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A STUDY ON EARTHQUAKE GROUND MOTIONS DURING THE MEXICAN EARTHQUAKE OF SEPTEMBER 19, 1985

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SUMMARY

An extensive study has been conducted to understand features specific to the ground motions in Mexico City due to the Mexican Earthquake of September 19,1985. Seismic characteristics such as attenuation with distance of the maximum accelerations and response spectra, as well as properties of non-linear response were investigated. An analysis was performed to interpret the strong motions observed on the soft soils in Mexico City. A seismic microzoning in Tlatelolco residential area was performed, and the ground motions in this area were, then, estimated. Non-linear response analysis of a mid-high building in this area was carried out utilizing the simulated ground motions, whose results were compatible with the damages.

INTRODUCTION

The earthquake of magnitude 8.1 occurred on the early morning of September 19,1985, and caused great loss of human lives as well as materials in Mexico City at the distance of 370km from the epicenter which is located near the coast of Michoacan State of Mexico (Refs.1,2). In Mexico City, high intensity ground motions with rather long predominant period were recorded at the accelerograph stations on soft soils(See Fig.1). Also, the later phases with large amplitudes and long duration were recorded at one of the stations on soft soils. Watabe,M. et al.(Ref.3) indicated that "Echo Phenomenon" due to the irregular topography occurred. Seo,K. et al. (Ref.4), Fukushima,Y. et al. (Ref.5), and Ohta,T. et al. (Ref.6) simulated the later phases by application of Ray path theory or FEM-BEM hybrid method. Another feature specific to the earthquake ground motions is that seismic characteristics of ground motions and damages to buildings were remarkably correlated with geological and topographical conditions. It was reported that the significant damages were concentrated in the central area of the city where deep soft soils exist with the highest density of medium to high story buildings. Kobayashi,H. et al. (Ref.7) estimated distributions of acceleration response spectra by use of the records of microtremors. Iglesias,J. (Ref.8) proposed an intensity map defining a new seismic microzonation in Mexico City.

In the present research, an extensive study was conducted to understand the features of the earthquake ground motions. First, several seismic characteristics specific to the ground motions of this earthquake were investigated. Next, the later phases with longer predominant period were simulated by the different method from the past works. Furthermore, a seismic microzoning was applied to Tlatelolco residential area considering the local soil conditions, and non-linear response analysis of a 14 story building was carried out utilizing the simulated ground motions in each zone, whose results were compared with the corresponding damages.

SEISMIC CHARACTERISTICS OF GROUND MOTIONS AND SOIL CONDITIONS

Attenuation with distance and response spectra To illustrate the relationship between the intensity of ground motions and the epicentral distance, the attenuation with distance of the maximum acceleration as well as the response spectra at various sites are shown in Fig.2 and Fig.3, respectively. In Fig.2, Guerrero Array Sites are almost on rocks, while Mexico City Sites are on rocks or on soft soils. In Fig.3, La Villita Site is on rock in the epicentral area, UNAM Site is on lava flows, and Tacubaya Site is on hard soils. In both figures, the values proposed by Watabe,M. et al.(Ref.9) are provided. It is noticed that the observed maximum acceleration and response spectra are smaller than the calculated values in the vicinity of the epicenter. Assuming that the earthquake ground motions are saturated in the epicentral area and that the epicentral distance used is the spherical radius of which volume is equivalent to that of aftershocks, 53km, the calculated values by use of Watabe's method are in good agreement with the observed ones within the epicentral area, as shown in Fig.2 and Fig.3. On the other hand, it is noticed that the observed maximum accelerations are far larger than the calculated values in Mexico City(See Fig.2), and that the response spectra obtained in Mexico City are larger than those proposed by Watabe in the range of longer period (See Fig.3). These results are considered to be due to the soil conditions at the sites in Mexico City. Several accelerograph stations such as SCT Site and CDAO Site shown in Fig.1 are on the lacustrine soft soil deposits. Tacubaya Site is located on the hard layers formed by sand, gravel, and weathering rocks, which are layered on the basin of the Valley of Mexico and corresponding to the firm layers overlaid with the soft soil deposits (See Fig.4). UNAM Site is located on the volcanic lava flows which flowed on the deep lacustrine soft soils about 2400 years ago (Ref.10). It is considered that the responses of the formations on the basin of the Valley and those of the lacustrine soft soils under the lava flows influence the characteristics of ground motions at Tacubaya Site and at UNAM Site, respectively. The soil conditions mentioned above indicate that the records obtained at Tacubaya Site are more suitable for input motions for analyses of the responses of soft soil layers.

Properties of duration and non-linear response The ground motions with very long duration were recorded at CDAO Site, as shown in Table1. In this table, the maximum acceleration and the maximum velocity ,as well as duration time defined in Fig.5 are provided with those of the other earthquake ground motions. Also, To investigate damage potentials to buildings, non-linear response spectra of ductility factor and duration time of non-linear response were calculated. The assumption used for the analysis is as follows ; (1) Relationship between load and deformation is employed as degrading tri-linear(See Fig.6). (2) $Ky=Qy/(m\cdot g)$, $Kg=Amax/g$, here, Qy: yield strength, Amax: the maximum acceleration of ground motions, m: mass, g: acceleration of gravity. Fig.7 shows the relationship between the period and ductility factor(μmax), calculated for Ky/Kg=1.0. It should be noticed that the maximum ductility factors required for SCT-EW and CDAO-NS which indicate large destructive potentials to structures with rather longer period are much larger than those for EL CENTRO-NS and HACHINOHE-EW. In this non-linear analysis, the sum total time when the response displacements exceed 80% of the maximum ones were calculated, as shown in Fig.8. It can be seen that the ground motions observed at CDAO Site have very long duration with large destructive potentials in the range of longer period.

AN ANALYSIS OF HIGH INTENSITY GROUND MOTIONS WITH LONG DURATION

To understand the later phases with large amplitudes and long duration observed at CDAO Site, an analysis using the equivalent linear method for the response of horizontally layered soil was carried out. In this analysis, the ground motions recorded on the hard soils, at Tacubaya Site, was used as incident waves to the hard soil layer overlain by the lacustrine soft soil deposits (See

Fig.4). Fig.9 and Fig.10 show parameters and non-linear characteristics for the dynamic response analysis, respectively. These parameters were assumed on the basis of the data presented in the past studies(Refs.6,10,11), being modified in consideration of the location of the site. As results of this analysis, it is found that the simulated earthquake ground motions at the surface include the waves with longer period and large amplitudes in the latter part of the time history, as shown in Fig.11. However, the latter phases such as recorded ones were not realized in the case synthetic waves which have constant Fourier amplitudes and random Fourier phases with Jennings' type intensity function were used as input motions (See Fig.12). Therefore, the observed surface waves, so called "Echo phenomenon" seems to be primarily caused by the topography peculialities of the Valley of Mexico.

A SEISMIC MICROZONING IN TLATELOLCO RESIDENTIAL AREA CONSIDERING LOCAL SOIL CONDITIONS

Tlatelolco residential area is located to the north-west of the down town (See Fig.1) and is one of the zones where buildings were heavily damaged. Although the area is as wide as approximately 2km x 0.4km, the damages were not uniformly distributed. The area may be zoned as shown in Fig.13, according to the observation of damages(Ref.2). In this figure, the damages to buildings in each zone are classified as follows ; Zone(a): 14 and 21 story RC buildings were severely damaged, while one of 14 story RC buildings collapsed. Zone(b):14 and 21 story RC buildings were moderately damaged. Zone(c): 8 story RC buildings were severely damaged while 14 story RC buildings were moderately damaged. Zone(d): Structural damages were not observed, but non-structural damages observed. Also, the equal depth of the deep deposits(Ref.12) is provided in this figure. It is recognized that the distribution of the damages may be related to the thickness of the soft soils. On the other hand, a seismiczoning map in this area is proposed, taking into account the soil conditions and the predominant periods of microtremors, as shown in Fig.14. In this figure, the area is zoned into 4 parts which may be consistent with those presented in Fig.13.

To investigate the relationship between damages and ground motions, earthquake ground motions were generated in each zone, and an elasto-plastic response analysis of a MDOF system was carried out using the simulated ground motions. In the former analysis, the same procedure introduced in the previous section was applied to generate the ground motions, i.e. the equivalent linear response analysis for horizontally layered soils utilizing the recorded accelerogram at Tacubaya Site as input motions. The parameters used for this analysis were assumed, considering the soil conditions at Alameda Park (Ref.11), and the thickness of the soft soils, as well as the predominant periods of microtremors recorded at various stations. Fig.15 and Fig.16 show the wave forms and the velocity response spectra of the simulated ground motions in each zone, respectively. According to the acceleration response spectra, the acceleration response with the damping ratio of 5% takes the approximate values from 100 gals at Zone(D) to 400 gals at Zone(A) in this area, which is in a moderately good agreement with the results proposed by Kobayashi,H. et al.(Ref.9).

Next, an elasto-plastic response analysis of a 14 story RC building was performed using the simulated ground motions in each zone. In this analysis, the following conditions were assumed. (1) The structure was designed according to the asseismic code by the Federal District of Mexico revised in 1977(Ref.1). The required ductility factor was 4. (2) The weight of each level was 1000tons. (3)The lateral shear stiffness was estimated from the predominant period obtained by the microtremor measurement (1.96sec.,Ref.2). (4) Rocking and sway of the base was considered. Fig.17 shows the maximum response displacements and the maximum ductility factors along the height of the building in each zone. In this figure, it should be noticed that the ductility factor of the structure obtained in Zone(A) exceeds the required value at the lowest level. This result corresponds to the fact that one of the 14 story RC buildings collapsed. As results of these analyses, it is understood that the simulated ground motions may lead to realistic results compatible to the damages, and that a seismic microzoning should be applied in this area.

CONCLUSIONS

The earthquake ground motions observed on soft soils in Mexico City had large amplitudes with long duration, as well as large destructive potentials to structures with rather longer fundamental period. The observed waves with longer period and large amplitudes in the latter part of the duration, so called "Echo phenomenon", is considered to be caused by the topography peculialities of the Valley of Mexico. It is essential to perform a seismic microzoning in areas where soil conditions vary, irrespective of width of the areas. Local soil conditions should be taken into account for the seismic microzoning.

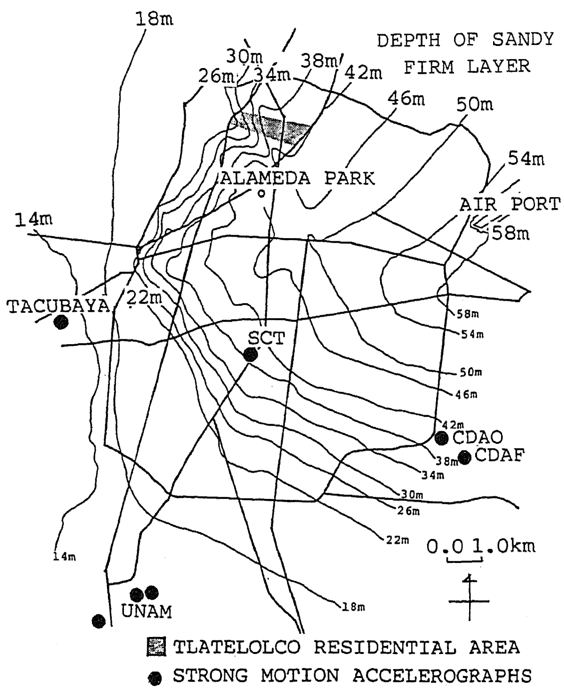


Fig.1 Mexico City (after UNAM)

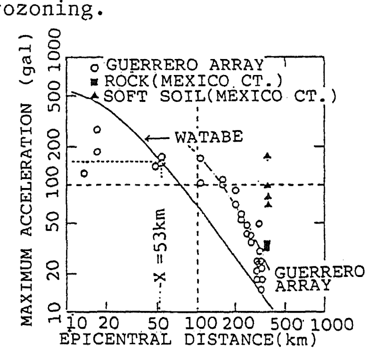


Fig.2 Attenuation with Distance of Maximum Acceleration

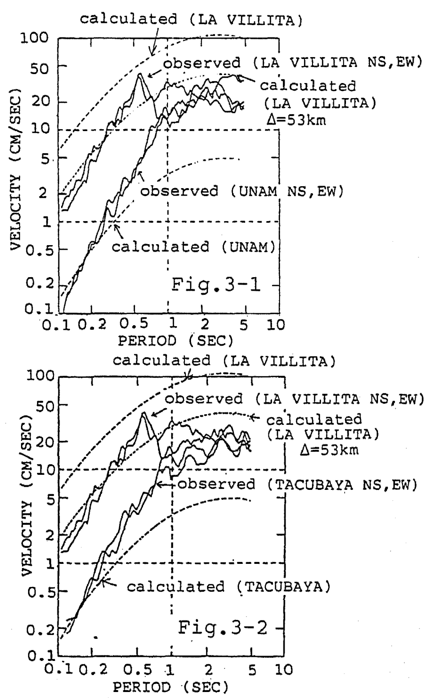


Fig.3 Velocity Response Spectra with Those Calculated by Watabe's Method

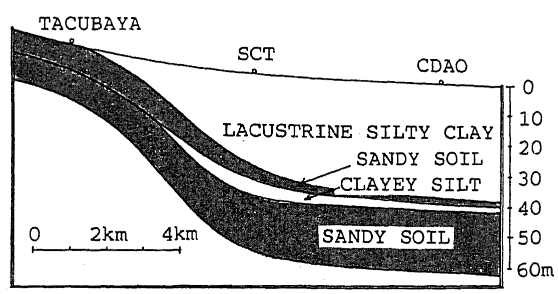


Fig.4 Geological Section of Mexico City

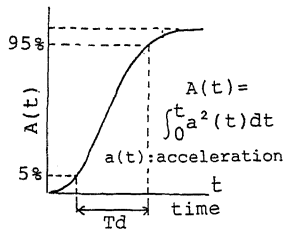


Fig.5 Definition of Duration Time

Table1 Seismic Characteristics of Several Ground Motions

	Amax(gal)	Vmax(kine)	Td(sec)
MEXICO 1985 CDAO-NS	69.2	35.0	102.6
MEXICO 1985 SCT-EW	167.9	65.5	38.8
ELCENTRO 1940-NS	41.7	34.1	24.3
HACHINOHE 1968-EW	204.1	37.8	28.7
SYNTHETIC TOKAI (TOKYO-NS)	67.9	10.6	66.7

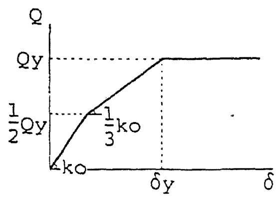


Fig.6
Assumed Characteristics Between Load and Deformation for Non-linear Response Analysis

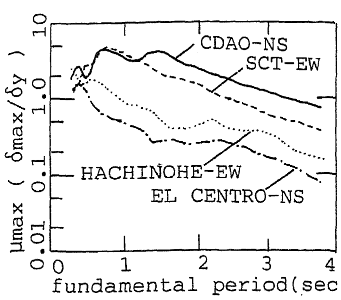


Fig.7 Non-linear Ductility Factor Response Spectra

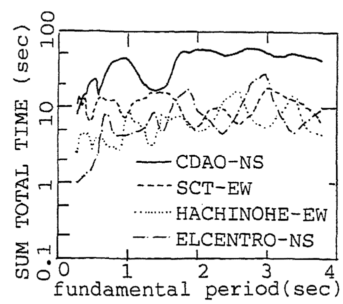


Fig.8 Duration time of Non-linear Response (over 80% of Max.Disp)

TACUBAYA

H(m)	Vs(m/sec)	ρ(t/m³)	
4.0	149	1.77	S1
8.0	250	1.75	S2
∞	300	2.00	

F :FILL
C1:SILTY CLAY
C2:SILTY CLAY
S1:SANDY SOIL
S2:SANDY SOIL

CDAO

H(m)	Vs(m/sec)	ρ(t/m³)	
5.0	70	1.66	F
10.0	38	1.10	C1
15.0	49	1.17	C1
7.0	61	1.24	C1
2.0	149	1.77	S1
4.0	87	1.27	C2
24.0	250	1.75	S2
∞	300	2.00	

Fig.9 Parameters for Response analysis of Layered Soils at CDAO Site

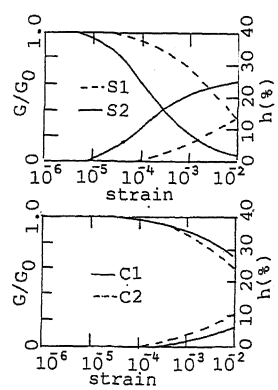
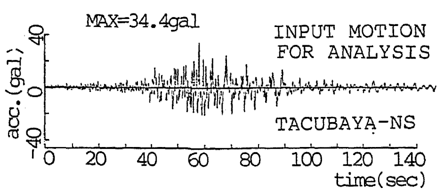


Fig.10 Assumed Non-linear Characteristics of Subsoils at CDAO Site (See Fig.9)



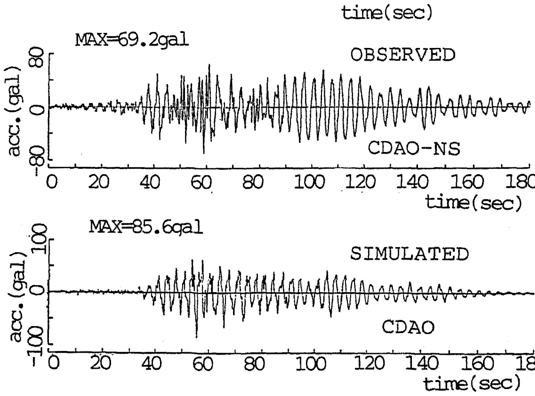


Fig.11 Simulation of the Later Phases Observed at CDAO Site

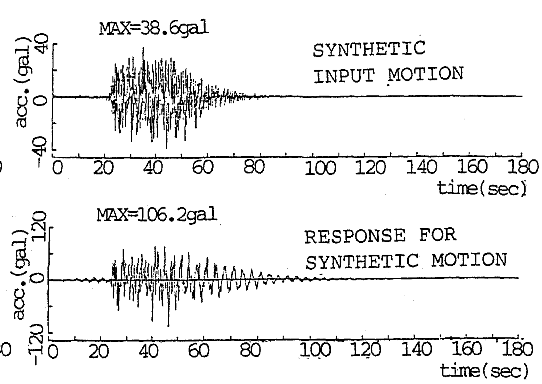


Fig.12 Incident Synthetic Motions and Response

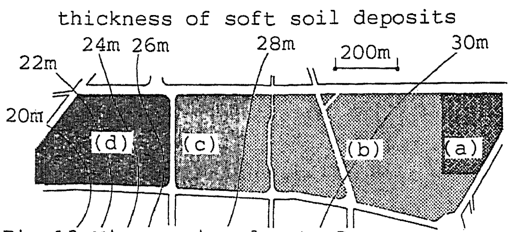


Fig.13 Microzoning due to Damage Observation in Tlatelolco Residential Area

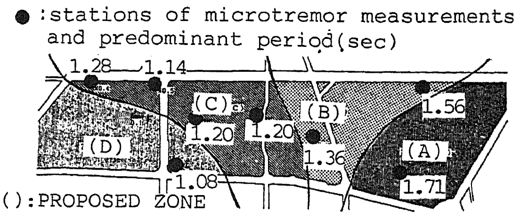


Fig.14 Seismic Microzoning in Tlatelolco Residential Area

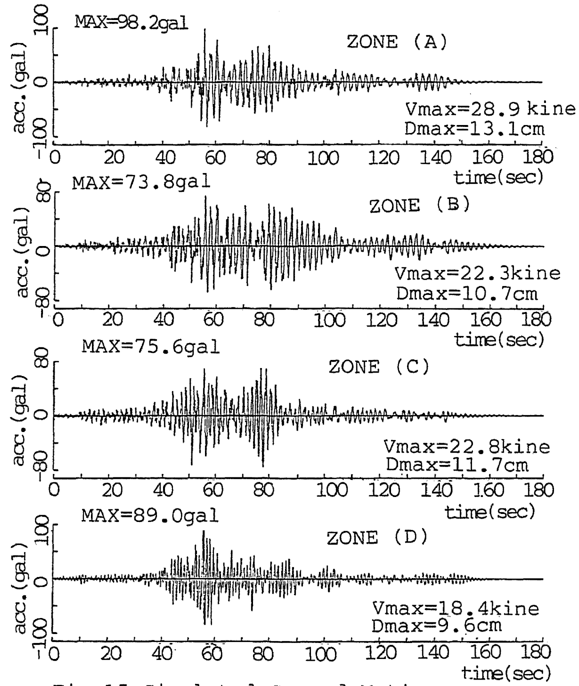


Fig.15 Simulated Ground Motions in Each Zone Shown in Fig.14

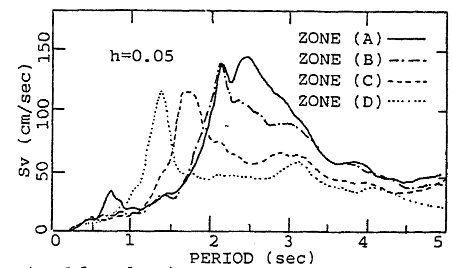


Fig.16 Velocity Response Spectra of Simulated Ground Motions in Each Zone Shown in Fig.14

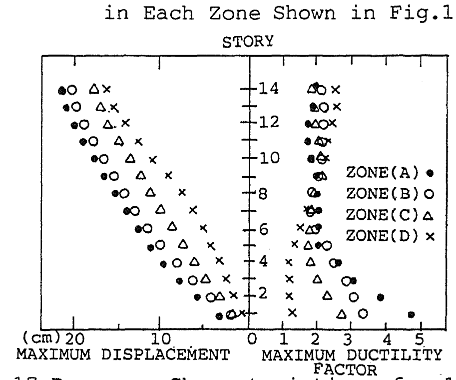


Fig.17 Response Characteristics of a 14 Story Building in Each Zone Shown in Fig.14

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