

## 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-Neveda 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.



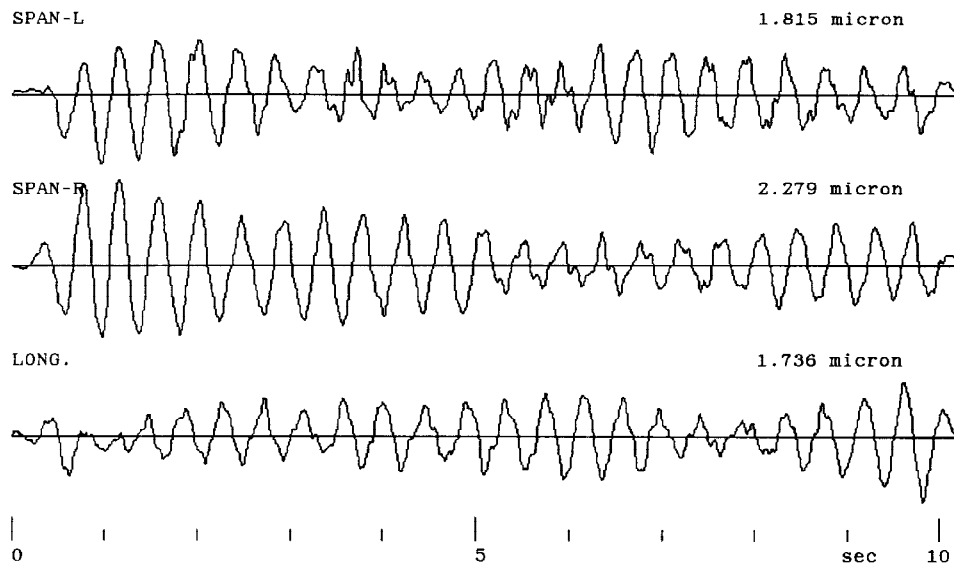


Fig. 1(b) Integrated displacement microtremors for the following analyses.

GRAP11 no.03 PLAZA DE TOROS RF 94/09/05 10:45:54  
 LONGITUDINAL Period T = 0.431sec Damping h = 4.3%  
 Power Spectrum (micron.sec)<sup>2</sup> Max 1.736 micron

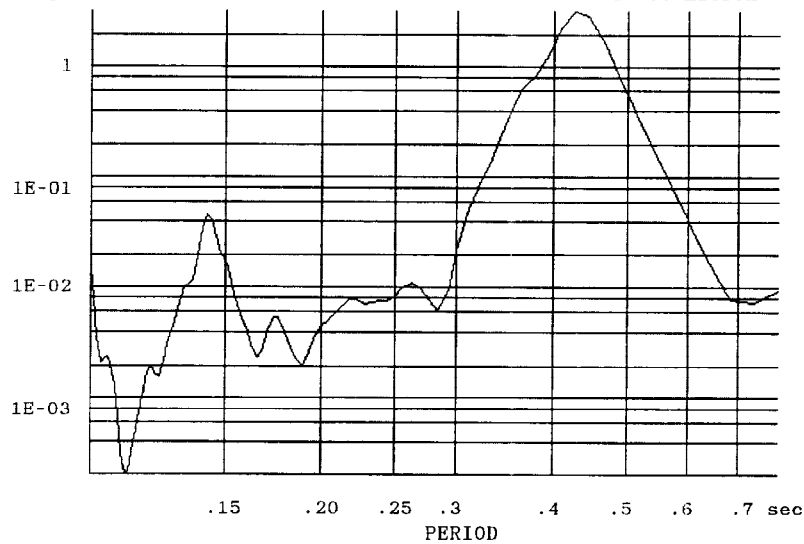


Fig. 1(c) Power spectrum of the longitudinal swaying motion.

GRAP11 no.03 PLAZA DE TOROS RF 94/09/05 10:45:54  
 TORSION Period T = 0.412sec Damping h = 7.5%  
 Power Spectrum (micron.sec)<sup>2</sup> Max 2.101 micron

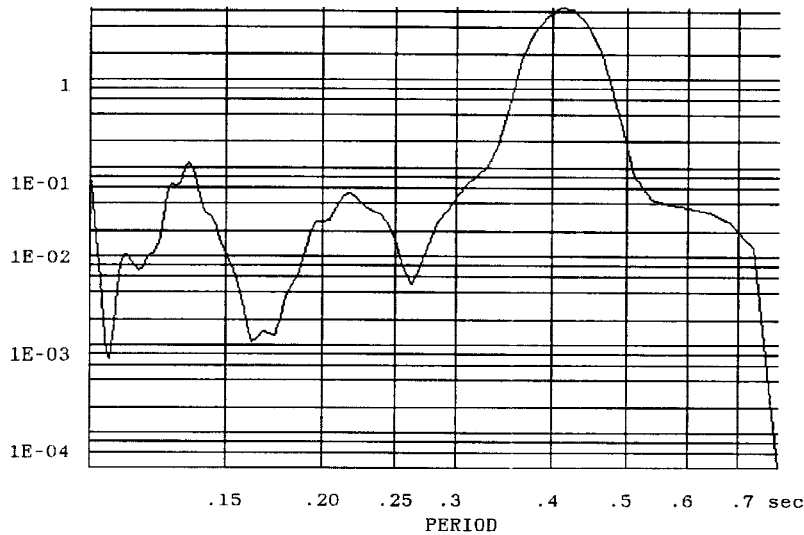


Fig. 1(d) Power spectrum of the torsional motion identified from the lateral motion.

CENTER of TORSION [LONG.]

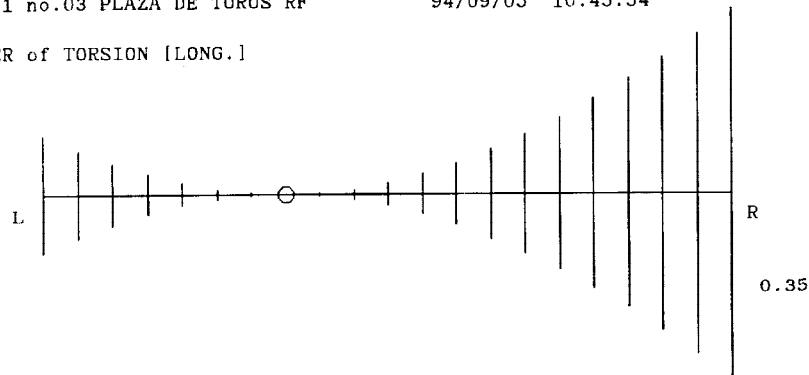


Fig. 1(e) Vibration mode and nodal point in the torsional motion.

SPAN Period T = 0.426sec

Damping h = 4.5%

Power Spectrum (micron.sec)<sup>2</sup>

Max 1.828 micron

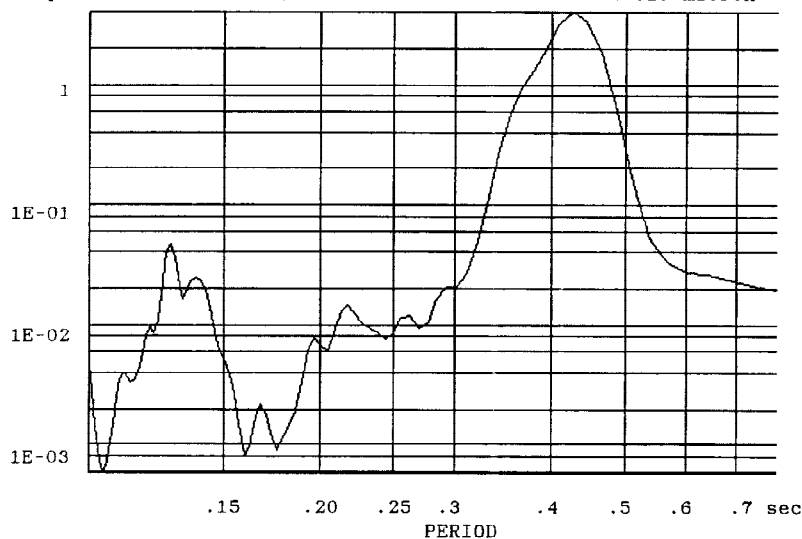


Fig. 1(f) Power spectrum of the resultant lateral swaying motion after eliminating the torsional motion.

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

BLDG. NUMBER	NUM.OF STORIES	BLDG. TYPE	BLDG. CONS. YEAR	BLDG. SIZE	SWAY(LONG.)			SWAY(SPAN)			TORSION			NAME OF BUILDING
					AMP	PRD	DAMP	AMP	PRD	DAMP	AMP	PRD	DAMP	
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
GRAPO1	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
GRAPO2	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
GRAPO3	7F	RC	1976	35x18	1.75	0.29	6.0	0.92	0.35	2.8	1.79	0.22	10.3	APARTMENT SOLARILLO
GRAPO4	7F	RC	1948	40x20	1.25	0.36	2.9	1.25	0.31	22.8	1.04	0.33	4.2	MANUEL APARTMENT
GRAPO5	8F	RC	1958	30x20	1.19	0.37	5.5	1.11	0.32	14.7	2.06	0.31	2.3	ANDALUCES APARTMENT
GRAPO6	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
GRAPO7	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
GRAPO8	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
GRAPO9	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
GRAPO10	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
GRAPI1	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
GRAPI2	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
GRAPI2'	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.

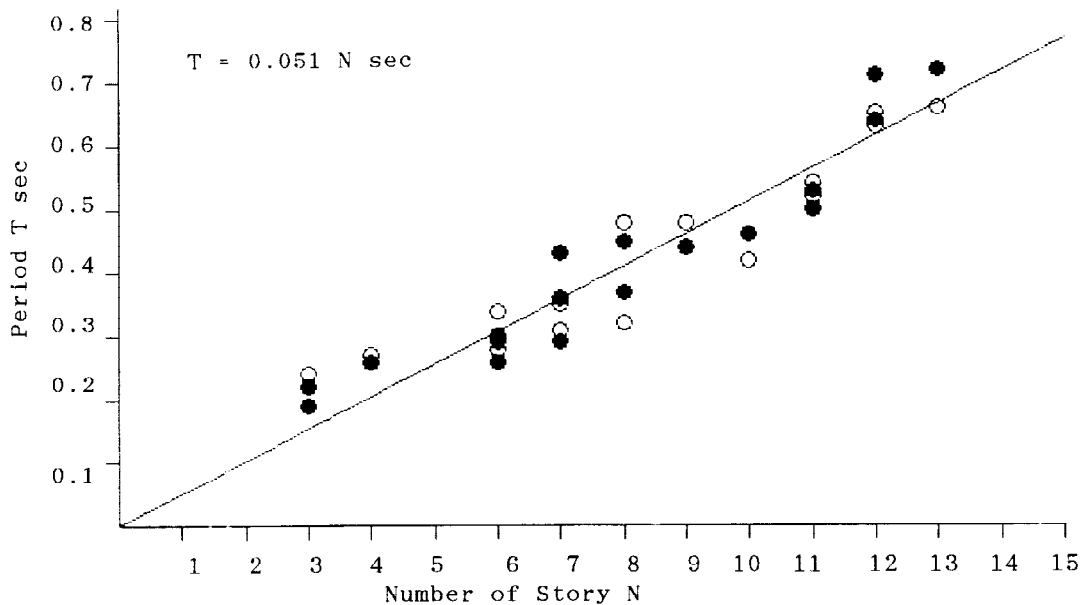


Fig. 2(a) Relationship between natural period and number of stories for swaying motion.

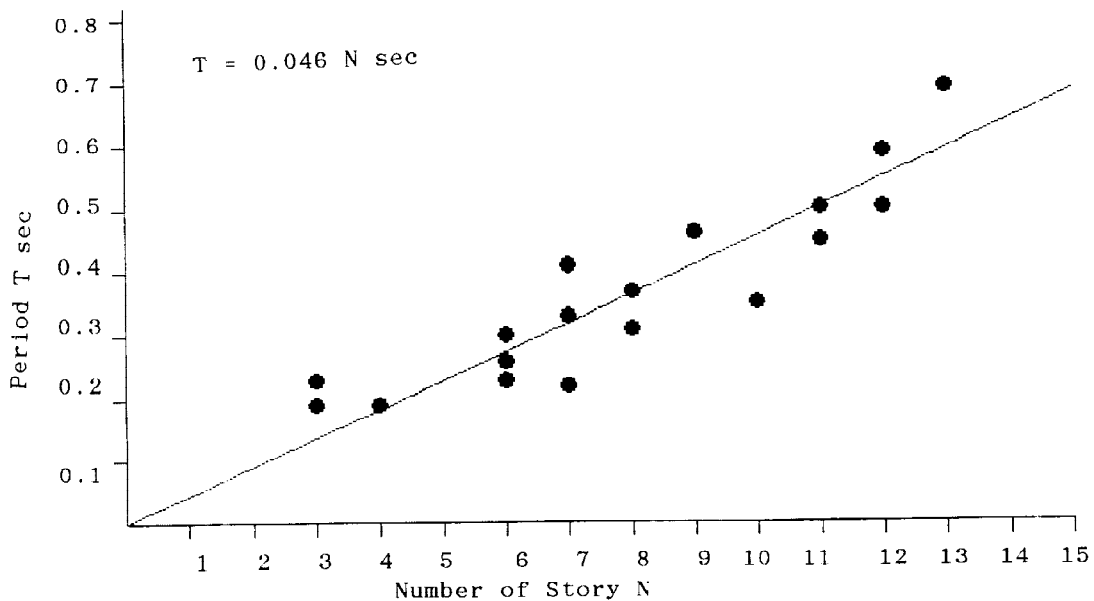


Fig. 2(b) Relationship between natural period and number of stories for torsional motion.

In this case, the relationship  $T = 0.046N$  was obtained. It may be noted that the natural period of torsional motion tends to show slightly 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.

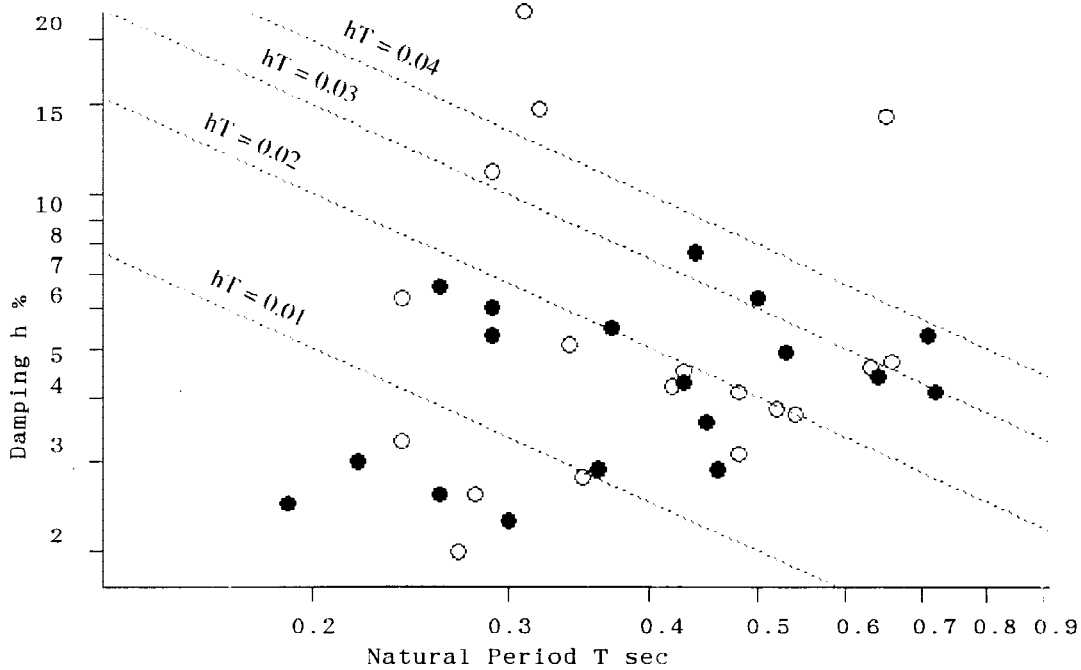


Fig. 3(a) Relationship between damping coefficient and natural period for swaying motion.

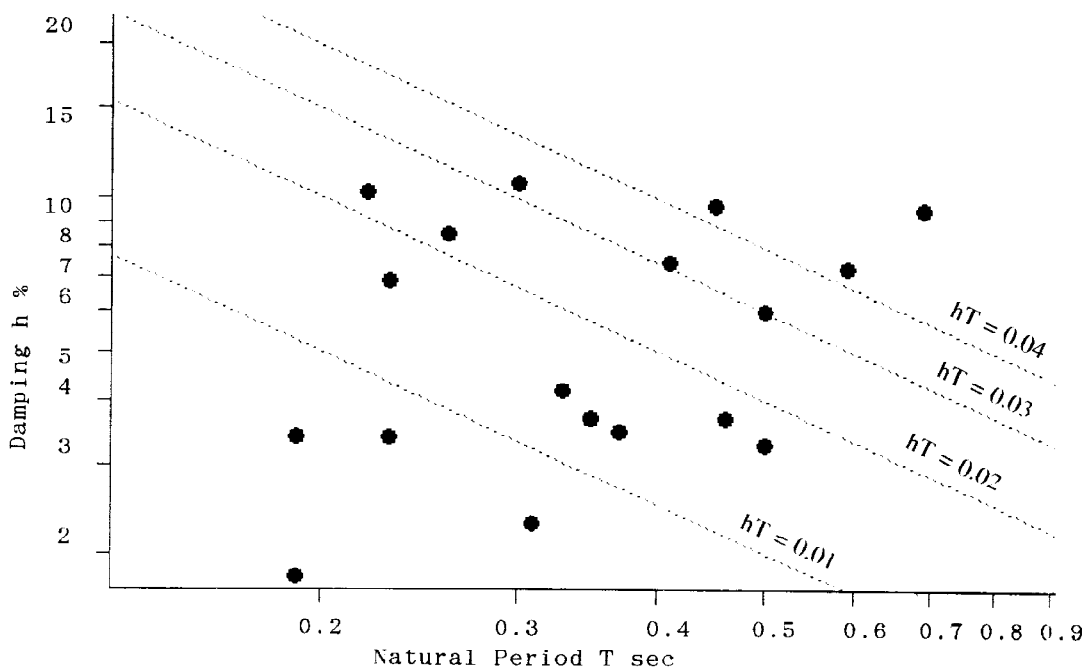


Fig. 3(b) Relationship between damping coefficient and natural period for the torsional motion.



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