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Recommendations on seismic actions on bridges

R.Cuvillo
Ministerio de Obras Públicas y Transportes (MOPT), Spain
C.Huerta & J.J.Lopez Cela
Sociedad de Investigación, Estudios y Experimentación (SINEX, S.A.), Spain
E.Alarcón
ETS Ingenieros Industriales, Universidad Politécnica de Madrid (UPM), Spain

ABSTRACT: The paper describes the main features of a technical Recommendation first draft on Seismic Actions on Bridges, promoted by the Spanish Ministry of Public Works (MOPT).

1 INTRODUCTION

Bridges are key elements inside the transportation network; their serviceability in the postearthquake step is fundamental to guarantee both the arrival of help and the evacuation of injured people. In addtion to that, recent earthquakes have put into the limelight the vulnerability of works that have been traditionally considerd as very safe structures. This is why the Dirección General de Carreteras (DGC) of the Spanish Ministerio de Obras Públicas y Transportes (MOPT) decided to prepare the Recommendations to take into account the seismic action on bridges which first draft was recently prepared by the Instituo J.A. Artigas at the Universidad Politécnica de Madrid. The status of the Recommendatios is still tentative; they have not been submitted to the public consideration so that currently they only reflect the oppinion of the authors. In spite of that it is felt that they can be used as a global approach where, in addition to the minimum conditions there established, it is possible to find general guidelines to use more refined approaches in special circunstances. Also they have to be considered as a complement to the already enforcing Code (ref.1): "Acciones a considerar en el Proyecto de Puentes de Carretera" (Actions to be considered in the design of route bridges) where the load combinations and safety checks are completely established.

2 RISK ASSESMENT. IMPORTANCE CATEGORIES

As it is well know, the risk is defined as the composition of the seismic hazard, the vulnerability of the structure and the estimated value of the losses.

The seismic hazard in Spain is not well defined in the current Code (ref.2) so that the basis to define the risk is a map prepared by the Instituto Geográfico (ref.3) where the seismic hazard is defined specifying for a site the maximum acceleration to be expected there with a probability of 10 % and a return period of 500 years for a life duration of 50 years. In order to establish the Importance Categories it has been (ref.4) decided to use the approach defined in a companion paper (ref.5). The design acceleration "a" is computed as a ratio to the basic acceleration included in the map "a_b" by using the formula

$$\frac{a}{a_b} = \left(\frac{L}{500E}\right)^{\frac{1}{2,7}} \qquad (1)$$

where L is the expected life of the structure and E is the admissible risk. In order to give some guidance four ratios, called Importance Categories have been defined simplifying the results obtained by applying (1) to table I and II of ref.5. As the current bridge Code (ref.1) considers the seismic action inside the combination of catastrophic actions and, in general, the loss of a bridge represents an expensive event it is considered that the seismic risk has to be varied between 0,10 and 0,05. The last number is used when loss of lives is expected, what has to be considered in the bridge case as a side product if it fails to help, for instance, the evacuation of injured people. To fix the minimum life three safety levels and two types (general or specific interest) have to be considered. The combination of those ideas in eq.(1) allows the composition of the following table I.

Table I. Design acceleration ratio.

	Importance level					
	Local		General		Supranational	
	R	E	R	E	R	E
General Use	0,77	1,0	1,0	1,3	1,3	1,67
Limited Use	0,64	0,83	0,77	1,0	1,0	1,30

* R: Reduced Loss of human lifes.
E: Expected Loss of human lifes.

As can be seen four Categories (table II) can be defined simply by using as a parameter the design acceleration ratio. The hope is that this procedure will adjust the vulnerability to the expected hazard and accepted risk in a fashion compatible with the value given by the society to the bridge.

Table II. Importance Categories.

Importance Category	Design acceleration ration
Low	0,8
Medium	1
High	1,3
Very High	1,7

For the construction duration L^* the design acceleration a^* can be obtained by equalizing the risk to that obtained for the expected life L of the structure. The repeated application of (eq.1) produces

$$\frac{a^*}{a} = \left(\frac{L^*}{L}\right)^{\frac{1}{2,7}} \qquad (2)$$

so that for $L^* = 1$ year $L = 50$ years a reduction of about 25 % is obtained to analize the seismic behaviour during the construction. That can be very important in cases where the shape of the bridge differs substantially during the construction step and in the final situation. Depending on the bridge it should have to be considered then the possibility of manteining the computations in an elastic level or to admit a certain degree of plastification in selected zones where an a-posteriori reinforcing work could be accepted.

3 DEFINITION OF THE ACTION

The action is defined as described in (ref.5) using a design spectrum although any computer-simulated compatible accelerograms can also be used as well as compatible power spectral density curves.

The elastic spectrum is defined in reference 5 and includes the effects of three different soil types as well as the influence of near or far-field earthquakes. The damping for the standard spectrum is 5 % although some corrections cn be done according to a formulae proposed in reference 6. The correction factor is

$$\nu = \sqrt{\frac{5}{\zeta}} \qquad (3)$$

The standard spectrum is given by the pseudo-acceleration PSA for the horizontal displacements. For vertical accelerations 2/3 of the horizontal ones are taken. It is also recommend to analyze the sensitivity of high piles to soil rotations. The formula of ref.6 part III are tentatively proposed, i.e.: the spectrum of the rotations around horizontal axis is given as

$$\theta_{x,y} \; \frac{1,7\pi}{\lambda_S} PSA \qquad (4)$$

while the rotations around vertical axis is

$$\theta_z = \frac{2\pi}{\lambda_s} PSA \qquad (5)$$

in both cases λ_s is the wave-length of the predominant shear wave (see ref.5).

To allow the use of different soils on every base column (figure 1) two proposals are recommend following Eurocode III part II draft: either an envelope spectrum or a weigthed combination where the weights are proportional to the relative column stiffnesses.

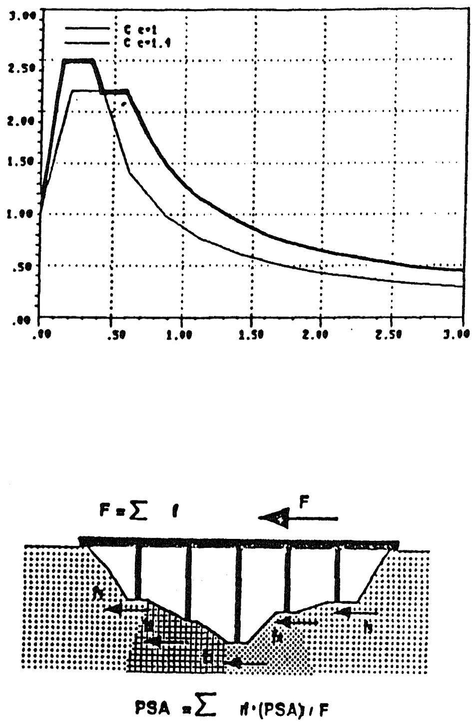

Figure 1

A modal damping approach is accepted to take into account the contribution of soil-structure interaction at the pile foundations and abutments.

The design spectrum is obtained correcting the elastic one for long periods and dividing by a behaviour factor which takes into account the accepted global ductility (see ref.5).

The modal truncation is controlled by the minimum condition related to the mobilized mass although some advices are given to avoid the overpassing of local modes (ref.8;9) that can be of importance (see figure 2) both for piles and deck.

The mode superposition is controlled by a CQC rule and the action combination follows the Newmark's type approach

$$X_i + 0,3\ X_j + 0,3\ X_k \qquad (6)$$
$$i,\ j,\ k = 1,\ 2,\ 3$$

where 1, 2 corresponds to horizontal actions and 3 to vertical action.

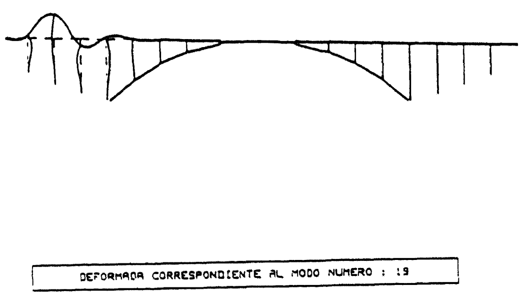

Figure 2

4 COMPUTATIONAL METHODS

In general a modal spectral approach is recommended but other alternative are also accepted. It is recognized that, in most cases, the continuous distibution of mass and stifness in transversal and vertical directions preclude the use of a small amount of modes so that a modal acceleration-residual mode is recommended. For the residual mode the soil acceleration is taken as the worst corresponding to the flat of the sprectrum or to the maximum soil acceleration (depending on the values of the behaviour factor).

A simplified computation is also admissible wheter a reasonable one degree of freedom model can be established through a Rayleigh approach conducing to a series of equivalent forces of the type

$$F_{eq}^{i} = \frac{a}{g}\ \alpha(\omega,\zeta)\ m_i\ d_i\ \frac{\sum P_j d_j}{\sum m_j d_j^2} \qquad (7$$

where a if the design acceleration

g is the gravity acceleration

$\alpha(\omega,\zeta)$ the PSA spectrum

m_j the mass concentrated at degree of freedom j

$P_j = m_j\, g$

d_j the assumed displacement at degree of freedom j

The displacement vector $\underline{d}$ can be obtained from the compulsory static analysis for braking load, self weight (or partial live load) and wind load even although the stiffnes characteristics could be different in that situations (for instance fissured or non fisured section properties).

5 FOUNDATIONS AND ABUTMENTS

The Recommendations include comments on densification, liquefaction and slope stability along well established simplified methods that can al least be used as indicators for the need of more refined studies. A special chapter is devoted to the modelling of soil-structure interaction at foundations and abutments. Here a parametric study reported elsewhere (ref.12) has been done using the Boundary Element Method, to analyze the dynamic impedances of abutments following the lines open by Tajimi (ref.11) and Woods (ref.13). Figure 3 represents for instance, the dynamic impedances for a simplified abutment in a plane deformation state. The real part can be related to an equivalent spring while the complex part represents the damping properties. As a simplified formula it has been proposed to relate the static properties (ref.12) through a factored formula.

The same approach can be used to obtain the dynamic soil pressures. A typical example can be seen in Figure 4, although in general a more practial approach iwolves the use of an inverted triangular law as explained in ref.5.

6 CONCLUSIONS

The draft of Seismic Recommendations for Bridges tries to present in an ordered fashion the most important problems affecting those structures. When possible, simplified formula useful to analyze qualitatively the problem have been recomended. In other occassions only the general Guidelines to treat specific problems

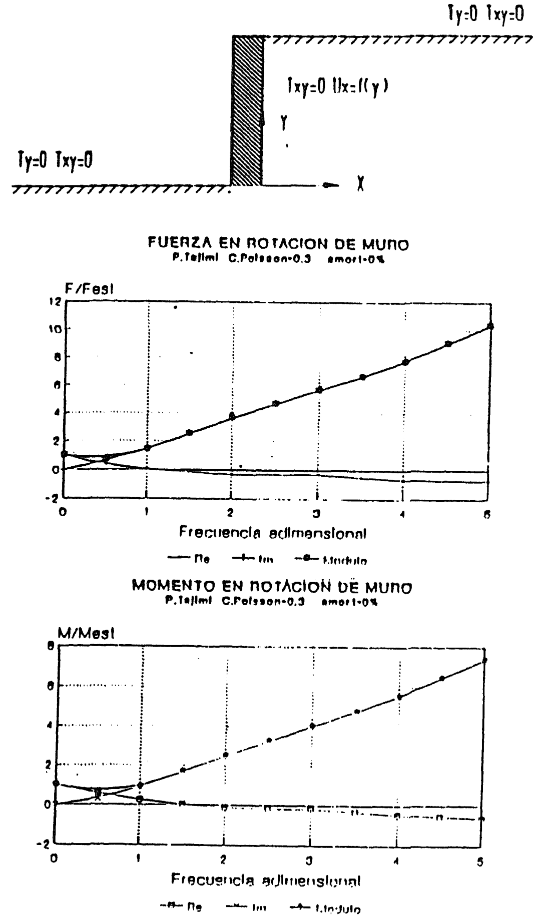

Figure 3'

have been included. The effort has produced a reconsideration of the state-of-the-art knowledge and some new material has been produced. Although more effort is needed to complete the topic it is felt that the profession will use the proposal as an stimulus to pay more attention to the subject.

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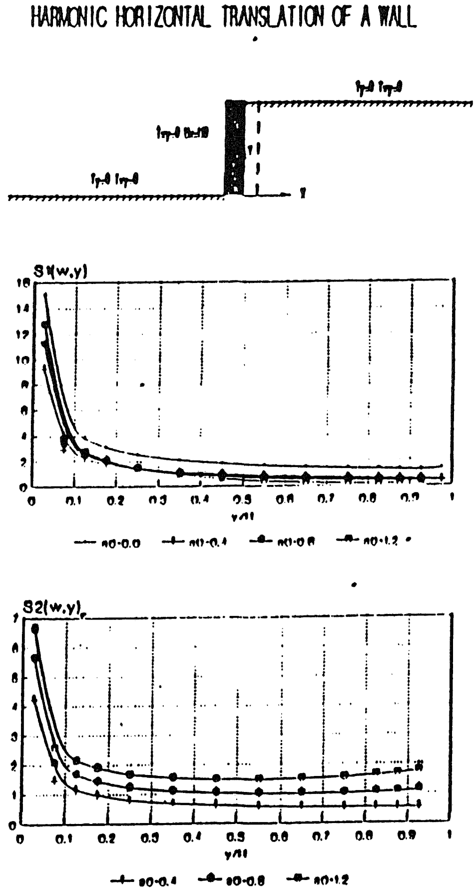
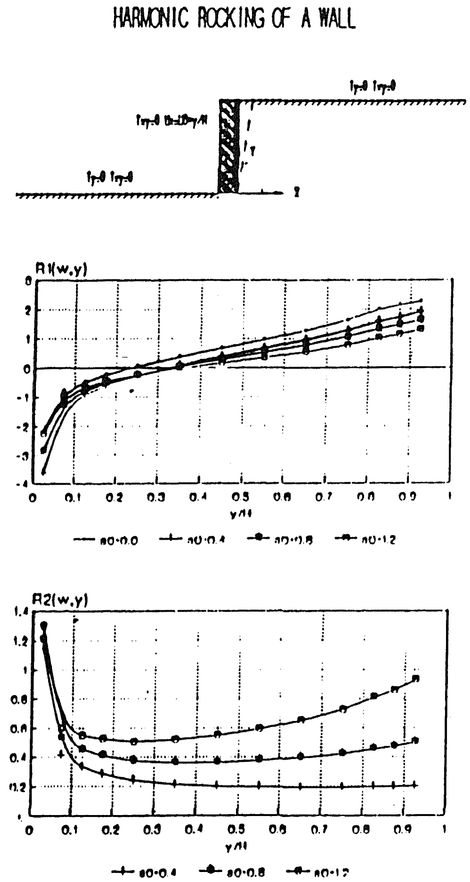


$$\sigma_x(0,y) = \frac{G u_0 e^{i\omega t}}{H}[S_1(\omega,y) + i\, S_2(\omega,y)]$$

$$a_0 = \frac{\omega H}{C_s}\ ;\ C_s = \sqrt{\frac{G}{\rho}}$$

$$\nu = 0.4375\ ;\ \frac{C_s}{C_p} = \frac{1}{3}$$

Figure 4a



$$\sigma_x(0,y) = \frac{G u_0 e^{i\omega t}}{H}[R_1(\omega,y) + i\, R_2(\omega,y)]$$

$$a_0 = \frac{\omega H}{C_s}\ ;\ C_s = \sqrt{\frac{G}{\rho}}$$

$$\nu = 0.4375\ ;\ \frac{C_s}{C_p} = \frac{1}{3}$$

Figure 4b

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