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EVALUATION OF DYNAMIC BEHAVIOR OF BUILDING STRUCTURES WITH MICROTREMORS FOR SEISMIC MICROZONATION MAPPING

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ABSTRACT

A Spanish-Japanese research project titled "Joint Study on Seismic Microzonation in Granada Basin, Spain" has been carried out since 1992. The final output of the project is to prepare a risk map for the region against expected earthquakes through a series of experiments like earthquake motion observation, evaluation of surface and subsurface geologic effects on seismic motion, vulnerability evaluation of existing building structures, etc. In this paper, the principal characteristics of dynamic behavior of typical buildings in Granada city were confirmed with microtremors (ambient motions) by evaluating natural period and damping coefficient for torsional and swaying motions. An empirical relationship between the natural period:T(s) and the number of stories:N was proposed as T(s) = 0.05N mainly for reinforced concrete building structures. The damping coefficient distributed from 2% to more than 10%, depending on soil condition of the site. We are going to apply such results to the vulnerability evaluation and the risk analysis for the earthquake disaster mitigation program of the region.

KEYWORDS

microtremors, natural period, predominant period, damping coefficient, site condition, vulnerability, risk map, microzoning, Granada basin

1. INTRODUCTION

Granada city is located on a brim of the Granada basin in the Andalusian district, Spain. The early developments of the city were made with masonry structures on a foot of the Sierra-Nevada mountain including the famous Al Hambra and Albaicin region by Moorish people. After that, the old Spanish people constructed the central town with stone and brick masonry structures on the firm diluvium formation. Recent developments in new city area and reconstructions in downtown area are made with reinforced concrete or steel frame structures. In general, the number of stories of these building structures distributes from three to more than ten. The city planning looks well organized by keeping the uniform height in each region (see Photo.1, e.g.). One of the problems from the view point of earthquake disaster mitigation is that the modern city area is going to spread toward the soft alluvial basin year by year, because of the increase of its population. The seismicity around Granada city is almost the highest within the country, something like one M5 earthquake per year and one M6 earthquake every ten years on an average, for instance. In fact, the city has suffered not a few losses by past earthquakes.
Based on such earthquake engineering and seismological background, we are carrying out a joint research project on seismic microzonation in this region since 1992. It consists of four important subjects as; 1) observation of strong and moderate earthquake ground motions, 2) survey of deeper and shallower subsurface structure, 3) vulnerability analysis including the evaluation of dynamic behavior of building structures, and 4) risk analysis and risk mapping for an expected future earthquake. Among these subjects, we will mainly discuss the topics concerning the third subject mentioned above.

Photo.1 A view of the recently developed area in Granada city.

2. MICROTREMOR MEASUREMENTS ON BUILDING STRUCTURES

Microtremor measurements on building structures were made in Granada city to confirm their natural period and damping coefficient as fundamental characteristics during earthquakes. The previous works which have been made already in other districts by Kobayashi(1973), Kobayashi et al.(1977, 1986, 1987), and Midorikawa (1990) are providing useful databases about the relationship among the type and the size of building, their dynamic behavior mainly evaluated with natural period and damping coefficient, and subsurface soil condition. Therefore the purpose of this study is to apply the similar measurements in Granada, as a case study in European countries, and to prepare a fundamental database as a part of the research project on seismic microzonation in this region. As we use the common system in measurement and analysis, the results are available to be compared each other among different districts.

In this paper, we will describe the results mainly about reinforced concrete structures, because most of the measurements were carried out on such buildings. The measurement was performed on the top floor of each building using three horizontal accelerometers, one in longitudinal direction of the building, and other two at both ends of the building in lateral (span) direction. The latter two sensors are used to identify torsional motion from swaying motion. Figure 1(a) shows a typical example of observed records in acceleration on a 7-story reinforced concrete apartment building named Plaza de Toros. After the translation into displacement as shown in Fig.1(b), the natural period and the damping coefficient of longitudinal direction are obtained directly from the power spectrum in Fig.1(c). As for the lateral

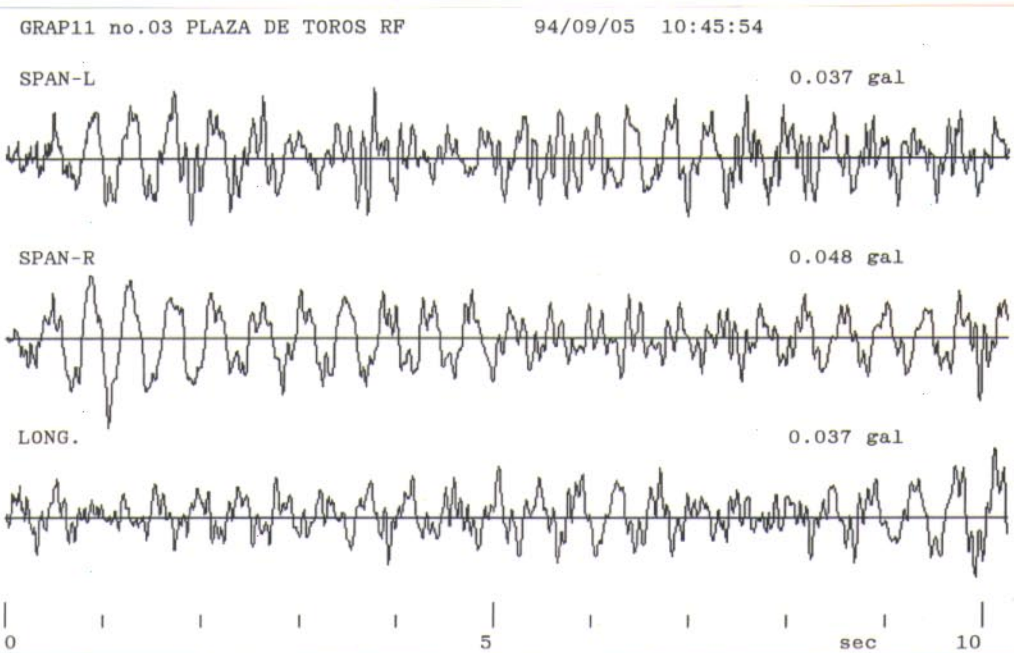

Fig. 1(a) An example of measured microtremors in acceleration on a 7-story RC building.

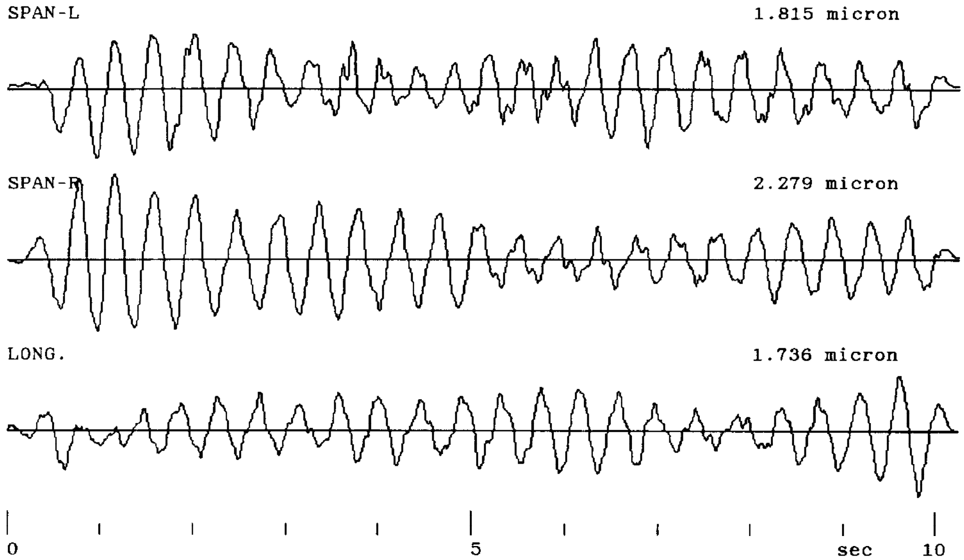

Fig. 1(b) Integrated displacement microtremors for the following analyses.

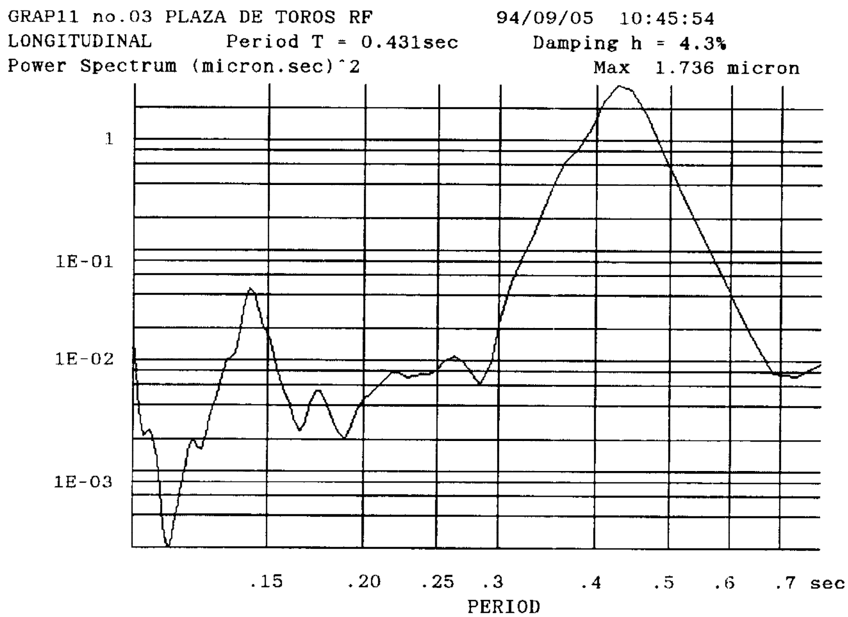

Fig. 1(c) Power spectrum of the longitudinal swaying motion.

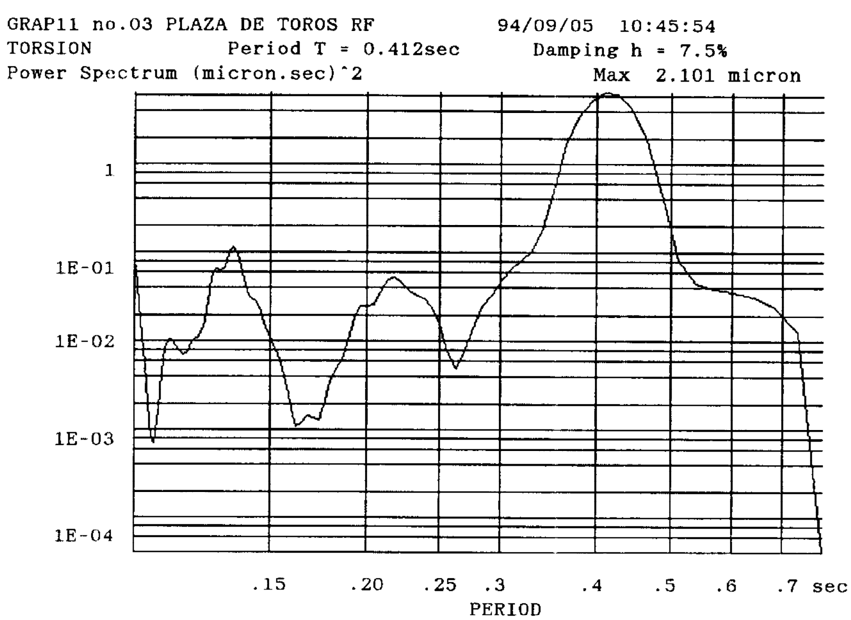

Fig. 1(d) Power spectrum of the torsional motion identified from the lateral motion.

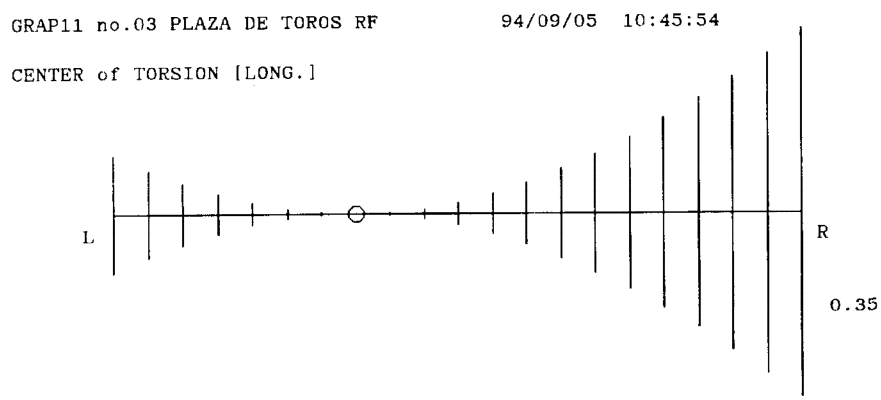

Fig. 1(e) Vibration mode and nodal point in the tortional motion.

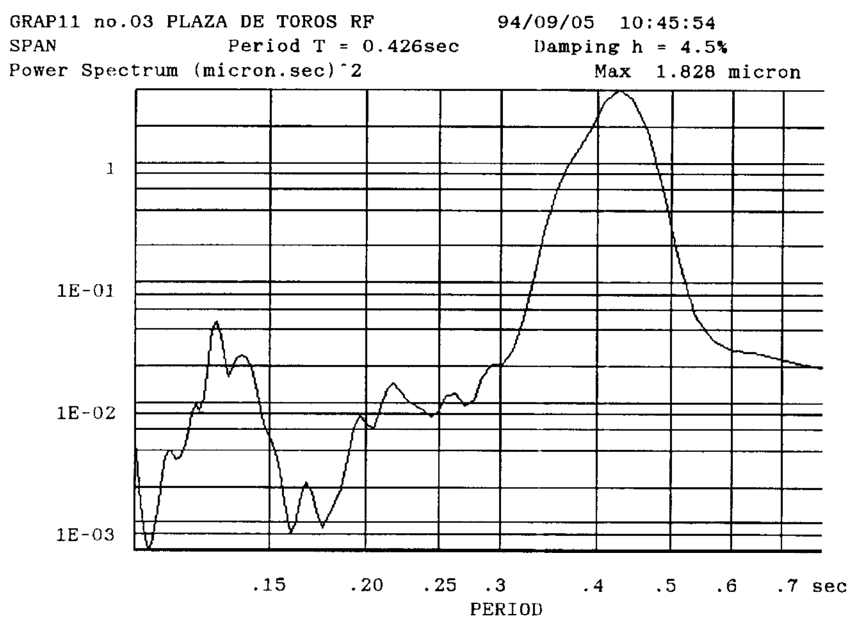

Fig. 1(f) Power spectrum of the resultant lateral swaying motion after eliminating the torsional motion.

Table 1 List of measured natural period and damping coefficient for each building structure.

BLDG. NUMBER	NUM.OF STORIES	BLDG. TYPE	CONS. YEAR	BLDG. SIZE	SWAY(LONG.) AMP	PRD	DAMP	SWAY(SPAN) AMP	PRD	DAMP	TORSION AMP	PRD	DAMP	NAME OF BUILDING
GROF01	4F/1BF	S	1972	60x20	1.72	0.29	4.2	1.33	0.33	2.8	1.98	0.25	6.2	FACULTAD DE CIENCIAS
GROF02	12F/1BF	RC	1957	30x10	3.03	0.71	5.3	3.30	0.63	4.6	2.88	0.59	7.3	HOSPITAL CMQ RUIZ DE ALDA
GROF02'	12F/1BF	RC	1957	40x10	1.83	0.64	4.4	2.23	0.65	14.2	2.67	0.50	6.0	HOSPITAL CMQ RUIZ DE ALDA
GROF03	8F/2BF	RC	1972	42x15	2.38	0.45	3.6	2.67	0.48	4.1	3.32	0.37	3.5	HOSPITAL MATERNO INFANTIL
GROF04	15F/2BF	S	1975	21x13	2.38	0.91	2.5	2.11	0.87	2.7	1.70	0.90	2.7	MINISTRY OF PUBLIC WORKS
GROF05	3F	BRICK	1920	20x18	3.10	0.19	1.7	2.43	0.19	2.3	3.06	0.13	6.2	DELEGACION DE CULTURA
GROF06	4F/2BF	RC	1980	25x25	3.24	0.26	2.6	3.38	0.27	2.0	3.98	0.19	1.8	SANTA LUCIA UNIV OFFICE
GROF07	3F/1BF	RC	1987	90x90	0.71	0.22	3.0	0.64	0.24	3.3	1.03	0.23	3.4	FACULTAD DE CIENCIAS
GRAP01	10F	RC	1976	17x17	3.16	0.46	2.9	1.97	0.42	4.2	3.57	0.35	3.7	BARRIO DE CARTUJA OSUNA 34
GRAP02	6F	RC	1981	18x18	1.48	0.26	6.6	1.77	0.28	2.6	1.92	0.23	6.9	SIERRA ALMIJARA 1
GRAP03	7F	RC	1976	35x18	1.75	0.29	6.0	0.92	0.35	2.8	1.79	0.22	10.3	APARTMENT SOLARILLO
GRAP04	7F	RC	1948	40x20	1.25	0.36	2.9	1.25	0.31	22.8	1.04	0.33	4.2	MANUEL APARTMENT
GRAP05	8F	RC	1958	30x20	1.19	0.37	5.5	1.11	0.32	14.7	2.06	0.31	2.3	ANDALUCES APARTMENT
GRAP06	11F/1BF	RC	1970	20x18	1.76	0.50	6.3	1.96	0.54	3.7	3.00	0.45	9.7	GONGORA APARTMENT 9
GRAP07	11F/1BF	RC	1970	20x18	3.94	0.53	4.9	2.12	0.52	3.8	5.40	0.50	3.3	GONGORA APARTMENT 7
GRAP08	3F/1BF	RC	1981	40x12	0.99	0.19	2.5	0.65	0.24	6.3	1.11	0.19	3.4	GARZON APARTMENT
GRAP09	13F/1BF	RC	1969	50x30	1.30	0.72	4.1	1.90	0.66	4.7	2.68	0.69	9.5	EDIFICIO TORRE NEPTUNO
GRAP10	9F/1BF	RC	1968	40x25	2.06	0.44	7.7	3.08	0.48	3.1	4.29	0.46	3.7	VIRGEN BLANCA APARTMENT
GRAP11	7F/3BF	RC	1994	51x27	1.74	0.43	4.3	1.83	0.43	4.5	2.10	0.41	7.5	PLAZA DE TOROS
GRAP12	6F/1BF	RC	1970	30x17	1.38	0.30	2.3	2.06	0.29	11.1	2.97	0.30	10.7	EDIFICIO JERONIMO
GRAP12'	6F/1BF	RC	1970	30x17	1.97	0.29	5.3	1.83	0.34	5.1	3.40	0.26	8.5	EDIFICIO JERONIMO

Note: Building size in meter, Amplitude in micron, Natural period in sec., Damping coefficient in %.

point as shown in Fig.1(e). Then eliminating the torsional motion, the resultant swaying motion of lateral direction will be obtained as Fig.1(f). Here the longitudinal motion in Fig.1(c) is also considered as the swaying motion. These measurements were examined for 20 buildings as listed in Table 1, most cases for reinforced concrete structures, and a few cases for steel or brick structures. The symbol GROF in the table means an office building in Granada, in the same manner GRAP means an apartment building. In the column of "number of stories", 4F/1BF shows a four-story building including the ground floor plus one basement floor, for example.

3. EMPIRICAL EVALUATION OF NATURAL PERIOD FOR BUILDING STRUCTURES

Taking the measured natural periods for swaying and torsional motions, we will obtain the relationship between the natural period and the number of building stories. This relationship is important not only to confirm the natural period but to evaluate the rigidity of each building structure. Figure 2(a) shows such relationship for the longitudinal and the lateral swaying motions with solid and open circles, respectively. Although we obtained the relationship between natural period;T(s) and number of stories;N on an average as T = 0.051N, office buildings seem to have little bit longer period than apartment buildings. Such feature may be understood that an office building will have wider windows and lesser walls compared with an apartment building. Figure 2(b) also shows for the torsional motions.

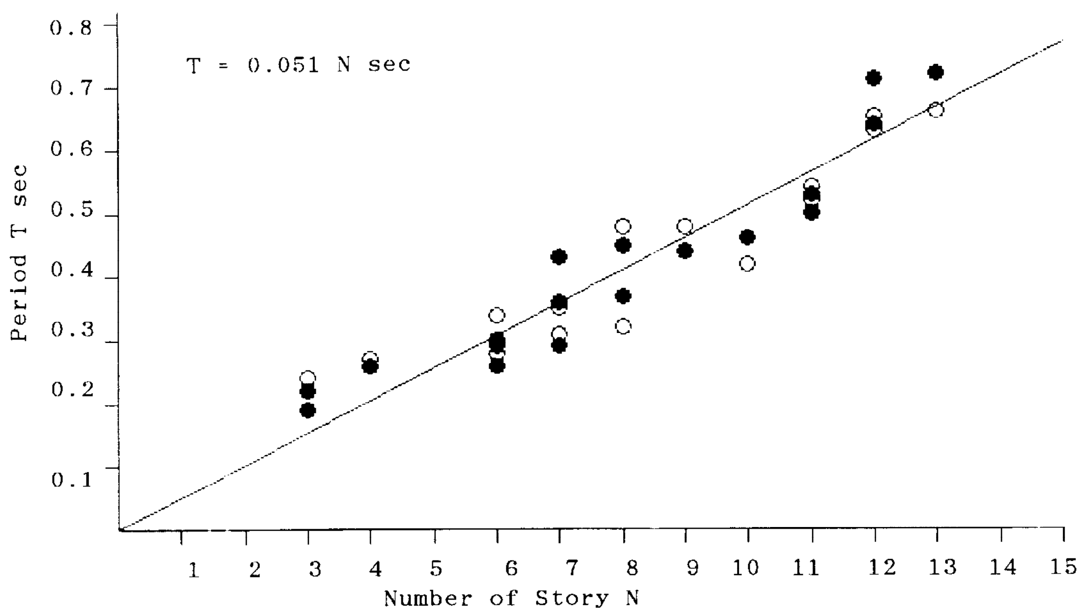

Fig. 2(a) Relationship between natural period and number of stories for swaying motion.

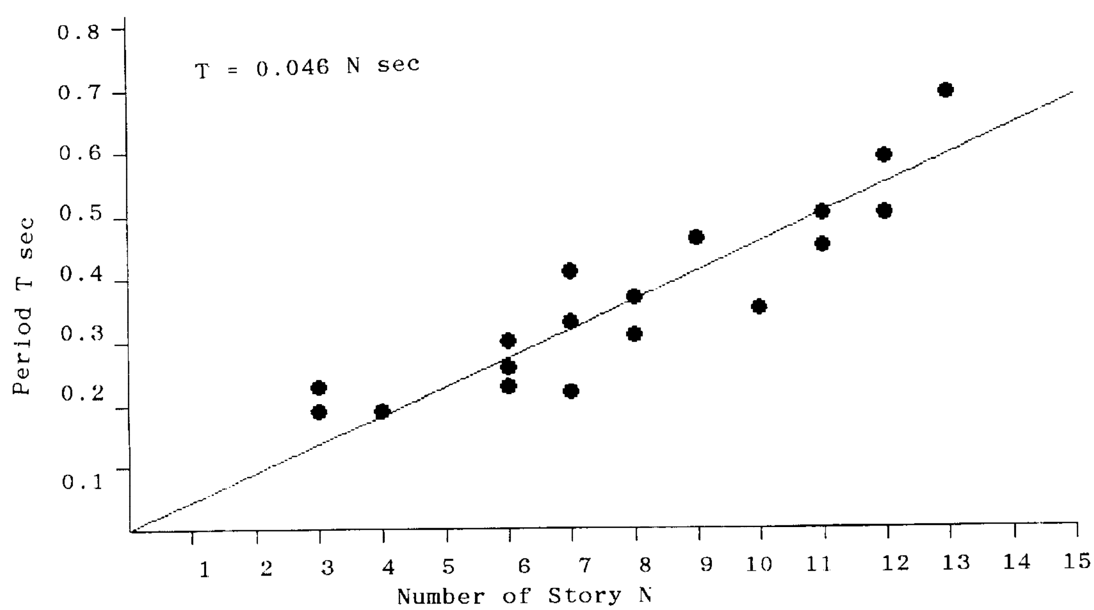

Fig. 2(b) Relationship between natural period and number of stories for torsional motion.

In this case, the relationship T = 0.046N was obtained. It may be noted that the natural period of torsional motion tends to show slicely shorter than that of swaying motion. And as results, the empirical relation T(s) = 0.05N including swaying and torsional motions was confirmed as the fundamental characteristics of reinforced concrete buildings in this region.

4. DAMPING COEFFICIENT OF BUILDING STRUCTURES AND SITE CONDITION

Damping coefficient corresponding with the natural period mentioned above can be evaluated with the shape of power spectrum (Kobayashi et al., 1987). As this value is obtained from microtremors, it means a very small strain level, the dynamic behavior of a building structure must be elastic. Then the damping we are discussing here means the viscous damping including the effect of subsoil condition. Such damping coefficients with related natural period of each building are presented in Fig.3(a) for the longitudinal and the lateral swaying motions with solid and open circles, respectively, and in Fig.3(b) for the torsional motion.

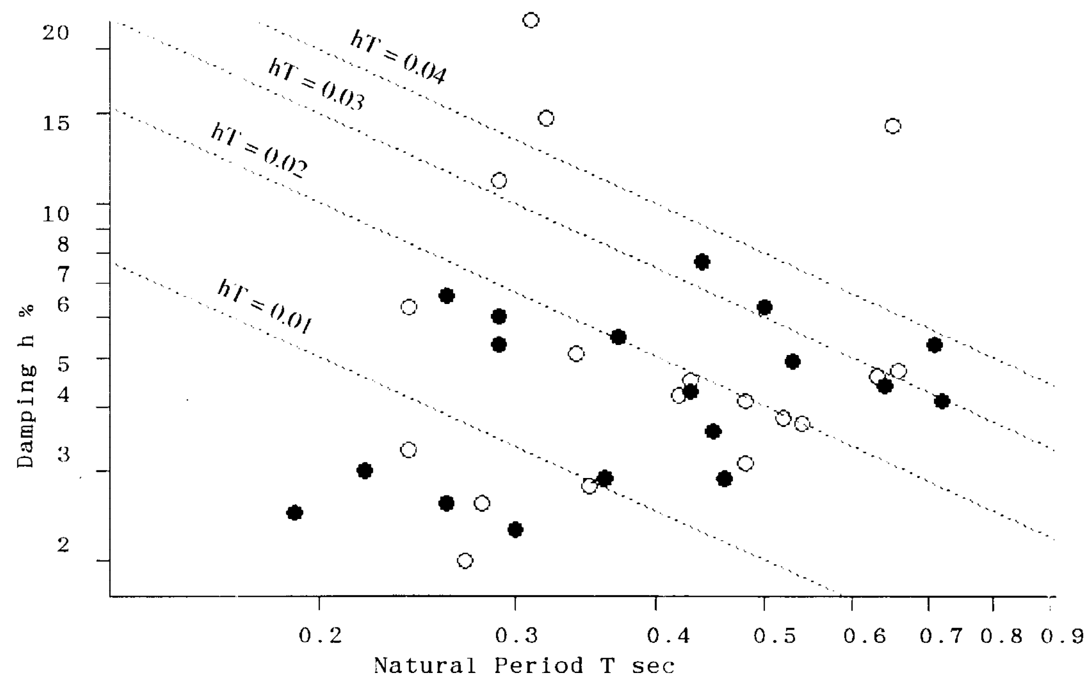

Fig. 3(a) Relationship between damping coefficient and natural period for swaying motion.

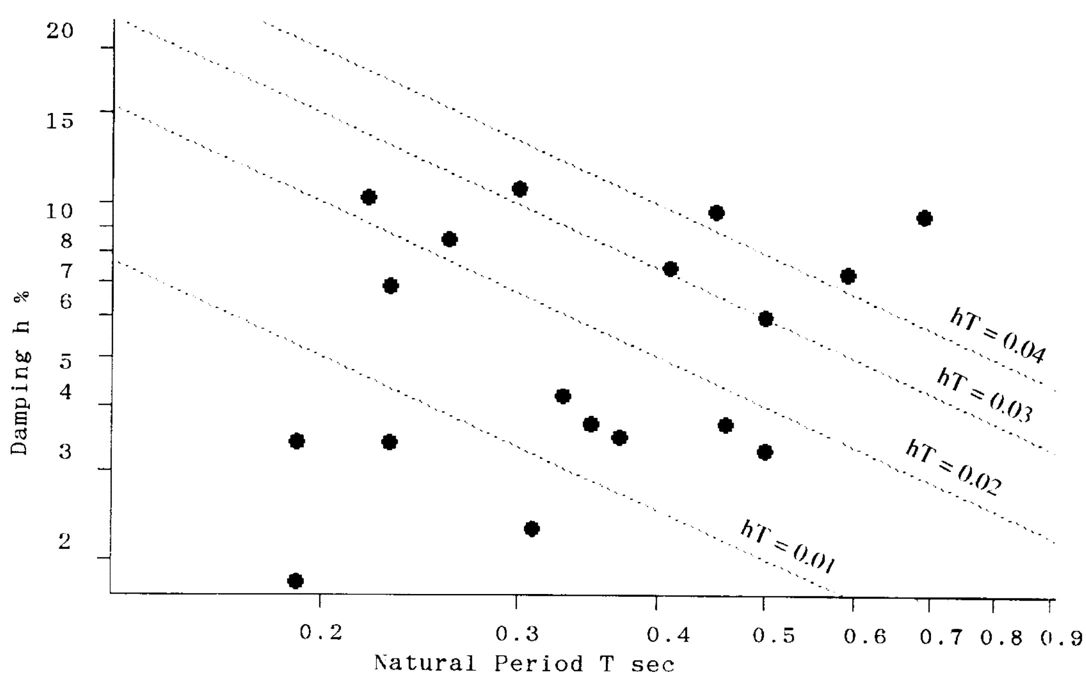

Fig. 3(b) Relationship between damping coefficient and natural period for the torsional motion.

According to Kobayashi(1973), the product of such damping coefficient;h and the natural period;T should be almost constant among different types of structures, different vibration modes of each structure and different amplitude levels, and the most effective factor dominating the h·T-value could be the soil condition of each site. Then the h·T-value can be evaluated with the kind of ground;K in the older Japanese Building Code (Kanai et al., 1961) as $h \cdot T = 0.01K$ (here, K=1 - 4). Such h·T-values were also drawn in Fig.3. As results, the larger h·T-value used to correspond with the softer soil condition, and the smaller h·T-value with the harder soil condition, respectively.

5. DISCUSSION AND CONCLUDING REMARKS

In this paper, we made a preliminary survey to understand the fundamental characteristics about the dynamic behavior of building structures in Granada city. We evaluated such characteristics with natural period and damping coefficient as important factors. As we used microtremor measurements to obtain these values, the discussion should be made within elastic range. With respect to the relationship between natural period and number of stories of buildings; $T(s) = 0.05N$ obtained in Granada, it looks quite reasonable compared with those from other districts. According to recent studies (Midorikawa, 1990, e.g.), the similar relationship, almost $T=0.05N$, has been confirmed in Japan and in Chile. The exceptional result; $T=0.10N$ for reinforced concrete building structures, has been noticed in Mexico city (Kobayashi et al., 1986).

Another interest is the shifting of natural period that we found at Plaza de Toros (GRAP11 in Table 1). When we measured the natural period there one year ago, the building was under construction as shown in Photo.2. At that time, we obtained 0.6 second as the natural period. But now we have 0.4 second that can be seen in Fig.1 and Table 1. At that time, the building was almost accomplished as Photo.3. It will be clear that the shifting of the period from 0.6s to 0.4s was affected by putting brick walls. Therefore at the final stage when we will make a risk analysis by taking into account a possible future earthquake, the contribution of such brick walls during the strong shaking must be checked very carefully.

The obtained h·T-values lie scattered from 0.005 to 0.1 as shown in Fig.3. In roughly speaking, it can be said that the larger value appears on soft alluvial site and the smaller value on the hill site or firmer diluvium site. As we are making the evaluation of soil condition also with microtremors in parallel (Morales et al., 1993, e.g.), we will be able to conbine the both results in the near future. Additional measurements for building structures mentioned in this paper are also being made in Granada and Almeria districts for the reinforcement of the results.

Photo. 2 Apartment building, Plaza de Toros (under construction in 1993)

Photo. 3 Apartment building, Plaza de Toros (almost accomplishing in 1994)

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