Future soil dynamic response in Mexico City

Futur réponse dynamique de sol á Mexico

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ABSTRACT

Using ground surface subsidence information, the evolution of the Mexico's valley behavior is studied. With all of this data, the reduction of thickness compressible layer in Mexico City for the coming years is approached. The effect on dominant vibration period due to ground surface subsidence is studied. These results are applied to compute the change on soil dynamic response. For this analysis have been calculated response spectra with time dependence. The changes in structural dynamic response due this phenomenon are shown. The results obtained show that some structures in Mexico's valley could be in risk due to the changes in soil dynamics properties and its response.

RÉSUMÉ

Utilisant l'information extérieure au sol d'affaissement, l'évolution du comportement de la vallée du Mexique est étudiée. Avec toutes ces données, la réduction d'une couche compressible d'épaisseur à Mexico pendant les années à venir est approchée. L'effet la période dominante de vibration due à l'affaissement extérieur au sol est étudié. Ces résultats sont appliqués pour calculer le changement sur la réponse dynamique de sol. Pour cette analyse, ont été les spectres calculés de réponse avec la dépendance de temps. Les changements de la réponse dynamique structurale due ce phénomène sont montré. À l'avenir, quelques structures en vallée du Mexique ont pu être dans le risque dû aux changements des propriétés dynamiques de sol et de leur réponse associée.

Keywords : ground surface subsidence, soil dynamic properties, soil dominant period, response spectra, seismic response

1 INTRODUCTION

The ground surface subsidence in Mexico City is produced by the consolidation of highly compressible clays. It is induced by water subsoil extraction. The increase in effective stresses due to this phenomenon produces changes in soil structure. It consequently may generate changes in soil dynamic properties.

It is known that shear wave velocity, material damping and dominant soil period, in addition of the thickness compressible layer, control the dynamic soil response. A study of the changes in these parameters in time is made. The effect of the changes in future soil dynamic response is computed.

It is known that the soft soil deposits generate dynamic amplifications due site effects. The shear wave velocity, the material damping, the dominant period of vibration and the thickness of the deposit are dominant parameters in the soil dynamic response. Particularly, the soft soils of Mexico's Valley present extreme properties. In some sites the shear wave velocity is lower than 50 m/s, dominant periods of vibration are nearest to 5 sec and deposits that generate a strong dynamic amplification present thicknesses over to 70m. Besides that, the relatively proximity to different seismic sources, produce conditions of high vulnerability.

The changes generated in the soil dynamic properties, by the consolidation process, produce alterations in the ground surface seismic response. It could strongly affect to the structural dynamic response of buildings.

2 COMPRESSIBLE SOIL THICKNESS

With the aim to observe the changes in the compressible soil thickness of Mexico's valley, the analysis of references on the ground surface have been studied. The analysed data corresponds to different measure periods, since 1983 to 1998 (SACM 2005). The ground surface references are distributed in zones within compressible soils deposits. The special position of these references is shown in Figure 1.

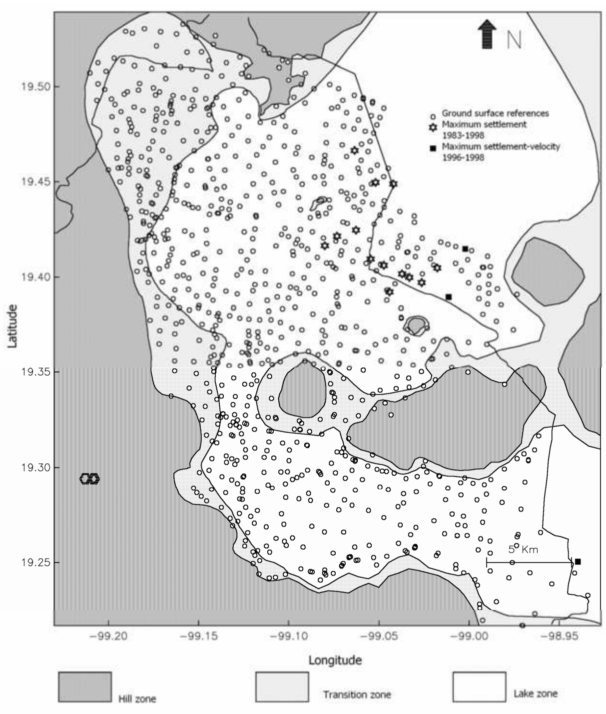

Figure 1. Location of ground surface references.

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Some sites in Mexico's valley present more than 40cm of settlements per year. In other cases there are sites with more than 4m of settlement in the fifteen years of monitoring. With the most recent information, there are sites with 8.7m of settlement between 1983 and 2005.

With the analysed information and considering that the water subsoil extraction will continue in the coming decades, it could be inferred the behaviour of the ground surface of Mexico's valley for the future.

It is clear that those sites with the small compressible soil thickness present the lower velocities of settlement. Those sites with large thickness layer present the higher velocities of settlement. Therefore, for the future, it is assumed that the settlement velocity is attenuated as function of the reduction of compressible soil thickness. With this hypothesis, a relation between settlement velocity and compressible soil thickness in Mexico's valley was founded. Figure 2 illustrates the curves of the same compressible soil thickness in the principal area in Mexico's valley (NTC-DCC 2004). In Figure 3 the relationship between thickness layer (H) and settlement velocity (V_H) is shown. The adjusted curve showed in the same Figure 3, is expressed as,

$$V_H = 0.0012 H^{2.4} \quad (1)$$

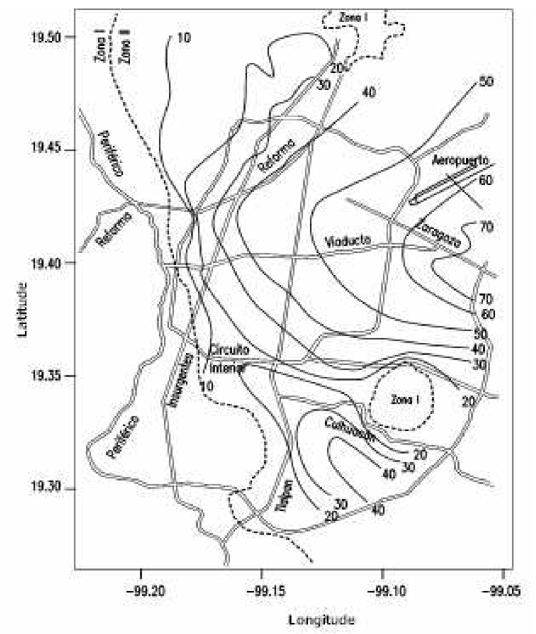

Figure 2. Curves of the same compressible thickness layer.

To predict the future behaviour of ground surface, it has been studied seven sites with original thickness layer from 10 to 70m. It has been considered that these sites are representatives of the geometrical characteristics in the Mexico's valley subsoil. In the Figure 4 the expected reduction of the thickness layer for the next 50 years in the seven sites studied is shown. As it was inferred, for long time periods the curves are like consolidation curves. It is illustrated in the upper part of the same Fig. 4. It is noticed that the behaviour of one of the curves is contained in the curves of large thickness layer. So, it is possible construct a unique curve to show the future ground surface behaviour in Mexico's valley subsoil. The curve observed (continue line) and the approximated curve (dashed line) are presented in Figure 5. With these results, the equation to associate the thickness layer with the time is the follows,

$$H = 70 - 1.6\left(\frac{t}{0.85}\right)^{0.52} \quad (2)$$

The Equation 2 is only valid for thickness layers in Mexico City between 20 and 70m.

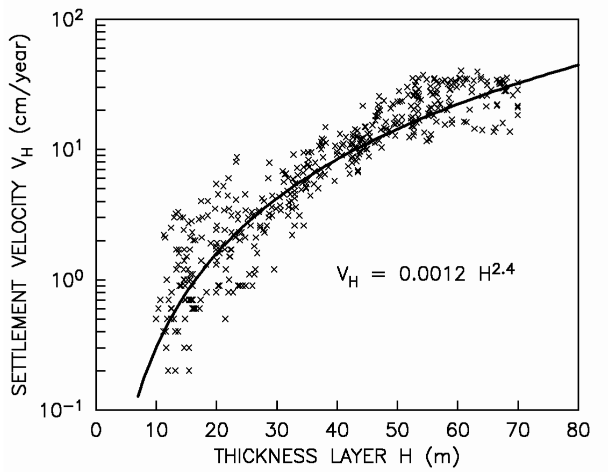

Figure 3. Relationship between compressible thickness layer and settlement velocity.

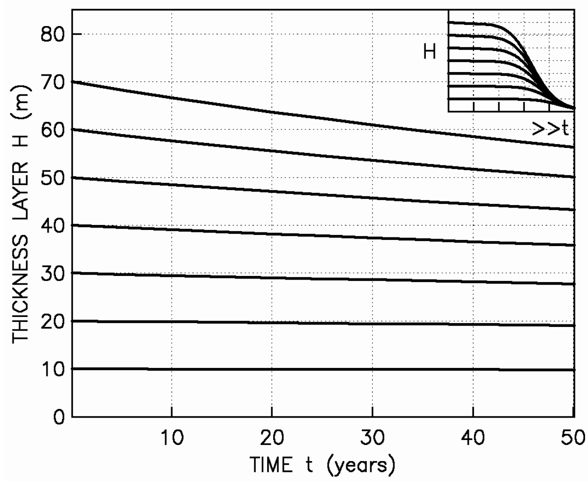

Figure 4. Change of the compressible thickness layer.

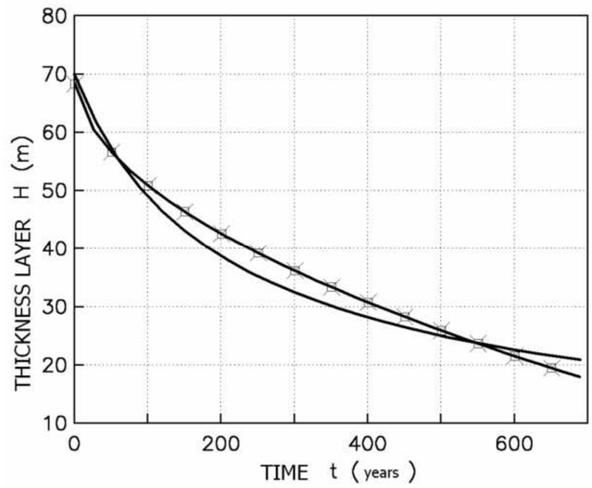

Figure 5. Reduction of thickness layer for the future.

3 FUTURE COMPRESSIBLE THICKNESS LAYER BY GROUND SURFACE SUBSIDENCE

With the unique relationship between thickness layer and time, it is possible obtain the reduction of the thickness layer, knowing the original thickness (H_0) and the time of interest (ΔT). The reduced thickness layer is computed by,

$$H = 70 - 1.6\left(\left(\frac{H_0 - 70}{-1.6}\right)^{1/0.52} + \frac{\Delta T}{0.85}\right)^{0.52} \quad (3)$$

Considering the reduction of the thickness layer in 50 years for the seven sites studied, the estimated future compressible thickness is shown in Table 1.

Table 1. Reduction of the thickness layer in 50 years.

Initial thickness layer	Reduced thickness
10.0 m	8.3 m
20.0 m	18.0 m
30.0 m	27.6 m
40.0 m	36.9 m
50.0 m	45.7 m
60.0 m	53.1 m
70.0 m	56.7 m

4 CHANGE IN SOIL DOMINANT PERIOD BY GROUND SURFACE SUBSIDENCE

Using the information of settlement velocity, the thickness layer and the soil dominant period, a relationship between thickness and dominant period was obtained. The results are shown in Figure 6.

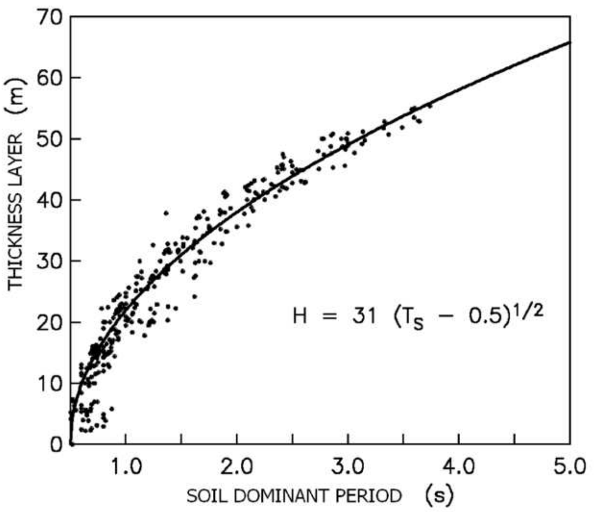

Figure 6. Relationship between thickness layer and soil dominant period.

The adjusted equation for soil dominant period and thickness layer is,

$$H = 31(T_S - 0.5)^{1/2} \quad (4)$$

With the relationship obtained and its inclusion in the reduced thickness layer equation (Equation 3), the future soil dominant period can be computed. This parameter is getting again by the original thickness layer (H_0) and the time of interest (ΔT):

$$T = \left(2.258 - \frac{1.6}{31}\left(\left(\frac{H_0 - 70}{-1.6}\right)^{1/0.52} + \frac{\Delta T}{0.85}\right)^{0.52}\right)^2 + 0.5 \quad (5)$$

Being T the estimated soil dominant period after ΔT years.

In the Table 2 the initial and the final soil dominant period are shown for the seven sites studied (see Table 1).

Table 2. Variación del periodo de vibración en 50 años.

Initial thickness layer	Initial soil dominant period	Reduced thickness	Modified soil dominant period
10.0 m	0.60 s	8.3 m	0.57 s
20.0 m	0.92 s	18.0 m	0.84 s
30.0 m	1.44 s	27.6 m	1.29 s
40.0 m	2.16 s	36.9 m	1.92 s
50.0 m	3.10 s	45.7 m	2.67 s
60.0 m	4.25 s	53.1 m	3.44 s
70.0 m	5.60 s	56.7 m	3.84 s

5 DYNAMIC SOIL RESPONSE

To evaluate the changes in dynamic soil response, acceleration response spectra were computed. For this task an original soil stratum was proposed with initial thickness, shear wave velocity and dominant period. After 50 years the changes in its properties were evaluated. Both models were excited in its base with representative bedrock strong motion records registered during the 1985 Mexico's earthquake (M_S=8.1). The layer transfer functions were evaluated by Thomson-Haskell method (Haskell 1962) and the response spectrums were computed using the Fast Fourier Transform (Claerbout 1976).

To show the principal changes detected in the dynamic soil response considering the ground surface subsidence, the results of two sites with 1.6 and 3.5 sec of original soil dominant period are presented. For this analysis the density and the material damping of the soil were assumed as constants.

For the site with 1.6 sec of soil dominant period, an original compressible thickness layer of 32.5m and a shear wave velocity of 81.3 m/s were associated. The response spectra for this site is presented with continue line in Figure 7. Considering now the changes in geometrical and material properties after 50 years, the response spectra is that showed with dashed line in the same Fig. 7. For this case, the soil dominant period is now 1.43 sec, the reduced compressible thickness is 29.9m and the shear wave velocity is 83.6 m/s.

A sliding of the spectral accelerations in left direction is observed in the results showed en Fig.7. It is attributed to the reduction of the soil dominant period. In this case, it is seem that changes in soil dynamic properties produce a benefit in the dynamic soil behaviour. It produce that the configuration of the predicted spectra presents, in general, a reduction in spectral accelerations, compared with the response spectra calculated 50 years before.

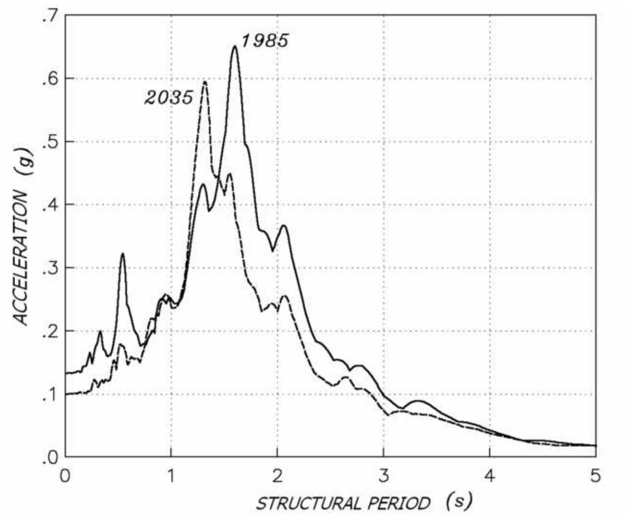

Figure 7. Changes in response spectra for a site with 1.6s of original soil dominant period.

For the site with 3.5 sec of soil dominant period, 53.7m of compressible thickness layer and 61.4 m/s of original shear wave velocity were adopted. After 50 years the changes in soil dominant period, the thickness layer and the shear wave velocity are 2.96 sec, 48.7m and 65.7 m/s, respectively. In Figure 8 the response spectrum are presented. With continue line the original response is shown and with dashed line the modified response spectra is illustrated.

In Fig. 8 the sliding of the spectral accelerations due to the reduction of the soil dominant period is more evident. In this case, besides the sliding, there is a considerable increase in the spectral accelerations, particularly in that zone where the new soil dominant period is located.

It is known that the Mexico's valley is particularly vulnerable to earthquakes coming from the subduction zone in the Pacific coast, in those sites with 2 sec of soil dominant period. That explain why in the first site (see Fig. 7) when the soil dominant period move away from the 2 sec zone, the spectral accelerations diminishes. For the second case (Fig. 8), when the soil dominant period approaches to 2 sec zone the spectral accelerations increase.

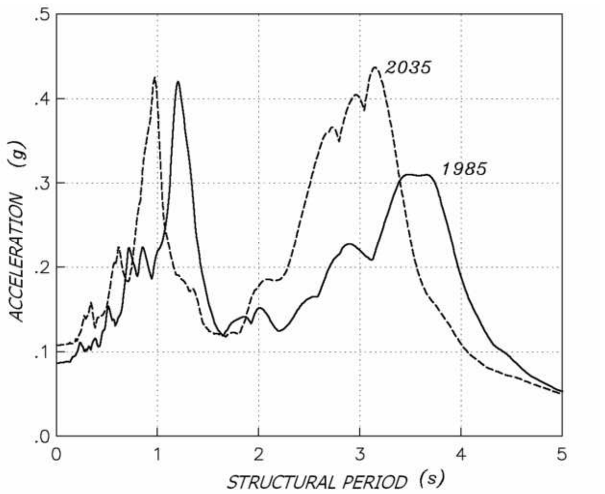

Figure 8. Changes in response spectra for a site with 3.5 sec of original soil dominant period.

Applying the results obtained to the local code in Mexico City (NTC-DS 2004), seismic design spectra were computed. Including the specific site effects for computing the design spectra for the studied site with 3.5 sec of original soil dominant period, the results are shown in Figure 9. With continue line the seismic design spectrum computed with 3.5 sec of soil dominant period is presented. With dashed line, for the same site 50 years after, the seismic design spectrum with 2.96 sec is illustrated. Fig. 9 clearly shows the strongly effects that could produce the changes in soil dynamic properties in Mexico City due to ground surface subsidence.

6 CONCLUSIONS

With the available information of ground surface settlement by subsidence phenomenon in Mexico's valley, a procedure to predict the reduced compressible thickness layer is presented. An equation to obtain the future thickness layer for an original thickness and an established time is proposed. With the relationship between the soil dominant period and the compressible thickness layer, an equation to predict the future soil dominant period is presented.

The results obtained show that the reduction of the soil dominant period could generate an increase in spectral accelerations for those structures with fundamental period lower than the original soil dominant period.

The changes in soil dynamic response was evaluated by comparing the response spectra for two sites in Mexico City with original properties, against the response spectra for the same two sites with changes in their dynamic properties 50 years later. The results showed that those sites with soil dominant period under 2 sec generate a reduction in their spectral accelerations. In the other hand, those sites with soil dominant period above 2 sec produce an increase in their spectral accelerations. It is explained by the vulnerability of the Mexico's valley to earthquakes coming from the Pacific coast, in those sites with 2 sec of soil dominant period. When the soil dominant period approaches to this value the amplification occurs.

The same mechanism mentioned above is observed in the design spectra for the Mexico City code.

It is possible that some structures located in zones with large soil dominant period could be exposed, in future, to stronger spectral accelerations than those applied in their original design.

It is recommended to include in structural seismic design, the evolution of soil dynamic properties and its consequences in soil and structural dynamic response.

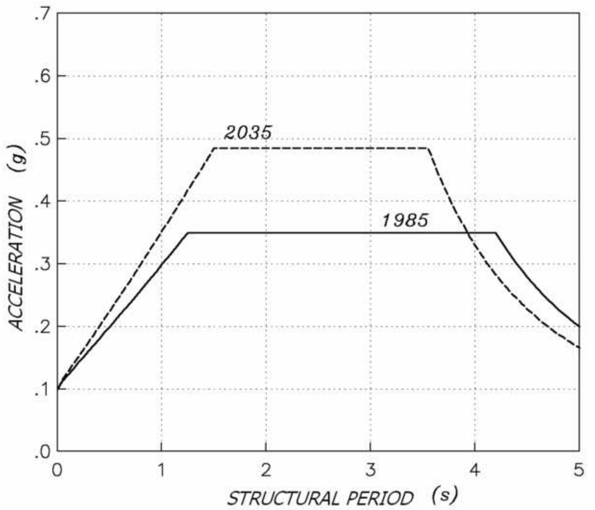

Figure 9. Changes in seismic design spectra for a site with 3.5 sec of original soil dominant period.

REFERENCES

Claerbout, J. F. 1976. *Fundamentals of geophysical data processing.* McGraw Hill Book Co, New York.

Haskell, N.A. 1962. Crustal reflection of plane P and SV waves. Journal Geophysics, Head of cattle 67.

NTC-DCC 2004. Complementary Code for Design and Construction of Foundations. Official Newspaper of the Government of the Federal District.

NTC-DS 2004. Complementary Code Earthquake Design. Official Newspaper of the Government of the Federal District.

SACM 2005. Data base with monitoring of ground surface references. Water system of the Mexico City. Government of the Federal District.