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URBAN BRIDGE STABILITY STUDY IN ENSENADA, BAJA CALIFORNIA, MEXICO

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SUMMARY

Ensenada, Mexico, is a zone located to the south of California, affected by intense earthquakes. Therefore, studies of seismic risk of the regional infrastructures are required.

A procedure to evaluate the dynamic properties of a typical bridge of the city is shown. This procedure is pretended to apply in the study of other bridges. The proposal research consists of the following stages: 1) determining the fundamental period of the bridge using ambient vibration, 2) determining the vulnerability index through fuzzy method (Maldonado Method) and 3) comparing with a structural model of finite elements.

The procedure combines different techniques to study the dynamic behavior of bridges. The first step is to evaluate the fundamental period using an ambient vibration study. Second, the result of the fundamental period will be compared with the obtained result using a model of finite element. Finally, the bridge's vulnerability index is calculated using a method developed by one of the authors.

BRIDGE DESCRIPTION

El Gallo urban bridge is located in the México Avenue (Figure 1), which. is form by four tracks. For the bridge's analyses , the alive loads were considered using the criterions of the regulation of the AASHTO[1]; while the accidental loads were considered the criterions of the manual of civil works of

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the Electrical Federal Commission (CFE) [2]; at last the different elements of concrete reinforced were design in agreement with the Regulation of the Constructions of Concrete Reinforced ACI-318-95 [3].

Figure 1. Frontal view of the bridge El Gallo.

MALDONADO METHOD

To calculate the vulnerability index (Iv) were considered the most important and influential parameters on the bridge behavior. These parameters (Table 1) were determined by Maldonado [4].

PARAMETERS OF THE MODEL	
Symbol	**Description**
K_1	Year of project and construction of the bridge
K_2	Type of superstructure
K_3	Shape of the superstructure
K_4	Existence of internal joints
K_5	Material of the superstructure
K_6	Type of pile
K_7	Type of foundation
K_8	Material of pile
K_9	Longitudinal irregularity in geometry or stiffness
K_{10}	Length of stirrup
K_{11}	Soil type
K_{12}	Type of stirrup
K_{13}	Length of abutment
K_{14}	Type of support
K_{15}	Conservation condition

K_{16}	Constructive procedure
K_{17}	Constructive procedure of the piles (concrete)
K_{18}	Liquefaction potential
K_{19}	Nonstructural elements

Table 1. Maldonado method uses 19 parameters that were determined with base in the studies realized on behavior seismic of bridges, experiences postearthquake, studies of existing models and opinions of experts.

CALCULATION OF VULNERABILITY INDEX

Since the model is based on expert opinions, whose in some cases are subjective and imprecise, techniques of fuzzy sets were used. The fuzzy mathematics are used to quantify the qualitative thing and in this work they are used to relate the qualifications of each parameter and its respective values of importance. The traditional method of combination of several pieces of information, with unequal importance or weights is used in this work to calculate the seismic vulnerability index of the El Gallo Bridge. The vulnerability index is expressed in the following formula:

$$IV = \frac{\sum_{i=1}^{19} W_i K_i}{\sum_{i=1}^{19} W_i}$$

Where *IV* is the seismic vulnerability index of the bridge, K_i is a measurement of the degree of vulnerability of the category of parameter *i*. The W_i values (weights) are the measurement of the opinion of the importance associated to parameter *i* with respect to the other parameters. The values K_i and W_i are fuzzy numbers.

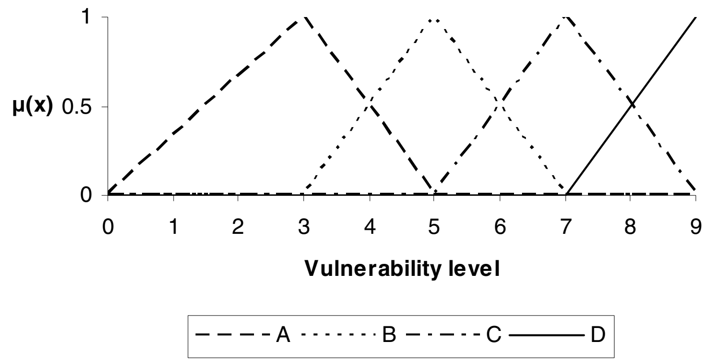
FUZZY SETS

The concept of fuzzy sets is introduced by Zadeh in 1965, like an attempt to overcome the severity of the classic theory of sets and be able to group proposals that, by the nature of which they represent, contain uncertainty, ambiguity, errors, approaches. Sight from another perspective, the diffuse sets are a generalization of the conventional theory of sets, which Zadeh incorporated to represent the unclearness of the daily life and to be able, through them to make calculations with words (Sinha et. al [5]).

MEMBERSHIP FUNCTION

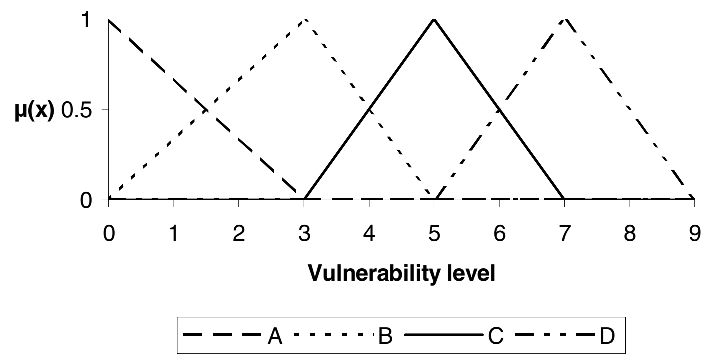
The theory of the fuzzy sets defines the degree in which element x of set X is including in the subset A by means of the membership function $\mu A(x)$. This function is a set of ordered numbers if the variable is discret, or a continuous function if it is not it. The value of $\mu A(x)$ indicates the degree in that value x of variable X is including in the concept represented by label A. For the construction of the membership function the information took advantage of the answers of the obtained surveys of experts of five countries: Spain, Colombia, Ecuador, Venezuela and Mexico. The values of property calculated on the basis of the number of favorable answers of each classification.

The defined membership function for the parameters K1 (year of project and construction of the bridge) and K2 (type of superstructure) are showed in figures 2 and 3, whereas the corresponding functions of weight appear in figures 4 and 5.



A={0|0, 1|3, 0|5, 0|7, 0|9}
B={0|0, 0|3, 1|5, 0|7, 0|9}
C={0|0, 0|3, 0|5, 1|7, 0|9}
D={0|0, 0|3, 0|5, 0|7, 1|9}

Figure 2. Year of project and construction of the bridge (K_1)



A={1|0, 0|3, 0|5, 0|7, 0|9}
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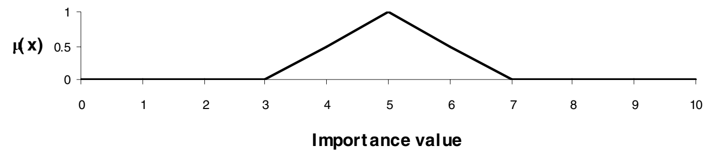
C={0|0, 0|3, 1|5, 0|7, 0|9}
D={0|0, 0|3, 0|5, 1|7, 0|9}

Figure 3. Type of superstructure (K_2)

I= {0|0, 0|1, 0|2, 0|3, 0|4, 0|5, 0|6, 0|7, 0|8, 0|9, 0|10,}

Figure 4. Function of weight of K_1 (year of project and construction of the bridge).



I= {0|0, 0|1, 0|2, 0|3, 0.5|4, 1|5, 0.5|6, 0|7, 0|8, 0|9, 0|10,}

Figure 5. Function of weight of K_2 (type of superstructure).

INDEX OF VULNERABILITY CALCULATED

Using the data of the bridge, the membership functions and the functions of weight for each one of the parameters of the bridge, according to the Maldonado method, the value of Index of Vulnerability is obtained = 2.8 that corresponds to a low vulnerability bridge.

AMBIENT VIBRATION MEASUREMENTS

Measurements of ambient vibration were made placing sensors as it showed in Figure 6. To measure the two components horizontal, longitudinal (in the direction of the traffic of vehicles) and transversal (in the direction of the flow of the stream), and the vertical component. The sensors were placed in the corners of the bridge and free field. Figure 7 shows the Fourier spectra of the three components in the point A and at free field, as well as the transference function.

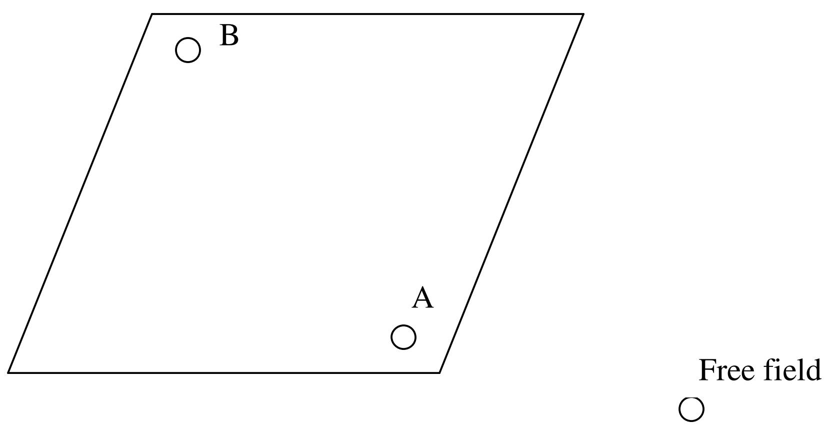


Figure 6. Outline of bridge and the measurements points.

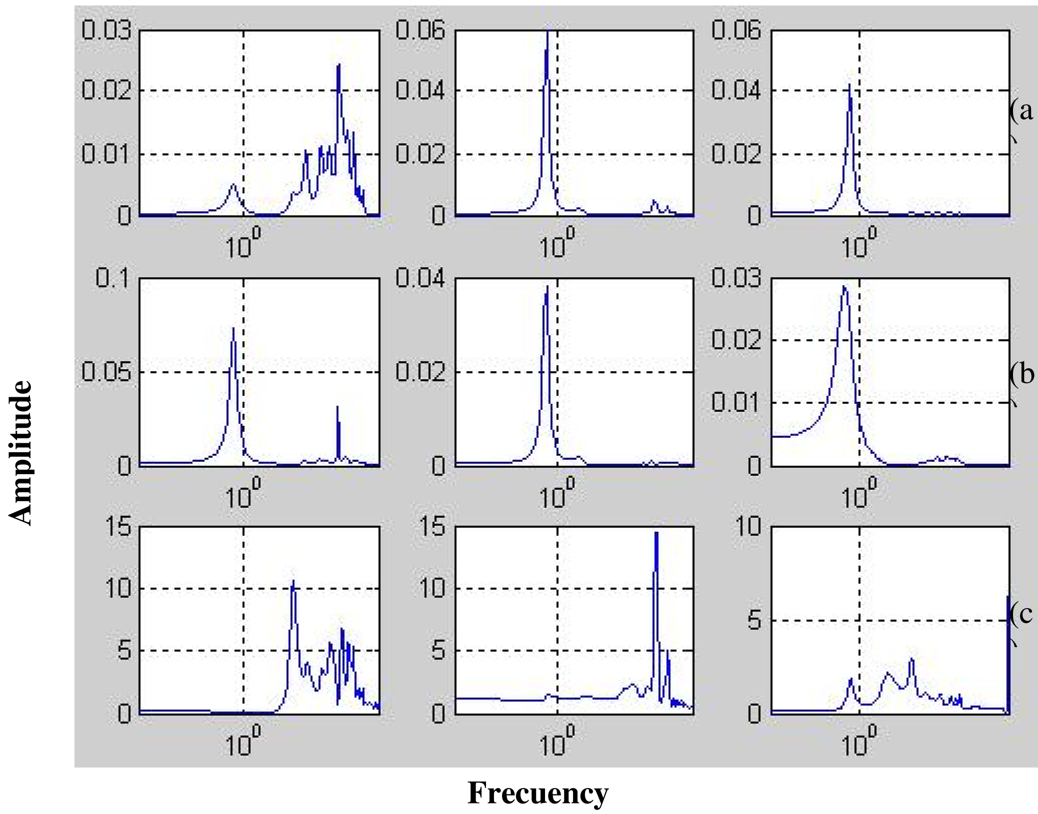


Figure 7. Fourier spectra (a) bridge, (b) free field and (c) transference function. The first column show longitudinal component, the second one the vertical and the third one is the transversal component.

The main frequencies are observed in Figure 8, 3 Hz in the longitudinal component, 8.3 Hz in the vertical and 0.9 Hertz in the transversal component. This figure has linear scale while Figure 7 has semilog scale.

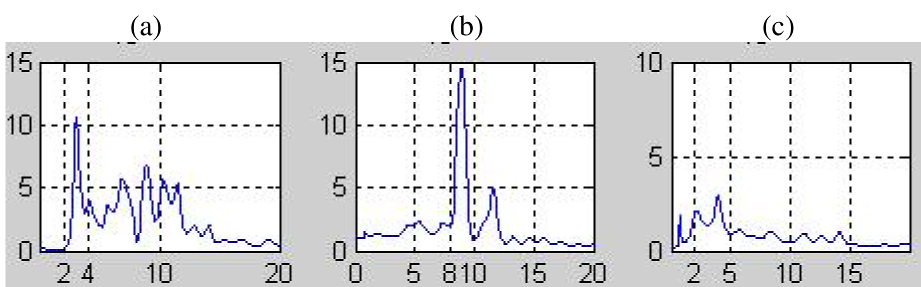


Figure 8. Transference function with linear scale.

FINITE ELEMENT MODEL

In this part of paper a three-dimensional finite element modeling techniques for slab-on-girder bridges was used. The finite element method was used to verify the experimental tests. Figures 9 and 10 shows a model of a standard single span of the so-called El Gallo bridge.

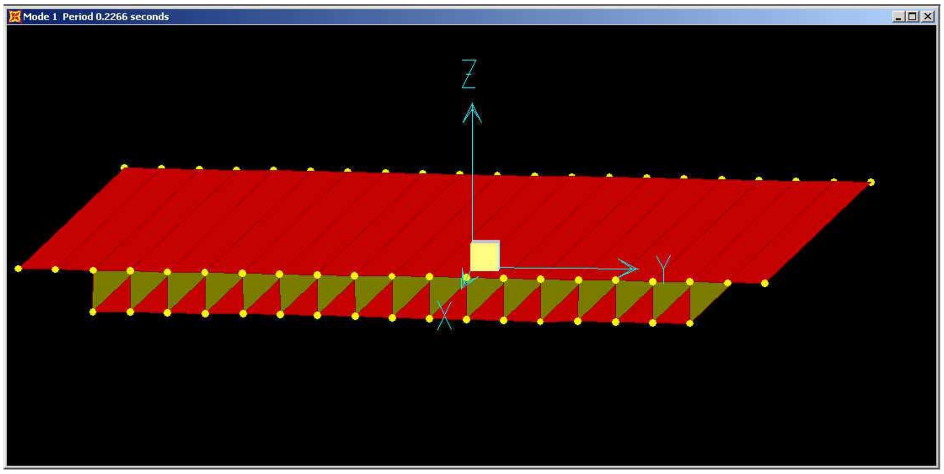


Figure 9. Lateral view of El Gallo Bridge

A structural analysis program was used to perform analyses. As shown in Figures 9 and 10, the model includes shell elements for the superstructure. The bridge members properties were fy = 4,200 kg/cm^2 and f'c = 250 kg/cm^2. The total dead load was 1,470 kg/m^2 and the alive load was 2,903 kg/m^2. Furthermore, a concentrated load of 3,132 kg was considered in agreement of AASHTO code.

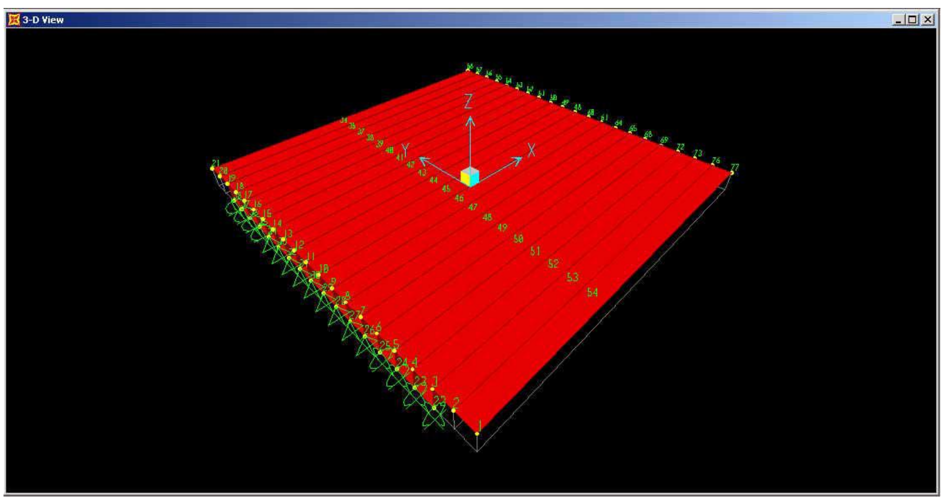


Figure 10. Perspective view of El Gallo bridge.

The results obtained of the modal analysis are shown in the Table 2. In this table are shown the first six vibration modes of the bridge.

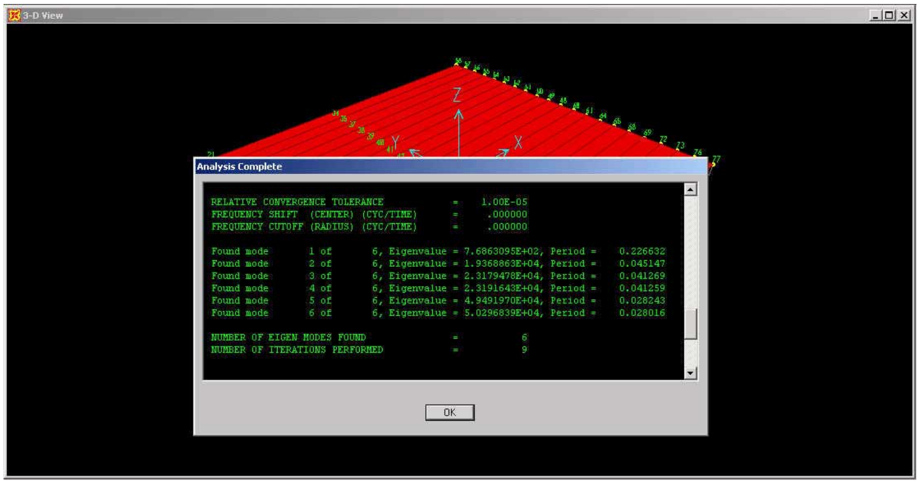


Figure 11. Results of the modal analysis.

Modal analysis	
Mode	**Period**
1	0.2266
2	0.0451
3	0.0413
4	0.0412
5	0.0282
6	0.0280

Table 2. First six vibration modes of the bridge.

RESULTS

In view of the obtained results, it is possible to be considered that the El Gallo bridge behaves rigidly. The frequencies obtained with the finite element model are bigger than those obtained with ambient vibration (Table 3). These differences is probability caused because in the numerical model, the bridge is supposed completely isolated and the real bridge is not isolated, the slab interacts with the supports being more flexible. Furthermore, the value of the calculated vulnerability index indicates a low vulnerability, 2.8.

(a)

AMBIENT VIBRATION	
Component	Frequency
transversal	0.9 Hz
longitudinal	3.0 Hz
vertical	8.3 Hz

(b)

MODEL	
Modes	Frequency
1	4.4 Hz
2	22.2 Hz
3	24.2 Hz

Table 3. Frequencies obtained with ambient vibration measurements in three components(a) and three first modes with a SAP2000 model (b).

ACKNOWLEDGMENTS

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REFERENCES

1. AASHTO. "Standard Specifications for Highway Bridges". Fifteenth Edition, American Association of State Highway and Transportation Officials. 1992.
2. CFE. "Manual de Diseño de Obras Civiles, Diseño por Sismo". CFE - Instituto de Investigaciones Eléctricas (In Spanish), México. 1993.
3. ACI 318-95. "Building Code Requirements for Structural Concrete and Commentary", ACI Committee 318.
4. Maldonado E. "Metodología para la Evaluación de la Vulnerabilidad Sísmica en Puentes". PhD Thesis (In Spanish). Universidad Politécnica de Cataluña, Barcelona, España. 2000.
5. Sínha S. Narres, Gupta Madan M. Soft Computing & Intelligent Systems. Department of Electronics, United States of America. 2000.