ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
ID: TG-20161002131245

Original scientific article

EFFECT OF SOIL PROPERTIES ON RC WALL RESPONSES

Widad BOUROUAIAH, Salah KHALFALLAH, Dhahbia GUERDOUH

Abstract: All reinforced concrete structures and buildings in contact with soil are directly affected by the interaction between the soil foundation and the structure. In this work, a nonlinear analysis of wall and flexible foundations under monotonous loading is investigated. The plasticity theory using the finite element concept is used to simulate the structure and the soil media responses. This work integrates the behavior of the soil and the structure to obtain the whole structure response. The fixed base assumption does not reflect the real behavior of the structure, but soil properties show an influence on the system response. As conclusion, vertical displacements are significant through the foundation space but horizontal ones are very important in deep levels of soil.

Keywords: soil-structure interaction, soil-properties, plasticity, nonlinear analysis, soil-wall system, monotonic loadings.

1 INTRODUCTION

In reality, all reinforced concrete structures often in contact with the soil require the integration of the behavior of the interface between the structure and the soil. For this reason, the behavior of the entire structure depends on the structure itself, the soil foundation, and the continuum interface between them. The structure and the soil contribute together against the external loadings. This phenomenon is known as the soil-structure interaction (SSI), which is generally neglected in the design codes of civil buildings. However, for structures and buildings resting on soft soils, the effect of the soil-structure interaction becomes a very significant factor [1].

In civil construction calculations, the assumption of fixed base is often considered. This consideration neglects the flexibility of the resting soil. In reality, supporting soil influences the structural response by permitting movement to some extent due to its natural ability to deform. The soil-structure interaction effect enables designers to evaluate real displacements of the soil-structure system under static and/or seismic loading.

In the literature, numerous studies have been published taking into account the effect of soil-structure interaction under static loading [2]. Some of these works have been elaborated with simplified models for several reasons [3-6] showing that the stiffness of the soil has an important effect on the distribution of internal actions in the structure. Moreover, numerous studies have been conducted to estimate internal forces in structural members. Zolghadr et al. [7] investigated the modeling of coupled soil-structure interaction using the decomposition technique. Chore et al. [6] studied the effect of soil-structure interaction of a single storey having two bay space frames resting on a group of piles.

The soil-structure interaction has been studied using analytical models [8], numerical models [9], and nonlinear models [10]. In this concept, Rajashekhar et al. [11] modeled soil-structure interaction of a 3D-frame resting on deformable foundation to study the interaction elements between the mat foundation and the soil; they concluded that the interface elements do not have an effect on the member end actions of the building but can highly affect the displacement field.

The interaction phenomenon has become a very important task in the design phase. Until now, the soil structure interaction has been taken into account only in research [12-14]. In this study, the influence of soil nature basing on the soil mechanical properties is established.

The soil behavior is different from traditional materials such as steel or concrete. The mechanical behavior of soil can be considered linear when deformations are not too large. However, mechanical properties of soils are often strongly nonlinear with plastic deformations during loading and unloading process. Additionally, the inhomogeneous structure of soil and the mechanical behavior are hard to predict the real response of soil and structure.

Important publications in the last three decades showed that most of the investigators take into account the effect of soil structure interaction. In this field, Toutanji [15] presented a simplified procedure based on the continuum approach for static analysis of regular structures combined with shear walls and frames and investigated the effect of flexibility of foundation using Winkler spring model. Badie et al. [16] presented a new method for analyzing wall-structures built on elastic foundations. Here, the soil is modeled using three-nodded elements including the vertical sub grade reaction and soil shear stiffness.

Baknahad et al. [17] and Nadjai et al. [18] investigated the importance of base flexibility on the elastic behavior of planar shear walls subjected to lateral loading. Oztorun et al. [19] presented a 3D finite element analysis of multi-story building structures composed of opening shear walls and flat plates. Boroschek et al. [20] developed a simple analytical model considering basic assumptions that were used to compare with recorded responses.

For these objectives, Tabatabaiefar et al. [21] studied the responses of frame under lateral seismic loading. This work leads to the conclusion that the dynamic soil-structure interaction plays a considerable role in seismic behavior of frames including large lateral deflections and inter-storey drifts.

Finally, this work is the first one that must be established before initiating the nonlinear dynamic analysis of the soil-structure interaction.

2 MODELING OF THE SOIL STRUCTURE SYSTEM

Many methods have been already developed to study the soil-structure interaction. In this work, the direct method is employed, where the entire soil-structure system is modeled in a unique step. The use of the direct method required the development of a numerical program, which can treat the behavior of both soil and structure with identical rigidities [22]. The structure is submitted to external loads, which can be static and/or dynamic loadings (Fig. 1).

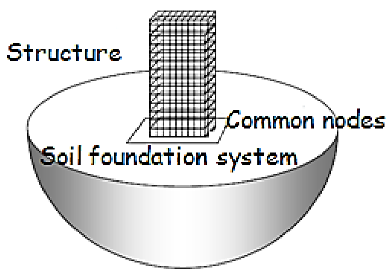

Figure 1 Idealization of soil-structure system

To obtain desired results, a numerical program was developed to simulate the nonlinear soil-structure behavior. The structure is a reinforced concrete wall resisting on soil media. The structure and the soil are discretized into two-dimensional quadrilateral finite elements. Each element behaves according to the prescribed nonlinear stress-strain law.

Two-dimensional plane strain and plane stress elements are used to model the soil medium and the wall structure, respectively. Along the frontier, fixed boundaries are used to represent the bed rock and quiet boundaries to avoid horizontal displacements.

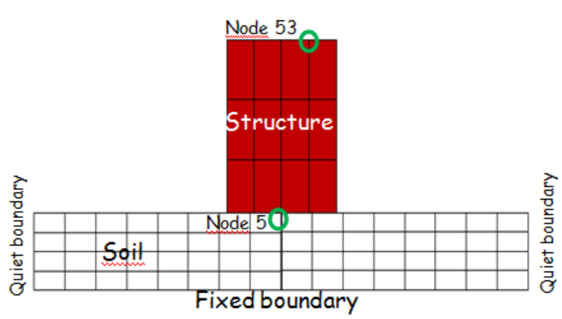

Figure 2 2D Soil-wall system

3 CONSTITUTIVE MODELING

In this section, the elasto-plastic model is considered. The constitutive laws governing the elasto-plastic behavior of 2D-dimensionnel solid elements are described by the plastic potential, the normality condition, plastic flow, and the hardening of the material. The mathematical theory of plasticity leads to provide the constitutive relationship between stress and strain vectors. The plastic behavior of materials is characterized by an irreversible straining, which depends on the level of stress that has been reached.

The external loading is applied in monotonous manner to describe the material behavior and the interface continuum. In general, (1) a relationship between stress and strain must be formulated to describe the elastic material behavior, (2) a yield criterion must be chosen to differentiate between elastic and elasto-plastic behaviors, and (3) a relationship between stress and strain must be described in the post yielding range.

3.1 Material elastic behavior

Before the initial yielding surface, the relationship between stress and strain obeys the linear elastic expression.

$$\sigma_{ij} = D_{ijkl}\varepsilon_{kl} \tag{1}$$

σ_{ij} and ε_{kl} are stress and strain components, respectively, and D_{ijkl} is the elastic tensor.

3.2 Yielding criterion

A surface function must be defined to delimit the elastic and the elasto-plastic behaviors. When the yielding curve is reached, then the material changes its behavior. In the elasto-plastic behavior range, the permanent deformation appears and is considered as an indicator of the beginning of elasto-plastic region. The criterion is defined in stress space by:

$$f(\sigma_{ij}) = K(k) \tag{2}$$

where f is a stress function and K is a material parameter describing the hardening phenomenon. In this study, the Von Mises criterion is adopted in the analysis.

3.3 Strain hardening

After initial yielding, the stress level depends on the plastic hardening. Thus, the yield surface varies with the plastic deformation. In this work, the actual yield surfaces are obtained by a uniform expansion of the initial yield surface "isotropic hardening". In this work, the total work hardening is postulated as the total work during the plastic strain.

$$W_P = \int_0^{\varepsilon_p} \sigma_{ij}\, d\varepsilon_{ij}^P \tag{3}$$

$d\varepsilon_{ij}^{P}$ is the plastic stain vector.

In this study, the hardening parameter is assumed to be defined as the equivalent plastic strain.

$$K=\sqrt{\frac{2}{3}}\quad (d\varepsilon_{ij}^{P})^{t}.(d\varepsilon_{ij}^{P}) \tag{4}$$

3.4 Elasto-plastic stress-strain relationship

The total strain can be divided into an elastic part and a plastic part.

$$d\varepsilon_{ij}=d\varepsilon_{ij}^{e}+d\varepsilon_{ij}^{p} \tag{5}$$

The plastic strain increment is proportional to the stress gradient of plastic potential using the associated plasticity. Then, it can be written as:

$$d\varepsilon_{ij}^{p}=d\lambda\frac{\partial f}{\partial\sigma_{ij}} \tag{6}$$

where $d\lambda$ is the plastic multiplier.

In the elasto-plastic region, the stress-strain relationship can be written as:

$$d\sigma_{ij}=D_{ijkl}^{ep}\varepsilon_{kl}^{e} \tag{7}$$

where D_{ijkl}^{ep} is the elasto-plastic tensor that can be expressed by:

$$D_{ijkl}^{ep}=D_{ijkl}^{e}-\frac{D_{ijkl}^{e}\cdot\frac{\partial f}{\partial\sigma_{ij}}.(\frac{\partial f}{\partial\sigma_{ij}})^{t}D_{ijkl}^{e}}{-\mathrm{A}+(\frac{\partial f}{\partial\sigma_{ij}})^{t}.D_{ijkl}^{e}\cdot\frac{\partial f}{\partial\sigma_{ij}}} \tag{8}$$

The hardening parameter A is neglected for elasto-perfectly plastic behavior.

4 NUMERICAL EXAMPLES

The proposed approach has been applied to analyze the behavior of a wall-structure combined with the soil media. The geometrical data of the structure, the soil media and loading are presented in Fig. 3.

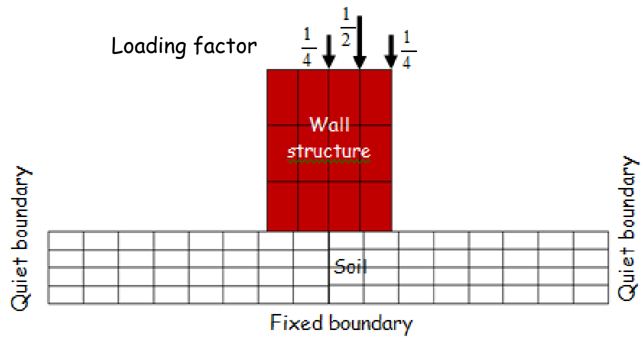

Figure 3 Geometry and loading of wall-structure system

To establish this investigation, the following finite element mesh was arranged (Fig. 3) considering:

- Non-interactive model.
- Interactive nonlinear material model for the wall and the soil media.
- To investigate the effect of different soil stiffness, three types of soil have been selected. The material properties of the soil media are adopted covering the general idea.
- To pronounce the behavior of the interface, horizontal and vertical displacements are deducted.
- Finally, the influence of the wall height on the interface level is established.

The Tab. 1 regroups the mechanical properties of materials used in this work.

Table 1 Properties of materials used

Material	Young's modulus (MPa)	Poisson's ratio	Width (m)	Yielding stress (MPa)	Friction	Hardening
Concrete	207.E+7	0.20	0.30	18.E+6	0.00	0.00
Soil	0.7E+6	0.40	12.0	0.1E+5	0.00	0.00

The dimensions of wall-structure and the soil media are:

- The wall-structure is (1): 4×9×0.3 m, (2): 4×18×0.3 m and (3): 4×27×0.3 m)
- The soil media is 12×5×12 m
- The weight of the structure is neglected and only the external load is applied monotonically.

5 RESULTS AND DISCUSSION

RC walls are largely used in buildings as main element of stiff buildings. Walls present an important aptitude to resist to vertical and horizontal loading, indifferently. In this section, the approach was applied to soil-wall system to quantify the response of the structure and the interface between super-structure and soil response.

5.1 Negligence of soil flexibility

In this case, the wall-structure is fixed at its base level.

The applied load vs. the vertical displacement at the node A (Fig. 5) is plotted. This case shows a performance and a strong aptitude of the wall-structure when the rigid base is considered. The curve can be composed into two branches reflecting the linear and elasto-plastic behavior of the wall, respectively. Fig. 5 presents load versus displacement of the node A.

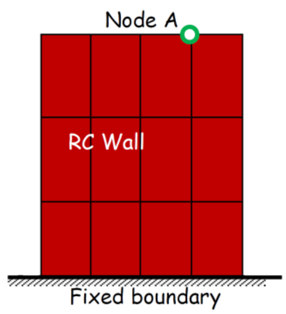

Figure 4 The wall structure fixed at base level

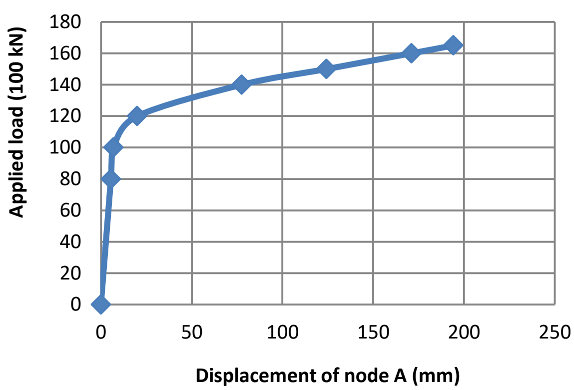

Figure 5 Load versus displacement of fixed wall

5.2 Linear and elasto-plastic analyses

Figs. 6 and 7 plot the linear and elasto-plastic analyses of wall-structure node (Fig. 6) and of interface node (Fig. 7), respectively. For small load values, analyses show concordance between linear and nonlinear analyses until 35% of the limit load. The interface node explains an important deflection compared to the wall node one. In figures (6-7), elasto-plastic curves concave due to the plastic behavior of materials that interprets mechanical degradation corresponding to this level of loading.

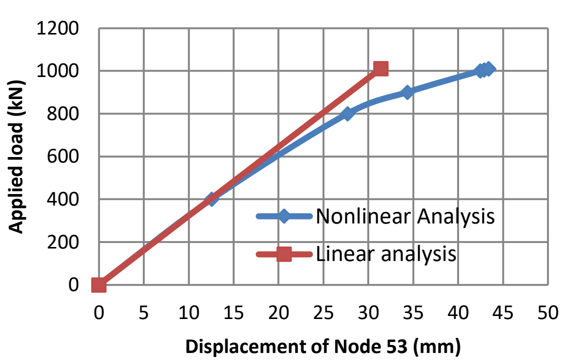

Figure 6 Linear and elasto-plastic analyses of wall node

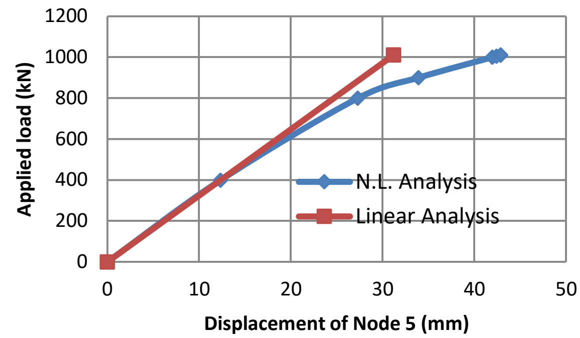

Figure 7 Linear and elasto-plastic analyses of interface node

5.3 Influence of soil properties

For different soil properties, Figs. 8 and 9 show the super-structure node behavior and the interface node behavior, respectively. They present a decrease of mechanical properties of the super-structure and of the soil media in function of the Young's modulus. The vertical displacements are very important in the super-structure node and in the interface level according to the feebleness of Young's modulus values.

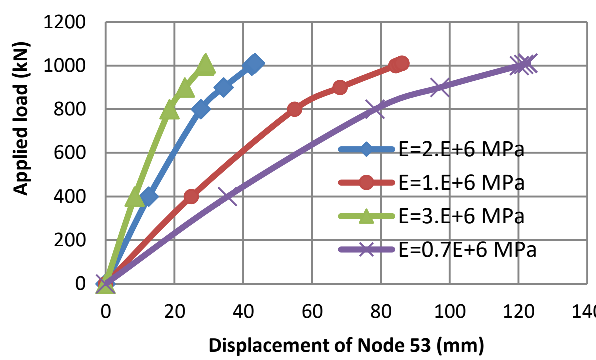

Figure 8 Soil effect on the super-structure node

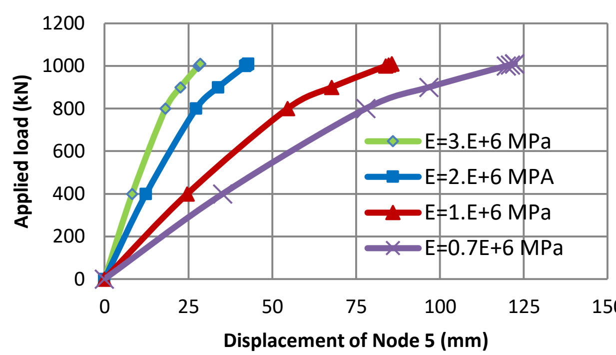

Figure 9 Soil effect on the interface node

5.4 Interface medium responses

Vertical displacements of different deepness are plotted in Fig. 10. The interface medium presents a considerable displacement and apprising far from the contact space between super-structure and soil. The deep level shows a small vertical displacement and neglected apprising for from the foundation (Fig. 10).

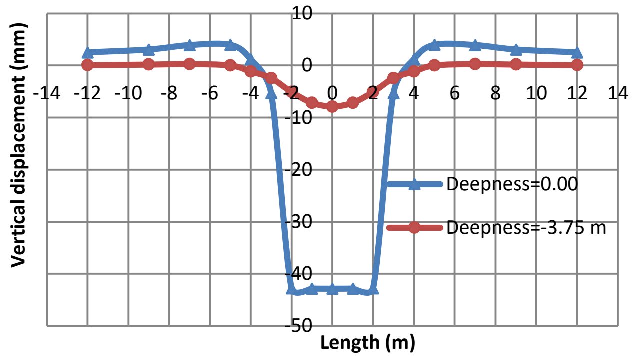

Figure 10 Vertical displacement of different deepness

Opposite to the above conclusions, horizontal displacements are very important if the deepness level is so important in the region under the foundation but they become important for weak deepness far from the foundation. Also, horizontal displacements under foundation are very small at near levels of the foundation (Fig. 11). The horizontal displacements present reciprocal effects for different deepness.

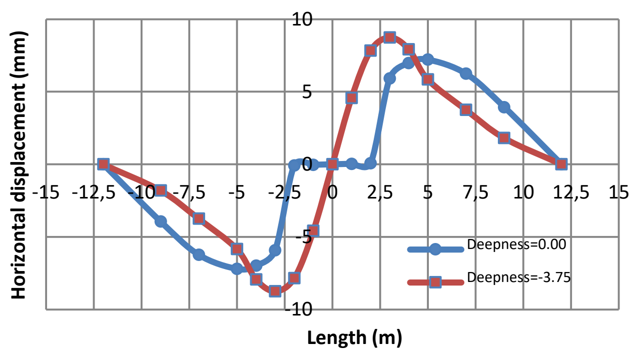

Figure 11 Horizontal displacement of different deepness

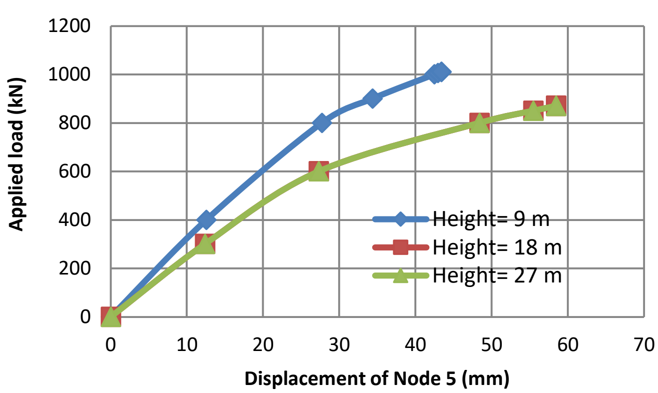

Figure 12 Influence of the wall height

5.5 Interface of the wall height

Only in this case, the wall height does not have an effect on interface continuum from high walls are grater then 18 m (Fig. 12). It seems that soil has been fully sustained a satisfactory and becomes apt to applied loads with very weak deformations.

6 CONCLUSION

Based on obtained results using this approach, the following conclusions can be drawn:

- The fixed base of building presents a performance and an attenuation of structures but this hypothesis is not valid in reality as soon as the bond nature between the structure and the soil.
- Nonlinear analysis of the structure and the soil reproduces faithfully the behavior of the structure. An increase of 15 % of displacement compared to the linear analysis is observed.
- The soil mechanical properties influence primordially on the response of the structure and the interface continuum. In this case, the displacements become important passing from E_s = 300 GPa to E_s = 100 GPa and become very important when E_s = 70 GPa. So, it is recommended to improve the mechanical properties of the soil.
- Vertical displacements are remarkable in the zone localized under the foundation region. These displacements decrease with the increase of the deepness.
- Horizontal displacements are pondering at deep levels under the foundation and become very weak at contact levels.
- In this example, the stability of the interface media behavior is well notable for the wall height (18 m). Probably, it seems that soil has been sustained a satisfactory and becomes apt to support vertical loadings with very weak deformations.

7 REFERENCES

[1] Wolf J. (1985), Dynamic Soil-Structure Interaction. Prentice-Hall International Series in Civil Engineering and Engineering Mechanics. Prentice-Hall.

[2] Dalili S. M., Huat B. B. K., JaafarM. S. and Alkarni, A., (2013), Review of static soil-framed structure interaction. Interaction and Multi-scale Mechanics, Vol. **6(1)**, pp. 51-81.

[3] Lee I. K. and Harrison H. B. (1970), Structure and foundation interaction theor, J. Struct. Div. - ASCE, **96**, pp. 177-197.

[4] King G. J. W. and Yao Z. E. (1983), Simplified interactive analysis of long framed building on raft foundation, J. Struct. Eng., **61B(3)**, pp. 62-67.

[5] Kumar A., Walia B. J. S. H. and Saran S. (2005), Pressure–settlement characteristics of rectangular

footings on reinforced sand, Geotech. Geolog. Eng., **23**, pp. 469-481.

[6] Chore H. S., Ingle R. K. and Sawant V. A. (2010), Building frame – pile foundation –soil interactive analysis: a parametric study, Interact. Multi-scale Mech., **3(1)**, pp. 55-79.

[7] Zolghadr J. H., Izzuddin B. A. and Zdravkovic L. (2007), Partitioned analysis of nonlinear soil-structure interaction using iterative coupling, Interact. Multi-scale Mech., **1(1)**, pp. 33-51.

[8] Teodoru I.-B. (2009), Beams on elastic foundation: The simplified continuum approach. Bulletin of the Polytechnic Institute of Jassy, Constructions, Architechture Section, **55**, pp. 37-45.

[9] Colasanti R. J. and Horvath J. S. (2010), Practical sub-grade model for improved soil-structure interaction analysis: software implementation. Practice Periodical on Structural Design and Construction, **15(4)**, pp. 278-286.

[10] Mazzoni S., Sinclair M. (2013), Modeling of Nonlinear Soil-Foundation-Structure Interaction in Response History Analysis-An Existing-Building Evaluation Case Study. Paper presented at the Structures Congress.

[11] Rajashekhar S. H. M., Krishnamoorthy A., Prabakhara D. L. and Bhavikatti S. S. (2011), Relevance of interface elements in soil structure interaction analysis of three dimensional multi-scale structure on raft foundation, Electron. J. Geotech. Eng., **16B**, pp. 199-218.

[12] Shoaei D., Huat B. B. K., Jaafar M. S., Elkarni A. (2015), Soil- framed interaction analysis – A new interface element. Latin American Journal of Solids and Structures.**12**, pp. 226-249.

[13] Bezih K., Alaa C., Kalla M., Bacconnet C. (2015), Effect of soil structure interaction on the reliability of reinforced concrete bridges. Ain Shams Engineering Journal, **6(3),** pp. 755-766.

[14] Rougui M., Boubel H., Elmarabet O. (2015), Study of the fundamental impact of soil-structure interaction on response of reinforced concrete bridges. 3rd Turkish conference on earthquake and seismology, October 14-16, Izmir, Turkey.

[15] Toutanji H. A. (1997), The effect of foundation flexibility on the interaction between shear walls and frame, Engineering Structures, **19(12)**, pp. 1036 – 1042.

[16] Badie S. S. and Salmon D. C. (1996), A quadratic order elastic foundation finite element, Computers & Structures, **58(3)**, pp. 435-443.

[17] Paknahad M., Noorzaei J., Jaafar M. S., Waleed A. Thanoon (2008), Non-linear soil structure interaction of shear wall system with super element, The 12th International Conference of International Association for Computer Methods and Advances in Geomechanics, 1-6 october 2008, Goa, India.

[18] Nadjai A., Johnson D. (1998), Elastic and Elasto-plastic analysis of planar coupled shear walls with flexible base, Computers and Structures, **68**, pp. 213-229.

[19] Oztorun N. K., Citipitioglu E., Akkas N. (1998),Three-dimensional finite element analysis of shear wall buildings, Computers and Structures, **68**, pp. 41-55.

[20] Boroschek R. L., Fernando, Yanez V. (2000), Experimental verification of basic analytical assumptions used in the analysis of structural wall buildings, Engineering Structures, **22**, pp. 657-669.

[21] Tabatabaiefar S. H. R, Fatahi B. and Samali B. (2013),Lateral seismic response of building frames considering dynamic soil-structure interaction effects, Structural Engineering and Mechanics, **45(3)**, pp. 311-321.

[22] Kramer S. L. (1996), Geotechnical Earthquake Engineering, Prentice Hall Civil Engineering and Engineering Mechanics Series.

Authors' contacts:

Widad BOUROUAIAH,
Laboratoire de Génie Civil et Environnement (LGCE),
Université de Jijel, Jijel, Algérie

Salah KHALFALLAH,
(Corresponding author)
Ecole Nationale Polytechnique de Constantine, Algérie
khalfallah_s25@yahoo.com

Dhahbia GUERDOUH
Laboratoire de Génie Civil et Environnement (LGCE),
Université de Jijel, Jijel, Algérie