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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 seudo-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 appart, 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 seudo-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

Be cause of the in ter est that has aroused in the ap pli- cation of the Seismo-Geodynamics theory to solve seis mic prob lems in the sub soil and foun da tions, the au thor has re vised and en larged the orig i nal ver sion of this work "Sgedfalt" pub lished in de cem ber 1999, now the au thor pres ents here again the method to cal cu late the ac cel er a tion in the floors of build ings by means of the seismo-dynamic the ory.

It is very im por tant to foresse the dy namic force to which the ob jects on the floors of build ings may be subjected and to verify if the struc ture of the build ing can take the seis mic forces.

The ex pe ri ence has in di cated the im por tance in the seismic behavior of buildings, and the struc-tural prob lems in the upper floors of tall build ings, durung de struc tive earth quakes. The ac cel er a tion in the top floors is much higher than the ac cel er a-tion assigned at the ground surface, "Because of the ef fect of the ver ti cal and hor i zon tal seis mic ro-ta tions of the foun da tion".

Knowing the acceleration to each floor of the building and the individual mass of the objects. The seis mic force in each one of them may be cal-culated by means of the following dynamic law Force = Mass x Ac cel er a tion, (New ton), 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 act ing in each floor level can be calculated and the structural re sis-tance and lat eral dis place ments ver i fied.

Fur ther more, the knowl edge of the rel a tive dis-placement between the floors are requiered to fore see the gap to be given in the con struc tion to the float ing walls, win dows and stair ways be tween floors, and to take into account the dynamic dis-tortion induced in them as well as in other arhitectonic el e ments.

An important seismic observation was made by the au thor in 1962, from the re corded seudo-ac cel er a tion re sponse spec trums, ob tained at the ground sur face at the Alameda Cen tral and those ob tained at the base of the rigid foun da tion of the Tower La tino Americana in Mex ico City (Fig ure 1).

Notice in figure 1, that the ratio of the accelera-tions for 5.0% crit i cal damp ing be tween these two places, one hundred meters appart, show at the rigid box type foundation of the L.A. Tower to a total depth of 16 me ters of the "Sheet Piles", that the L.A. Tower shows only on the order of 50% seudo-acceleration with respect to the spectral acceleration at the ground sur face in the Alameda Park (Fig ure 1).

The above ob ser va tion was ver i fied the o ret i cally by the author, by means of an analysis he deve-loped and named "The Seismo-Geodynamic Theory", using the soil dynamics physical informa-tion of the site. The result of the calculation is shown in fig ure 2. Where the stra tig ra phy of the sub-soil is reported, also the quantitative dynamic pa-rameters corresponding to the site in ques tion.
The analysis in numerical and graphical form shows that the acceleration at the depth of the foundation grade el e va tion is on the order of 59% of the value given by the response acceleration spectrum at the ground surface, hence, the theo-retical calculation is co in ci dent with the re sponse of the ac cel er a tion spec trums, shown in figure1.

The phe nom e non herein re ported has been ob-served in other places. There fore, the con clu sion is that the ac cel er a tion im posed to the build ings cor-respond to that one the seismic wave induces at the foundation grade elevation. Therefore this value is a func tion of the foun da tion depth.

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

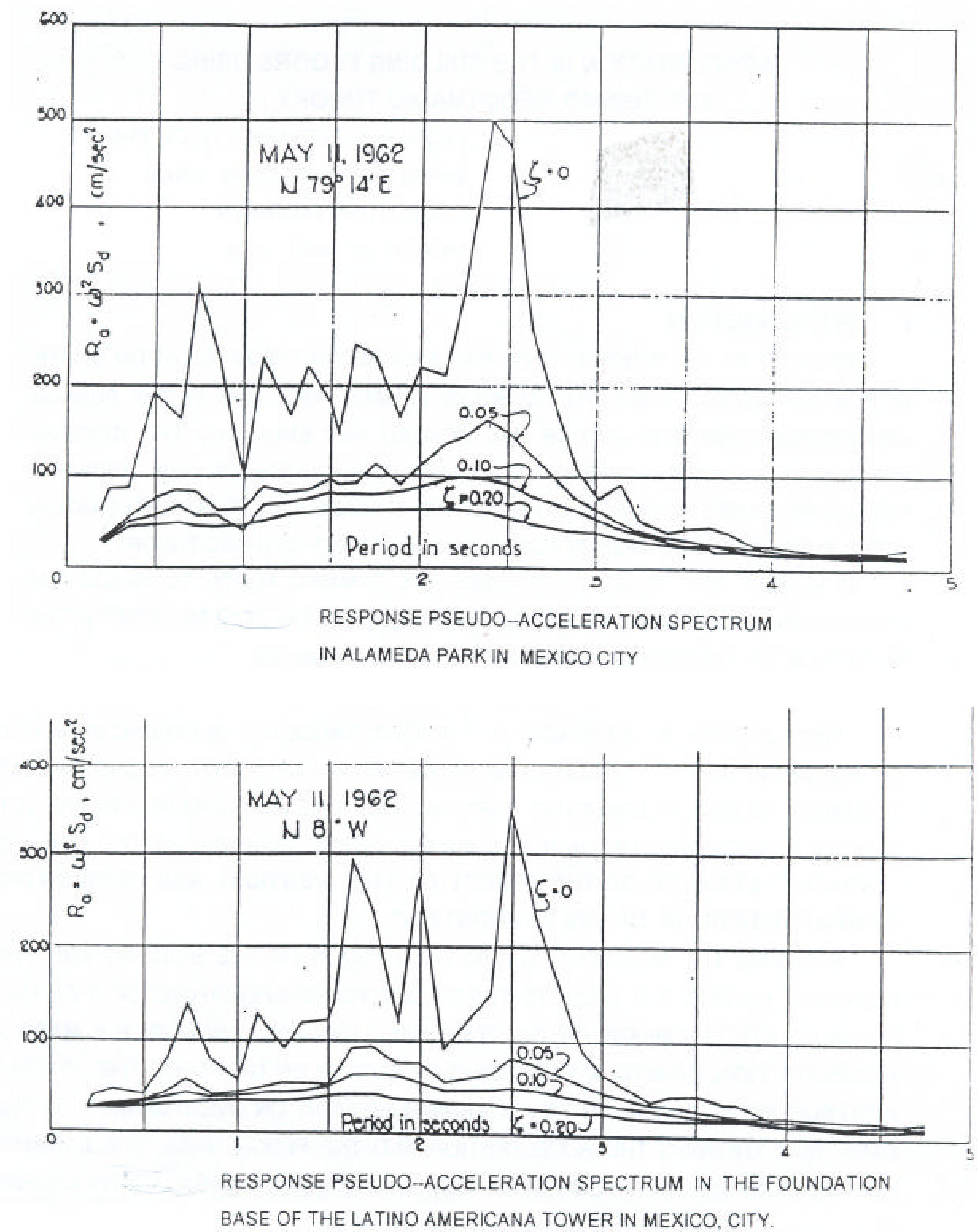

Figure 1. Response Pseudo-Acceleration Spec trums (9) (Zeevaert, 1972-1982)

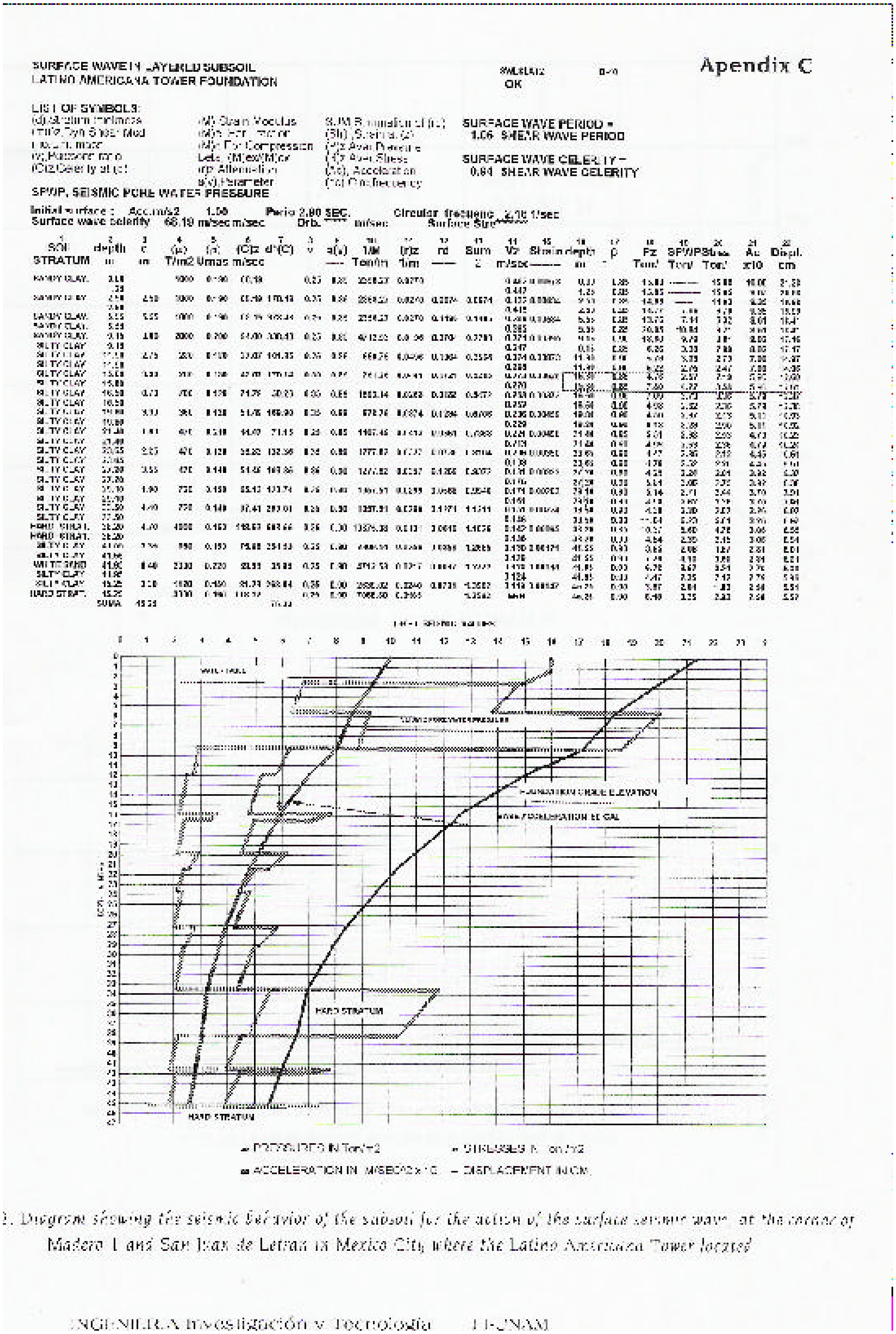

Figure 2. Diagram showing the seismic behavior of the subsoil for the action of the surface seismic wave, at the corner of Madero 1 and San Juan de Letran in Mexico City where the Latino Americana Tower located (continue...)

II. Information on the Problem

An ilustrative analysis is presented a head, 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, formimg structural bents every 4 meters. The analysis of the factors pertaining the computation will be analized with a surface unit orbital 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	O	**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	35.0	4.0	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). There fore, 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 registed 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, Mez and Mcx, 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, there after a torsional vi- bration is applied to the specimen and the vibration recorded. The above mentioned values corres- pond to the vertical expansion response (Mez), and (Mcx) for the direct horizontal compression. From them the Response Factor is defined as follows

$$\beta ex = Mex/Mxz \qquad (1)$$

The value of the seismic soil rigidity (μ) and the response factor ß 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 1.064x1.1.850= 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 stregth 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 in shown in calculation sheet number 4.

From the mentioned analysis the follow in results are obtained:

1. Acceleration at the center of mass of the building 1.694 m/seg^2, 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*12.11=20.51 Ton/ml.

5. Rigid vertical foundation rotation (?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 bacause of the vertical rotation (θv) 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

$$To^{2} = Te^{2} + Ts^{2} \qquad (2)$$

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 frecuency (Column 9).

Coupling circular frequency ?=(2p/To)

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/s2, 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 multipling 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 bulding. 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 (?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?) by the square of the circular frecuency ?o²=(6.2832/To)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 adventurning moment 315.66 Tonxm/ml. The soil foundation reaction stresses reported in calculation sheet 4 shall be inceased by a factor 315.7/258.48 = 1.22.

5. In order to verify the total displacements (S?) and the correct final values for each floor, the calculation is respeated, 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 (?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 architectonic 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 analize.

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 (?h) 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 magnitud 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 wich 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 0.99cm/seg^2.

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

do = 4.06 cm

Symmetrical displacement in the head-frame

d = 8.93 cm

Total at the head-frame

(do+ d) = 13.0 cm

Displacement ratio

R = 1.45

Increment of actions at the head-frame

(a %) = 45%

Call ? (Shear n) = (Shear n) xa % the increment of the sherar 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

$$(Shear\ n)x = (Shear\ n)(1 + a*(x)/L) \qquad (3)$$

The torsion moment of each rigid floor in its plane is

$$Tn = 2(Shear\ n)x\,a\,L^2/3 \qquad (4)$$

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 Te = 0.50 seg.

Never the less, 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 stablish 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/m^2

For (?), the equivalence is M/Bd, $Ton*\underline{Seg}^2/m^4$

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

$$C_z\hat{\ }2 = (K)*d^2/m \quad (5)$$

Here

- (K) Structural rigidity per floor and per lineal meter, Ton/m.
- M Mass per floor and per lineal meter, $Ton*Seg^2/m/ml$.
- B Width coresponding 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

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

The period of vibaration obtained with this method for the proposed building is Te = 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 stablish 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 forsee 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.

Notice, that the soil acceleration at the foundation grade elevation is on the order of 77 cm/seg^2 for 100 cm/seg^2 at the ground surface, and in the case of normal “Wipping Action” without torsion including the flexibility of the proposed building structure. The acceleration at the foundation grade elevation is 169.4 cm/seg^2, and at the roof floor of the building is on the order of 251.5 cm/seg^2 (Computation sheet 5b).

When the torsional whipping is considered then this value increases to 1.45*251.5 = 364.66 m/seg^2 at the Head-Frame the above phenomenon indicates the importance to learn on the seismic stability of the building.

Therefore, when the phenomenon here 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 (?v) and horizontal (?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 durung 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 subsoil at the site, as the stratigraphy and the quantitative dynamical soil properties in all the strata forming the subsoil deposit for the requiered depth. The seismo-geodynamic behavior of the subsoil 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 whiches 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 orthographycal manuscript revision.

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

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:

$$C^2s = \mu/?, (m/s)^2 \qquad (1)$$

The dynamic soil rigidity for the shear stress distortion is

$\mu = ?t/??$ Ton/m^2, and the unit mass $? = W/g$, Ton*Seg^2/m^4, and W is the unit weight Ton/m^3.

The distortion in a vertical selection "d" is $?? = ?d/d$, here $?d$ is the relative horizontal displacement of the vertical section "d" hence

$$\mu = ?t*d/?d \qquad (2)$$

For the structure the rigidity per floor and lineal meters is $K = ?F/?d$ or $K = ?t*B/?d$ in Ton/m^2, from which accordingto (2)(Zeevaert) the following is obtained

$$\mu = \underline{K*d/B}, \text{Ton/m2} \qquad (3)$$

In the structure the mass per floor and lineal meter $M = w*d*B/g$, in Ton*Seg^2/m^2, and the equivalent unit mass is

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

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

$$C^2s = \underline{K*d^2/M}, (m/s)^2 \qquad (5)$$

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

$$Y_{xy} = Y_o \, COS(2\pi z/H) SIN(2x3.14/T(t-x/Cs) \quad (1)$$

Here for z = 0

- Y_{xy} Horizontal shear displacement
- Y_o Maximum horizontal surface shear displacement
- T Wave period and length L = TxCs
- t Any time
- X Position coordinate
- Cs 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 y x = L/2, therefore:

$$dY_{xy}/dx = Y_o((2x3.14/T)/Cs) \; COS \; p(t-x/Cs \quad (2)$$

substituting values to obtain the maximum for z = 0

$$dY_{xy}/ \, dx = TAG. \, \alpha = Y_o(2x3.14/T)/Cs \quad (3)$$

Here Y_o = Az/p^2, for x = L/2, Y_o = Az/(2x3.14/T)^2, substituting t = T/2 the maximum rotation value is

$$?_{xy} = \; Az*T/6.28 \; Cs \quad (4)$$

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

$$TANG \; ?_{xy} = Az*T/6.28*Cs, \; TAG \; ?_{xy} = a \quad (5)$$

Computation sheet 10.

Apendix 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 clasification		
2.	Depth	**z**	**m**
3.	Thickness of each stratum	**d**	**m**
4.	Effective stress, (weight of soil γ_z)	$\sigma\varepsilon o$	**Ton/m²**
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*sec²/m⁴**
8.	Poisson´s ratio	ν	
9.	Shear wave celerity in each stratum	C_z	**m/sec** $= \sqrt{(\mu / \rho)_z}$
10.	Depth exponent factor	$a(\nu)$	
	$a(\nu) = \sqrt{1 - \alpha^2 ((1-2\nu)/2(1-\nu)}$ **ref. 6 page 48**		
11.	**Response factor ref. 6 page 98-100**	$\beta_{cx} = Mez/Mcx$	
12.	Seismic compression modulus **ref. 6 page 48**	$1/Md = 2\rho * C_z \wedge 2/(1-\nu)$	
13.	Circular frequency	**fc**	
14.	Attenuation, depth factor	$(r)_z = (p_{z/}cz)*a(\nu)$	
15.	Depht factor for each stratum	$(r)^d$	
16.	Sum of factors with depth	$\sum(r)^d$	
17.	Surface unit strain	$\varepsilon_o = Vo/Co$	
18.	**Orbital velocity, fc = circular frequency**	**Vz = Az/fc**	
19.	Unit strain with depth	$\varepsilon_z = Vo*e^{-rz}/Cz$	
20.	Sourface wave soil pressure	$Pz = (2\rho/(1-\nu))*Cz*(Vo*e^{-rz})$	
21.	Seismic pore water pressure in the soil	**(SPWP) ref. 6 chapter 5**	
22.	Seismic wave effective stress	$\sigma z = Pz-(SPWP)$ **Ton/m²**	
23.	Acceleration with depth	**Az m/sec²** $= As*\varepsilon z/eo$	
24.	Surface acceleration	**Ao m/sec²**	
25.	Horizontal displacement with depth	δz **m** $= Az/fc \wedge 2$	

XI. References

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Ilustrative 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	6.60
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/m^2**	**Mtrs**	**Ton $\times$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°	1.10	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*seg ^ 2/m**
FREE HEIGHT FOR WIND ACTION	**19.50**	**Mtrs.**

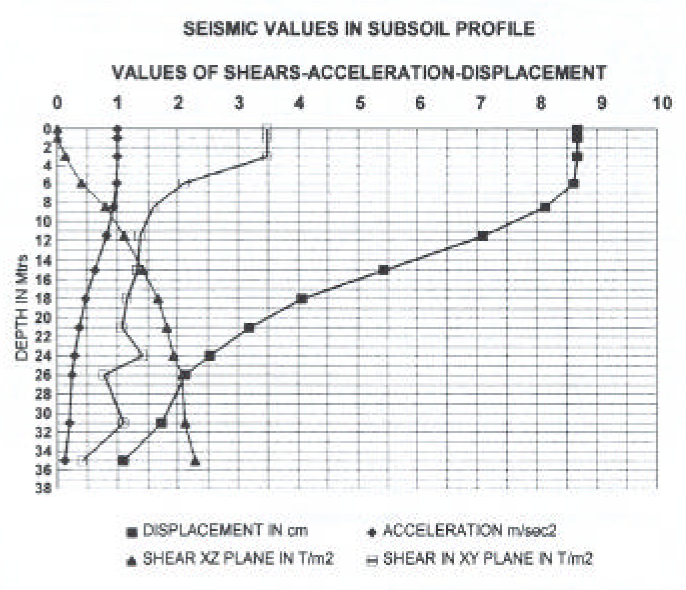
CALCULATION SHEET 1

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**	**A z**	**(tau)yx**	δ	γ
		m	**Ton/m ²**	**mass**	**m/sec**					**M**	**T/m ²**	**m/sec²**	**T/m ²**	C m	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**		



CALCULATION SHEET 2

SURFACE WAVE IN LAYERED SUBSOIL SWLS198 D-20

List of symbols:

(d)	Stratum thickness	I/(M)	Stress modulus	2(rho)*Cz ^ 2/(1–v)	
(mu)	Dynamic shear modulus	(M)	Starin modulus	(ε)	Strain at depth Z
rho	Unit mass	(M)e	Traction modulus	(P)z	Aver. Pressure
(v)	Poisson ratio	(M)c	Compression	(S)z	Aver. Stress
(C)z	Celerity at centre stratum	(r)z	Atenuation	(Az)	Orbital Acceleration Az = Ao(εζ/εo)
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

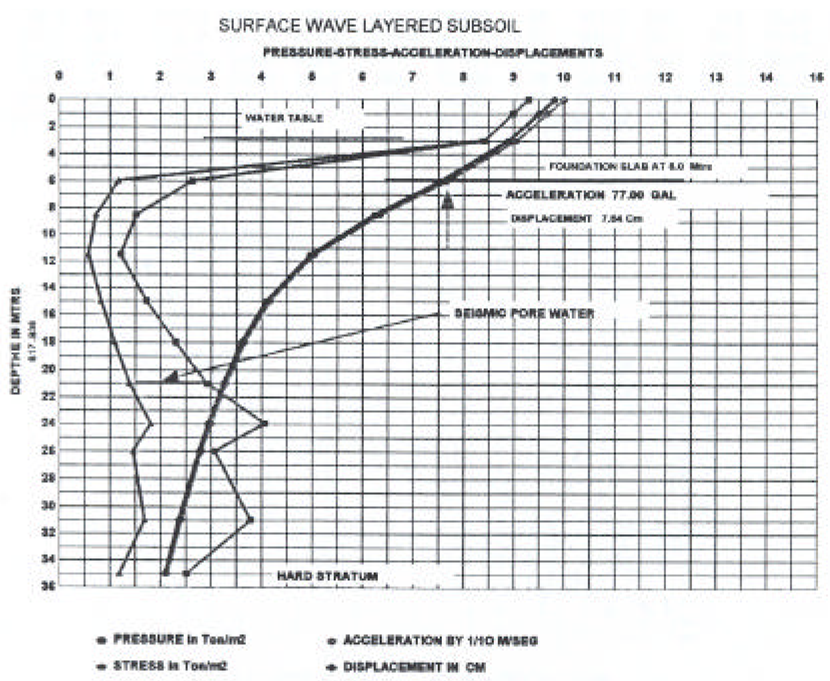
Sand α 0.92

SILTY α 0.94

SURFACE ORBITAL L ACL Ao = 1.00 M/s ^{2} T = 1.968 sec Fc = 3.192 rad (Vo) = 0.313 M/sec

SURFACE CELERITY (C)o = 81.80 M/s (ε) 0.00383 ORBITAL STRAIN

SOIL	z	d	σεo	ω	μ	ρ	ν	c	a(v)	Bcx	1/M	r	rd	SUM	STRAIN	Pz	spwp	(S)z	Acc × 10	DEPL.
		m	T/m²	%	T/m²	mass	nu	m/sec	–	–	Ton/m²	1/m	–	–	–	T/m²	T/m²	T/m²	m/s²	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
SWT	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
		35.00																		



CALCULATION SHEET 3

SURFACE WAVE IN LAYERED SUBSOIL SWLS198 D-20

List of symbols:

(d)	Stratum thickness	I/(M)	Stress modulus	2(rho)*Cz ^ 2/(1–v)	
(mu)	Dynamic shear modulus	(M)	Strain modulus	(ε)	Strain at depth Z
rho	Unit mass	(M)e	Traction modulus	(P)z	Aver. Pressure
(v)	Poisson ratio	(M)c	Compression	(S)z	Aver. Stress
(C)z	Celerity at centre stratum	(r)z	Atenuation	(Az)	Orbital Acceleration Az = Ao(εζ/εo)
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

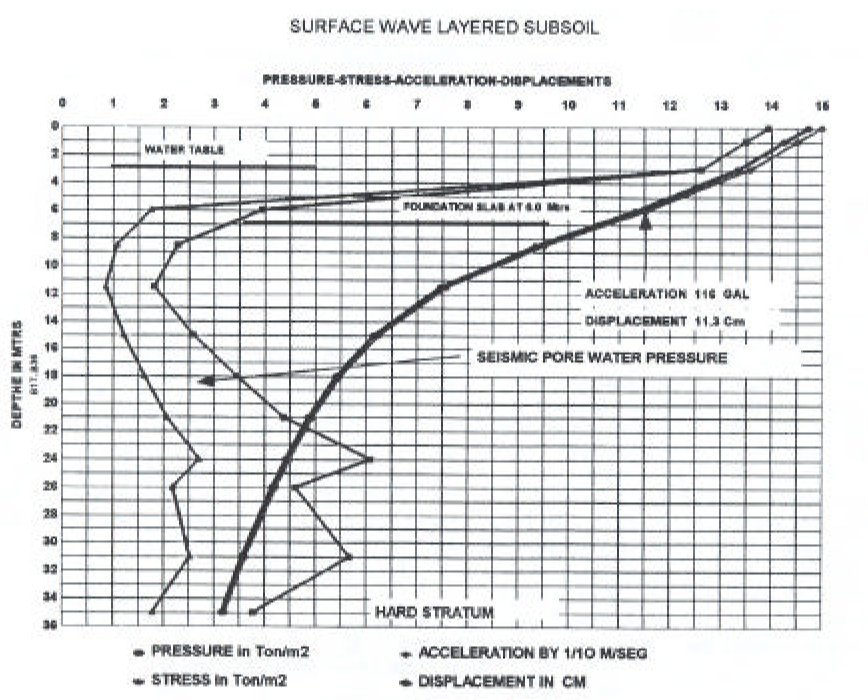
Sand α 0.92

SILTY α 0.94

SURFACE ORBITAL L ACL Ao = 1.50 M/s ^{2} T = 1.968 sec Fc = 3.192 rad (Vo) = 0.470 M/sec

SURFACE CELERITY (C)o = 81.80 M/s (ε) 0.00574 ORBITAL STRAIN

SOIL	z	d	σεo	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
SWT	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
		35.00																		



CALCULATION SHEET 3a

COMPESATED FOUNDATION. "ISES5IN" SEISMIC ROCKING D-20
FLEXIBILITY OF THE STRATIFY SOIL MASS IN
THE FOUNDATION SYMMETRY AXIS CHI = 2
STRIPE 2B/2 = 1200 LAMBDA = 200 cm

COORDENATE X IN CM.

ESTR	DEPTH	ESTR	α	(PSI)1	(PSI)2	(I)i	μ	ν	(Alpha)	Displ..
	MTRS	H-cm				kg/c2	kg/cm 2		c3/kG	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
									SUM	4.428

POINT		FLEXIBILITY c 3/kg								
(x)i	0	200	400	600	800	1000		'ANTI-SYMETRIC REDUCED MATRIX		
	C1	C-2	C-3	C-4	C-5	C-6		C1	C-2	C-3
C1	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			
					Cm	Kg/c2 rd	Ton/m2/rd	m	Tonxm
	C1	C-2	C-3		di	q/0	Xi/10	x	Kb
C1	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
									6371.43

SPRING CONSTANT FOR BASE ROTATION		Kb=	25486
SPRING CONSTANT FOR WALL ROTATION		Kw=	42185
Kw=(1+ν) d ^ 2*(1)*μ	TOTAL CONSTANT	Kb+Kw=	67671

OVERTURNING M. Ovt=((Kb+Kw) θ

μ=	868.00	Ton/m2
L =	1.00	m
d =	6.00	m
ν =	0.35	POISSON

MASS CENTER	hc	12.600	Mtrs
MASS PER LINEAL METER	M	12.110	Ton*seg2/m
FOUNDATION PERIOD OF ROTATION	Ts	1.059	seg
BUILDING PERIOD FROM CALCULATION SHEET 7	Te	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/seg2
ACCELERATION AT 6.0 METROS DEPTH		0.770	M/seg2

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/s2			
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	q/0	q	q	Osb	
	MOMENT	Txm/m	Mtrs	T/m/m2/rd	Ton/m2	Kg/cm2	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	OK
IN FOUNDATION WALL	8.952		–3.000	–295.74	–1.130	–0.113		
	Ton/m2		–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^2
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 foor 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

$\sum\Delta = \delta + \Delta 2$

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	$\Delta 1$	$\Delta 2$	$\sum\Delta$	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
Couppled 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
$\Delta 2$	Displacement because of flexure induced by the foundation rotation	Column 7
$\Delta 3$	Displacement because 1rst vibration mode of the structure	Column 8

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

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**
		PIS/ml	**δ**	**FLOOR**	**$\Delta 1$**	**$\Delta 2$**	**$\Delta 3$**	**$\sum\Delta$**	**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	10.830	**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	2.759 cm
Added with the torsional whipping at the head - frame	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) Coordenate from the torsion center

Tn Torsion per floor level Tn=2*(Shear n)*(0.45)LxL/3

12 Mtrs. One half lenght 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 × 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/	CELERITY
		M	Ton/m	FLOOR	Cs
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	
Δδ	Decrement displacement	
f	Floor horizontal force	(p ^ 2)*M(δ–Δδ)
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 ^ 2		157.79 1/seg ^ 2
	Average celerity	31.987 m/seg

FLOOR	d	K	m	f	V	Δδ	δ–Δδ	REAL VALUES FROM CALCULATION SHEET 6: REAL	Ac	REAL
		Ton/m	Tsec²/m	Ton	Ton	m	m	δ	m/sec²	V
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	**f/d = 12 (EI/h ^ 3)**	**σ = M/(D ^ 3/6)**	
FOUNDATION WIDTH	**12 Mtrs**	**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 sheer, 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 × 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 OVERTUR.	AXIAL σε	Σσ	
Mtrs	Mtrs	Ton/m ^ 2	Ton/M	Mtrs	Ton×m	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	PB-FOUNDATION
0.68	3.20	14127	7064	0.68	49.92	0.0524	952.57	95.26	9.88	20.50	125.64	OK
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 α%

CALCULATION SHEET 8

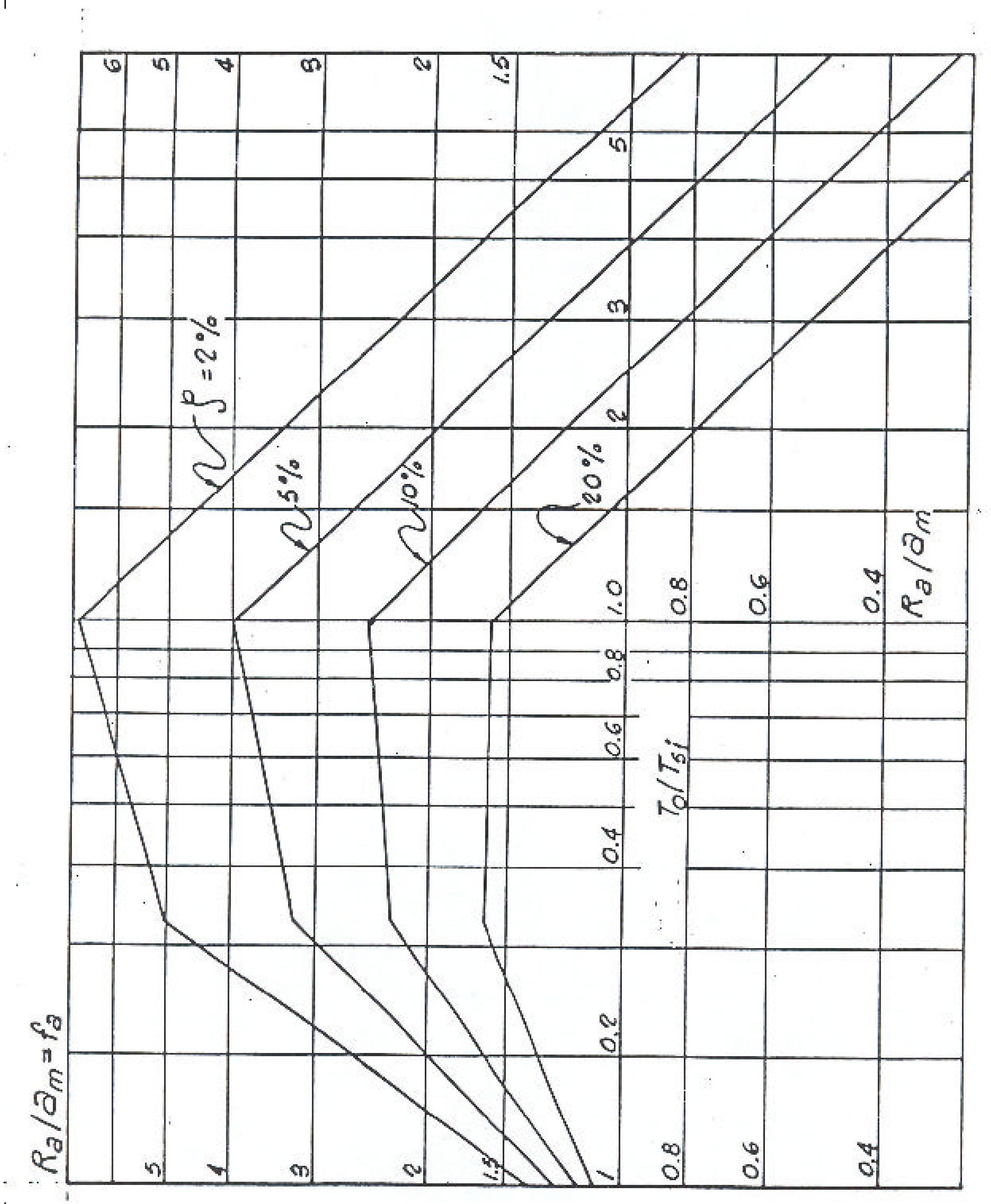


Figure 3. IDAESI, "design acceleration envelope spectrum"

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

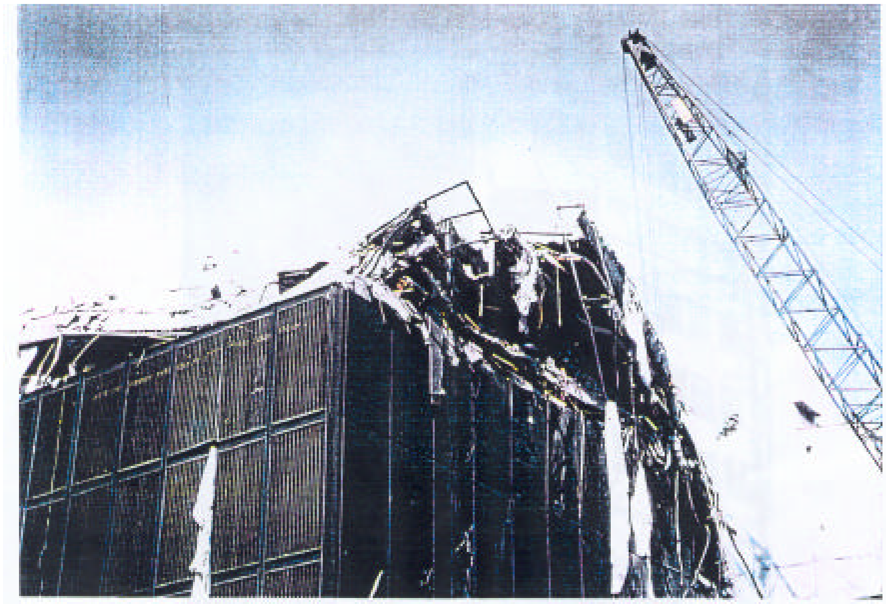


Photo 4. "Whip ping effect" in the upper floors because of seismic action

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

Photo 6. Failure og head-frames in the upper floors because of seismic "torsional whip ping 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.