13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 1240

SEISMIC CHRACTERISTICS OF SURFACE GEOLOGY AND DYNAMIC CHRACTERISTICS OF LOW-RISE BUILDINGS ESTIMATED BY MICROTREMORS TO DISCUSS ON THE BUILDING DAMAGES IN TEHUACAN CITY CAUSED BY THE 1999 EARTHQUAKE.

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SUMMARY

This paper is a report on the field surveys on the ground and buildings in Tehuacán City, Mexico, using with refraction test and microtremors observations on the ground, and microitremor only for the buildings. Tehuacán city locates in the epicenter zone of the 1999 Tehuacán Earthquake. After a report of the Tehuacán City office, the affected areas for buildings caused by the earthquake were ubiquitous in the city. These projects had conducted to investigate the relationships between surface geology and damages of buildings caused by the earthquake, and to allow seismic microzonation in the area.

From the refraction test, we conclude that the ground surface stratums in Tehuacán City are fairly hard and the layers are very shallow. Observed microtremors show short predominant periods in the observed area in the city, but the forms of spectra are not same.

Natural periods of the same types of buildings affected by the 1999 earthquake are very short. Using these results, we can roughly explain the relations between the seismic characteristics of surface geology and the damages of buildings caused by the 1999 earthquake. We can also make a seismic microzonation of the city by this survey results.

INTRODUCTION

Surveys on seismic disasters of buildings, infrastructure and other social facilities caused by a great earthquake are important in order to mitigate seismic disasters in the cities and to improve seismic resistant design methods for the future. In particular surveys from the viewpoint of seismic microzonation will be useful for urban safety in urbanized areas. Many researchers in the world now recognize the importance of microzonation.

At 20:06.4(GMT), July 15, 1999, an Earthquake of the magnitude M=6.7(Mw=7.0) occurred at 18°20 N latitude and 97°47W longitude of 92km depth.19 persons died by the quake. The quake is called the 1999 Tehuacán Earthquake. (After EERI Report July 16, 1999 : Tehuacán,6/15/1999, Earthquake). The 1999 Tehuacán Earthquake affected many cities in Puebla State and some cities in neighboring states. Tehuacán City is the nearest city to the epicenter of the earthquake.

These projects were conducted after the 1999 quake in Tehuacán City to investigate the damages in the city. After the quake, the City Office of Tehuacán conducted various surveys in the city including a questionnaire survey among citizens about building damages. And before the 1999 Earthquake, very interesting survey conducted by E. Osorio et al(1998) using microtremor observation to use microzoning in the city.

This paper is a report on the ground seismic characteristics in Tehuacán City estimated by the data of refraction tests and microtremor observations, and also on the dynamic characteristics of buildings estimated by microtremors. These projects were conducted mainly in September of each years from 2000 to 2002.

ON THE TEHUACAN CITY

Outline of Tehuacán City

Tehuacán City is the second great city in the Puebla State and is located near the boundary of Oaxaca State in a direction to southeast from Puebla City, the capital city of the state. It is situated at 18°27 40 ″ latitude and 97°03 31 ″ longitude , and the height above sea level is 1620 m. As of 1995, the area of the city is 390.36$km^2$and it's population is 190,468 persons.

In the city, there are not so many high raise buildings; major stories of buildings are mainly one or two. Table 1 shows the population increase from 1895 to 1995, over this period the city has been developing very rapidly. The city shows a similar urbanized pattern of the other rapidly developing cities in the world.

Table 1 Population increase in Tehuacán City (Seiten 1998 and Balderas 1998)

Year	Population	Increase ratio for each decade %	Averaged increase ratio each year %
1895	12290		
1910	12987		
1950	33642	33.5	2.9
1960	45149	34.2	3.0
1970	68332	51.3	4.2
1980	115107	65.5	5.2
1990	155563	37.5	3.2
1995	190468	22.4（Half decade）	4.48

Topology and Geology

Tehuacán City is in the Mexican Central Heights and in the Tehuacán Valley that is composed of joining with Tlacotepec and Santiago Miahuatlán valleys at last south parts of them. Central area of Tehuacán City is composed of flat land generally, although very high mountains surround the valley.

Great earthquakes are generated in the subduction zone between Coco's Plate and North American plate. The city was being affected frequently by large historical earthquakes occurred in the zone.

Surrounding parts of ground of the valley belong to the origin Cretaceous deposits. In the valley, surface layers are composed of alluvial deposits. Fig.1 is the geological map after Osorio et al 1998. Tehuacán City locates on the alluvial deposit in the central part of the Fig.1.

Fig.2 is a geological section of surface layers by subsoil sounding in San Lorenzo provided by The City Office (After Blanco 2000). This subsoil sounding had been conducted to estimate bearing capacity of the ground for the design of residential buildings. This sounding had not included the standard penetration test, so we could not see N-values of the layers. But the consultant company recommended a layer of 60 cm deep from ground surface as the basement layer for the building foundation, and the bearing capacity of the basement layer is 12.0tf/m^2.

Fig.1 Surface geology around Tehuacán Valley (Osorio et al 1998)
-Tehuacán City locate in the wholly alluvial deposits-

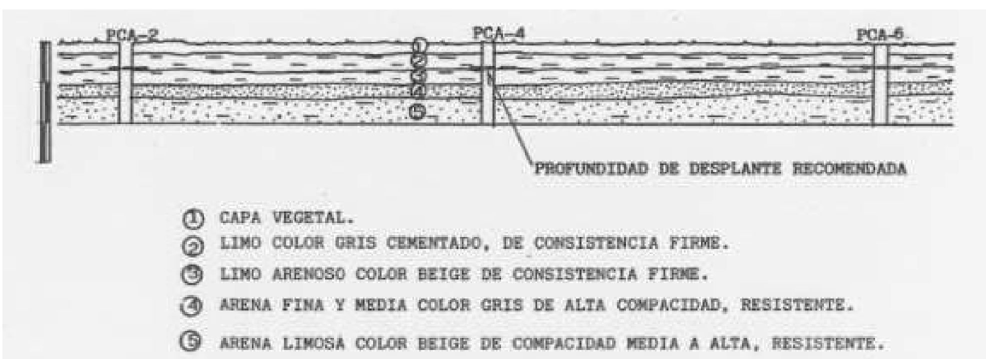


Fig.2 A Section of Surface Geology at San Rolenzo (Blanco 2000)

This data gave us very important documents on surface geology, but unfortunately only one site, for very shallow layers, and without penetration data, etc.

We can say that the seismic damages in Tehuacán city caused by the 1999 Earthquake are not catastrophically, although the Magnitude was large and epicenter was very near. However, after the earthquake, 138 housings should be required to demolish as the building dusts.

Table 2 shows the condition of housings damages in the city. By the table, we can see that 68 housings had been demolished totally. And the damages of the buildings were ubiquitous in the central area, commercial buildings, church and public buildings as like the city office.

ESTUDIO: DE MECANICA DE SUELOS PARA EL PREDIO "SAN LORENZO" UBICADO EN TEHUACAN, PUE.

POZO	P.C.E.E.	MUESTRA	PROF.	GRANULOMETRIA %			DESCRIPCION	W	LL	IP	CL	Ss	Ym	e	Gw	Qu
No.	m	No.	m	G	S	F		%	%	%	%	-	T/m^3	-	%	Tm^2
		1	0.2				CAPA VEGETAL									
4	0.4	2	0.4	48	41	11	MEZCLA DE FRAGMENTOS DE MATERIAL CALIZO COLOR AMARILLO CLARO INTEMPERIZADO CON ARENA GRUESA Y COMPACTO	9.2			2.1	2.5	1.36			
FIN DEL SONDEO NO SE DETECTO EL N.A.F.							MATERIAL CALIZO MUY COMPACTO NO EXCAVABLE CON RETROEXCAVADORA									

Fig.3 Sounding data at San Rolenzo (Blanco 2000)
Seismic Damages in Tehuacán City

Table 2 Numbers of Affected housings required demolition
(Cierre parcial al 24 de Julio de 1999.)
-From Tehuácan City Office-

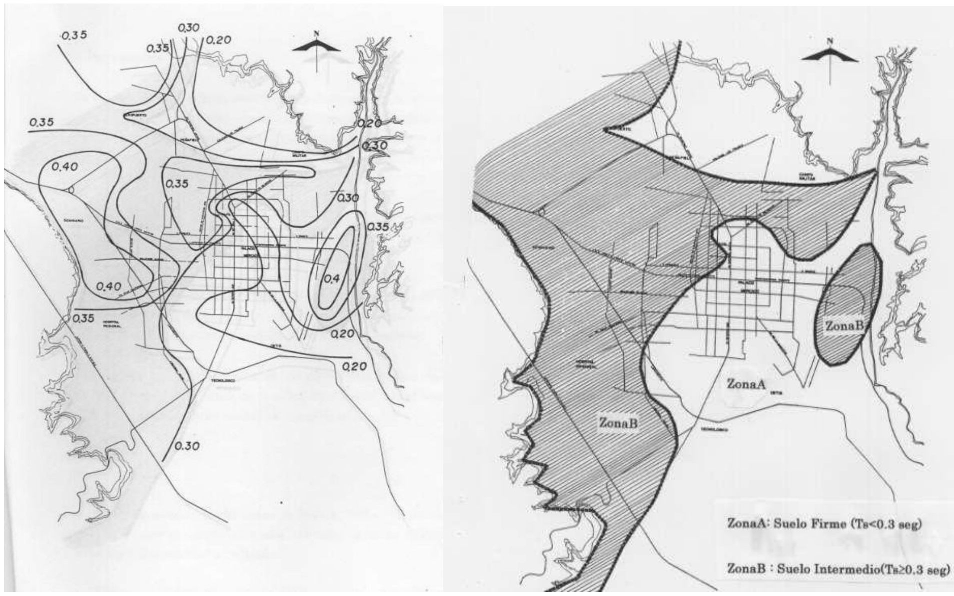
Affected Housings	1,800 Habitación.
Demolished Housings -Totaly -Partialy	68 45
Demolishing Housings	9
Compulsory Demolitions	2
Demolitions that owners went out their housings	8
Demolitions without agreement	6
Total	***138 Housings***

PREVIOUS RESEARCHES ON SEISMIC MICRO ZONATION IN THE TEHUACANCITY

Map of predominant period distribution using with microtremors observations

Before the 1999 Tehuacán Earthquake, Osorio et al (1998) had conducted a project of seismic microzoning of Tehuacán City using with microtremors observation. We can say that the work is a very pioneering research in this city. Firstly they had made a contour map with same period lines of the estimated predominant periods using microtremors.

Finally, they proposed a microzoning map with only two different type zones in the city, one of them is firm subsoil zone and media firm zone (see Fig.4). The scale for dividing to two type zones is predominant period of microtremors, firm soil area in the predominant periods $Ts < 0.3$ second, and media firm area in $Ts > 0.3$ second. Those maps are shown in Fig.4. In this research, the original Fourier Spectra of horizontal components of microtremors were used to estimate the predominant periods; H/V spectral ratio called the Nakamura's technique was not used.



(A) **(B)**

Fig.4 Same Predominant Contour Map(A) and Zoning Map with Two Zones(B) (Osorio et al 1998)

Zoning of damaged building areas caused by the 1999 Tehuacán Earthquake

Buildings damages by the quake were ubiquitous in the central area in the city. Affected parts were the roofs of commercial buildings, roofs and belfries of churches, and walls and columns of many buildings including the city office.

The Tehuacán City Office had conducted questionnaire survey on the damages of buildings used with their official format to citizens. By the replies from citizens, the city office had made many useful and interesting statistics graphs.
Fig.5 is a sample of these statistics graphs on the numbers of damaged housings for each colony. Using this graphs, the City Office made a zoning map of damaged areas, see Fig.6.. We can see that the affected areas by the 1999 Earthquake were ubiquitous in the central region.

Microtremors observed after the 1999 Theuacán Earthquake

Javier Lermo et al (2003) observed microtremors at 8 sites in Tehuacán City after the 1999 Tehuacán Quake. The observed sites are 5 locations in Zone A and 3 sites in Zone B in Fig.4(B) by E. Osorio et al.

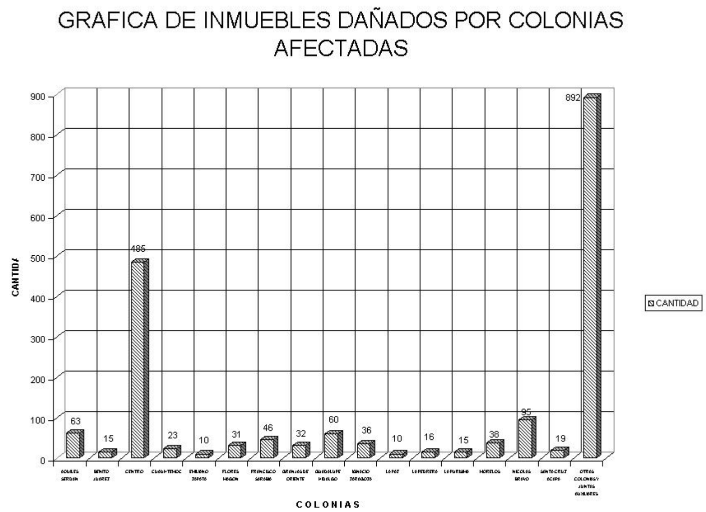


Fig.5 A Sample of Statistic Graphs of Affected Buildings by The 1999 Quake in each colonies.

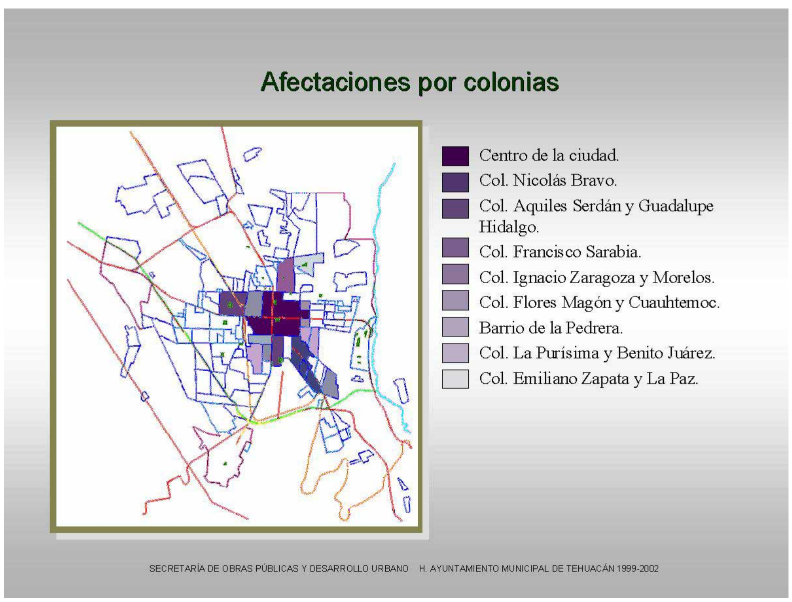


Fig.6 Affected Zones on each Colonies by the Questionnaire Surveys for Citizens.

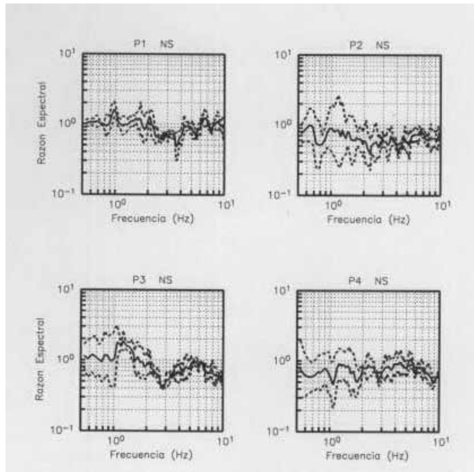


Fig. 7 H/V spectral ratios observed in the central area by Lermo et al(1998).

Spectra at four sites in the central area (Zone A, in Fig.4 (B)) are shown in Fig 7. They used H/V spectral ratio of the Nakamura's technique. They compared with the data in the town of Acatlan de Osorio where had been damaged more severely than Tehuacán City's. They commented as the deferent level of the damages that the amplification factors of the H/V spectral ratio in Tehuacán are lower than its in Acatlan de Osorio fortunately.

THE SEISMIC GROUND CHARACTERISTICS IN THE TEHUACAN CITY ESTIMATED BY THIS PROJECT

Measurement of S-wave velocity by using Board Banging Method

Strong motions on ground surface during an earthquake are strongly affected by S-wave velocity structure of subsoil. The sites covered with soft sediment have high seismic response

Table 3 Tehuacán Refraction survey sites and their soil model; (Shear wave velocity Vs, Thickness of Layer H, Soil Density ρ)

NO.	SITE	Vs1	Vs2	Vs3	H1	H2	ρ1	ρ2	ρ3
		m/s	m/s	m/s	m	m	G/cm3	g/cm3	
1	San Lorenzo	500	1,080		3.6		2.1	2.4	
2	El Carmen	650					2.1		
3	San Rafael	280	340		1.1		1.8	1.9	
4	Col. Valle	290	420		4.1		1.8	2.0	
5	Plz. Tehuacan	370	510		2.0		1.9	2.1	
6	Huizachera	260	720		2.7		1.8	2.1	
7	Pedrera	130	330	540	1.0	9.1	1.7	1.9	2.1
9	Rio Tehuacan	350	630		2.9		1.9	2.1	
10	Unid. Deportiva	260	610	900	4.1	25.0	1.8	2.1	2.2
11	Calle Veinte	345	650		6.1		1.9	2.1	

with long period. It must be important to survey soil structure and S-wave velocity in and around the city area. In order to know seismic conditions of soil, refraction surveys were carried out at 10 points in Table 3 and in the map of Fig.10. Using the Board Banging Method measurements were performed. The wooden plate of 10cm×10cm×200cm was pressed on ground surface by a car weight. By banging both edges of a plate from left and right sides, shear waves are generated and

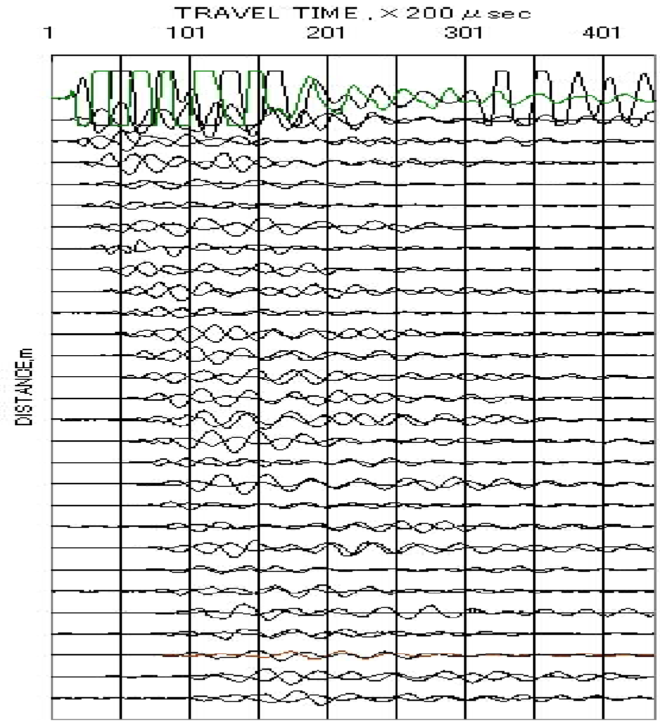


Fig.8 A Sample of the Past-up of the Record at Site 1

propagated to perpendicular direction. Sensors were installed on the ground surface to measure arrival signals of every 1 m. Fig.8 shows the paste-up of the records obtained at Site 1. Reversed phases of the records show that arrived signals are shear wave. The distances of the survey line were 40 to 80 meters, so that soil structures of 15 to 30 meters in depth were examined.

Table 3 shows the shear wave velocities and thickness of uppermost, middle and deeper layers. Bulk densities of each layer were estimated with S-wave velocities. It is mentioned that Site 1 and Site 2 have not soft soil, however other sites have. The thickness of soft soil(300m/sec) are less than 3m at Site 5,6,9, may be 4 to 6m at Site 3 and 4 , and more than 6m at Site 10 and 11 . Site 7 has soft deposit of 10m.
The second layer of velocity 1,080m/s observed at the site 1(San Lorenzo) must be the bedrock constituting a base of the valley. At the other sites, the bedrock could not be observed, but underlies the second and third layer in Table 3.

Microtremors Observations of This project:
Continuous Observations on every one-hour during long time at Fixed Sites
Continuous microtremors observations had down at 4 sites, during from minimum 8 hours to maximum 19 hours. On every one hour, they were observed 3 minutes automatically. Observed 4 sites are shown in the Map of Fig.10 with Δ marks.

Natural period of seismometer set up at one second period, so the amplitude in the range of period longer than one second was damped strongly.

All Fourier spectra and H/V spectral ratios are shown in Fig.9. By these spectra, we can see that the amplitude of Fourier spectra at each sites varies with time dependently, exclusive the data CASASAN. During time of observations includes at mid night times and day times, exclusive the data CASASAN. Only the data CASASAN had been observed only in the day times on a Sunday. Only the amplitude of Fourier spectra of CASASAN is stable, is not so strong variable. So the variation of amplitudes of microtremor are affected by artificial urban activity's level depend times in day times and mid night times.

But in spite of the variation of Fourier spectra, all H/V spectral ratios have without time dependent. In the range of shorter than 1second period, one or two peaks are observed the H/V spectral ratio in each data except the data CASARON. The ratios of the peaks are not large value, only two times or less, these values coincide with the comments by J.Lermo et al above-mentioned. The data CASAROM did not show anything clear peaks only but shown frat value with unity under 1 second range.

Moving Observations
The sites for moving observation were decided at the crossing points with two grid lines generally that divided by 1 km×1km grid lines for whole area of the Tehuacán City. Observed sites are shown in Fig. 10.

Moving microtremors observations had been conducted only day times, about from 9 am to 6 pm on the weekdays.

Fig.11(A) shows the Fourier spectra of NS components of microtremors in each enclosed 1 km^2 squared by grid lines including moving observation sites. We can say roughly that the types of spectra are deferent with east side including line 69 and west side including line68. Namely, amplitude peaks of east side are in the very short range about equal or less than 0.1 second in the graph and amplitudes are large values compared with west side. In contrast, the spectra of the west side in the city show various types and amplitude are not so large compared with east side.

Discussion on the relation with results of refraction survey and microtremors observation
We can see that the results of S-wave measurement by refraction survey and Fourier spectra by microtremors observations coincidence roughly at the test site 7(near 69and 70-42 coordinates for microtremors observation sites) and 10(near 71-38) of refraction surveys in Fig.10. On the other site, we can say that generally surface deposits are very shallow or anything in this city, and predominant frequency of amplification factor shall be very high. So the results of high frequency of those periods are reasonable.

But we need more detail discussion and comparison on the relation using with both data.

DSCUSSION WITH PREVIOUS WORKS OF SEISMIC MICRO ZONATION

E. Osorio et al proposed a seismic microzonation maps above-mentioned in Fig.4 (A) and (B). I. Balderas made a building damaged distribution map Fig.6 in the report of the city office above mentioned too.

The buildings damaged areas coincide in Zone A of Fig.4(B) by E. Osorio et al. We are interested with this coincidence for discussing to be explaining damaged area concentration in Fig. 6.

Above mentioned, authors mentioned that Fourier spectra types are different in east side area and west side in the city(Fig.11(A)). We can say roughly that Zone A in Fig.4(B) coincides with south-east side zone of Fig.11 that the spectra peaks are in the very short range about equal or less than 0.1 second and amplitudes are large values. We consider that the dividing scale of predominant period 0.3 by E. Osorio et al shall be recheck with their data and us.

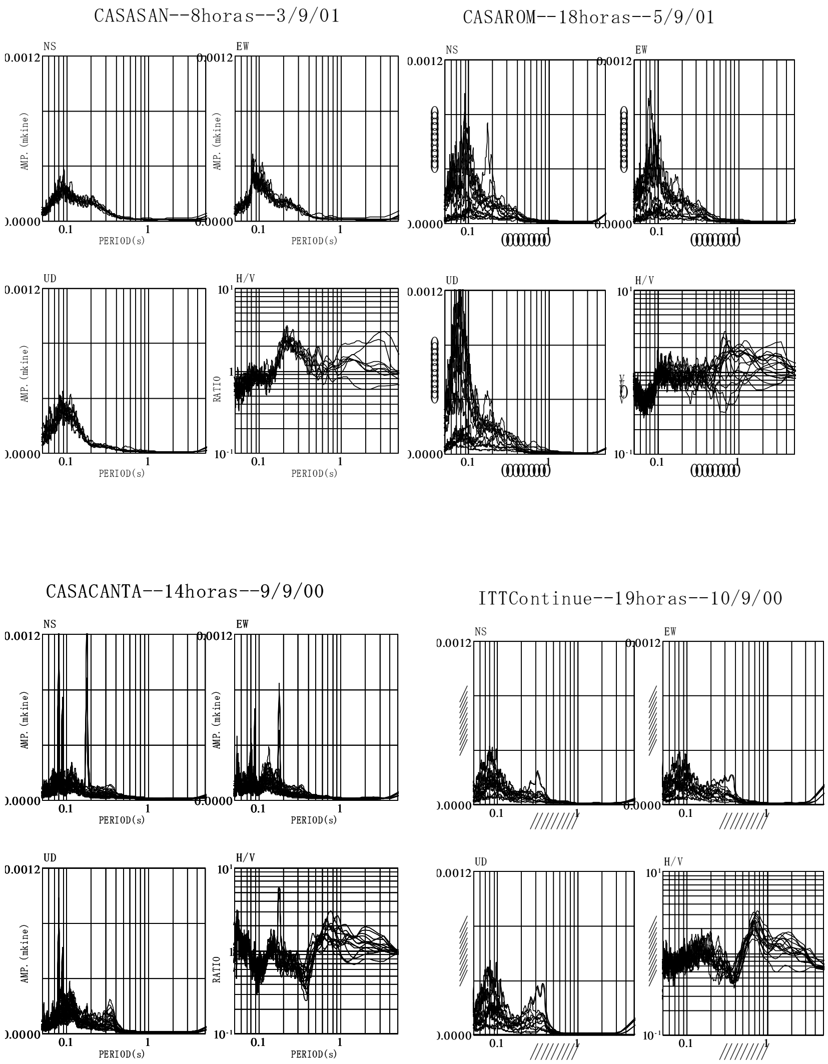


Fig.9 Fourier Spectra and H/V Spectral Ratios of Continuous Observation at 4 sites.

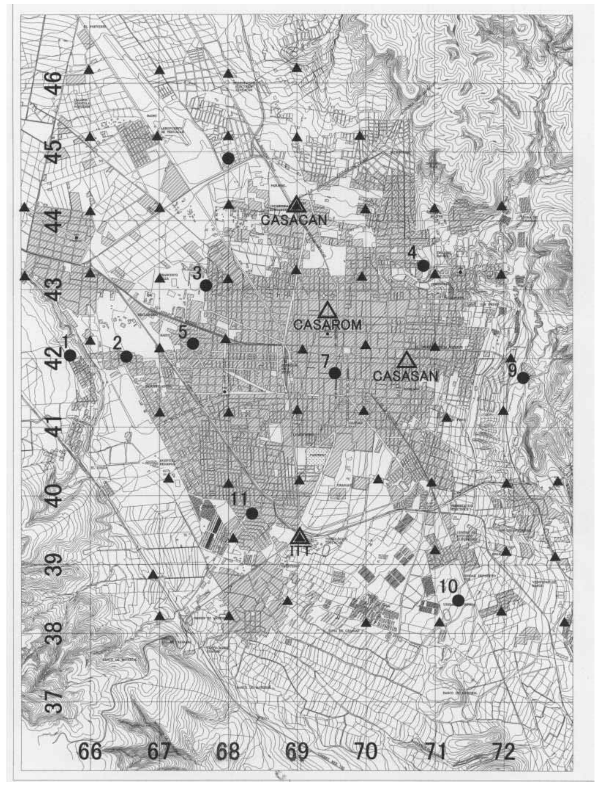


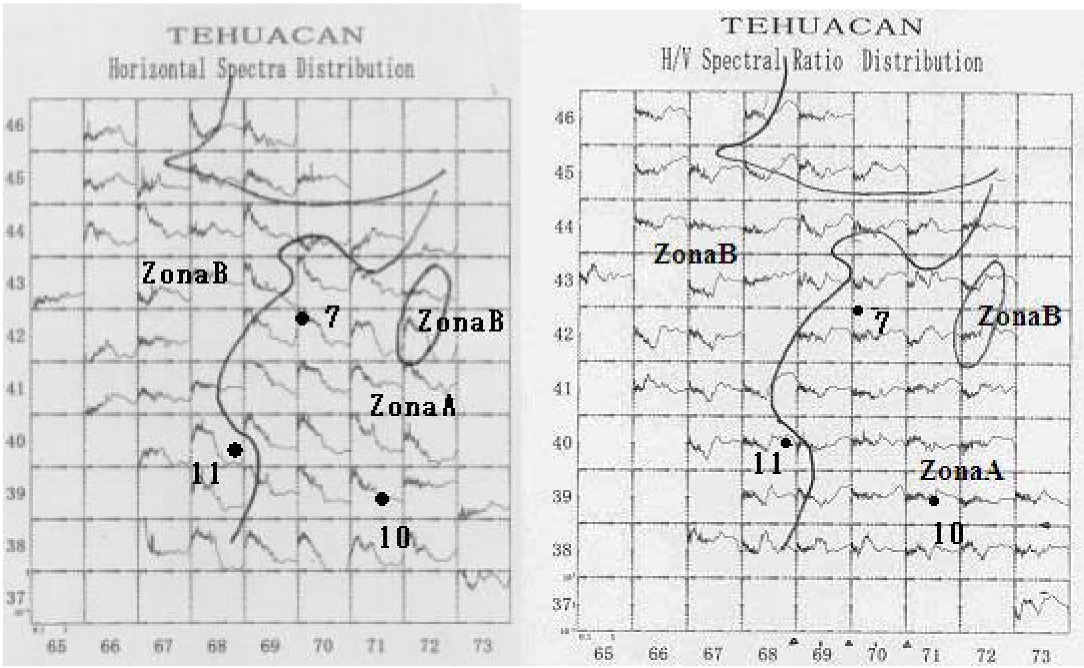
Fig.10 Sites of Refraction Test
and Microtremors observation
• Refraction Test Sites
▲ Moving Microtremors Ob. Sites
Δ Continues Microtremors Ob. Sites

The works of E. Osorio et al(1998), Lermo et al (2003) and this present results shall be adjusted to make a more useful zoning map. Authors show a distribution map of H/V spectral ratios in Fig.11 (B) together with Fourier Spectra distribution map of NS components.

The types of H/V spectral ratios are various, but the magnitudes of the ratios are not so large that J. Lermo mentioned. Probably we can explain this phenomenon with Table 3, because the surface layers generally are hardness and lower impedance ratios.

By the comparison with damaged area in Fig.6 and Fig.11(A), we can see that microtremors are amplifying the very short period zone, 0.1 second or less, but H/V spectral ratios did not show any peaks in the short range. Though the damaged areas composed with very hard geological layers, authors considered that damaged buildings were affected by short component of the earthquake ground motion, near about 0.1-second periods. We shall compare with periods of the ground and buildings.

H/V spectral ratios in Fig 11(B) show peaks in the region between 0.3 -second to 1.0-second. The peaks suggest us that those peaks are affected with deeper geological layers in the city. But now, we have not anything data for the deeper layers.



(A) **(B)**

Fig. 11 Comparison with iso predominant periods distribution by E. Osorio and Fourie spectra (A) and H/V spectral ratios (B) by this research.
(Marks•: Test sites of Refraction Survey)

MICROTREMOR OBSERVATION OF LOW RISE BUILDINGS IN THE TEHUACAN CITY

Observed buildings

Author**s** had measured microtremor of 23 buildings in Tehuacán city. Those buildings are 12 housing buildings, seven school buildings, a catholic church building, a city office building, a hotel and a shopping store building that was under construction at the time. (see Table 4)

Five buildings with one story are using as school building. And four buildings (No.1-No4) of them are class room types that have concrete block partition walls for each class in short direction. Another only one building (No.5) is using as laboratory, so nothing rigid wall is not in any direction.

Averaged predominant periods of the class room type school buildings are 0.075 sec in short direction and 0.18 sec in long direction of the building. The averaged period in long direction is longer than the averaged period in short direction. The periods of laboratory building for both directions are nearly equal values, 0.17 and 0.16 sec. The 1999 earthquake did not affect these buildings.

Major numbers of building in the City are residential buildings with two stories. The averaged predominant periods of the buildings (No.10-No.16) are 0.11 and 0.10 sec in short and long directions. The residential buildings with three stories (No.17—No.19) show natural periods between 0.12 and 0.11 sec of averaged predominant periods in each direction of short and long. The residential buildings with four stories (No.21-No.22) show 0.15 and 0.16 sec of averaged predominant periods in each direction of short and long. The measured these buildings are not so old, otherwise affected residences were so old.

The buildings in additional housing are various structural types and stories, so the predominant periods are deferent. City office that was severely affected by the 1999 Tehuacán earthquake, it shows 0.19 and 0.15 sec in short and long directions. And another important building, Catholic Church that is arch type structure and was affected by the quake too, show 0.39 and 0.16 sec in short and long directions.

Table 4 List of Buildings Observed Microtremor

No.	Short Direction	No Fls.	Prd (s)	Amp	Long Direction	Prd (s)	Amp	Building Name Use	Structure Masterial
1	Short Direction	1F	0.08	2.65	Long Direction	0.13	19.64	ITT19 School	Frame Steel
2	Short Direction	1F	0.07	8.81	Long Direction	0.17	37.03	2ITT School	Frame Steel
3	Short Direction	1F	0.08	9.30	Long Direction	0.22	21.20	ITT19 School	Frame Steel
4	Short Direction	1F	0.09	2.22	Long Direction	0.19	6.46	ITT37 School	Frame Steel
5	Short Direction	1F	0.17	12.7	Long Direction	0.16	26.62	ITTLBO School	Frame Steel
6	Short Direction	2F	0.19	4.22	Long Direction	0.15	2.88	AYT CityOffice	Wall Stone
7	Short Direction	2F	0.39	3.42	Long Direction	0.16	3.54	Igrecia Church	Arch Stone
8	Short Direction	2F	0.17	7.44	Long Direction	0.28	7.94	ITT23 School	Frame Steel
9	Short Direction	2F	0.23	11.9	Long Direction	0.38	16.60	ITT30 School	Frame Steel
10	Short Direction	2F	0.11	8.61	Long Direction	0.09	6.76	1BIB House	Muddy Brick
11	Short Direction	2F	0.09	8.41	Long Direction	0.11	5.34	2BIB House	Brick+Con
12	Short Direction	2F	0.11	7.95	Long Direction	0.09	4.83	4BIB House	Brick+lCon
13	Short Direction	2F	0.11	1.97	Long Direction	0.08	3.52	5BIB House	Brick+Con
14	Short Direction	2F	0.07	2.88	Long Direction	0.09	3.37	7BIB House	Wall Brick
15	Short Direction	2F	0.06	11.0	Long Direction	0.09	9.14	11BIB House	Muddy Brick
16	Short Direction	2F	0.08	4.30	Long Direction	0.06	3.62	13BIB House	Wall Brick
17	Short Direction	3F	0.11	9.02	Long Direction	0.10	8.33	3BIB House	Muddy Brick
18	Short Direction	3F	0.11	7.35	Long Direction	0.14	9.70	6BIB House	Brick+Con
19	Short Direction	3F	0.13	9.10	Long Direction	0.09	7.78	8BIB House	Brick+Con
20	Short Direction	3F	0.42	136.	Long Direction	0.41	121.9	12BIBShopping	Frame RC
21	Short Direction	4F	0.14	16.1	Long Direction	0.16	24.09	9BIB House	Brick+Con
22	Short Direction	4F	0.16	27.9	Long Direction	0.16	31.90	10BIB House	Brick+Con
23	Short Direction	6F	0.48	23.5	Long Direction	0.24	13.48	BSHTL Hotel	Frame RC

A hotel with six stories shows 0.48 and 0.24 sec in short and long directions. This building was not affected by the quake, however the location is very close from the city office.

A shopping store building with three stories and with very slender columns that was under construction shows 0.42 and 0.41 sec in short and long directions. And we shall pay to that amplification values are very large, 136 and 122. Authors can say on the concrete frame type buildings in this area are generally, before the fin of construction, very flexible. The flexibility of these types building depend by very slender columns, but finally periods are changed to rigid building, because partition wall build with rigid material, as like concrete bricks.

DSCUSSION ON THE RELATIONSHIPS BETWEEN SURFACE GEOLOGY AND DAMAGES OF BUILDINGS BY THE EARTHQUAKE

From the refraction test, we conclude that the ground surface stratums in Tehuacán City are fairly hard and the layer is very shallow. Observed microtremors show short predominant periods in the whole area in the city, although the forms of spectra are not the same. Natural periods of affected types of buildings are very short. Using these results, we can roughly explain the relations between the seismic characteristics of surface geology and the damage of buildings caused by the 1999 earthquake.

For example, building No.6 was affected severely by the quake, but building No.23 was not anything however those buildings locate very close. Predominant periods of building No.6 are 0.19 and 0.15 sec., and building No.23's periods are 0.48 and 0.24 sec.

Only one story buildings were not affected however their periods are very short. Authors can say that the reason were quiet for the quake is on the structural material, steel columns made these structures of buildings. Residential buildings with two stories were not severe affected by the quake however the periods were very short, but the residences have many rigid walls to participate each rooms. But city office and Catholic church that were affected severely, have large spaces in the buildings.

CONCLUTION

1) We can say by the refraction survey that the ground layers in Tehuacán City are generally hard and deposits on the basement are very shallow.

2) Amplification factors of the ground layers showed low values.

3) Fourier Spectra in the south-east area where were severe damaged areas in the city are deferent with its of another area, so we can suppose that the periods of the spectra correlated with the concentrated area of damages. In the concentrated damaged area, Fourier spectra are amplified in very shorter region, 0.1-second or less.

4) H/V spectral ratios in damaged area are flat in the shorter period region, but clear peaks be shown in longer period region. We can say that these longer period's peaks are affected by more deeper ground layers. And generally natural periods of the buildings in the damaged area are very short, so that the long periods of ground motion did not affect the damages.

5) The damages of buildings were related with ground surface seismic condition, and in the same way were related with structural types of buildings and materials.

We shall discuss still more with the documents of the buildings to be clear explaining the damages. Further more we need more detailed documents of geologies for deep layers in the city, and the records of strong seismic ground motion.

ACKNOWLEDGEMENT

Authors present our sincerely thanks for all Engineers and Architects attended this projects from City Office and Technological Institute of Tehuacán, and for the City Mayer of Tehuacán and the Director of the Technology who had supported us with many materials and man powers.

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