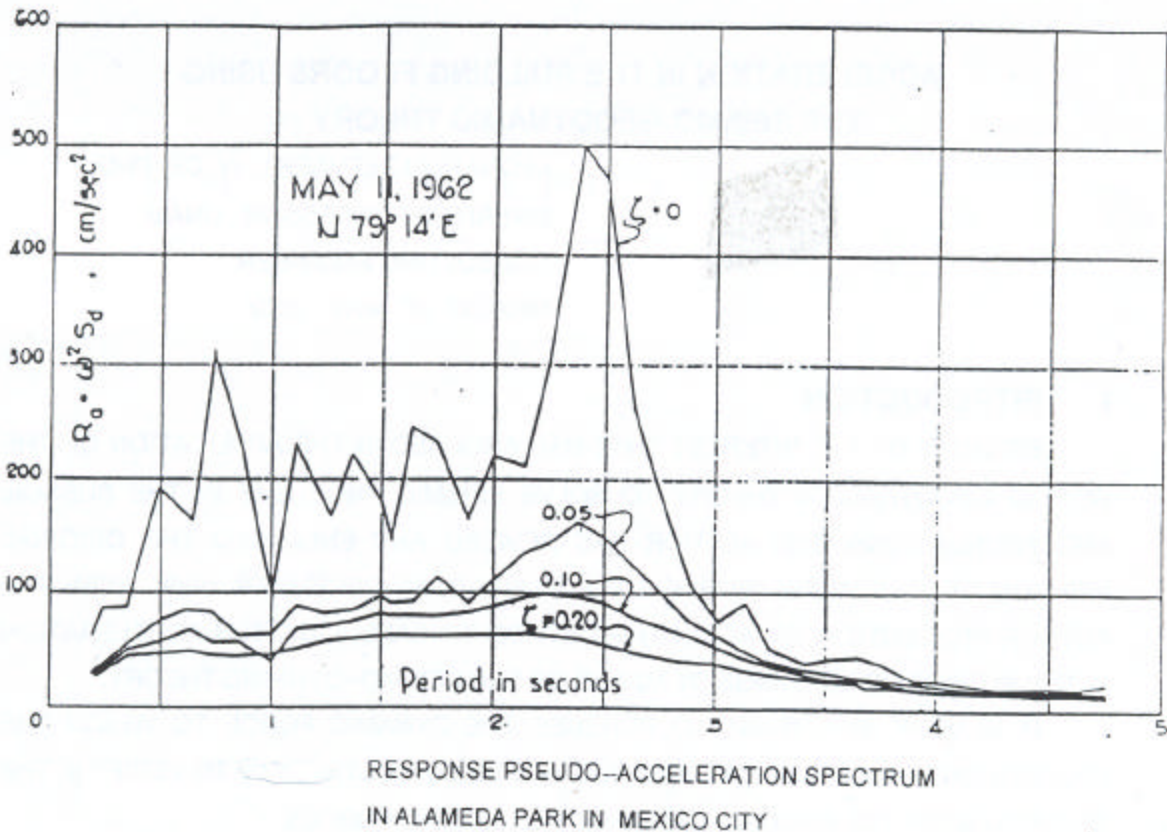


Figure 1. Response Pseudo-Acceleration Spectrums (9) (Zeevaert, 1972-1982)

II. Information on the Problem

An illustrative analysis is presented ahead, for a building acted by the horizontal component of the seismic surface wave, applying the concepts introduced here by the author.

The building is located in the area of Mexico City and will be analyzed by means of the seismo-geodynamic theory. The building has 6 floors including the roof level, and will be supported on a monolithic concrete box type "Lez" foundation at a depth of 6 meters containing a basement (11) (Zeevaert, 1998b).

The building foundation has a width of 12 meters and a length of 24 meters. The structure will be formed of two rows of columns in the longwise direction and separated in the transversal direction 12.0 meters, forming structural bents every 4 meters. The analysis of the factors pertaining the computation will be analyzed with a surface unit or bital acceleration of 100 GAL, (1 meter/sec²), corresponding to the horizontal component of the surface wave.

The geometry of the building, the weight on the floors and the foundation as well as the mass of the building and the floors elevation are given in calculation sheet number 1.

The stratigraphy of the site is as follows

Stratum	(z)	(d)	Description
	0	0	Ground Surface
A1	1.0	2.0	Silty-Clayey Sand
S.W.T	3.0		Surface Water Level
A2	6.0	3.0	Silty-Clay Sand
B1	8.50	2.5	Soft Silty Clay
B2	11.0	3.0	Soft Silty Clay
C	15.0	3.0	Soft Silty Clay
D	18.0	3.0	Semi Rigid Silty Clay
E	21.0	3.0	Semi Rigid Silty Clay
F	24.0	3.0	Rigid Silty Clay
G	26.0	2.0	Rigid Silty-Clayey Sand
H	31.0	5.0	Rigid Silty-Clayey Sand
I	<u>35.0</u>	<u>4.0</u>	Rigid Silty-Clay
			Rigid Stratum

(z) Depth of Strata, (d) Thickness of Strata in meters.

III. Seismo-Geodynamic Computations

Theoretically, the celerity of the surface wave is for clayey soils 94% from the celerity of the shear wave. The period takes the approximate value of 6.4% greater than the period of the shear wave (6) (Zeevaert, 1988c). Therefore, the analysis of the shear wave will be made first, to obtain the period corresponding to the surface wave of 1.064 (Ts). The calculation is presented in calculation sheet number 2.

The physical characteristics of the soils, as well as the representative dynamic parameters are registered in calculation sheets 2 and 3. They were carefully determined in the laboratory from specimens of undisturbed soil samples. The dynamic soil rigidity (μ) was determined with "The Torsion free Vibration Pendulum" (1) (Zeevaert).

The values of the dynamic strain moduli, M_{ez} and M_{cx} , were investigated with undisturbed soil samples in "The Hollandish Modified Chamber", designed by the author for this purpose.

The soil sample is confined in the triaxial chamber at a volumetric stress representative of the octahedral field stress, thereafter a torsional vibration is applied to the specimen and the vibration recorded. The above mentioned values correspond to the vertical expansion response (M_{ez}), and (M_{cx}) for the direct horizontal compression. From them the Response Factor is defined as follows

$$\beta_{ex} = M_{ez}/M_{cx} \quad (1)$$

The value of the seismic soil rigidity (μ) and the response factor β_{ex} are found in calculation sheet 2 and 3 respectively (4) (Zeevaert, 1988). In calculation sheet number 2, the maximum resonant period of the ground is presented on the order of 1.850 seconds corresponding to the fundamental period of the subsoil deposit and equivalent to that of the shear wave, hence the period for the

horizontal surface wave is $1.064 \times 1.1.850 = 1.968$ Seg. (5)(Zeevaert, 1996).

The computation for the horizontal component of the surface wave (6)(Zeevaert, 1988c) is given in sheet number 3, from which the following information was obtained with depth: the soil pressures, the seismic pore water pressure, (SPWP), the effective stresses, the horizontal soil displacements and accelerations (7)(Zeevaert, 1998a).

The soil pore water pressure is of vital importance to analyze the soil shear strength in stability problems of sandy soils, as the load capacity in foundations, slope stability, retention walls, seismic stability of the ground surface and other engineering problems induced by destructive earthquakes (4,7)(Zeevaert, 1988b y 1998a) (Photo 1).

For the present case it was found in calculation sheet number 3, that the acceleration at the foundation grade elevation of the building at 6 meter depth, shows on the order of 77 Gal (77cm/sec²) with a displacement of 7.54 cm, corresponding to a surface orbital acceleration of 100 Gal. See calculation sheet number 3, (9)(Zeevaert, 1973-1982, pp. 508).

With the data obtained in calculation sheet number 3, the soil structure interaction was performed for seismic vertical rotation of the building foundation structure (8)(Zeevaert, 1980), this is shown in calculation sheet number 4.

From the mentioned analysis the following results are obtained:

1. Acceleration at the center of mass of the building 1.694 m/seg², and the seismic surface wave period of 1.968 seg.
2. Overturning moment, the building considered rigid 258.48 Tonxm/ml.
3. Coupled Foundation-Rigid structure period found of 1.059 seg.
4. Total shear at the foundation base $1.694 \times 12.11 = 20.51$ Ton/ml.
5. Rigid vertical foundation rotation (θ_v) = 0.00382 Rad.

6. Soil-Foundation contact stresses because of the vertical rotation.

With the information obtained in calculation sheets 1,2,3 and 4, the analysis to find the seismic acceleration in each floor of the building is achieved, as well as the shear forces acting on the structure.

IV. Calculation Sheets 5a y 5b

In calculation sheet 5a, column 4, the horizontal displacements have been computed because of the vertical rotation (θ_v) of the foundation and assuming the building rigid. Hence obtaining a lineal distribution of the displacements in the floors with the height of the building. Furthermore, the displacements because of the flexibility of the floors acted by the shear forces. Have been added.

To obtain the total displacements of the floors it is necessary to add those displacements because of the free period of vibration of the building and obtain finally the accelerations and shears in the floors of the building. See calculation sheet 7b.

Knowing the structure flexibility for each floor (1/k) per lineal meter the total displacements are calculated (S?). This calculation is found in computation sheets number 5a-b. To calculate the acceleration, the coupled period of vibration was used, obtained from the individual periods of the "Structure and foundation rocking", respectively.

The calculation is as follows

$$T_o^2 = T_e^2 + T_s^2 \quad (2)$$

Here

To Equivalent period of the system.

Ts Rocking period of the building, considered rigid.

Te Free period of the building.

See computation sheet number 4.

Computation Sequence

1. From the computation sheet number 5a, the displacements for each floor of the building, induced by the vertical rotation of the foundation are shown in column 4. To obtain this action the foundation rotation is multiplied by the height of the floors, and the acceleration is obtained multiplying the displacements by the square of the coupling circular frequency (Column 9).

Coupling circular frequency $\omega = (2\pi/T_0)$

2. In column 10, the acceleration correction is performed with the help of (DAES) (9) (Zeevaert, 1973-1982) computation sheet number 4, to make it compatible with the amplification of the acceleration of 1.694 M/s^2 , obtained at the center of mass of the building because of the vertical rotation of the foundation corresponding to "The design acceleration envelope spectrum", (Figure 3) (9) (Zeevaert, 1973-1982, pp. 510).

3. In computation sheet 5a, column 11, the acting shear forces are calculated for the floors of the building. They are obtained multiplying the mass by the acceleration corrected with "DAES" for all floors (Column 10). The gradual sum gives the shear force along the height of the building. Columns 12 and 14 indicate the increments of the seismic overturning moment and the sum the corresponding overturning moment to which the different floors of the structure are subjected only because of the vertical rotation (ω_v) of the foundation.

4. In computation sheet 5b the accelerations of the floors may be high because the flexibility of the structure. The accelerations of the floors are obtained multiplying the total displacements (S_v) by the square of the circular frequency $\omega^2 = (6.2832/T_0)^2$, column 10 and the acceleration is adjusted in proportion to "DAES" as shown in column 11.

This value so obtained is multiplied by the mass of the floors per lineal meter, to obtain the floor

shear forces column 12, the sum of the floor shear forces per meter is found in column 13.

The final values for the floor shears and overturning moments correspond to the action of the surface wave, the values obtained are the following; for the base shear 20.64 Ton/m and for the overturning moment 315.66 Tonxm/ml . The soil foundation reaction stresses reported in calculation sheet 4 shall be increased by a factor $315.7/258.48 = 1.22$.

5. In order to verify the total displacements (S_v) and the correct final values for each floor, the calculation is repeated, thus obtaining the new floor shears column 12, the sum of the shear floors is shown in column 13, and the calculation follows in the next columns.

V. The Horizontal Rotation on the Floors

Another important phenomenon is originated in the rigid structure of the foundation, because of the horizontal rotation (ω_h) induced by the equivolumetric shear wave. This action generates important torsion in the building floors, the phenomenon is known as "Torsional Whipping Action", and is present when the structural flexibility is high mainly in the upper floors, as compared with the lower floors.

On account on the former discussion, the higher floors accelerate motivating damage to the structure and collapse in occasions, causing damage to architectural details in the building and the displacement of objects on the floors (Photo 2, 3 and 4).

This phenomenon has been obvious during earthquakes and has been frequently observed in the upper floors of the buildings, and failure of the building "Head Frames". The upper frames are usually designed with minor rigidity, hence with major flexibility, as the interior and lower frames. The head frames are exposed to a stronger seismic torsion. Such phenomenon has been very important in long buildings (Photos 5 and 6).

The torsion is originated by the twist induced in the foundation at the supporting soil stratum by the shear wave (Appendix "B"). The increment in the acceleration in the structural head frames of the building is increased to a value $(a\%)n$, with respect to the symmetrical condition, as an example, this concept will be applied to the building here analyze.

The seismic response of the elements is proportional to the acceleration, this is shown in computation sheet 3a.

Therefore, the increment $(a\%)$ of the actions in the floors can be calculated to determine the shear forces, the accelerations and displacements along the length of the building, at the head-frames and intermediate frames of the building.

With respect to the values of the horizontal rotation (θ) of the rigid building floors, a lineal distribution of the value $(a\%)$ is obtained along the length of the building, permitting the calculation of the building frames. The increment in the displacements, shear forces and torsion moments from the symmetrical values are shown in computation sheet 6.

The theoretical analysis to find in each case the order of magnitude of the value $(a\%)$, is obtained analyzing the rotation originated at the ground surface by the shear wave. The theoretical analysis is presented in appendix B, in which the following is obtained

$$TANG a = Az * T / (6.28 * Cs)$$

The increment for the "Torsional Whipping Action" in shears, accelerations, and displacements in the building head-frames in the present problems is as follows:

- (a) Rotation of the rigid floor of the building.
- Az Orbital acceleration at the supporting stratum for the shear wave, calculation sheet 2 0.99 cm/seg².
- Ts Period of the shear wave 1.85 seg
- Cs Celerity of the supporting stratum 87 cm/seg

d Average displacement of foundation from the surface wave calculation sheet 3 8.93 cm.

L/2 One half the length of the foundation 1 200 cm

TANG a = 0.00338

Displacement for rotation in head-frame

$$d_0 = 4.06 \text{ cm}$$

Symmetrical displacement in the head-frame

$$d = 8.93 \text{ cm}$$

Total at the head-frame

$$(d_0 + d) = 13.0 \text{ cm}$$

Displacement ratio

$$R = 1.45$$

Increment of actions at the head-frame

$$(a\%) = 45\%$$

Call θ (Shear n) = (Shear n) $\times a\%$ the increment of the shear forces per lineal meter, based on the symmetrical case (Shear n), obtained for frames distant (x) from the center of rotation of the floor. Hence, the following value for the shear along the building is

$$(\text{Shear } n)_x = (\text{Shear } n)(1 + a^*(x)/L) \quad (3)$$

The torsion moment of each rigid floor in its plane is

$$T_n = 2(\text{Shear } n)_x a L^2 / 3 \quad (4)$$

Here (L) is one half the length of the building. The result of the calculation of the "Torsional Whipping Action", is presented in computation sheet number 6.

VI. Structural Period of Vibration of the Building Computation Sheets 7a and b

The free period of vibration of the building is calculated with the well known method of "Holzer", used for the present problem in computation sheet 7b where the value is $T_e = 0.50$ seg.

Nevertheless, the author gives a method based on seismo-geodynamics, to find the period. This method is the same as the one applied to obtain the period of vibration of the soil mass. Here the Average Celerity of the shear wave is used, traveling across the building structure.

In order to achieve the mentioned method it is necessary to establish the correlation between the average of the dynamic rigidity shear modulus (μ) with the average rigidity (K) of the building structure, also the correlation between the unit soil mass (?) with the unit mass corresponding to the floors weight of the building (Appendix A).

The following is obtained per floor

For (μ), the structural equivalence is (K)d/B, Ton/m²

For (?), the equivalence is M/Bd, Ton*Seg²/m⁴

The wave celerity of the building structure per floor is (C_z), and the average celerity of the wave (C_m).

$$C_z^2 = (K) \cdot d^2 / m \quad (5)$$

Here

- (K) Structural rigidity per floor and per lineal meter, Ton/m.
- M Mass per floor and per lineal meter, Ton*Seg²/m.
- B Width corresponding to the base of the building.
- d Height between floors.

Knowing the average celerity C_m and the height of the building (H) from the support at the foundation base, the period calculated

$$T_e = 4 \cdot (H) / C_m, \text{ Seg} \quad (6)$$

The period of vibration obtained with this method for the proposed building is $T_e = 0.498$ seg, and used in computation sheets 4, 5a and 5b.

VII. Computation Sheet 8

Shows a table to facilitate the verification in the selection of column dimensions, to establish the proper rigidities to take the seismic moments, axial and shear forces to which the building structure is subjected, taking in consideration the important "Torsional Whipping Action" in the structural frames of the building, (Calculation sheet 6).

VIII. Conclusions

Here is given a method of computation with the help of the "The Seismo-Geodynamic Theory" to analyze the accelerations in the floors of buildings, and be able to foresee the forces acting on all and each one of the floors, and calculate the necessary force to fix the objects to the floor, and analyze the building structure in order to withstand the seismic forces for the assigned surface acceleration.

Note, that the soil acceleration at the foundation grade elevation is on the order of 77 cm/seg² for 100 cm/seg² at the ground surface, and in the case of normal "Whipping Action" without torsion including the flexibility of the proposed building structure. The acceleration at the foundation grade elevation is 169.4 cm/seg² and at the roof floor of the building is on the order of 251.5 cm/seg² (Computation sheet 5b).

When the torsional whipping is considered then this value increases to $1.45 \cdot 251.5 = 364.66$ m/seg² at the Head-Frame the above phenomenon indicates the importance to learn on the seismic stability of the building.

Therefore, when the phenomenon here in described is not properly considered in design, to resist adequately the destructive seismic forces, and because of excessive structural flexibility (1/K), and the displacements in the floors are not restricted, then damage may be expected and even structural collapse. During destructive earthquakes (9) (Zeevaert, 1973-1982) these actions have been frequently observed in Mexico City and other cities (Photos 1-6).

"The Torsional Whipping Action" takes place in all the floor levels of the building induced by the

combined vertical (δ_v) and horizontal (δ_h) rotations on the foundation. Hence, when the structure shows very flexible it is necessary to reduce its flexibility.

"Torsional Whipping Action" is frequently present in buildings during destructive earthquakes, the head-frames take the worst of the torsional rotation of the building with larger forces in all intermediate frames, than for the symmetrical case. Hence, it is necessary to reinforce them, accordingly with the results of the calculation as here described.

Computation sheet 8 gives a procedure to facilitate the election of the size of columns and the rigidity of the frames for the building structure.

The author calls to the importance on the study and knowledge of the seismic physical conditions of the sub soil at the site, as the stratigraphy and the quantitative dynamical soil properties in all the strata forming the sub soil deposit for the required depth. The seismo-geodynamic behavior of the sub soil has an important and basic bearing in the calculation results on the seismic forces acting in the structure of the building and its foundation, as well as in any other seismic problem pertaining the soil deposit.

Gratitude

Finally, the author wishes to acknowledge the assistance of his secretary Zita del Carmen Vázquez for her interest in helping to obtain a better and cleaner edition of the subject, and not less, to her former secretary and now teacher Diana Alpizar de Balseca for the orthographical manuscript revision.

Understanding nature's phenomena is a time difficult task, for the scientist engineer, to discover without despair"

Leonardo Zeevaert W. (1984).

IX. Appendix A

Analysis to find the Structural Celerity of the Buildings, Related to the Soil Celerity in Seismo- Geodynamics, the soil celerity in Seismo-Geodynamics is given as follows:

$$C^2_s = \mu / \rho, \text{ (m/s)}^2 \quad (1)$$

The dynamic soil rigidity for the shear stress distortion is

$\mu = \tau / \gamma$ Ton/m², and the unit mass $\rho = W/g$, Ton*Seg²/m⁴, and W is the unit weight Ton/m³.

The distortion in a vertical section "d" is $\gamma = \delta/d$, here δ is the relative horizontal displacement of the vertical section "d" hence

$$\mu = \tau * d / \delta \quad (2)$$

For the structure the rigidity per floor and lineal meters is $K = F / \delta$ or $K = \tau * B / \delta$ in Ton/m², from which according to (2) (Zeevaert) the following is obtained

$$\mu = \frac{K * d}{B}, \text{ Ton/m}^2 \quad (3)$$

In the structure the mass per floor and lineal meter $M = w * d * B / g$, in Ton*Seg²/m², and the equivalent unit mass is

$$\rho = M / B * d, \text{ Ton*Seg}^2/\text{m}^4 \quad (4)$$

From the former analysis, the structural celerity for the structure is governed by the following formula

$$C^2_s = \frac{K * d^2}{M}, \text{ (m/s)}^2 \quad (5)$$

X. Appendix B

Foundation Maximum Angle of Torsion because of the Seismic Equivolumetric or Shear Wave. Horizontal Rotation of the Box Type Foundation

The equation governing the shear wave, for $z=0$

$$Y_{xy} = Y_o \cos(2\pi z/H) \sin(2\pi x/L - \omega t) \quad (1)$$

Here for $z=0$

Y_{xy} Horizontal shear displacement

Y_o Maximum horizontal surface shear displacement

T Wave period and length $L = T \cdot C_s$

t Any time

X Position coordinate

C_s Wave celerity

The derivative of the equation (1) for $z=0$, represents the surface rotation of the shear wave, is maximum when $t = T/2$ and $x = L/2$, therefore:

$$dY_{xy}/dx = Y_o \cdot (2\pi/L) \cdot \cos(\pi t/T) \quad (2)$$

substituting values to obtain the maximum for $z=0$

$$dY_{xy}/dx = TAG. \alpha = Y_o \cdot (2\pi/L) \quad (3)$$

Here $Y_o = Az/p^2$, for $x = L/2$, $Y_o = Az/(2\pi/L)^2$, substituting $t = T/2$ the maximum rotation value is

$$\theta_{xy} = Az \cdot T / 6.28 \cdot Cs \quad (4)$$

Here Az is the acceleration of the stratum holding the foundation structure, which rotates an angle θ_{xy}

$$\text{TANG } \theta_{xy} = Az \cdot T / 6.28 \cdot Cs, \text{ TAG } \theta_{xy} = a \quad (5)$$

Computation sheet 10.

Appendix C

Definitions of the subsoil physical formulas for the analysis for the seismo-geodynamic theory used in calculation in figure 2

Column

1.	Soil stratum classification		
2.	Depth	z	m
3.	Thickness of each stratum	d	m
4.	Effective stress, (weight of soil γ_z)	σ_o	Ton/m ²
5.	Water content ω , soil degree of saturation	$s\%$	
6.	Soil dynamic rigidity ref. 6 chapter V	μ_z	Ton/m ²
7.	Unit mass	ρ_z	Ton*sec ² /m ⁴
8.	Poisson's ratio	ν	
9.	Shear wave velocity in each stratum	C_z	m/sec = $\sqrt{(\mu / \rho)_z}$
10.	Depth exponent factor $a(\nu) = \sqrt{1 - \alpha^2} ((1 - 2\nu) / 2(1 - \nu))$ ref. 6 page 48	$a(\nu)$	
11.	Response factor ref. 6 page 98-100	$\beta_{cx} = M_{ez} / M_{cx}$	
12.	Seismic compression modulus ref. 6 page 48	$1 / M_d = 2 \rho * C_z^2 / (1 - \nu)$	
13.	Circular frequency	fc	
14.	Attenuation, depth factor	$(r)_z = (\rho_z c_z) * a(\nu)$	
15.	Depth factor for each stratum	$(r)^d$	
16.	Sum of factors with depth	$\sum (r)^d$	
17.	Surface unit strain	$\epsilon_o = V_o / C_o$	
18.	Orbital velocity, $fc =$ circular frequency	$V_z = A_z / fc$	
19.	Unit strain with depth	$\epsilon_z = V_o * e^{-r z} / C_z$	
20.	Surface wave soil pressure	$P_z = (2\rho / (1 - \nu)) * C_z * (V_o * e^{-r z})$	
21.	Seismic pore water pressure in the soil (SPWP) ref. 6 chapter 5		
22.	Seismic wave effective stress	$\sigma_z = P_z - (SPWP)$ Ton/m ²	
23.	Acceleration with depth	A_z m/sec ² = $A_s * \epsilon_z / \epsilon_o$	
24.	Surface acceleration	A_o m/sec ²	
25.	Horizontal displacement with depth	δz m = A_z / fc^2	

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Illustrative Seismic Analysis of Foudantion and Building Behavior using "The Seismo-Dynamic Theory"

PROBLEM

D-19

BUILDING FOUNDATION	WIDTH	12.00 Mtrs.
BUILDING FOUNDATION	LENGHT	24.00 Mtrs.

COMPENSATED FOUNDATION			Ton/m ²
TOTAL COMPENSATION AT 6.0 m MTRS. DEPTH			10.00
Weight of foundation and walls			-2.00
Weight of ground floor			-1.30
			SUM
			6.70
FLOOR LEVELS	6	1.10	Ton/m ²
Height between floors	3.2 MTRS.	5	16.00
Ground floor			3.50
Basement and foundation			6.00
Height of building from foundation grade elev. total			25.50

CENTER OF MASS	T/m²	Mtrs	Ton × m
	WEIGHT	HIGHT	MOMENT
Foundation structure	2.0	1.00	2
Basement floor	1.30	6.00	7.8
Floor levels			
1°	1.10	9.50	10.45
2°	1.10	12.70	13.97
3°	1.10	15.90	17.49
4°	1.10	19.10	21.01
5°	1.10	22.30	24.53
ROOF	6°	25.50	28.05
TOTAL	9.90		125.3

HEIGHT OF MASS CENTER**12.66** Mtrs.**MASS PER LINEAL METER $9.90 \times 12/9.81$** **12.11** Ton*seg²/m**FREE HEIGHT FOR WIND ACTION****19.50** Mtrs.**CALCULATION SHEET 1**

SHEAR WAVE IN LAYERED SUBSOIL

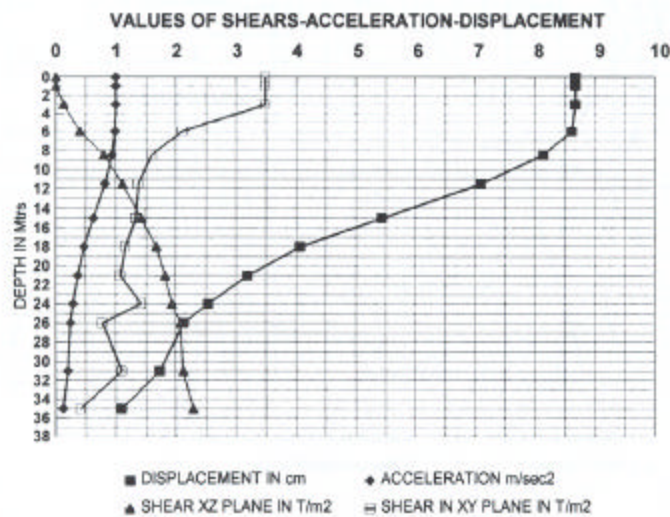
SHWLS298 D-20

List of symbols:

- | | | | | | |
|-------------|------------------------|----------------|----------------------|----------|---------------------|
| d | Stratum thickness | Az= | Orbital acceleration | γ | Distortion |
| μ | Dynamic soil modulus | Vz | Orbital velocity | | foundation rotation |
| ρ | Soil unit density | (tau)yz | Shear Sress yz | | |
| δ | Displacement in YZ | (tau)yx | Shear Sress yx | | |
| 12.00 Mtrs. | Semi-Largo Cimentation | z | Depth of Stratum | | |

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SURFACE ORBITAL VALUES				Ao=	1.00	m/s²	Vo	0.294	M/sec	T=	1.850	seg			
AVE. CELERITY	Cz	75.69		m/sec	SURF. DISPLACEMENT			0.0867	m	Fs	3.397	Rad			
SOIL	z	d	μ	ρ	Cz	Czxd	Ni	Ai	Bi	δ	(tau)yz	Az	(tau)yx	δ	γ
		m	Ton/m²	mass	m/sec					M	T/m²	m/sec²	T/m²	Cm	Rad.
	0.00	0.00	1030	0.136	87.0	87.03	0.00	1.000	0.000	0.0867	0.00	1.000	3.48	8.667	0.0034
A1	1.00	1.00	1030	0.136	87.0	87.03	0.000	0.999	0.001	0.0867	0.00	1.000	3.48	8.667	0.0034
SWT	3.00	2.00	1030	0.136	87.0	174.05	0.002	0.997	0.002	0.0866	0.14	0.999	3.48	8.660	0.0034
A2	6.00	3.00	380	0.136	52.9	158.58	0.009	0.982	0.008	0.0861	0.41	0.993	2.10	8.608	0.0055
B1	8.50	2.50	230	0.144	40.0	99.91	0.011	0.978	0.011	0.0813	0.80	0.938	1.59	8.131	0.0072
B2	11.50	3.00	230	0.141	40.4	121.16	0.016	0.969	0.013	0.0709	1.12	0.818	1.37	7.089	0.0071
C	15.00	3.50	397	0.131	55.1	192.68	0.012	0.977	0.009	0.0543	1.42	0.627	1.33	5.432	0.0052
D	18.00	3.00	600	0.116	71.9	215.76	0.005	0.990	0.005	0.0407	1.67	0.469	1.15	4.068	0.0041
E	21.00	3.00	850	0.114	86.3	259.05	0.003	0.993	0.004	0.0319	1.82	0.369	1.07	3.194	0.0034
F	24.00	3.00	1500	0.180	91.3	273.86	0.003	0.994	0.002	0.0253	1.93	0.292	1.41	2.532	0.0032
G	26.00	2.00	1047	0.110	97.6	195.12	0.001	0.998	0.002	0.0213	2.08	0.246	0.78	2.131	0.0030
H	31.00	5.00	1740	0.200	93.3	466.37	0.008	0.984	0.003	0.0173	2.13	0.200	1.10	1.729	0.0031
I	35.00	4.00	1130	0.110	101.4	405.42	0.004	0.991	0.004	0.0109	2.29	0.126	0.41	1.095	0.0029
		35.00			AVE. ACELERITY	75.69				0.0028	2.32	0.032	0.00		

SEISMIC VALUES IN SUBSOIL PROFILE



CALCULATION SHEET 2

Acceleration in the Building Floors Using the Seismo-Geodynamic Theory

SURFACE WAVE IN LAYERED SUBSOIL

SWLS198 D-20

List of symbols:

(d)	Stratum thickness	l/(M)	Stress modulus	$2(\rho)\cdot Cz \wedge 2/(1-\nu)$		
(mu)	Dynamic shear modulus	(M)	Starin modulus	(e)	Strain at depth Z	Sand α 0.92
rho	Unit mass	(M)e	Traction modulus	(P)z	Aver. Pressure	SILTY α 0.94
(v)	Poisson ratio	(M)c	Compression	(S)z	Aver. Stress	
(C)z	Celerity at centre stratum	(r)z	Atenuation	(Az)	Orbital Acceleration $Az=Ao(e\zeta/\epsilon o)$	
a(v)	Paremeter	SUM	Summation of (rd)	(pc)	Circular frequency	
T	Period = $Ts/0.94$	(z)	Depht	(Vz)	Orbital velocity	
				spwp	SEISMIC PORE WATER PRESSURE	

SURFACE ORBITAL L ACL

$Ao = 1.00 \text{ M/s}^2$

$T = 1.968 \text{ sec}$

$Fc = 3.192 \text{ rad}$

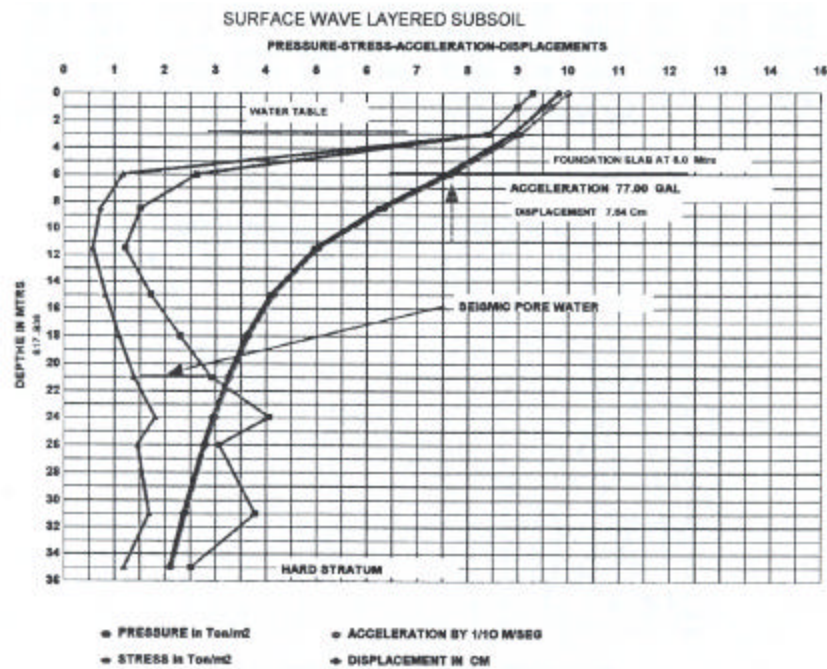
$(Vo) = 0.313 \text{ M/sec}$

SURFACE CELERITY

$(Co) = 81.80 \text{ M/s}$

(e) 0.00383 ORBITAL STRAIN

SOIL	z	d	σo	ω	μ	ρ	ν	c	a(v)	Bcx	1/M	r	rd	SUM	STRAIN	Pz	spwp	(S)z	$\times 10$	
																			Acc	DEPL
	m	m	T/m ²	%	T/m ²	mass	nu	m/sec	-	-	Ton/m ²	1/m	-	-	-	T/m ²	T/m ²	T/m ²	m/s ²	cm
	0.00	0.00	0.00	0.00	1030.00	0.136	0.25	81.80	0.85	0.80	2426.95	0.0332	0.0000	0.0000	0.003829	9.294		9.294	10.00	9.81
A1	1.00	1.00	1.80	50.00	1030.00	0.136	0.25	81.80	0.85	0.80	2426.95	0.0332	0.0332	0.0332	0.003705	8.991		8.991	9.67	9.49
SWF	3.00	2.00	5.40	50.00	1030.00	0.136	0.25	81.80	0.85	0.80	2426.95	0.0332	0.0663	0.0995	0.003467	8.414		8.414	9.05	8.88
A2	6.00	3.00	6.00	125.00	380.00	0.136	0.25	49.69	0.85	0.80	895.38	0.0546	0.1638	0.2634	0.002943	2.635	1.464	1.171	7.68	7.54
B1	8.50	2.50	7.50	300.00	230.00	0.144	0.35	37.57	0.90	0.90	625.32	0.0765	0.1912	0.4545	0.002431	1.520	0.800	0.720	6.35	6.23
B2	11.50	3.00	9.00	300.00	230.00	0.141	0.35	37.96	0.90	0.90	625.32	0.0757	0.2270	0.6815	0.001937	1.211	0.638	0.574	5.06	4.95
C	15.00	3.50	13.70	225.00	397.00	0.131	0.35	51.75	0.90	0.90	1079.35	0.0555	0.1943	0.8759	0.001595	1.722	0.906	0.816	4.17	4.09
D	18.00	3.00	18.00	100.00	600.00	0.116	0.35	67.60	0.90	0.90	1631.26	0.0425	0.1275	1.0033	0.001404	2.291	1.206	1.085	3.67	3.60
E	21.00	3.00	21.50	225.00	850.00	0.114	0.35	81.17	0.90	0.90	2310.95	0.0354	0.1062	1.1095	0.001263	2.918	1.536	1.382	3.30	3.24
F	24.00	3.00	25.00	50.00	1500.00	0.180	0.25	85.81	0.85	0.80	3534.40	0.0316	0.0949	1.2044	0.001148	4.059	2.255	1.804	3.00	2.94
G	26.00	2.00	27.75	250.00	1047.00	0.110	0.35	91.71	0.90	0.90	2846.55	0.0313	0.0627	1.2670	0.001079	3.071	1.616	1.454	2.82	2.76
H	31.00	5.00	29.00	45.00	1740.00	0.200	0.25	87.68	0.85	0.80	4099.90	0.0309	0.1547	1.4218	0.000924	3.789	2.105	1.684	2.41	2.37
I	35.00	4.00	31.00	120.00	1130.00	0.110	0.35	95.27	0.90	0.90	3072.21	0.0302	0.1206	1.5424	0.000819	2.516	1.324	1.192	2.14	2.10



CALCULATION SHEET 3

SURFACE WAVE IN LAYERED SUBSOIL

SWLS198 D-20

List of symbols:

(d)	Stratum thickness	l/(M)	Stress modulus	$2(\rho) \cdot Cz \wedge 2/(1-\nu)$		
(mu)	Dynamic shear modulus	(M)	Strain modulus	(e)	Strain at depth Z	Sand α 0.92
rho	Unit mass	(M)e	Traction modulus	(P)z	Aver. Pressure	SILTY α 0.94
(v)	Poisson ratio	(M)c	Compression	(S)z	Aver. Stress	
(C)z	Celerity at centre stratum	(r)z	Atenuation	(Az)	Orbital Acceleration $Az = Ao(e\zeta/\epsilon o)$	
a(v)	Paremeter	SUM	Summation of (rd)	(pc)	Circular frequency	
T	Period = $Ts/0.94$	(z)	Depht	(Vz)	Orbital velocity	
				spwp	SEISMIC PORE WATER PRESSURE	

SURFACE ORBITAL L ACL

$Ao = 1.50 \text{ M/s}^2$

$T = 1.968 \text{ sec}$

$Fc = 3.192 \text{ rad}$

$(Vo) = 0.470 \text{ M/sec}$

SURFACE CELERITY

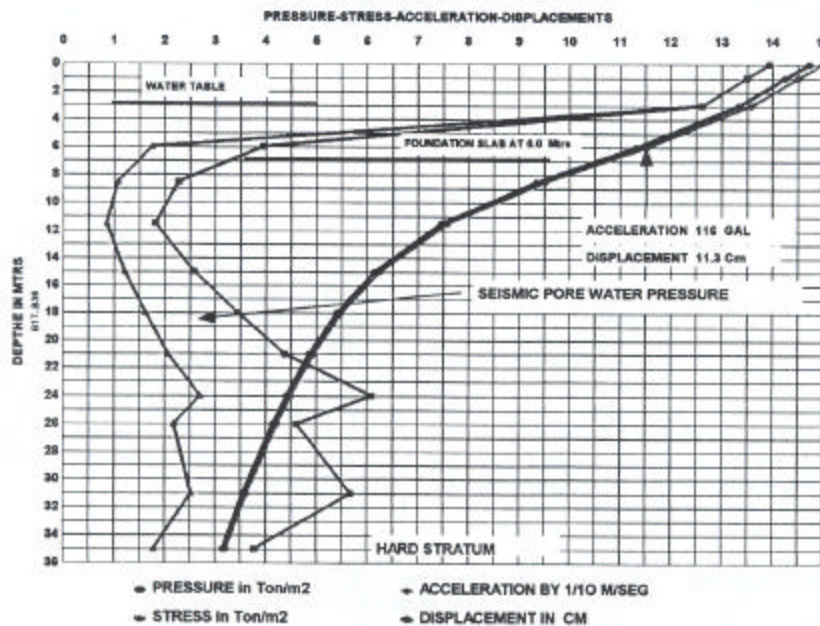
$(Co) = 81.80 \text{ M/s}$

(e)

0.00574 ORBITAL STRAIN

SOIL	z	d	σeo	ω	μ	ρ	ν	c	a(v)	Bcx	1/M	r	rd	SUM	STRAIN	Pz	spwp	(S)z	Acc	DEPL
		m	T/m ²	%	T/m ²	mass	nu	m/sec	-	-	Ton/m ²	1/m	-	-	-	T/m ²	T/m ²	T/m ²	m/s ²	cm
	0.00	0.00	0.00	0.00	1030.00	0.136	0.25	81.80	0.85	0.80	2426.95	0.0332	0.0000	0.0000	0.005744	13.941		13.941	15.00	14.72
A1	1.00	1.00	1.80	50.00	1030.00	0.136	0.25	81.80	0.85	0.80	2426.95	0.0332	0.0332	0.0332	0.005557	13.486		13.486	14.51	14.24
SWF	3.00	2.00	5.40	50.00	1030.00	0.136	0.25	81.80	0.85	0.80	2426.95	0.0332	0.0663	0.0995	0.005200	12.621		12.621	13.58	13.33
A2	6.00	3.00	6.00	125.00	380.00	0.136	0.25	49.69	0.85	0.80	895.38	0.0546	0.1638	0.2634	0.004414	3.953	2.196	1.757	11.53	11.31
B1	8.50	2.50	7.50	300.00	230.00	0.144	0.35	37.57	0.90	0.90	625.32	0.0765	0.1912	0.4545	0.003646	2.280	1.200	1.080	9.52	9.34
B2	11.50	3.00	9.00	300.00	230.00	0.141	0.35	37.96	0.90	0.90	625.32	0.0757	0.2270	0.6815	0.002906	1.817	0.956	0.861	7.59	7.45
C	15.00	3.50	13.70	225.00	397.00	0.131	0.35	51.75	0.90	0.90	1079.35	0.0555	0.1943	0.8759	0.002393	2.582	1.359	1.223	6.25	6.13
D	18.00	3.00	18.00	100.00	600.00	0.116	0.35	67.60	0.90	0.90	1631.26	0.0425	0.1275	1.0033	0.002105	3.436	1.808	1.627	5.50	5.40
E	21.00	3.00	21.50	225.00	850.00	0.114	0.35	81.17	0.90	0.90	2310.95	0.0354	0.1062	1.1095	0.001894	4.377	2.304	2.073	4.95	4.85
F	24.00	3.00	25.00	50.00	1500.00	0.180	0.25	85.81	0.85	0.80	3534.40	0.0316	0.0949	1.2044	0.001723	6.088	3.382	2.706	4.50	4.41
G	26.00	2.00	27.75	250.00	1047.00	0.110	0.35	91.71	0.90	0.90	2846.55	0.0313	0.0627	1.2670	0.001618	4.606	2.424	2.182	4.23	4.15
H	31.00	5.00	29.00	45.00	1740.00	0.200	0.25	87.68	0.85	0.80	4099.90	0.0309	0.1547	1.4218	0.001386	5.683	3.157	2.526	3.62	3.55
I	35.00	4.00	31.00	120.00	1130.00	0.110	0.35	95.27	0.90	0.90	3072.21	0.0302	0.1206	1.5424	0.001229	3.774	1.987	1.788	3.21	3.15

SURFACE WAVE LAYERED SUBSOIL



CALCULATION SHEET 3a

Acceleration in the Building Floors Using the Seismo-Geodynamic Theory

COMPESATED FOUNDATION. "ISES5IN" SEISMIC ROCKING
 FLEXIBILITY OF THE STRATIFY SOIL MASS IN
 THE FOUNDATION SYMMETRY AXIS
 STRIPE 2B/2 = 1200 LAMBDA =

D-20
 CHI = 2
 200 cm

COORDENATE X IN CM.

ESTR	DEPTH MTRS	ESTR H-cm	α	(PSI)1	(PSI)2	(θ) kg/c ²	μ kg/cm ²	v	(Alpha) °/KG	Displ. corregido
B1	100	200	1.488	0.785	-0.785	0.707	23.00	0.350	3.221	2.278
B2	350	300	1.287	0.278	-0.278	0.272	23.00	0.350	4.831	1.315
C	650	350	1.074	0.153	-0.153	0.145	39.70	0.350	3.265	0.472
D	950	300	0.901	0.105	-0.105	0.093	60.00	0.350	1.852	0.171
E	1300	300	0.745	0.077	-0.077	0.061	85.00	0.350	1.307	0.079
F	1650	300	0.629	0.061	-0.061	0.043	150.00	0.250	0.800	0.034
G	1900	200	0.563	0.053	-0.053	0.034	104.70	0.350	0.707	0.024
H	2250	500	0.490	0.044	-0.044	0.026	174.00	0.250	1.149	0.029
I	2700	400	0.418	0.037	-0.037	0.019	113.00	0.350	1.311	0.024

POINT	FLEXIBILITY c ³ /kg						ANTI-SYMETRIC REDUCED MATRIX			
(x)i	0	200	400	600	800	1000	C1	C-2	C-3	
α	4.428	2.042	1.038	0.618	0.399	0.273	C-1	4.155	1.643	0.420
C-2	2.042	4.428	2.042	1.038	0.618	0.399	C-2	1.643	3.810	1.004
C-3	1.038	2.042	4.428	2.042	1.038	0.618	C-3	0.420	1.004	2.386
C-4	0.618	1.038	2.042	4.428	2.042	1.038				
C-5	0.399	0.618	1.038	2.042	4.428	2.042				
C-6	0.273	0.399	0.618	1.038	2.042	4.428				

INVERTED MATRIX			Kg/c ³				TRANSVERSAL CONFIGURATION		
	C1	C-2	C-3	Om	Kg/c ² rd	Ton/m ² /rd	m	Tonxm	
α	0.290	-0.126	0.002	500	107.58	1075.78	5.00	5378.91	
C-2	-0.126	0.350	-0.125	300	29.57	295.74	3.00	887.22	
C-3	0.002	-0.125	0.471	100	10.53	105.30	1.00	105.30	

SPRING CONSTANT FOR BASE ROTATION
 SPRING CONSTANT FOR WALL ROTATION
 $K_w = (1 + \nu) d^2 (1) \mu$

TOTAL CONSTANT

Kb =	25486
Kw =	42185
Kb + Kw =	67671

OVERTURNING M. $Ovt = ((Kb + Kw) \theta$

MASS CENTER	hc	12600	Mtrs
MASS PER LINEAL METER	M	12.110	Ton*seg ² /m
FOUNDATION PERIOD OF ROTATION	Ts	1.059	seg
BUILDING PERIOD FROM CALCULATION SHEET 7	Tb	0.500	seg
COUPLED PERIOD OF THE BUILDING STRUCTURE	To	1.171	seg
CRITICAL DAMPING OF THE SOIL DEPOSIT	Ds	0.120	
CRITICAL DAMPING OF THE STRUCTURE	De	0.050	
EQUIVALENT CRITICAL DAMPING, REF 8	Do	0.132	
ACCELERATION FACTOR AT THE CENTER MASS	Fo	2.200	
ACCELERATION ASIGNED AT THE GROUND SURFACE	As	1.000	M/seg
ACCELERATION AT 6.0 METROS DEPTH		0.770	M/seg

μ =	868.00	Ton/m ²
L =	1.00	m
d =	6.00	m
ν =	0.35	POISSON

SOIL DYNAMIC ANALYSIS		
SOIL PERIOD	Ts =	1.960
SOIL FREQUENCY		3.204
RATIO OF PERIODS	To/Ts	0.597
FROM SPECTRUM (DAES)		2.200

Acc. CENTER OF MASS	1.694	Mtrs/g
OVERTURNING MOMENT Ost	MASA*Acc.*hc	
OVERTURNING MOMENT Ost	258.481	Ton/m/m
ROTATION	θ = 0.00382	rad

REACTIONS OF SEISMIC OVERTURNING

	Ovt	DOV	q0	q	q	Osb
	MOMENT	Mtrs	T/m/m ² /rd	Tonm ²	Kg/cm ²	VERFIC
FOUNDATION	Osb 97.348	5.000	1075.78	4.109	0.411	41.092
FOUNDATION WALLL	Ows 161.133	3.000	295.74	1.130	0.113	6.778
SUMA	Ost 258.481	1.000	105.30	0.402	0.040	0.804
HORIZONTAL UNIFORM STRESS	p	-1.000	-105.30	-0.402	-0.040	97.348
IN FOUNDATION WALL	8.952	-3.000	-295.74	-1.130	-0.113	
	Ton/m ²	-5.000	-1075.78	-4.109	-0.411	

CALCULATION SHEET 4

CALCOR31 D-22
CALCULATION OF THE SHEAR FORCES IN THE BUILDING FLOORS

BUILDING WITH SIX FLOORS
BASEMENT AND RIGID BOX TYPE FOUNDATION
CALCULATION OF THE SURFACE SEISMIC WAVE AND ROCKING ANALISIS

FROM CALCULATION SHEET 3 IS OBTAINED

Acceleration at the base of the foundation, SHEET 3	77.00	GAL
Acceleration at the center of mass, SHEET 4	1.694	m/sec
Displacement at the foundation grade elevation, SHEET 3	0.0754	M
Rotation of the foundation, SHEET 4	0.00382	RAD
Foundation rocking period, SHEET 4	1.059	Seg
Subsoil period, SHEET 3	1.964	Seg
Periodo acoplado estructura –cimentacion– subsuelo	2.231	Seg
System circular frequency	2.816	1/sec
Base shear, SHEET 4	20.51	Ton
Acceleration in the floor levels	(Ac)	

FROM CALCULATION SHEET 1, IS OBTAINED

Mass per frame and floor	1.346	T*s ² /m
Mass per frame and ground floor	1.590	T*s ² /m
Mass of the foundation	2.446	T*s ² /m
Mass of the foundation and added the ground floor	4.037	T*s ² /m
Total mass total eand foundation / ML	12.11	T*s ² /m
Height of center of mass	12.66	Mtrs
Structural flexibility per floor and frame for all the floor levels	1K	m/Ton

δ Displacement because or foundation vertical rotation column 4

$\Delta 2$ Displacement because of flexure induced by the foundation rotation column 7

$\Sigma \Delta = \delta + \Delta 2$

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FLOOR	h	MASS DESPL.		1/K	DISPL.	DISPL.	DISPL.	(Ac)	(Ac)	SHEAR	SUM	SECTION	Δ	SUM
		PIS/ml	δ	FLOOR	$\Delta 1$	$\Delta 2$	$\Sigma \Delta$	FLOOR	DAES	FLOOR	CORT.	d	MOM.	MOM.
FLOOR	Mtrs	T*s ² /m	MTRS	m/Ton	Mtrs	Mtrs	4+7	M/s ²	M/s ²	Ton/m	Ton/m	Mtrs	Ton x m	Ton x m
6	25.50	1.346	0.173	4.00E-04	0.00124	0.00494	1.1778	1.409	2.301	3.097	3.097	3.20	9.910	9.91
5	22.30	1.346	0.161	4.00E-04	0.00115	0.00370	0.1643	1.302	2.128	2.864	5.961	3.20	19.075	28.98
4	19.10	1.346	0.148	2.86E-04	0.00075	0.00256	0.1509	1.197	1.955	2.631	8.592	3.20	27.494	56.48
3	15.90	1.346	0.136	2.86E-04	0.00069	0.00181	0.1379	1.094	1.787	2.405	10.997	3.20	35.189	91.67
2	12.70	1.346	0.124	1.82E-04	0.00040	0.00112	0.1250	0.991	1.620	2.180	13.177	3.20	42.165	133.83
1	9.50	1.346	0.112	1.82E-04	0.00036	0.00072	0.1124	0.891	1.456	1.960	15.136	3.50	52.977	186.81
PB	6.00	1.590	0.098	1.82E-04	0.00037	0.00037	0.0987	0.783	1.279	2.033	17.170	4.00	68.678	255.49
CIM	1.00	2.446	0.079		0.00000	0.00000	0.0792	0.628	1.027	2.511	19.680	2.00	39.361	294.85
BASE	0.00		0.075				0.0754	0.598	0.977	0.000	19.680			294.85
TOTAL MASS		12.11						1.037	1.694	19.680	SUM	SUM	294.85	

CALCULATION SHEET 5a

CALCOR3E

D-22

CALCULATION OF THE SHEAR FORCES IN THE BUILDING FLOORS**BUILDING WITH SIX FLOORS****BASEMENT AND RIGID BOX TYPE FOUNDATION****CALCULATION OF THE SURFACE SEISMIC WAVE AND ROCKING ANALISIS**

FROM CALCULATION SHEET 3 IS OBTAINED

Acceleration at the base of the foundation, SHEET 3	77.00	GAL
Acceleration at the center of mass, SHEET 4	1.694	m/sec ²
Displacement at the foundation grade elevation SHEET 3	0.0764	M
Rotation of the foundation, SHEET 4	0.00382	RAD
Foundation structure period, SHEET 4	1.059	Seg
Subsoil period, SHEET 3	1.964	Seg
Coupled period structure subsoil foundation	2.231	Seg
System circular frequency	2.816	1/sec
Base shear, SHEET 4	20.51	Ton
Acceleration in the floor levels	(Ac)	

FROM CALCULATION SHEET 1, IS OBTAINED

Mass per frame and floor	1.346	T*s ² /m
Mass per frame and ground floor	1.590	T*s ² /m
Mass of the foundation	2.446	T*s ² /m
Mass of the foundation and added the ground floor	4.037	T*s ² /m
Total mass total eand foundation / ML	12.11	T*s ² /m
Height of center of mass	12.66	Mtrs
Structural flexibility per floor and frame for all the floor levels	1K	m/Ton

δ	Displacement because or foundation vertical rotation	Column 4
Δ2	Displacement because of flexure induced by the foundation rotation	Column 7
Δ3	Displacement because 1rst vibration mode of the structure	Column 8

$$\Sigma\Delta = \delta + \Delta 2 + \Delta 3$$

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
FLOOR	h	MASS	DEPL.	1/K	DISPL.	DISPL.	DISPL.	DISPL.	(Ac)	(Ac)	SHEAR	SUM	SECTION	Δ	SUM
FLOOR	Mtrs	PIS/ml	δ	FLOOR	Δ1	Δ2	Δ3	ΣΔ	FLOOR	DAES	FLOOR	CORT.	d	MOM.	MOM.
FLOOR	Mtrs	T*s ² /m	MTRS	m/Ton	Mtrs	Mtrs	Mtrs	4+7+8	M/s ²	M/s ²	Ton/m	Ton/m	Mtrs	Ton x m	Ton x m
6	25.50	1.346	0.174	4.00E-04	0.00135	0.00529	0.02230	0.2014	1.597	2.515	3.384	3.384	3.20	10830	10.83
5	22.30	1.346	0.162	4.00E-04	0.00125	0.00393	0.02040	0.1859	1.474	2.322	3.124	6.509	3.20	20.828	31.66
4	19.10	1.346	0.149	2.86E-04	0.00081	0.00269	0.01680	0.1688	1.339	2.109	2.837	9.346	3.20	29.908	61.57
3	15.90	1.346	0.137	2.86E-04	0.00073	0.00187	0.01320	0.1522	1.207	1.901	2.558	11.904	3.20	38.093	99.66
2	12.70	1.346	0.125	1.82E-04	0.00041	0.00114	0.00880	0.1349	1.069	1.684	2.266	14.170	3.20	45.345	145.00
1	9.50	1.346	0.113	1.82E-04	0.00036	0.00073	0.00560	0.1190	0.944	1.486	2.000	16.170	3.50	56.596	201.60
PB	6.00	1.590	0.099	1.82E-04	0.00037	0.00037	0.00220	0.1019	0.808	1.272	2.023	18.194	4.00	72.774	274.37
CIM	1.00	2.446	0.080		0.00000	0.00000	0.00000	0.0802	0.636	1.002	2.451	20.644	2.00	41.288	315.66
BASE	0.00		0.076					0.0764	0.606	0.954	0.000	20.644			315.66
TOTAL MASS		12.11						MEDIA	1.076	1.694	20.644	SUM	SUM	315.66	

Relative displacement at the roof
 Added with the torsional whipping at the head - frame

2.759 cm
 4.00 cm

CALCULATION SHEET 5b

TOREDIFE D-22

TORSIONAL WHIPPING IN THE UPPER FLOORS

(Shear n) Shear per floor and meter symmetrical case

((SHEARN))X TORSIONAL 'SHEAR / METER AT A DISTANCE (x) FROM THE ROTATION CENTER((Shear n)) X (shear n)*(1+0.45x/L)
(x) Coordinate from the torsion centerTn Torsion per floor level $Tn = 2 * (\text{Shear } n) * (0.45)LxL/3$

12 Mtrs. One half length of building

Factor $(1 + 0.45 * x/L)$

FLOOR	SHEET 5b SUM (SHEARN) TON / ML	HEAD-FRAME FOR TOR. PER FLOOR TON / ML	MOMENT TORSION PER FLOOR TON x M
6	3.384	4.907	133.19
5	6.509	9.438	256.19
4	9.346	13.552	367.86
3	11.904	17.261	468.54
2	14.170	20.547	557.73
1	16.170	23.447	636.45
PB	18.194	26.381	716.12

CIM.

**SHEAR FORCES PER METER OF THE TORSIONAL WHIPPING ACTION
IN THE SECTIONS AT THE INDICATED DISTANCES FROM THE ROTATION CENTER**

SECTIONS	CENTRO	m	m	m	HEAD FRAME
DISTANCE	0.00	2	6	10	12m
FACTOR	1.000	1.075	1.225	1.375	1.450
	((CORTn)) X	((CORTn)) X	((CORTn)) X	((CORTn)) X	((CORTn)) X
EN PISO	TON/ML	TON/ML	TON/ML	TON/ML	TON/ML
6	3.384	3.64	4.15	4.65	4.91
5	6.509	7.00	7.97	8.95	9.44
4	9.346	10.05	11.45	12.85	13.55
3	11.904	12.80	14.58	16.37	17.26
2	14.170	15.23	17.36	19.48	20.55
1	16.170	17.38	19.81	22.23	23.45
PB	18.194	19.56	22.29	25.02	26.38

CIM.

CALCULATION SHEET 6

PERIDIFE D-22

**CALCULATION OF THE AVERAGE CELERITY AND
FUNDAMENTAL PERIOD OF THE BUILDING STRUCTURE**

List of symbols:

d	Height between floors			
B	Width	12.00 M	K	Rigidez del piso
L	Lenght	24.00 M	Cs	Celerity per floor
Z	Altura de piso	M	Cs=RCUAD(K*d^2)/M)	
τ	Period seg by the celerity method			

Average celerity	Cm	188.93	M/Seg	0.4975
Period	Te=	0.4975	Seg	
Circular frequency	Fc=	12.629	1/seg	
OK with holzer				

1	2	3	4	5	6
FLOOR	z	d	K	MASS/ FLOOR	CELERITY Cs
		M	Ton/m		
6	23.50	3.20	2500.00	1.347	137.86
5	20.30	3.20	2500.00	1.347	137.86
4	17.10	3.20	3500.00	1.347	163.12
3	13.90	3.20	3500.00	1.347	163.12
2	10.70	3.20	5500.00	1.347	204.48
1	7.50	3.50	5500.00	1.347	223.65
PB	4.00	4.00	8500.00	1.590	292.44
CIM	0.00	23.50	AVERAGE CELERITY		188.932

SEE REF. 9, CAP. XII.3, PAG. 519

OK WITH HOLZER

CALCULATION SHEET 7a

HOLZERE D-23 D-30

HOLZER MODAL METHOD

δ	Floor displacement	
$\Delta\delta$	Decrement displacement	
f	Floor horizontal force	$(p \wedge 2) * M(\delta - \Delta\delta)$
V	Sum of floor shear forces	
K	Floor rigidity	
M	Floor mass	
T	Building period	0.5002 seg
p	Circular frequency	12.561 1/seg
$p \wedge 2$	Average celerity	157.79 1/seg \wedge 2
		31.987 m/seg

								REAL VALUES FROM CALCULATION SHEET 6		
FLOOR	d	K	m	f	V	$\Delta\delta$	$\delta - \Delta\delta$	REAL δ	Ac m/sec \wedge 2	REAL V
		Ton/m	Tsec \wedge 2/m	Ton	Ton	m	m			
6	3.20	2500	1.347	212.54	212.5	0.085	1.000	0.0223	3.521	4.742
5	3.20	2500	1.347	194.47	407	0.163	0.915	0.0204	3.221	4.339
4	3.20	3500	1.347	159.87	566.9	0.162	0.752	0.0168	2.648	3.567
3	3.20	3500	1.347	125.44	692.3	0.198	0.590	0.0132	2.078	2.799
2	3.20	5500	1.347	83.40	775.7	0.141	0.392	0.0088	1.381	1.861
1	3.50	5500	1.347	53.43	829.2	0.151	0.251	0.0056	0.885	1.192
PB	4.00	8500	1.590	25.24	854.4	0.101	0.101	0.0022	0.354	0.563
					829.2					18.500

BASE SHEAR FROM CALCULATION SHEET 5b **18.500 Ton**CORRECTION FACTOR 18.5 / 829.2 **0.0223****CALCULATION SHEET 7b**

RIGIBC31 D-23

**COLUMN RIGIDITY GROUND FLOOR – FOUNDATION
SYMMETRICAL ROCKING**IN ACCORDANCE WITH
FOUNDATION WIDTH $f/d = 12 (EI/h^3)$
12 Mtrs $\sigma = M/(D^3/6)$

LENGHT 24.00 Mtrs

FOR WHIPPING EFFECT MULTIPLY BY

1.45

GROUND FLOOR – FOUNDATION **PB-FOUND**

Ov	Seismic overturning moment, SHEET 5b	PB-FOUND	274.00	Ton xm/m
F	Seismic shear, SHEET 5b	PB-FOUND	18.20	Ton/m
Nt	Number of columns in transversal frames		2	
No	Total numbers of columns		14 Colms	
NL	Number of transversal frames		7	
L	Distance between frames		4 Mtrs	
f	Shaear in one column	18.2*24/14	31.20	Ton
h	Height between floors		3.20	Mtrs
D	Side of a square column			
σ	Column stress because moment			Ton/m ²
δ	Displacement			Mtrs
E	Modulus of dynamic elasticity of concrete			2,165,064 Ton/m ²
(K)	Rigidity of one column		11000.00	Ton/m
K	Rigidity per meter	5500	5500.00	Ton/m
Kt	Total rigidity	$Kt = 24 * K$	132000.00	Ton/m
Km	Rigidity per frame	$Kt/7$	18857.14	Ton/m
F	Shear force per frame		62.400	Ton
f	Shear force per column		31.200	Ton
M	Moment per column		49.92	T x m
Pv	Axial load in outside column p.b., overturning		45.67	Ton
Atri	Tributary area at corner column		12	m ²
Pest	Static reaction corner column pb.	7.90 Ton/m ²	94.80	Ton
fa	$1.35 * (0.45 * 300) = 182.3$			Kg/cm ²

FLEXION STRESSES, AXIAL SEISMIC AND STATIC

D	h	(K)	K	D	Mc	s	σ	σ	AXIAL	AXIAL	$\Sigma\sigma$
									OVERTUR.	$\alpha\epsilon$	
Mtrs	Mtrs	Ton/m ²	Ton/M	Mtrs	Tonxm	m ³	Ton/m ²	Kg/cm ²	Kg/cm ²	Kg/cm ²	
0.40	3.20	1691	845.7	0.40	49.92	0.0107	4680.00	468.00	28.54	59.25	555.79
0.44	3.20	2476	1238	0.44	49.92	0.0142	3516.15	351.62	23.59	48.97	424.17
0.48	3.20	3507	1754	0.48	49.92	0.0184	2708.33	270.83	19.82	41.15	331.80
0.52	3.20	4831	2415	0.52	49.92	0.0234	2130.18	213.02	16.89	35.06	264.97
0.56	3.20	6498	3249	0.56	49.92	0.0293	1705.54	170.55	14.56	30.23	215.35
0.60	3.20	8563	4281	0.60	49.92	0.0360	1386.67	138.67	12.69	26.33	177.69
0.64	3.20	11085	5543	0.64	49.92	0.0437	1142.58	114.26	11.15	23.14	148.55
0.68	3.20	14127	7064	0.68	49.92	0.0524	952.57	95.26	9.88	20.50	125.64
0.72	3.20	17756	8878	0.72	49.92	0.0622	802.47	80.25	8.81	18.29	107.34
0.76	3.20	22043	11022	0.76	49.92	0.0732	682.32	68.23	7.91	16.41	92.55
0.80	3.20	27063	13532	0.80	49.92	0.0853	585.00	58.50	7.14	14.81	80.45
0.84	3.20	32896	16448	0.84	49.92	0.0988	505.34	50.53	6.47	13.44	70.44
0.88	3.20	39623	19812	0.88	49.92	0.1136	439.52	43.95	5.90	12.24	62.09
0.92	3.20	47334	23667	0.92	49.92	0.1298	384.65	38.46	5.40	11.20	55.06
0.96	3.20	56118	28059	0.96	49.92	0.1475	338.54	33.85	4.96	10.29	49.10
1.00	3.20	66072	33036	1.00	49.92	0.1667	299.52	29.95	4.57	9.48	44.00

CORRECTION OF RIDIDITIES ACCORDING TO ACCEPTABLE DISPLACEMENTS AND
ALLOWABLE STRESSES

FOR TORTIONAL ROTATION THE HEAD-FRAME VALUES SHALL BE ADDED WITH

 $\alpha\%$

CALCULATION SHEET 8

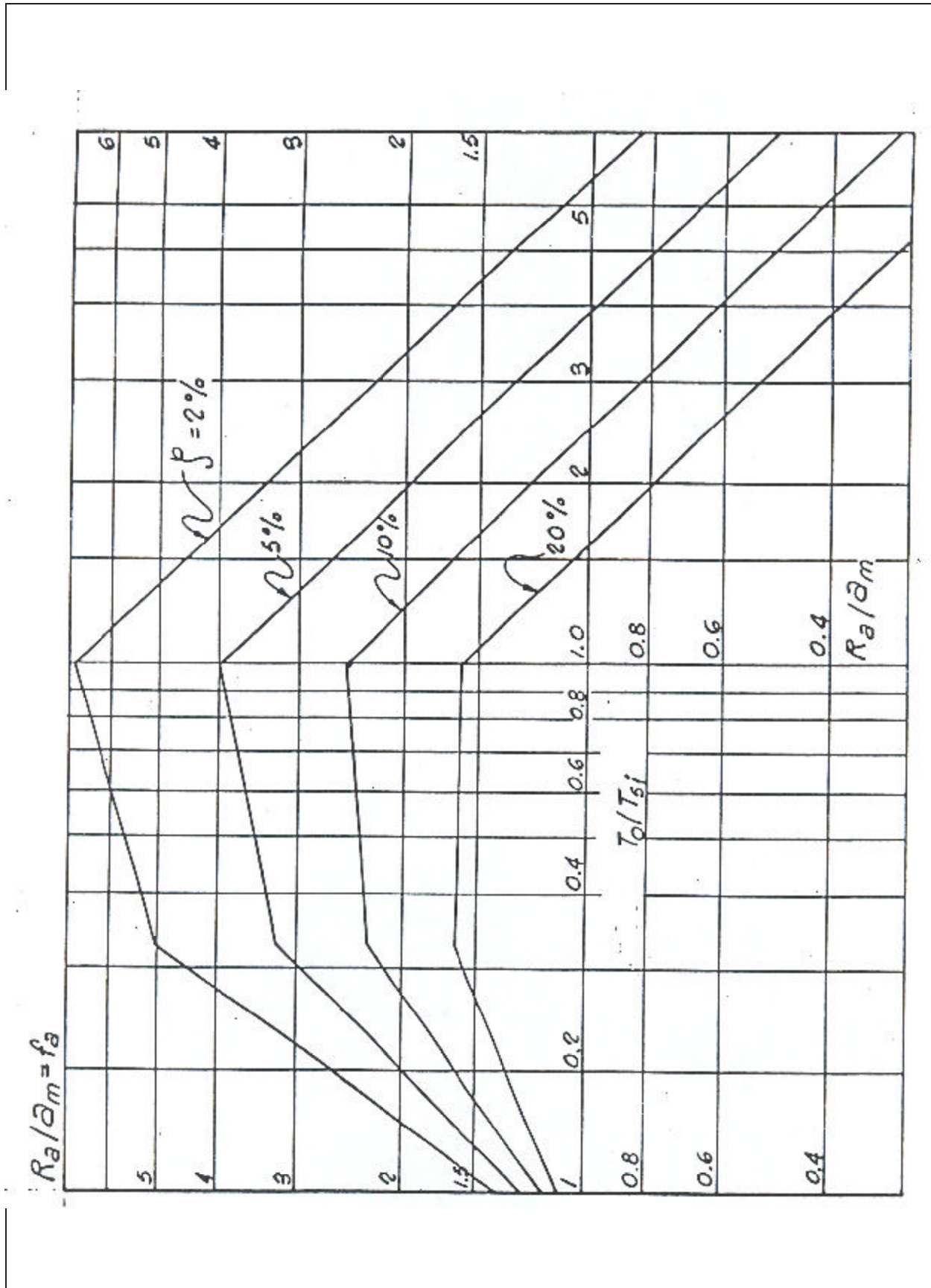


Figure 3. (DAE3), "design acceleration envelope spectrum"



Photo 1. Reduc tion of the foun da tion bearing capacity and extru sion because of the seismic pore water pressure

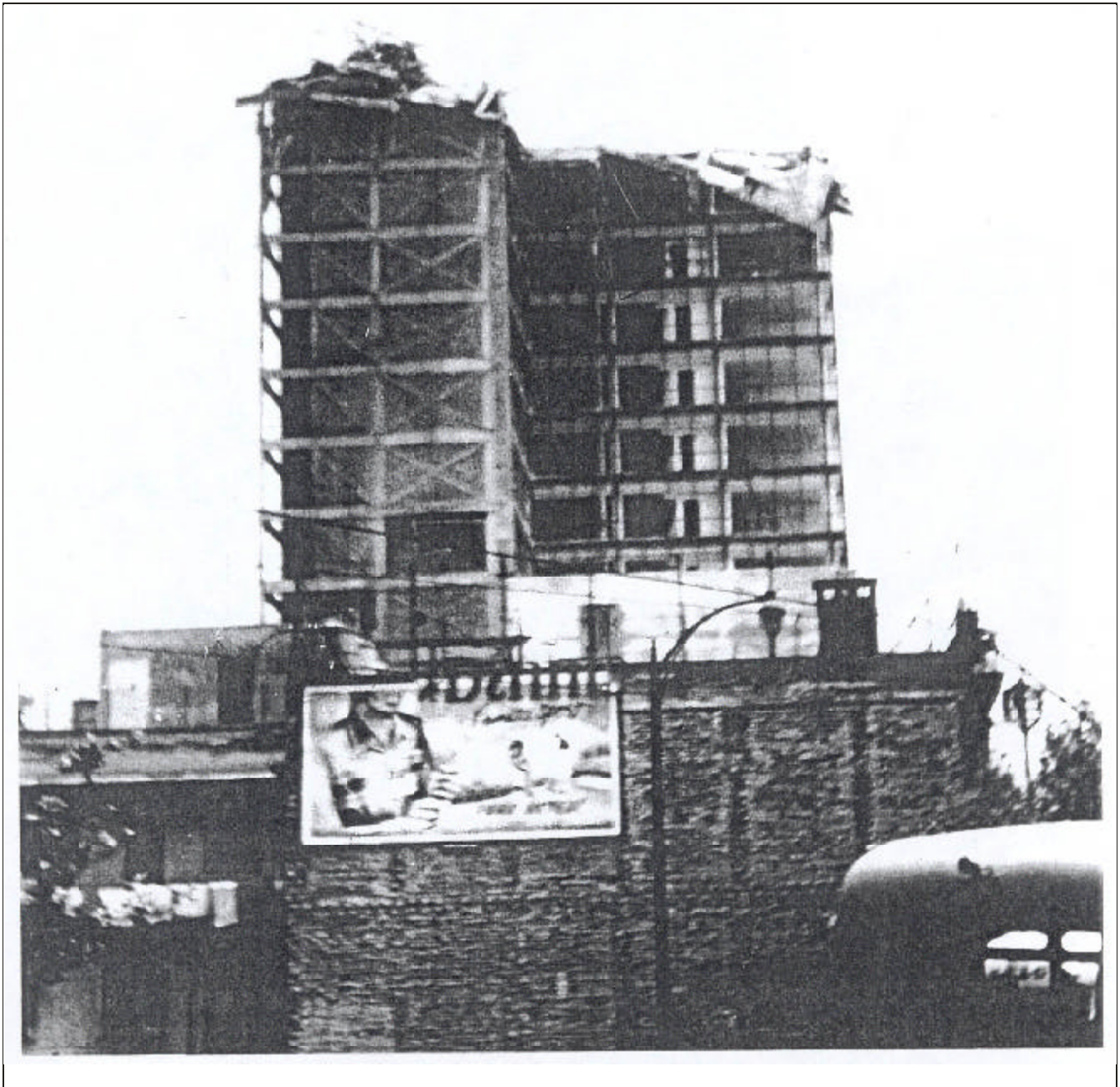


Photo 2. "Whip ping effect" in the upper floors because of seismic action



Photo 3. "Whip ping effect" in the upper floors because of seismic action



Photo 4. "Whip ping effect" in the upper floors because of seismic action



Photo 5. Failure of head-frame (corner) in upper floors because of seismic action



Photo 6. Failure of head-frames in the upper floors because of seismic "torsional whipping action"

Semblanza del autor

Leonardo Zeevaert-Wiechers. Obtuvo el título como ingeniero civil en 1939 en la Escuela Nacional de Ingenieros de la UNAM. Estudió el posgrado en el Instituto Tecnológico de Massachussets donde recibió el grado de maestro en ingeniería en 1940. En 1943, inició una estrecha colaboración con el Dr. Karl Terzaghi en una investigación acerca de la estabilidad de las cortinas de corazón hidráulico, construidas en México. A partir de 1940, cuando terminó su maestría en el Instituto Tecnológico de Massachussets, se dedicó a trabajar en problemas específicos de mecánica de suelos y en 1947, ingresó a la Universidad de Illi nois donde terminó en 1949, obteniendo el grado de doctor en filosofía de ingeniería (Ph.D) en ese mismo año. Ha recibido numerosos reconocimientos, entre ellos, la Medalla de Oro Profesional, otorgada por el Instituto Americano de Arquitectos, Diploma a la Innovación Tecnológica, la designación como Profesor Emérito en la UNAM y miembro de la Academia Nacional de Ingeniería de EUA, entre otros. El buen comportamiento de la cimentación y estructura de las obras de ingeniería que ha diseñado, entre ellas la Torre Latinoamericana, en donde introdujo el concepto de flexibilidad controlada en edificios altos y el desarrollo de la "Teoría de la Sismo-Geodinámica", le han valido para su reconocimiento a nivel internacional. Ha escrito más de 195 artículos, una gran cantidad de libros y ha presentado ponencias relacionadas con la mecánica de suelos e ingeniería sísmica para el diseño de las cimentaciones y estructuras de los edificios en las zonas sísmicas.