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Numerical simulation of seismic soil-structure interaction including site effects

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Abstract – *The seismic behavior and vulnerability assessment of buildings is a major concern in earthquake engineering. In this respect, we study in this research paper the effects of soil-structure and site-city interaction of structures that may be seen as a first level of vulnerability diagnosis. We present a finite element analysis of soil structure interaction, using representative soil models and structures from Annaba city (Algeria). The study highlights the main parameters that govern the mechanisms of the phenomenon and their influence on the modal features of the system. The given results allow a better physical insight on soil structure interaction and site-city effects at least in its fundamental aspect, as well as a first, reasonably accurate estimate of the importance of the phenomenon. The response to real accelerograms from Boumerdès (Algeria) earthquake is analyzed by considering an idealized city composed of five buildings designed following the Algerian code requirements. As a first approach, the effect of buildings is described, this enables to identify the magnitude of the interaction, and to provide an assessment of both free field soil motion and building motion.*

***Keywords**: Soil-Structure Interaction, Site-City Effects, Seismic Vulnerability, Finite Element Approach, Numerical Simulation.*

I. Introduction

It is now a well established fact that vibrations produced by structures are transmitted to the ground by the so-called soil-structure interaction phenomenon, these vibrations can travel large distances and interact with other adjacent structures [1]. The effect of these interactions on the seismic response of structures, especially in dense populated cities resting on soft soils, was a subject poorly studied. Seismic risk in urban areas is an important subject of special interest given its impact on human losses and economic stakes.

Soil conditions at a given site may amplify the response of a given structure on a soil deposit. Not taking into account these structural response amplifications may lead to an under-designed structure resulting in a premature collapse during an earthquake.

The main idea behind this investigation is motivated by the fact that there is still great uncertainty into significance of seismic soil-structure interaction which takes into account site effects. There may be both beneficial and adverse effects into interaction. However, in many cases, soil-structure-interaction (SSI) is simply ignored in design without establishing whether it will increase or decrease the response of the structure. A second objective is that the probability of an earthquake of magnitude 7 or larger may occur in regions that have experienced strong earthquakes such as Chlef or Boumerdès or areas where new active faults are discovered (Annaba) following the second campaign of MARADJA [2]. Therefore, studies which include SSI effects will help for a better prediction of a performance of structure for future earthquakes [3].

State of the art knowledge and analytical approaches require, that the structure-foundation system be represented by mathematical models that include the influence of the sub-foundation media. Analytical models were developed by finite element for numerical analysis. Different analyses were performed on a simulated city made of a group of structures composed of five storey reinforced concrete buildings. In fact structure types of 5, and 5 storey buildings are typically encountered in Algeria[4], [5], [6]. Such structures are generally designed following Algerian code requirements (RPA) neglecting SSI effects [7]. The objective of this study as reported herein focuses mainly on the numerical modeling of cities represented by structural building groups of 5 storey reinforced concrete buildings incorporating special soft soil conditions, in order to assess the effects of SSI and site effects on the dynamic response of structures [8], [9].

II. Evaluation of Site Effects in Annaba City

The city of Annaba situated in Northern Algeria is one of the areas of the Algerian territory where seismic risk is important. It is located on a sedimentary basin, overlooked by Edough's mountains.

The presence of saturated silty and plastic clayey formations on the upper 30 m thick layer "Figure 1.", suggests for seismic site effects. One-dimensional equivalent linear and one-dimensional nonlinear analyses are carried out to evaluate the dynamic site responses using DEEPSOIL computer program [5].

The average shear wave velocity of soil is given in "Figure 1.".

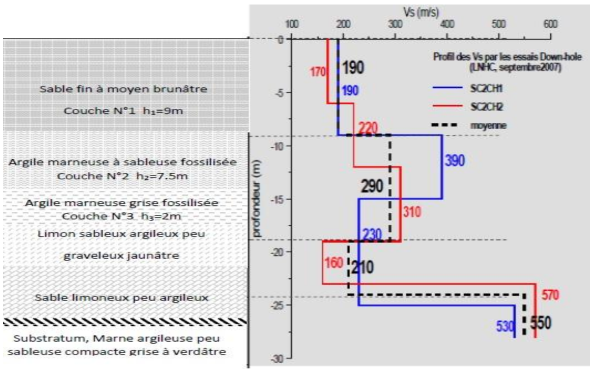

Figure 1. Soil profile and shear wave velocity from down hole test.

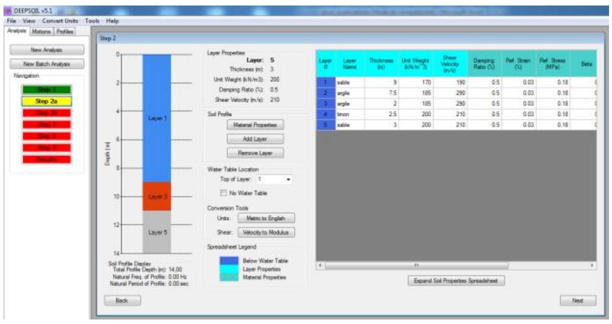

Figure 2. Characteristics of soil profile as introduced in DEEPSOIL.

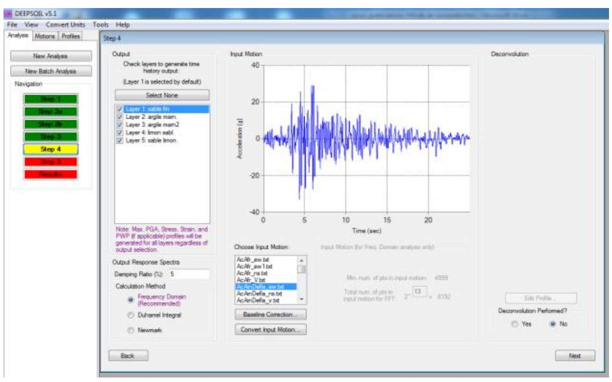

Figure 3. Earthquake accelerograms used for calculation.

The results of ground response analysis are presented in Figs 2 to 4 which indicate that the increase in maximum acceleration at the surface is as much as 3.21 times higher than at the bed rock. The results in the central basin, show that the eigenmodes are mainly controlled by the upper unconsolidated formations present above the relatively sandy–clayey layer.

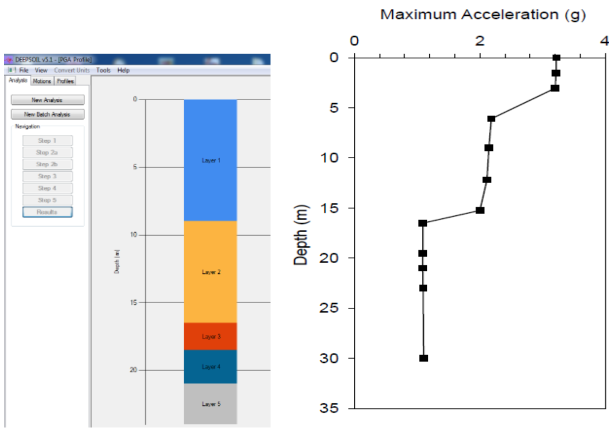

Figure 4. Soil profile and shear wave velocity from down hole test.

III. Modeling of Soil-Structure Interaction and Site-City

A simple analytical model is used, that takes into account soil structure interactions and site effects. This approach aims to develop general conclusions about the interaction effects on the response of structures, taking into account only key parameters that control soil structure interaction modeled by elementary models. The soil-structure interaction has been the subject of numerous studies, for a particular building [11] and [12] for a study including several structures.

The classical approach usually consists of two steps: first the calculation of the seismic hazard considering the effects of sites, and determination of the response of a structure taking into account the soil-structure interaction. The objective of this study is to identify the physical parameters that characterize the site effect and quantify the importance of these effects from simple approaches.

IV. Soil-Structure Interaction Problem Formulation

Foundation wave induced vibrations are caused by earthquakes that pass through the soil ("Figure 5."). A dynamic excitation is generated due to the interaction between the foundations and the soil, which requires the solution of a dynamic soil-structure interaction problem at the interface between the foundation and the soil. Waves generated in the far field in the soil do-main impinge on the foundation of the structure, which leads to an SSI problem at the interface between the soil and the structure.

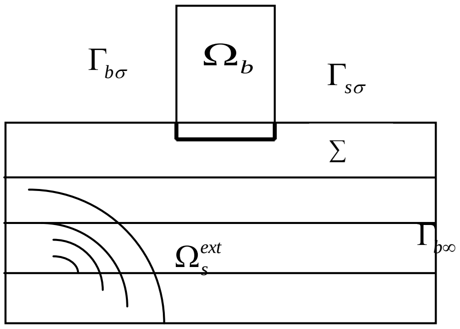

Figure 5. Geometry and notations of the subdomains.

The incident wave field interacts with the structure and generates vibrations. The foundation and the structure are coupled through the soil. First, the soil model is used to predict the incident wave field due to the passage of waves, accounting for dynamic foundation-soil interaction (DSSI). The incident wave field is defined on the semi-infinite layered soil domain and the foundation-soil interaction is accounted for by means of the direct formulation [5]. The continuity of displacement is taken into along the foundation-soil interface. The next step is the propagation of the incident wave field to the structure and the response is computed, accounting for soil-structure interaction.

V. Variational Formulation

In this section, the equation of motion of the DSSI problem is approached by variational form [13]. The principle of virtual work states that the equilibrium of the structure requires for any virtual displacement field imposed on the structure, the sum of the virtual work of the internal and the inertial forces is equal to the total virtual work of the external loads, which results in the following weak form integral equation:

$$\int_{\Omega_b} \varepsilon(\delta v) : \sigma_b(u_b)\, d\Omega - \omega^2 \int_{\Omega_b} \delta v.\rho_b u_b\, d\Omega = \int_{\Omega_b} \delta v.\rho_b b\, d\Omega + \int_{\Gamma} \delta v.\bar{t}_b\, d\Gamma + \int_{\Sigma} \delta v.t_b(u_b)\, d\Sigma \quad (1)$$

The volume integrals over Ω_b will result in the mass and the stiffness matrix of the structure. As the structure has a finite dimension, the mass and the stiffness matrix can be calculated using FEM. As is well known FEM procedures are widely used in structural analysis, only the basic principles of the FEM, needed in the discretisation of the scalar equation (1), will be presented. Over the boundary ∑, the tractions $t_s(u_{sc}(u_b))$ and $t_s(u_{inc}+u_{d0})$ given in the surface integral are computed using FEM.

For any virtual displacement field the virtual work equation must hold, and then the equation (1) is equivalent to:

$$\left(K_b - \omega^2 M_b + K_s\right)\underline{u}_b = f_b \quad (2)$$

The stiffness matrix Kb and the mass matrix Mb of the structure are given by:

$$K_b = \int_{\Omega_b} B_b^T D B_b\, d\Omega \quad (3)$$

$$M_b = \int_{\Omega_b} N_b^T \rho_b N_b\, d\Omega \quad (4)$$

The dynamic stiffness matrix Ks of the semi-finite layered half-space is given by:

$$K_s = \int_{\Sigma} N_b^T t_s\left(u_{sc}\left(N_b\right)\right) d\Sigma \quad (5)$$

The vector f_b due to the external forces on the structure is defined by:

$$f_b = \int_{\Omega_b} N_b^T \rho_b b\, d\Omega + \int_{\Gamma_{b\sigma}} N_b^T \bar{t}_b\, d\Gamma - \int_{\Sigma} N_b^T t_s\left(u_{inc} + u_{d0}\right) d\Sigma \quad (6)$$

Again finite element approach is used for the calculation of the tractions $t_s(u_{sc}(N_b))$ in the dynamic stiffness matrix K_s of the soil and $t_s(u_{inc}+u_{d0})$ in the external force vector f_b.

The solution of the elastodynamics problem on the exterior domain Ω_s^{ext} having an embedded region Ω_s^{int} of finite extent, using a discretisation form of a displacement equation, is not unique at the eigenfrequencies of the embedded interior domain Ω_s^{int} with Dirichlet boundary conditions along the soil-structure interface ∑ and free boundary conditions along the free surface [14], [15], [16] and absorbent boundary conditions at the vertical borders of the bounded soil domain. This numerical deficiency problem occurs in the high frequency range, and it depends on the geometry of the foundation and the stiffness of the excavated soil. Therefore, the problem of fictitious frequencies is not very stringent for applications in seismic engineering, where the excitation frequencies are low (typically between 0 and 5 Hz).

VI. Numerical application

The proposed analysis model is applied to study the dynamic responses of five storey reinforced concrete buildings to earthquake excitation in time domain. The computational model employed in this section is shown in (“Figure 6.”), where the numerical results are obtained using finite element method.

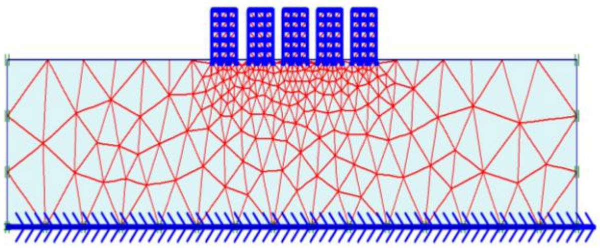

Figure 6. Geometry of the sub domain 1500mx400m.

Two cases are considered, case 1 corresponds to one R/C building resting on the surface of a soft soil layer (“Figure 5.”). While, case 2 corresponds to five R/C buildings resting on the surface of a soft soil layer (“Figure 6.”). Points A, B, C, D and E indicating locations where displacements and accelerations are calculated (Figs 7 and 8).

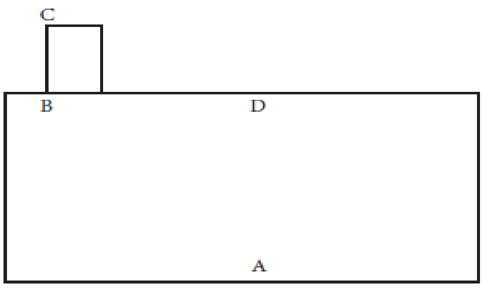

Figure 7. Case 1, corresponds to one building-soil system.

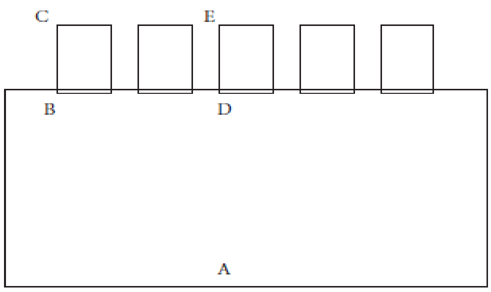

Figure 8. Case 2, corresponds to five buildings-soil system.

Automatic mesh generation of finite element meshes is used in this study. A special version of the triangle mesh generator is used [17], which results in unstructured meshes. The numerical performance of such meshes is usually better than for structured regular meshes.

Geometric nonlinearity is important in our case which involves buckling of slender beams and soil mediums. Therefore an updated mesh analysis is used based on the updated lagrangian formulation [18].

The model is submitted to 44 earthquake accelerograms 31 from Boumerdès earthquake and 13 from USGS office [20] as shown in (“Figure 9.”), where one can see on the left column the ground motions used in the numerical simulation.

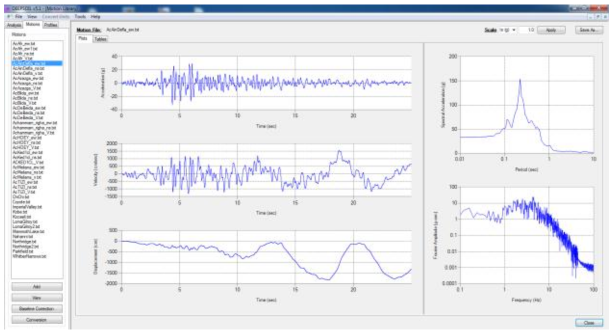

Figure 9. earthquake motions used in simulation.

The five buildings are of the same type (5 storey). They are 3.0m x 3 = 5.5m wide and their total height from ground level is 4.08 m x 6 = 24.48m. The dead load acting on each floor are up to 2.92 t/m and the live load up to 1.18 t/m.

The following material properties are used:

• Concrete : Young's modulus E = 33,300 x5^6 KPa, Poisson's ratio ν = 1/3 and Density ρ = 2500 kg/m^3

• Mohr-Coulomb Soil : Young's modulus E=4,532x5^4 KPa; Poisson's ratio ν = 0.2; cohesion c = 2 KPa; Friction angle =24°; Shear wave velocity and density as given in the soil column (“Figure 2.”); soil layer depth = 30.0 m.

VII. Discussion of Results and Conclusions

A numerical model for the prediction of wave induced vibrations in buildings has been developed and used for analysis. The coupled soil-structure system takes ac-count of the free field wave induced vibrations in buildings, the model is based on a direct formulation approach for dynamic SSI problems.

A study on the determining factors for wave induced vibrations in buildings has been performed, the response of the buildings has been calculated for one building type case and five buildings type case. The importance of SSI for two cases in dynamic SSI problem has been investigated. The conclusions from the investigation of the modal characteristics of the structure and response in terms of displacement and acceleration in different points of the SSI system are summarized as follows:

1. The stiffness of the soil plays an important role in the free field response. Higher vibration amplifications occur in the case of a soft soil.

2. The building displacements become large, but the motion dies away quickly in the building. There is an indication of rather large response not only in the buildings, but also on the ground level, and in the layer. This was also discussed by some authors for a periodic distribution of identical blocks [19].

The buildings constitute diffractors whereby seismic surface waves are locally generated, which then travel back and forth in between pairs of buildings, thus resulting in the coupling of the motions of the buildings via the soil so as the result will be a longer duration of the shaking inside the buildings which is longer than the one observed in the one-building case.

The time histories represented in Fig. 10-17, call for the following comments.

3. In Figs. 10-17, it can be observed that new effects, related to duration lengthening and beating, make their appearance in the response of the 5-buildings case ("Figure 6."). Collective causes such as interference and building-soil-building interaction dominate during the first phase of shaking and radiation damping dominates the response during the later phase.

4. The peak amplitude of building response is larger at locations of the 5-buildings case than in the 1-building case (Figs 11, 14), and the longer duration of response in certain blocks of the 5-building case makes these buildings more vulnerable than the isolated building.

5. The cumulative response at the top of the buildings varies significantly from one building to another, corresponding to increased vulnerability for the 5-buildings case (case 2), which suggests that some of the buildings may suffer severe damage, while others will go unaffected, as a result of an earthquake in a city such as this one.

6. The peak amplitude of building response is larger at locations of the 5-buildings case than in the 1-building case.

7. The effect of site to which one should expect the most spectacular lies in the upper layers, the amplification of the signal increases with the thickness of the sediments up to a factor of 3.2 ("Figure 4.").

8. Annaba geotechnical data are often limited to surface layers. Indeed, apart from these sites, particularly in the vicinity of the reliefs, it is difficult to predict the frequency or the frequencies that will lead to the greatest site effects.

These results will have to be substantiated by more computational results with continuum or other exact methods to account for the damping effects, in-plane motion, and 3D models. In addition, it will be necessary to examine to what extent anomalous structural responses are affected by the type and location of the seismic source as well as by the pulse duration.

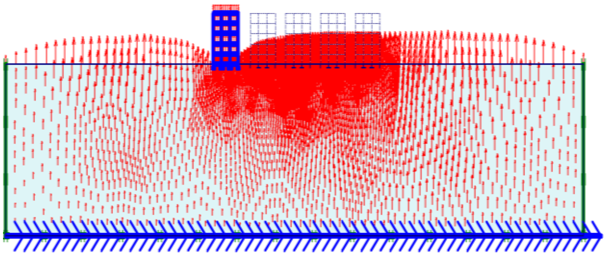

Figure 10. Vertical displacements (Uy) – Extreme Uy=502.43 mm.

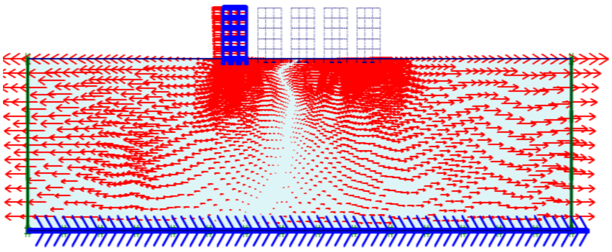

Figure 11. Horizontal displacements (Ux) – Extreme Ux=95.63mm.

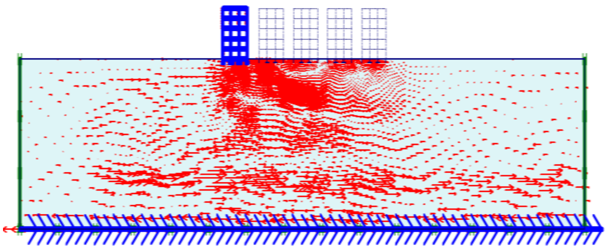

Fig. 12 Horizontal accelerations: Extreme horizontal acceleration 34 cm/s^2.

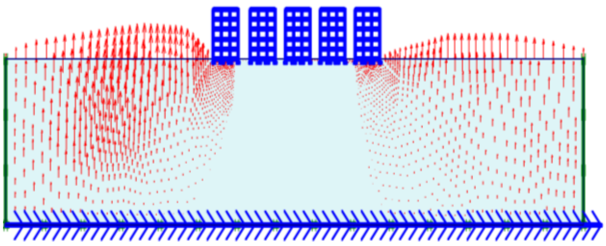

Figure 13. Vertical displacements (Uy) – Extreme Uy=218.82 mm.

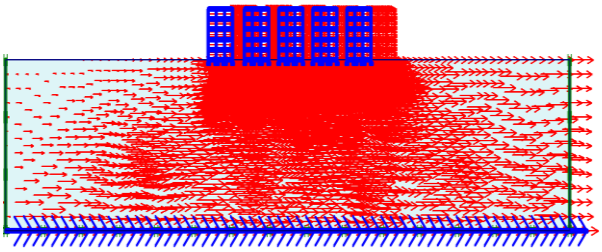

Figure 14. Horizontal displacements (Ux): Extreme Ux = 147.85 mm.

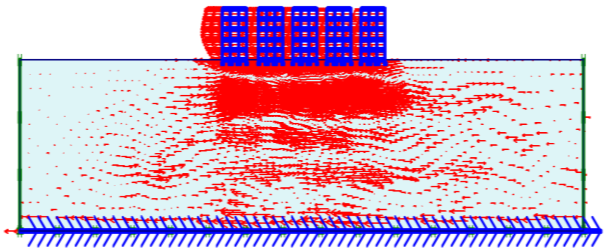

Figure 15. Horizontal accelerations: Extreme horizontal acceleration 74 cm/s^2.

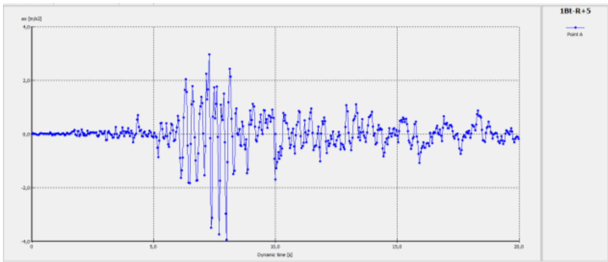

Figure 16. Displacement time history curves at bottom, foundation and top level of the 1-building case model.

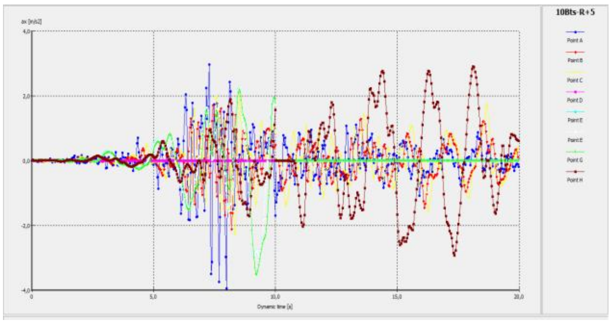

Figure 17. Acceleration time history curves at bottom, foundation and top level of the 5-buildings case model.

References

[1] P.C Jennings, J.Bielak, "Dynamics of building-soil interaction, Bulletin of the Seismological Society of America", 1973, 63: 9-48.

[2] A. Domzig, "Déformation active et récente, et structuration tectono-sédimentaire de la marge sous-marine algérienne", Thèse de doctorat, Université de Bretagne Occidentale. 2006, 343 p.

[3] "The Boumerdes, Algeria, earthquake of EERI learning from earthquakes reconnaissance report", Earthquake Engin. Res. Institute, 2003.

[4] A. Gouasmia, K. Djeghaba, "Effects of Nonlinear Dynamic Soil-Structure Interaction on the Response of Buildings", 4ème Symposium International sur la Construction, Chlef (Algeria) 22–24 Novembre. 2005.

[5] A. Gouasmia, K. Djeghaba, "Analyse Dynamique Non-linéaire des Systèmes Sols-Structures", Communication Sciences et Technologie, Publication COST. N° 6, Janvier 2006, p. 41–48.

[6] A. Gouasmia, K. Djeghaba, "Non-Linear Dynamic Soil-Structure Interaction Analysis of Buildings". Technological and Economic Development of Economy, Vol XIII, No 4, 2007, p. 266–271.

[7] Règles Parasismiques Algériennes RPA 99/Version 2003.

[8] P. Gueguen, "Interaction sismique entre le sol et le bâti: de l'interaction sol-structure à l'interaction site-ville", Thèse de doctorat, Université de Grenoble. 2000.

[9] V.K. Gupta, M.D. Trifunac, "Seismic response of multistory buildings including the effects of soil-structure interaction", Soil Dyn. Earthquake Eng. 5(8), 1991, pp.414-422.

[10] Y.M.A. Hashash, D.R. Groholski, C.A. Phillips, D. Park, and M. Musgrove, DEEPSOIL 5.1, User Manual and Tutorial, 2012, 57 p.

[11] G. Gazetas, G. Mylonakis, "Seismic soil-structure interaction: new evidence and emerging issues", Geotechnical Earthquake Engineering and Soil Dynamics III ASCE, Vol. II, 1998, pp. 1119-1174.

[12] J.P. Stewart, R. B. Seed, G.L. Fenves, "Seismic soil-structure interaction in buildings. II: empirical findings", Journal of Geotechnical Engineering ASCE 125(1), 1999, pp.38-48.

[13] T.J.R. Hughes, "The Finite Element Method: Lin-ear Static and Dynamic Finite Element Analysis". Prentice–Hall, Englewood Cliffs, New Jersey. 1987.

[14] J.P. Wolf, "Vibration Analysis Using Simple Physical Models", Prentice-Hall, Englewood Cliffs. 1994.

[15] A.J. Burton, G.F. Miller, "The application of integral equation methods to the numerical solution of some exterior boundary-value problems", Proceedings of the Royal Society of London, volume 323, 1971, pp.201-25.

[16] J.T. Chen, K.H. Chen, and C.T. Chen, "Adaptive boundary element method of time-harmonic exterior acoustics in two dimensions", Computer Methods in Applied Mechanics and Engineering, 191, 2002, pp.3331-3345.

[17] R.M. Mcmeeking, J.R. Rice, "Finite Element Formulations For Problems of Large Elastic-Plastic De-formation". International Journal of Solids and Structures, 11, 1975, pp. 606–616.

[18] F.J. Rizzo, D.J. Shippy, M. Rezayat, "A boundary integral equation method for radiation and scattering", International journal for numerical methods in engineering, 21, 1985, pp.115-129.

[19] D. Clouteau, D. Aubry, "Modifications of the ground motion in dense urban areas", J. Comput. Acoust., 9, 2001, pp.1659-1675.

[20] http://nsmp.wr.usgs.gov/docs/smcfmt.txt.

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