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Microzonation of ground dominant periods at city of Ensenada, Baja California

Microzonación de Periodos Dominantes del suelo la ciudad de Ensenada, Baja California

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Resumen
Las estructuras civiles son mayormente dañadas cuando el período fundamental de la estructura es cercano al período dominante (PD) del movimiento del suelo donde se encuentra cimentada. Para mejorar la seguridad de diseños antisísmicos de estructuras civiles nuevas o de reforzamientos de estructuras existentes, es de vital importancia la creación de mapas de microzonación del período dominante, donde se comprendan las manchas urbanas y aquellas áreas con altas posibilidades de desarrollo urbano futuro. En este trabajo se plasma un mapa con la distribución de PD del suelo en la ciudad de Ensenada, B.C., México, utilizando el método de cocientes espectrales a partir de vibración ambiental, obteniendo resultados confiables, ya sea por la distribución de la litología, así como el de estudios previos realizados en otras zonas, ya que los valores presentados se encuentran dentro de los rangos que se publican en otros trabajos en diferentes zonas del mundo. Es importante señalar que este trabajo forma parte de un proyecto, en el cual se midieron PD en cuatro centros urbanos del Estado de Baja California, México.

Palabras clave: Microzonación sísmica; respuesta de sitio; periodo dominante, cocientes espectrales, Nakamura.

Abstract
The civil structures are mostly damaged when the fundamental period of the structure is close to the dominant period of ground motion (DP) where it is founded. To increase the security of the seismic design of new structures or the reinforcement of existing structures, it is essential to develop microzonation maps of the dominant period, where urban spots and areas with high potential for future urban development will contain.
We presented a map with the distribution of DP of soils in the city of Ensenada, Baja California, México, using the method of spectral ratios with ambient vibration, obtaining consistent results, either by the distribution of lithology and like previous studies in other areas, as presented values are within the ranges published in other works in different areas at world. Importantly, this work is part of a project, in which DP were measured in four urban centers of the state of Baja California, México.

Keywords: Seismic microzonation; site response; dominant period, spectral ratios, Nakamura.

INTRODUCTION

The strongest earthquakes in memory of individuals are undoubtedly are those who have thrown more human and material losses. Among recent experiences in the past are: Japan 2011, Italy 2012, Chile and Haití in 2010. In these and other events, the importance of the effect on the production site of tragic damage associated with earthquakes is confirmed. The movement on the ground surface at a given with soft soils or weathered site may differ radically from that taken into rock, by alterations of seismic waves due to geological, topographic and subsurface stiffness effects.

The site effect is the result of procedures of deposition, weathering, erosion and other geological processes which generate strong differences in physical properties of the relatively small surface structures (Aki, 1988); for this, the last meters of travel seismic waves become important in the formation of ground motion. The soil response to the arrival of a seismic wave is determined by the type of incident waves, the direction in which they reach the surface as well as the consistency of the field where act. One component of site effect is the dominant period of ground motion (DP), which can be defined as the period (seconds) of the harmonica with greater amplitude of ground motion. Its value depends on the physical and geometrical characteristics of the shallow stratigraphy. This is a derivative of the spectral content of the seismic records parameter.

The civil structures are damaged more by earthquakes when the fundamental period of vibration of the structure is similar to the dominant period of ground motion where it is foundation on. The essential characteristics of the response of a simple structure reach estimate with acceptable accuracy to model the structure by a single degree of freedom system, just as the fundamental period of the structure. If several single degree of freedom systems are exposed to different periods, to a history of ground motion, each responds very differently; the amplitude of its response depends essentially on the relationship between the natural period of the structure (NSP), and the dominant period of soil motion (DP); (NSP/SP). As illustrated in Figure 1, if ratio is closer to the unit, then greater the amplitude of the response (Bazán and Meli, 2002).

Figure 1. *Ground motion amplification systems with different fundamental period of vibration. Source Ibarra et al., 2009.*

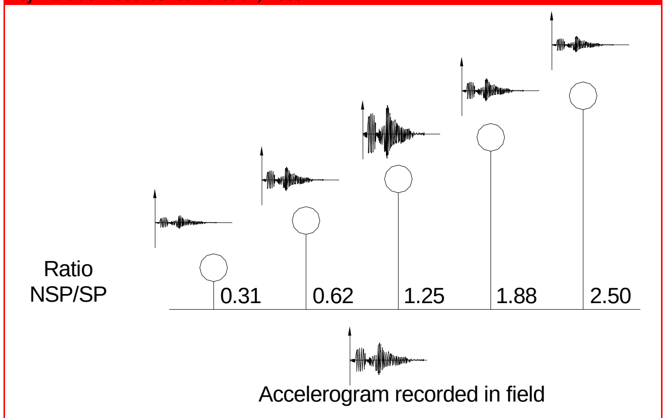

Figure 2. *Seismotectonic framework; major systems associated with the interaction of the Pacific and North American plates faults. Modified from Kahle et al., 1984.*

LITERATURE REVIEW

The long term objective of seismic microzonation of an urban area involves creating various types of maps, with the distributions of the different parameters of interest in the earthquake engineering, such as maps of acceleration, maximum velocities of soil, of seismic intensities, maximum response spectra and dominant periods of ground motion values. Different authors in the world have been working on microzonation maps that will request to incorporate into building regulations. (Gallipoli et al. 2004-Claudet Bonnefoy, S. et al. 2009). Acosta et al. (1994), initiated a study of seismic microzonation at Tijuana, México area, based on the distribution of dominant periods; they apply the method of Nakamura (1989) that relates the horizontal and vertical components of ground motion. In Ensenada, México there is a preliminary map of dominant periods of ground motion, presented by Alvarez et al. (1997), in which also the value of the dominant period is estimated from the spectral ratios technique.

Regional tectonic

Figure 2 shows the tectonic setting of the northern region of Baja California, in which the main active faults are shown. Tectonic activity in this region is correlated with three groups of faults. The first group is in the east of the region as part of the San Andreas Fault system, which can be considered as the most active (Raines et al., 1991) located along the Mexicali-Imperial Valley, including failures active: Imperial, Cerro Prieto, Cucapá, Elsinore, Brawley and Laguna Salada. The second group includes faults related to the main escarpment Gulf: San Pedro Mártir, San Felipe and Sierra Juárez Fault zone. The Sierra Juárez Fault system is particularly active in the central segment with two clusters located at the ends of this segment (Frez and Frias, 1998). In the third group are located to the west: ocean systems failures as Coronado Banks, depressions San Diego and San Clemente Fault (Stock et al., 1991), the first two extend his line to the coast of Ensenada and then continue inland south of the city, including the Agua Blanca (Gastil et al., 1975) fails. Northeast of Ensenada is the San Miguel-Vallecitos-Calabaza Fault system.

The marked area in Figure 2 also shows the city of Ensenada, Baja California, which is located near active faults mentioned above. According to the USGS (United States Geological Survey) is frequent detect earthquakes in this area, most with depths no greater than 10 Km, several magnitude ML> 6 caused by failures Cerro Prieto, Imperial and San Miguel (Frez and Gonzalez, 1991).

Surface geology

The importance of the surface geology of the city of Ensenada, México, reference is having different lithological contacts to see if there is a relationship with the values of DP of soil obtained in measurements. Selected sites within the city of Ensenada, México were according to the geological characteristics of soils, supported by geological maps of INEGI (Instituto Nacional de Estadística y Geografía), with scale 1: 50,000 and information was confirmed by visual recognition were identified five types of soils which are described below and shown in Figure 3.

- Bay mud. A narrow strip of this material is located parallel to the coast. This soil is composed of fine sandy beaches that are subject to continuous waves.
- Alluvium. The center of Ensenada is about this type of material. It consists of gravel deposits, clay and poorly consolidated sands; these particles come from the rocky outcrops around.
- Sandstone. Located at north side, exit to the city of Tijuana, Mexico. It consists sandy material mix and poorly consolidated sands.
- Rhyolitic tuff. It is located near the center of the city and extends to the north exit of the same. It is a rounded and angular consolidated rock, with sandy material mix.
- Extrusive igneous rock. IGEA. It is located at the ends of urban area, northeast and southwest of the city.
- Intrusive igneous rock. IGIA. This type of outcrop is located northeast of the city of Ensenada; upon this rock is constructed the Emilio López Zamora curtain dam.
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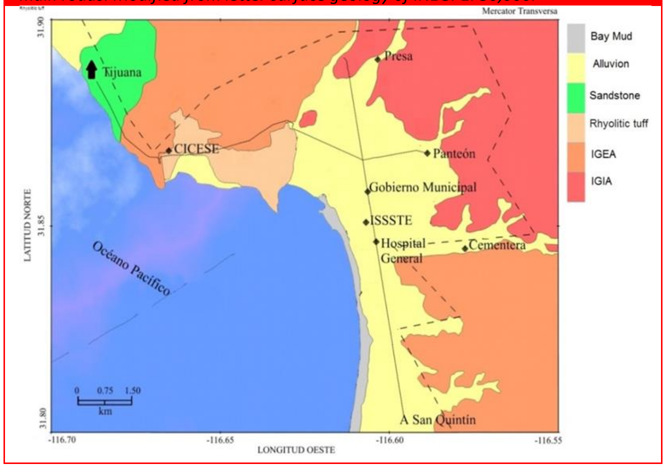
Figure 3. *Surface geology of the city of Ensenada, México, with some sites. The thick dashed line indicates the boundary of the urban area, thin solid lines the main roads. Modified from letter surface geology of INEGI 1: 50,000.*



METHOD FOR ESTIMATING THE SITE EFFECT

The estimate site effects from the analysis of empirical data obtained on the ground surface is based on the elimination of the effects of the source and the path and isolating the effects of the shallow lithology in the registration site. The literature states that you can use the ground motion induced by microtremor (seismic ambient noise) to a proper estimation of the dominant period of a site on the surface provided the source and path effects are properly removed.

Kanai (1957) proposed to use measurements of ambient vibration, which is a combination of microseisms and microtremors. The microseisms are globally induced by oceanic and atmospheric activities with periods longer than 4 seconds vibration; while microtremors are movements induced by urban noise of a local nature, during short periods. This author chooses this option, because soils respond equivalently to the sources of noise sources as earthquakes. A common technique for estimating the site effect measurements from microtremors is calculating spectral ratios of the horizontal and vertical components of the ground motion (Nakamura, 1989).

$$E = \beta T / 4 \qquad \text{(Eq. 1)}$$

where:
E = thickness of layer
β = speed of propagation of the S wave
T = dominant period of ground motion

$$C(f) = \frac{HS(f)}{VS(f)} \qquad (2)$$

The analytical approach of the Nakamura's technique is to consider spectra at the surface and at the base of the sedimentary layer, uses four spectra: a horizontal (HS) and vertical (VS) spectrums on the surface; and two more at the base of the sedimentary layer: a horizontal (HB) and vertical (VB) spectrums. The two spectra in depth, although they appear in the analytical development, really are not necessary for the application of the method, as discussed below. Seismic noise measurement of the horizontal component, recorded on the surface of the sediment layer contains natural sources distant effects which propagate as body waves (P and S) and local sources such as Rayleigh waves propagates. If the formula by Aki (1988) which relates the thickness of a layer with multi reflected wave length and propagation velocity of this wave is used (Eq. 1).

Can meet the thicknesses of the layers and can be observed by microtremor body waves vertically propagated. The layer thickness which may affect the vertical movement varies from 250 to 1250 meters, considering the periods of engineering interest are between 1 and 5 seconds, the P wave velocity is usually greater than 1000 m/s.

As the site effects are produced on the waves at the last 30 m before reaching the surface, and then it is considered that the site effect does not affect the vertical component of seismic noise records. An estimate of the site effect is given by the spectral ratio between the horizontal and vertical components of surface movement.

Data capture

Velocity records of ground motion were taken by means of ambient noise in dozens of sites within the city of Ensenada, México, trying to cover the different types of surface geology. The sensors used in capturing records are intermediate period, vertical and horizontal seismometers brand Kinemetrics, SV-1 and SH-1 models, the recorders are Kinemetrics model SSR-1.

Data processing

Once the database, consisting of digital seismograms of ambient noise, it is necessary to apply a series of processes to obtain results that may be relevant and easy to use for professionals in the earthquake engineering. The procedure is:

a) The first part involves the application of a series of numerical processes for transforming time series, until statistically stable Fourier spectra of the ambient noise representation; this is achieved by smoothing methods and averaging the spectral amplitudes.

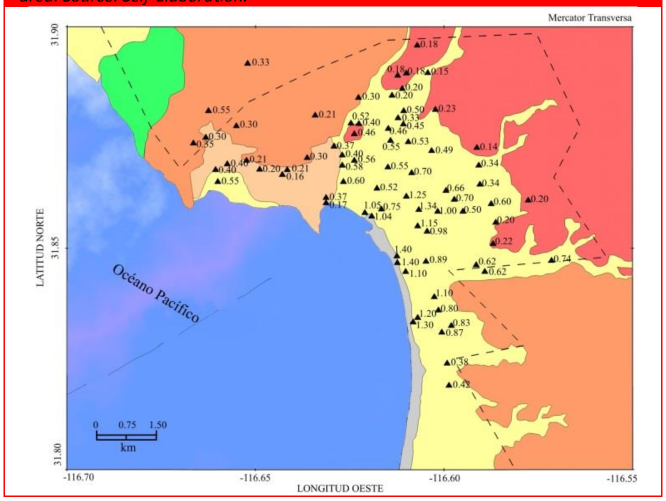
b) The second part of the procedure aims to isolate, or at least highlight, the local characteristics of ground motion, including the dominant period of the soil. For this, methods of spectral ratios and smoothing are applied.

c) Displaying the value of the dominant period of the ground motion is estimated from graphs of the spectral ratios.

d) A map of microzonation of DP of ground motion for each study area is developed, by means of the distribution of the values obtained in the measurement points.

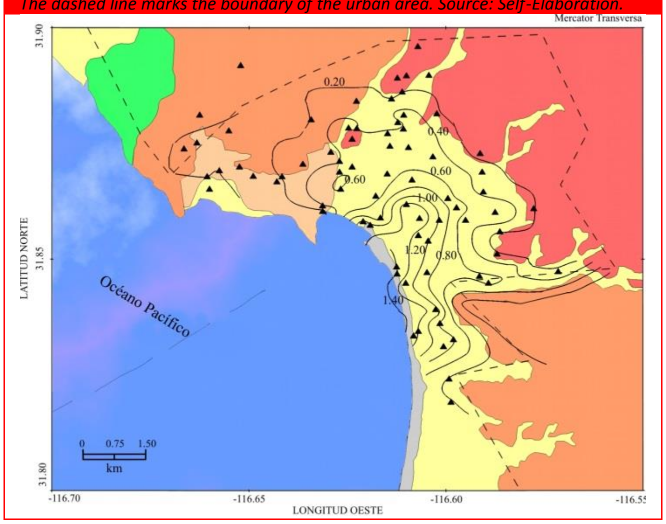
The values of the dominant soil period obtained in Ensenada are shown in Table 1, followed by a citymap where sensors and dominant period value obtained in each of them also apear (Fig. 4). Geographic distribution of the DP is shown in a DP isovalues map, that shows clearly the variation tendencies of that parameter (Fig 5)

Figure 4. *Surface geology of the city of Ensenada. With triangles sites where ambient noise records and beside the value of the dominant period of ground motion were taken are indicated. The dashed line marks the boundary of the urban area. Source: Self-Elaboration.*



Smaller values of DP of ground motion in the city of Ensenada are associated with rocky outcrops in different areas of the city, ranging from 0.14 to 0.22 seconds on intrusive igneous rock (IGIA) at north and east, from 0.20 to 0.55 seconds on rhyolitic tuff to the west of the city.

Figure 5. *Distribution curves contour maps of DP of land in the city of Ensenada. The dashed line marks the boundary of the urban area. Source: Self-Elaboration.*



The highest values of DP of ground motion are observed in loose sedimentary soils. As a general trend, a gradual increase from 0.60 to 1.40 seconds from the sediment-rock contact in the east of the city, towards the coast.

The records located on bay mud material, parallel to the coast, shown values from 1.04 to 1.40 seconds, those values being the highest for this city; and is where the greater thicknesses of sediments due to the direction of flow of alluvial material streams that traverse the area from east to west are expected. In alluvial ground, DP of ground motion values ranging from 0.40 to 1.34 seconds.

CONCLUSIONS

Microzonation map of dominant periods (DP) of ground motion in Ensenada, Baja California, Mexico was obtained. For this we applied the Nakamura´s technique of spectral ratios, on triaxial records of ambient noise. The geographical distributions of the values of DP show a good agreement with the surface geology in cities where there is lateral variation thereof also increased DP values approaching the coast can be seen, this behavior may associate the increase in the sediment thickness from east to west.

Using ambient noise for determining the DP of ground motion is a safe and convenient method because it is not necessary to have a basis of earthquake records.

The microzonation map of DP of ground motion presented in this paper is only a small part of a number of jobs characterization seismic effect in main cities at Baja California, México done, and have been done in medium and long term in the region, so as part of this work had already been presented (Ibarra et al., 2009), but for the city of Tijuana, Mexico.

However, the results reflected in the map of Ensenada, México helps to specialists in design of civil structures to perform calculations. So directly that lies in design a structure with a fundamental period far out of values of DP in the area where is planning to build the structure.

It is important to note that the *Normas Técnicas Complementarias para Diseño por Sismo* (2001) Cd. De México, appear equations that make up the design spectrum based on the expected longer period dominant of soil. The map presented has the limitation that the measurement points were made within the existing urban area at this time, so that in future it will be necessary to develop studies of dominant periods of vibration of the ground in areas where there is a new urban development which lies outside the area covered in this study.

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Table I. *Values of DP of ground motion for the city of Ensenada. B.C., México. Source: Self-Elaboration.*

Station number	Longitude West	Latitude North	Period (s)
1	-116.6665	31.8737	0.35
2	-116.6632	31.8750	0.30
3	-116.6625	31.8810	0.55
4	-116.6521	31.8917	0.33
5	-116.6551	31.8776	0.30
6	-116.6575	31.8690	0.40
7	-116.6524	31.8698	0.21
9	-116.6416	31.8677	0.21
10	-116.6313	31.8614	0.37
11	-116.6292	31.8730	0.37
12	-116.6313	31.8602	0.17
13	-116.6270	31.8687	0.58
14	-116.6238	31.8758	0.46
15	-116.6247	31.8782	0.52
16	-116.6071	31.8958	0.18
17	-116.6100	31.8895	0.18
18	-116.6138	31.8845	0.20
19	-116.6122	31.8794	0.33
20	-116.6148	31.8770	0.46
21	-116.6149	31.8683	0.55
22	-116.6166	31.8588	0.75
23	-116.6192	31.8572	1.04
24	-116.6043	31.8896	0.15
25	-116.6023	31.8813	0.23
26	-116.6033	31.8720	0.49
27	-116.5913	31.8727	0.14
28	-116.5908	31.8687	0.34
29	-116.5995	31.8630	0.66
30	-116.6067	31.8587	1.34
31	-116.6125	31.8482	1.40
32	-116.6102	31.8447	1.10
33	-116.6082	31.8333	1.30
Station number	Longitude West	Latitude North	Period (s)
34	-116.6045	31.8538	0.98
35	-116.5973	31.8610	0.70
36	-116.5905	31.8644	0.34
37	-116.5777	31.8608	0.20
38	-116.5863	31.8558	0.20
39	-116.5870	31.8510	0.22
40	-116.5915	31.8462	0.62
41	-116.6142	31.8743	0.55
42	-116.6429	31.8666	0.16
43	-116.6124	31.8467	1.40
44	-116.6070	31.8343	1.20
45	-116.6070	31.8550	1.15
46	-116.6210	31.8580	1.05
47	-116.5875	31.8600	0.60
48	-116.6178	31.8635	0.52
49	-116.6600	31.8650	0.55
50	-116.6270	31.8710	0.40
51	-116.6227	31.8840	0.30
52	-116.6123	31.8890	0.18
53	-116.6111	31.8860	0.20
54	-116.6107	31.8810	0.50
55	-116.6108	31.8780	0.45
56	-116.6095	31.8740	0.53
57	-116.6086	31.8670	0.70
58	-116.6048	31.8470	0.89
59	-116.6026	31.8390	1.10
60	-116.6015	31.8360	0.80
61	-116.6006	31.8310	0.87
62	-116.5992	31.8240	0.38
63	-116.5987	31.8190	0.42
64	-116.6363	31.8704	0.30
65	-116.5981	31.8325	0.83
66	-116.6606	31.8677	0.40
67	-116.6226	31.8781	0.40
Station number	Longitude West	Latitude North	Period (s)
68	-116.5715	31.8472	0.74
69	-116.6238	31.8698	0.56
70	-116.6342	31.8800	0.21
71	-116.6267	31.8650	0.60
72	-116.6100	31.8617	1.25
73	-116.6017	31.8583	1.00
74	-116.5950	31.8583	0.50
75	-116.5892	31.8447	0.62