

Study of the fundamental impact of soil-structure interaction on response of reinforced concrete bridge

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ABSTRACT:

The objective of this study is to treat the seismic stability of bridges taking into account the soil structure interaction and to study the influence of soil structure interaction on the dynamic behavior of structures. This study is applied to a bridge crossing the river BOUTYOUS PK 635 + 200 National Route 12 in the town of Zagora (Morocco).

In particular, we are interested in the foundation soil interaction which is an important phenomenon to consider for a good assessment of the vulnerability of structures.

In this work, we determine the natural frequencies and the corresponding modes of a multi-span bridge. The proposed approach is based on the modal method, which differs from other approaches to the decomposition of the function defining the natural modes. This method applied the advantage of not using the iterative calculation.

The analysis with ANSYS demonstrated that for different conditions delimitation, distribution of travel and the fundamental frequency for each soil type change according to its mechanical properties. The results obtained in this article show that it is necessary to take into account the phenomenon of structural soil interaction in the bridge design and also demonstrates that the proximity of the fundamental frequencies of the structure and soil strongly influences on soil-structure interaction.

KEYWORDS: Interaction soil structure, Modal, Dynamic Analysis, Finite element model, ANSYS.

1. Introduction:

The soil-structure interaction (ISS) is a discipline of applied mechanics that support the development and investigation of theoretical and practical methods for the analysis of structures subjected to dynamic loads, taking into account the behavior of foundation. The effects of the ISS on the seismic answers have been given serious consideration after the 1971 earthquake in San Fernando and early nuclear build in California [1].

The catastrophic consequences of several recent earthquakes in different region of the world have posed a serious problem for engineers to better understand the seismic behavior of the structure taking into account the effect of the ISS. Analysis of free vibrations Highway Bridge is the first essential step study forced vibrations that are caused by passing vehicles. This analysis allows determine the frequencies and natural modes of vibration. The deck slabs Road bridges have generally rectangular resting on supports intermediate in the longitudinal direction and free in the transverse direction.

The objective of this study was to analyze using a numerical modeling using computational logiciel ANSYS, the influence of foundation soil-structure interaction on bridges and to study the behavior effect of nonlinear soil on soil structure interaction foundation.

1.1. *Description of the case study:*

The project site is located on the neighborhood of Ouad Boutyous The study area is located about four kilometers west of the town of Zagora Note that the RN 12 used to connect the two important cities of Zagora and Tata.



Figure 1: Project Location.

The new reinforced concrete bridge will be a bridge following characteristics: It is a bridge through grade 78.61; including the deck slab is 0.50 m thick with 1.65 m cantilevers. The slab rests on the stack and the abutments by means of the support devices for fretté elastomer Fig.2. The intermediate support is a stack height 5.90m, 1m thick and 10m in length. Sills banks are Batteries-abutments backfilled with: a front wall 4.75 m high to the abutment C1 and C2 5.45m for the battery - The thickness of the two batteries is 0.7m. - A return wall of 4.00 m in length and a thickness of 0.35 m - a transition slab 4.00 m long and 0.3 m thick Foundations consist of soles _lantes super_cielles of 10.8m long, 4.50 m wide and the battery 4.35m for the abutment C1, 4.45m for the abutment C2, and 1.00 m thick. They are based on a blinding concrete layer B5 concrete 10 cm thick.

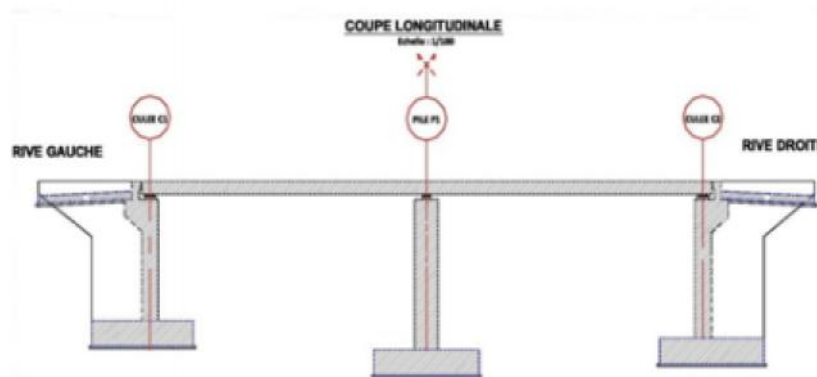


Figure 2: Longitudinal cutting project.

Building materials have the following characteristics:

Table 1 :Characteristic of Reinforced Concrete.

Compressive strength at 28 J	Fc28= 30 MPa
The dosed concrete	350 Kg/m ³
Tensile strength to 28J	Ft28 = 2.4 MPa

The deferred deformation of Young's modulus	$E_v = 11496.76 \text{ MPa}$
The Young's modulus of instantaneous deformation	$E_i = 34179.56 \text{ MPa}$
The permissible compressive stress in service	$\delta_{bs} = 17 \text{ MPa}$
The expansion coefficient	$\lambda = 1.10^{-05}$

Table 2 : Characteristic of Steel.

Nuance	HA
Yield	500MPa
Coef Ys	1.15
Cracking	Detrimental

1.2. soil used:

Three types of sites are defined by table 3, as soil characteristics (the density and fish module). Once the various classified sites, we use Table 3 gives the values and physical characteristics (density, Poisson coefficient and Young's modulus E_s of supposedly homogeneous soil.

Table 3: Mechanical characteristic soil.

	Physical characteristics of the soil		
	Young's modulus $E_s(\text{Mpa})$	Density (Kg/m3)	Module fish (ν)
Soil type	1000	2200	0.3
	800	1800	
	400	1200	

2. Modeling :

➤ Modeling of the structure.

The bridge is modeled by a monolithic structure with linear properties, elastic and isotropic.

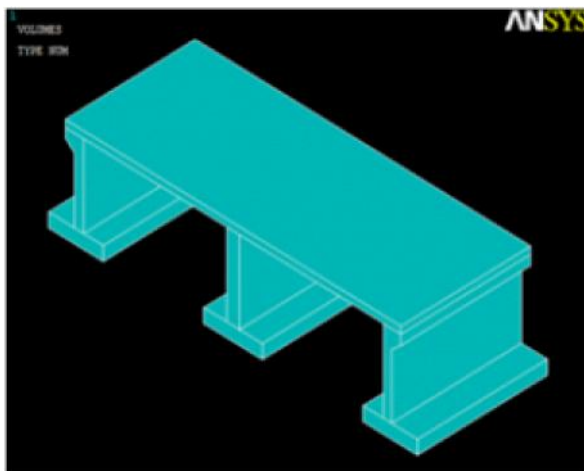


Figure 3: Bridge Modeling.

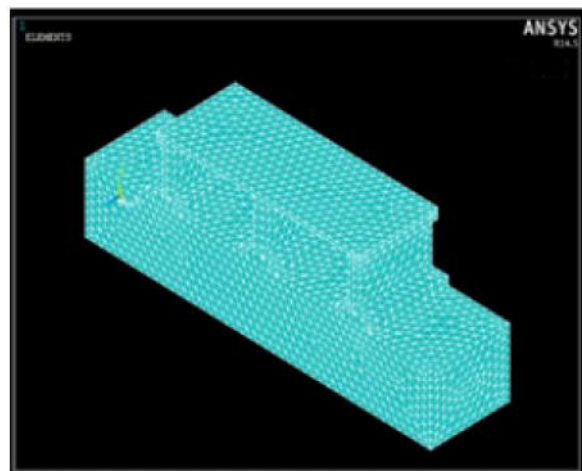


Figure 4: Mesh Bridge.

3. Analysis Results:

3.1. Influence de la rigidité du sol sur l'I.S.S.

In order to see the influence of the stiffness of the soil, several analyzes were conducted by varying the modulus of elasticity of the floor 1000 MPa (very firm ground) to 800, 400.

Table 4: Bridge model with three types of soil.

Methods	Frequency (Hz)		
1	1.4835	1.3269	0.93825
2	2.6804	2.3974	1.6952
3	2.8532	2.552	1.8046
4	3.4792	3.119	2.2004
5	3.6183	3.2363	2.2884

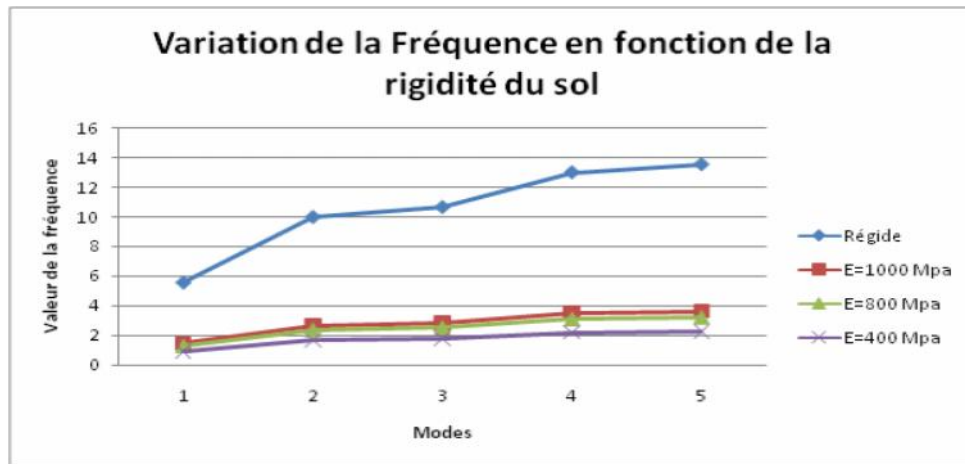


Figure 5: Varying the frequency depending on the rigidity of the floor.

With the increase of the rigidity of the foundation, periods of vibrations converge to the natural periods for the case of a bridge Built considered at its base Fig.5.

3.2. Influence of the stiffness of the soil on the displacement.

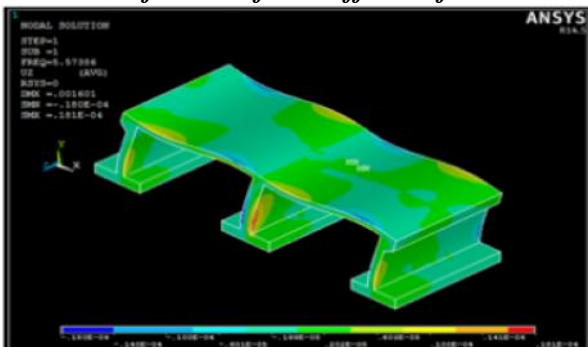


Figure 6 :Moving the bridge built at its base.

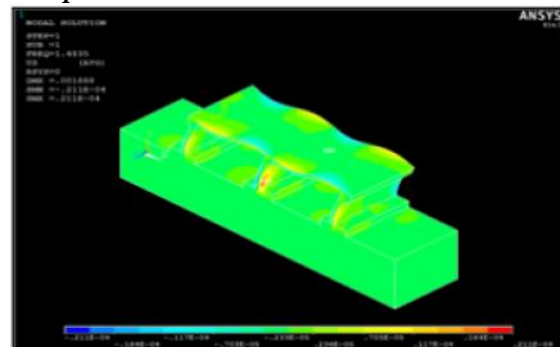


Figure 7: Moving the bridge with soil type 1.

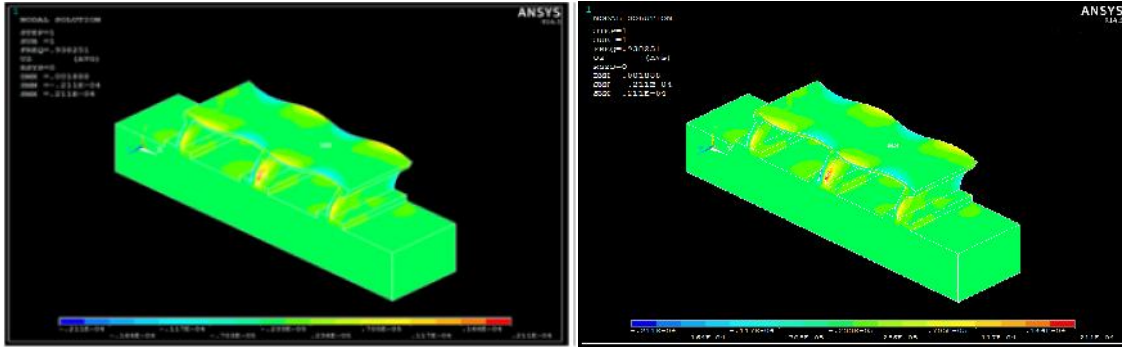


Figure 8: Moving the bridge with soil type2 Figure 9: Moving the bridge with soil type3

3.3. discussion:

Analysis of the soil type influence on the fundamental frequency of the bridge, performed for different soil conditions, demonstrated by numerical calculations using the ANSYS software: The distribution of travel and the fundamental frequency for each type of soil changes function of soil mechanical properties. -The Analysis is performed using a numerical modeling by finite elements. -The Behavior of the soil and the structure is assumed elastic type [2]. Analyses with ANSYS demonstrated that for support conditions, the distribution of displacements and the fundamental frequency for each type of soil changes depending on the soil mechanical properties. This returns us to the seismic design stage bridge structures that must never omit the interactive phenomenon Soil-Structure, a fact that has been ignored in studies in the past. The calculation of different maximum sizes also ignores the often harmful effects of ground movement surrounding which in turn is influenced by many factors inter alia the geological and geotechnical conditions of the site [3]. - Analysis is performed using a numerical modeling by finite elements. - The behavior of the soil and the structure is assumed elastic-like. Analyses with ANSYS demonstrated that for conditions of support, the distribution of displacements and the fundamental frequency for each type of soil changes depending on the mechanical properties of the soil. This returns us to the seismic design phase bridge structures that must never omit the interactive Sol-phenomenon structure, an effect that was ignored in studies in the past. The calculation ignores the different maximum sizes also often adverse effects of the movement of the surrounding terrain which in turn is influenced by several factors including geological and geotechnical conditions of the site [4].

4. Probabilistic model of soil behavior.

4.1. Nonlinear behavior model

Before considering the interaction effects, it is necessary to specify the soil behavior model to be introduced in the mechanical analysis of soil–structure system. In the present section, the nonlinear behavior of natural soils is defined and introduced in the finite element model, using ANSYS software to calculate displacements and stresses in the structure. It is proposed in this study to examine the hyperbolic model developed in the work Kondner [7]. Soil behavior law is based on the approximation of the stress-strain curve obtained in drained triaxial compression tests. The hyperbolic relationship Kondner proposed by [7] is written as (Fig 10):

$$q_1 - q_3 = \frac{e_1}{E_1 + \frac{e_1}{q_1 - q_3} \text{ult}} \quad (1)$$

Where q_1 and q_3 denote the major and minor principal stresses, respectively, e_1 is the axial strain, E_i is the initial tangent Young's modulus and $(q_1 - q_3)_{ult}$ is the asymptotic value of the deviatoric stress.

Duncan and Chang [8] extended the Kondner's law by introducing the initial tangent modulus proposed by Janbu [9]:

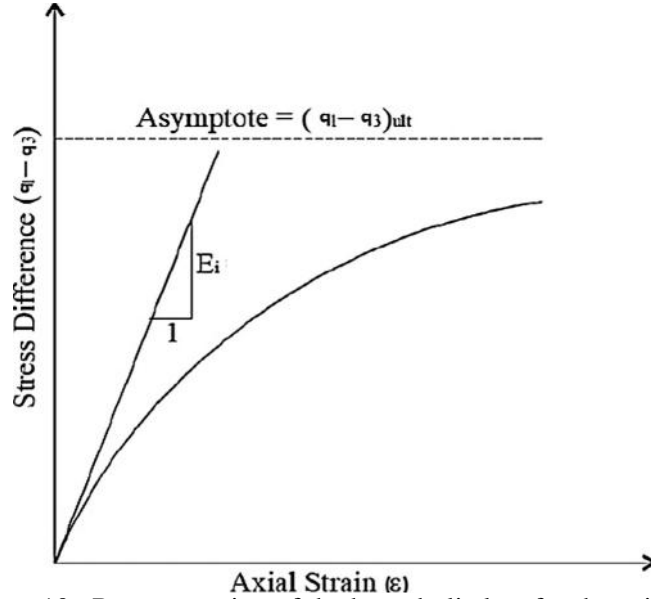


Figure 10. Representation of the hyperbolic law for the soil [7].

$$E_i = k \cdot P_a \cdot \left(\frac{q_3}{P_a}\right)^n \quad (2)$$

Where P_a is the atmospheric pressure, K and n are parameters calibrated by drained triaxial compression tests, performed at different confining pressures q_3 . This model considers a hyperbolic stress-strain relationship and depends on the stress history and deformation properties of the soil volume. Duncan and Chang [8] introduced the parameter R_f as the ratio between the failure deviatoric stress $(q_1 - q_3)_f$ and the maximum asymptotic stress $(q_1 - q_3)_{ult}$ as follows:

$$R_f = \frac{q_1 - q_3}_f}{(q_1 - q_3)_{ult}} \quad (3)$$

As the rupture happens before reaching the asymptotic curve, this parameter is always less than one ($R_f < 1$). The state of stress at failure is also supposed to verify the Mohr-Coulomb plasticity criterion:

$$(q_1 - q_3)_f = \frac{2(c \cos \varphi + q_3 \sin \varphi)}{1 - \sin \varphi} \quad (4)$$

Where c and φ represent the cohesion and the internal friction angle of the soil, respectively. As a result, the final expression of the tangent Young's modulus E_t is:

$$E_t = K \cdot P_a \cdot \left(\frac{q_3}{P_a}\right)^n \left[1 - \frac{R_f (1 - \sin \varphi) (q_1 - q_3)}{2(c \cos \varphi + q_3 \sin \varphi)}\right]^2 \quad (5)$$

4.2. *Method of Nonlinear Spectral Analysis:*

The non-linear spectral analysis method is based on the assumption that the response is basically controlled by a single mode of vibration, and that the shape of this mode remains constant throughout the duration of the seismic excitation.

This method established by P.Fajfar experimentally in 1999 and assisted on a test-structure the laboratory (European Laboratory for Structural Assessment) in Italy. This method is mainly based on the combination of two mathematical models taking into account the non-linear behavior:

- The curve of the capacity obtained by analyzing "Pushover" of a system with several degrees of freedom[6].

Table 5 : Mechanical parameters used for the jet-grouted soil.

Location	(KN/m ³)	C'(Kpa)	(°)	
Below the foundation	22	1530	15	0.3

➤ Numerical results:

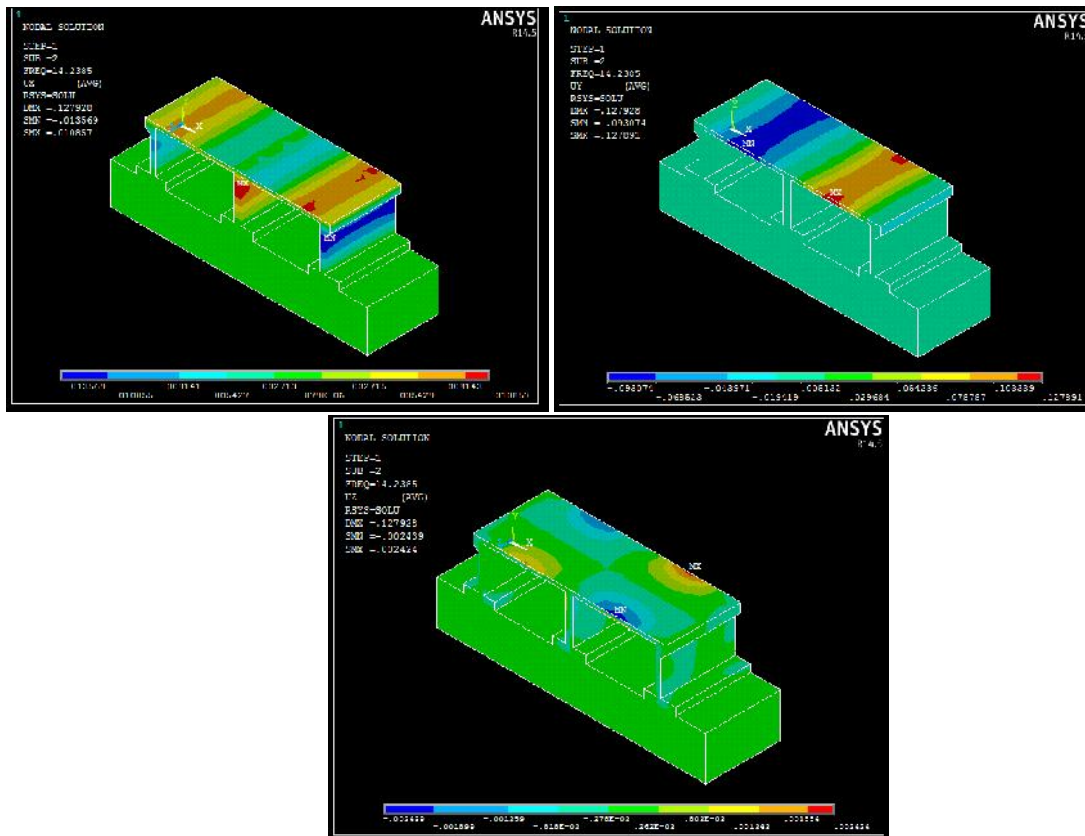


Figure 11: Distribution of displacement for the first vibration mode.

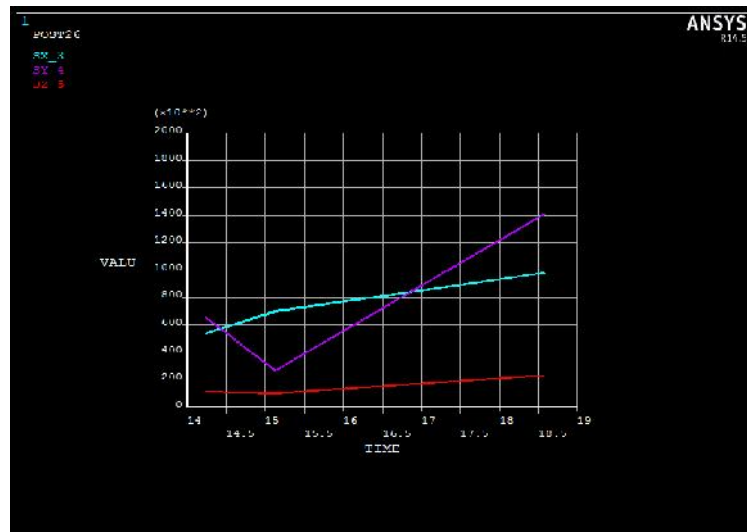


Figure 12: Distribution of horizontal, vertical and shear stress for the first mode vibration in the non linear.

4.3. discussion:

This section includes an analysis of the influence of the nonlinear behavior of the soil on the seismic response behavior of the soil structure system. The analysis was performed for two types Soil . The plasticity of the soil may significantly affect a seismic response of the system. For cohesive soil, plasticity spreads from the base of the massif which dampens the surface energy transmission and superstructure. The consideration of the plasticity of the soil results in a lessening of effort especially for soils with low cohesion furniture. To a rubbing ground, plasticity propagates from the surface because of low surrounding soil in the area which degrades structure.

The seismic response of a structure is highly dependent on the mechanical characteristics and the geotechnical soil layer near the surface. On the other hand, soil behavior varies with the level of stresses and deformations they undergo. Non-linearities in the soil appear in small deformations (10-6 to 10-4). However, we must distinguish between reversible elastic deformations, and those developing Residual deformations has higher amplitudes (10-4 to 10-3).

The use of a non-linear elastic model soil makes the analysis of very complex soil-structure interaction due to the appearance of multiple frequencies in the response of the soil mass. The influence of these frequencies can be low in case they are far from the dominant frequencies of the load.

5. Conclusion:

This article included an analysis of the influence of the nonlinear behavior of the soil on the response of seismic performance of the bridge. The analysis was performed for three types of soil. The plasticity of the soil may significantly affect a seismic response of the system. For cohesive soil, plasticity spreads from the base of the mass which dampens the transmission of energy at the surface and to the superstructure.

Three-dimensional analysis of the seismic behavior of soil-foundation-structure system showed that the seismic response of the structure depends on a sensible way of soil-structure interaction. The latter involves complex mechanisms that depend on the frequency content of the load, the natural frequencies of the massive soil and the structure and the nonlinear behavior of the soil. The use of a non-linear elastic model soil makes the analysis of very complex soil-structure interaction due to the appearance of multiple frequencies in the response of the soil mass. The influence of these frequencies may be low in case they are far from the dominant frequencies of the load. The study of the influence of the plasticity of the soil on the soil-structure interaction showed that the plasticity of the soil induces two effects, namely an additional damping due to dissipation by plastic deformation and a

reduction in "natural frequency" soil-foundation system due to the reduction of the "rigidity" induced plasticity. The magnitude of the influence of plasticity depends on its extension in the solid soil, which depends on the amplitude of the loading, its frequency content and natural frequencies of the soil-foundation system structure.

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