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Preface

Madrid, 20 de Junio de 2018,

La dinámica estructural es un campo de interés común y de importancia creciente en diversas especialidades de la ingeniería y de la ciencia. Mientras que en algunos campos como las máquinas o los vehículos de transporte ha sido siempre un elemento básico, en otros como la ingeniería civil y la arquitectura, más preocupados tradicionalmente con la estática, se ha convertido en un aspecto muy relevante.

Esta primera conferencia a nivel nacional pretende ser un foro en el que tengan cabida los trabajos de investigación, desarrollo y aplicaciones, permitiendo la discusión, difusión, contacto con otros grupos y establecimiento de colaboraciones. Se organiza con proyección internacional y europea, contando con el apoyo de la European Association for Structural Dynamics (EASD) organizadora de los congresos EURODYN, así como con el apoyo de la Sociedad Española de Métodos Numéricos (SEMNI).

La participación incluye tanto trabajos basados en métodos teóricos y computacionales como experimentales. Por otra parte abarca todos los campos de la dinámica estructural, como son la ingeniería mecánica, el transporte, ingeniería civil y arquitectura, ingeniería sísmica e ingeniería de materiales. Aunque ubicados en especialidades de ingeniería distintas todos estos campos comparten conceptos y métodos comunes de dinámica.

Esta primera conferencia pretende iniciar una serie que se desarrolle de forma periódica. Asimismo se propone constituir una Asociación Española de Dinámica Estructural que articule las actividades de colaboración y difusión, y que sirva de interlocutora con otros órganos nacionales e internacionales como la EASD.

Desde el comité organizador queremos dar la bienvenida a todos los participantes y ponernos a disposición para el desarrollo de la conferencia.

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LOOKING FOR CRITERIA TO ASSESS THE RELEVANCE OF STRUCTURAL FLEXIBILITY ON THE RESPONSE OF LARGE BURIED STRUCTURES SUBJECT TO SEISMIC ACTION

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Abstract. This work analyzes the requirements of the models needed to estimate the seismic motions observed along large cylindrical buried structures by performing a parametric analysis of the problem using two models: one in which the structure is considered as perfectly rigid, and another one in which its actual structural flexibility is taken into account. The properties of the soil, the flexibility of the structure and the variability of the seismic incident field along the buried length are the three key aspects that affect the seismic response of the system. The parametric analysis has been carried out using a wide range of properties for both, structure and soil. Thus, computing the seismic response of a relatively large number of configurations is needed and it makes advisable the use of a numerical tool of low computational cost but accurate enough. This is why the study is performed using two models based on a Beam-on-Dynamic-Winkler-Foundation approach. These two models were previously verified by comparison against results obtained for the problem at hand using a more rigorous 3D multidomain boundary element model. The amount of results obtained by comparison of the seismic responses estimated by both models is significantly large and needs to be synthesized. These results are used to build and propose a specific criterion that can be used to elucidate under which circumstances is it possible to neglect the structural flexibility. It is found that, contrary to what is commonly assumed, the structural slenderness ratio alone cannot be used, in general, to predict the validity of the rigid structure approach: embedment lengths, soil stiffness, depth of interest and natural period of study are, also, key parameters that need to be taken into account. A close-form criterion is proposed in table form taking all such parameters into account.

Key words: Buried Structures, Seismic Response, Structural Flexibility, Design Criterion

1 INTRODUCTION

One aspect to consider when setting up a model for studying the motions of seismic origin within a buried structure is whether it is really needed to take into account its actual structural flexibility or, on the contrary, a perfectly rigid representation of it is enough. It might be tempting to consider large non-slender structures as perfectly rigid in relationship with the surrounding soil. The kinematic response of an actual structure of that kind was studied for instance in Vega et al. [4], where differences between rigid and flexible approaches were quantified and, even though the structure was non-slender and, apparently, very rigid. The rigid and flexible models provided results with important discrepancies.

This work contributes to this issue by presenting a criterion that can be used for practical purposes by structural and geotechnical engineers to establish if a structure under seismic excitation can be considered as a rigid body or, on the contrary, its real flexibility can not be neglected. The criterion is based on a parametric analysis that studies the errors between the motions of seismic origin provided by two Beam-on-Dynamic-Winkler-Foundation (BDWF) models in which the buried structure is considered respectively from both points of view (perfectly rigid or with its actual flexiblity).

2 PROBLEM DESCRIPTION

The structure is idealized geometrically as a completely buried solid cylinder of diameter D or a cylindrical shell with constant outer and inner diameters D and $D_{\rm int}$, and length L. The type of section will be specified by a parameter $\delta = D_{\rm int}/D$ defining a hollow ($0 < \delta < 1$) or solid ($\delta = 0$) cross section. Welded contact conditions are assumed at the interface between the structure and the surrounding soil, which is assumed to be a isotropic and homogenous half–space with Poisson's ratio ν_s, density ρ_s and shear wave velocity V_s. The system, for which a linear–elastic behaviour is assumed, is subjected to vertically–incident shear waves.

The properties of the soil, the flexibility of the structure and the variability of the seismic incident field along the buried length of the structure are three key aspects that affect the seismic response of the system. In this study, the flexibility of the structure depends on the type of cross section (solid or hollow), the material properties, and the slenderness ratio. The variability of the incident field, on the other hand, is related to the soil wave velocity (or soil stiffness) and the characteristics of the seismic waves. Thus, the study will be performed varying the following four parameters of the problem: a) Type of structural cross section: hollow ($\delta = 0.85$) or solid ($\delta = 0.00$); b) Slenderness ratio of the structure ($L/D = 2-10$); c) Soil shear wave velocity ($\mathrm{V}_s = 200 - 1000\,\mathrm{m/s^2}$) and; d) Embedment lengths of the structure ($L = 20$, 40, 60 and 80 m).

The rest of properties, considered as non–relevant for the aim of this study, are kept constant. The following properties, characteristic of concrete, are assumed for the structure: Young's modulus $E = 2.76 \cdot 10^{10}\,\mathrm{N/m^2}$, Poisson's ratio $\nu = 0.2$ and density $\rho = 2500\,\mathrm{kg/m^3}$. On the other hand, Poisson's ratio $\nu_s = 0.3$ and density $\rho_s = 1570\,\mathrm{kg/m^3}$ are kept constant for the soil. With all this, a wide range of values for the ratio E/E_s is covered, going from below 3 for ground type A to over 200 for ground type D (see Eurocode–8 [1]).

The vertically–incident S wave field that impinges the system generates free–field ground surface accelerations compatible with the type 1 design elastic horizontal ground motion acceleration response spectra also provided by Eurocode–8 [1] for each ground type. Therefore, different synthetic accelerograms, one for each ground type, are used as excitation motion according to the shear wave velocity defining the soil in each configuration.

The results need to be synthesized and presented in terms of the deviation of the response obtained from the rigid body assumption with respect to a flexible structure model. This deviation is defined as differences between the horizontal acceleration elastic response spectra characterizing the horizontal motions at different depths z/L. These differences will be quantified in terms of average differences along every one of the three branches defining the elastic response spectra used (see figure 1). The average difference $\bar{\epsilon}(z)_j$ along branch j is defined as

$$\bar{\epsilon}(z)_j[\%] = \frac{1}{n_j}\sum_{i}^{n_j}\left|\frac{S_e^f(T_i,z) - S_e^r(T_i,z)}{S_e^r(T_i,z)}\right|\Psi_i \quad ; \quad j = \begin{cases} 1,\, T_i \;\; / \;\; T_i \leqslant T_{\rm B} \\ 2,\, T_i \;\; / \;\; T_{\rm B} \leqslant T_i \leqslant T_{\rm C} \\ 3,\, T_i \;\; / \;\; T_{\rm C} \leqslant T_i \leqslant 2 \end{cases} \tag{1}$$

where

$$\Psi_i = \frac{1 + \mathrm{sign}\left(S_e^f(T_i,z) - S_e^r(T_i,z)\right)}{2} \times 100 \tag{2}$$

and n_j is the number of specific periods at which the elastic response spectrum is computed along branch j, while $S_e^r(T_i, z)$ and $S_e^f(T_i, z)$ are the elastic horizontal acceleration response spectra characterizing the horizontal motions of the embedded structure either as a perfectly rigid or flexible body, respectively. The values of the periods T_B and T_C depend on the ground type according to Eurocode–8 [1]. For the present study, the responses are always computed at 120 different periods distributed from $T = 0.01\,\mathrm{s}$ to $T = 2\,\mathrm{s}$. Note that errors are not added when the solution provided by the rigid model is more conservative than that of the flexible one. The rotational motions along the structure are not taken into account when computing those elastic horizontal acceleration response spectra.

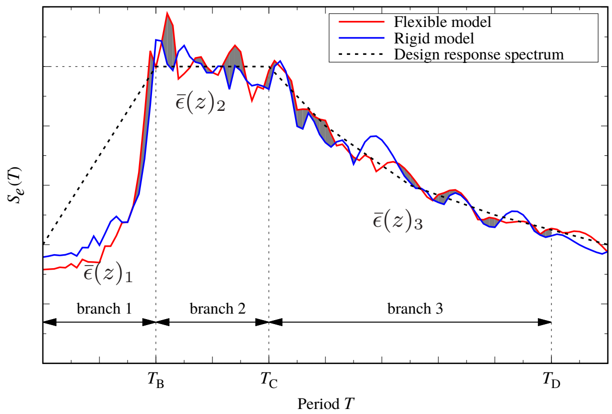

Figure 1: Representation of average difference $\epsilon(z)_j$ (shaded area) between rigid body assumption and flexible response spectra along three branches defining the design response spectrum.

3 METHODOLOGY

Carrying out the wide parametric study established in the previous section makes advisable the use of a numerical tool of low computational cost but accurate enough. This is why the present study is carried out through the use of a frequency domain analysis procedure in which the frequency response functions (FRFs) for each case are computed by means of a linear–elastic model based on the Beam-on-Dynamic-Winkler-Foundation (BDWF) approach, considering a vertically–incident S wave field as excitation. The response of the system is then computed for a given seismic input signal compatible with the corresponding response spectrum. In order to be able to adequately represent the behaviour of the non-slender configurations, the Timoshenko beam formulation [3], as part of a BDWF approach, is adopted in this work to model the buried structure. Verification and detailed explanation of these BDWF models can be seen at Santana et al. [2].

4 RESULTS

The amount of results obtained from the parametric analysis is significantly large, and need to be synthesized. First, a cut–off value for the average error (as defined in equation (1)) is established as the maximum error for which the rigid approach can still be considered adequate for the problem at hand. For practical applications, and taking into account the uncertainties associated to data and models, an average error below 10% is considered acceptable and is used as limit value.

The average errors obtained in the low-periods branch when using the rigid assumption are much larger than along the intermediate-periods branch, while they are generally below 10% in the high-periods branch for the values of the slenderness ratios (L/D) and wave propagation velocity (V_s) considered in this study. In any case, discrepancies increase with the embedment length L of the structure, with softer soils and also, as expected, for more slender structures, although in many cases, and contrary to what was anticipated, the error is quite independent of the slenderness ratio. The discrepancies also tend to increase for hollow structures, but this is not always true and, in any case, the differences between the errors in the solid and hollow configurations are not significant, which allows to propose a criterion not dependent on this character.

The obtained results can be synthesized in table form with the aim of serving as a practical guide for helping to know if the hypothesis of infinite rigidity of a large buried structure (with the mentioned safety margin of 10%) is applicable when evaluating its seismic response (see Table 1). The criterion is proposed only for the low- and intermediate-periods branches, as the rigid model is considered always valid for calculations in the high-period branch. As an application example, consider a

Table 1: Conditions that should hold for considering the rigid assumption as valid for computing the spectral seismic response of a buried structure for each spectrum branch and depth of interest ($\bar{\epsilon}(z) \leqslant 10\%$)

	Low-periods branch	Intermediate-periods branch
$z/L = 0$	$L \leqslant 60$ and $\frac{V_s}{L} \geqslant 12$	$\frac{V_s}{L} \geqslant 7.5$
$z/L = 0.25$	$L \leqslant 40$ or $600 \leqslant V_s \leqslant 900\,\mathrm{m/s}$	$L \leqslant 60$ or $-6 \leqslant \left(\frac{L}{D} - \frac{V_s}{85}\right) \leqslant 2$
$z/L = 0.50$	$L \leqslant 40$ and $V_s \geqslant 600\,\mathrm{m/s}$	$L \leqslant 60$ and $\frac{V_s}{L} \geqslant 10$
$z/L = 0.75$	$L \leqslant 40$ and $V_s \geqslant 600\,\mathrm{m/s}$	$L \leqslant 40$ or $\frac{V_s}{L} \geqslant 8$
$z/L = 1.00$	$\frac{V_s}{L} \geqslant 10$	$\frac{V_s}{L} \geqslant 4$

structure with slenderness ratio $L/D = 7$ embedded in a soil characterized by a wave propagation velocity $V_s = 700\,\mathrm{m/s}$ (ground type B). Following the criterion defined in table 1, using a rigid model for computing the response at $z/L = 0.25$ is always suitable for the embedment lengths studied herein. However, for a different wave velocity $V_s = 400\,\mathrm{m/s}$ (even if it is the same ground type), the rigid body assumption is only valid if $L \leqslant 40\,\mathrm{m}$ in the low-periods branch, or $L \leqslant 60\,\mathrm{m}$ in the intermediate-periods branch.

5 CONCLUSIONS

It is not possible to elucidate whether a buried structure behaves as rigid or not, based only on the slenderness ratio L/D. It is also necessary to take into account soil stiffness and embedment length, as both parameters are directly related to the variability of the seismic excitation along the buried structure. Besides, the depth of the point of study and the value of the period of interest can also influence the type of response.

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