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Seismic analysis of bridges with non-linear soil-structure interaction

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ABSTRACT

This study is concerned to the investigation of the stability of bridges by taking into account the soil structure interaction and their impact on the dynamic behavior of the structures. The bridge studied is localized at PK 318 + 750 at the national level, between the city of Al Hoceima and Kassetta (Morocco). The analyses are carried out with the ANSYS code demonstrated that for conditions of support, the distribution of displacements and the fundamental frequency for each type of soil change according to its mechanical properties. This work also indicates that the proximity of the fundamental frequencies of the soil structure and strongly influences the soil-structure interaction.

KEYWORDS

soil-structure interaction, non-linear dynamic analysis, finite element method, ANSYS code

1. INTRODUCTION

Soil-structure interaction is a field of mechanics implemented interest in the development and research of theoretical and realistic techniques for the analysis of structures subject to dynamic loads taking into account the behavior the soil of the foundation. The consequences of the earthquake response on soil structure were seriously considered after the 1971 earthquake in San Fernando and the early nuclear construction in California. The catastrophic effects of numerous latest earthquakes posed a serious hassle for engineers to higher apprehend the seismic behavior of structures by taking into account the effect of Interaction Soil-Structure (ISS) [1]. The seismic analysis of a structure taking into account the local properties of the site, differs from the one considered embedded at its base. As a result, it is particularly important to consider the ISS in seismic zones where the dynamic response of soils can change the response of structures subjected to seismic excitation [2]. A few seismic codes inclusive of the USA code FEMA 450 suggest consideration of the ISS for seismic layout of structures [3]. Also the seismic code ATC-3 proposes a simple component for the estimation of the fundamental duration and the coefficient of damping of the structures based on a homogeneous half-of-space. Although, the seismic policies in pressure endorse a category of the four classes of site, in line with the properties of the soils that represent them. Each site category is associated with an elastic response spectrum calculated according to the characteristics of the site considered and those of the studied structure. A few authors have proposed, for every degree of freedom of the foundation, soil models alike a greater or lesser quantity of loads, springs and dampers with coefficients impartial of the frequency. The most effective way to bear in mind the ground is to represent it with the aid of springs connecting one or greater nodes to an inflexible base, to which one imposes a movement. In the case of a flat model, a sole under an isolated fulcrum is represented by two springs acting on translation and one spring on rotation; under an invert, the ground is modeled by one horizontal and one vertical spring at each node. Currently, as a result of the rapid increase in computer

performance, the methods of numerical simulations are widely used in the study of the soil–structure interaction phenomenon [4]. Numerical simulation techniques are labeled into three kinds, which include substructure, finite detail approach and hybrid technique. In an analysis of soil–shape interplay, the dynamic coefficients of soil stiffness at the origin rely upon the frequency. In the case of regular subsoil conditions, the stiffness matrices, the mass, and the damping of the ground–foundation system are obtained by using the formulae classic ones that are independent of frequency. Frequency-independent ground stiffness's are calculated for a primary approximation with the aid of the Newmark–Rosenblueth approach. Rigidities and geometric damping can be calculated in a particular manner, within the case of round foundations or similar on a semi-endless medium, in keeping with Deleuze's technique. For other styles of superficial foundations, stiffness can be determined from Sieffert and Cevaer [5].

2. MODELING THE SOIL-STRUCTURE INTERACTION

The system considered is a linear shape of mass m , lateral stiffness k and damping c , linked at its base to an inflexible rectangular plate of a negligible thickness of mass m_0 , uniformly distributed and moment of inertia I_0 . This plate bears on a Winkler kind foundation. The soil–structure interaction has been schematized by spring and damping elements dispensed over the whole width of the inspiration (Fig. 1). The horizontal slip is thought to be negligible. The foundation coefficients k_w and c_w are assumed to be steady and independent of the displacement amplitude or the excitation frequency [6].

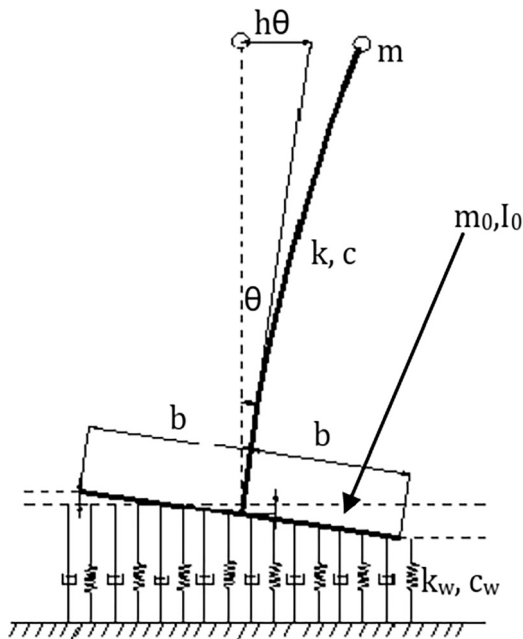


Fig. 1. Flexible structure on Winkler foundation

2.1. Fundamentals of dynamics analysis

Each structure acts statically and dynamically whilst problem to displacements or masses. In dynamic responses, the systems can have additional inertial forces, which consistent with the second one law of Newton, are identical to their mass improved by using acceleration. Consequently, if the loads or displacements are enforced very slowly, the inertia forces may be ignored for the reason that time may be assumed as 0 and a static load analysis can be justified. Consequently, dynamic evaluation is an easy extension of static analysis. Wilson stated that the pressure equilibrium of a multi-degree-of-freedom lumped mass system as a feature of time can be expressed by using the following rating [7]:

$$\mathbf{F}_I(t) + \mathbf{F}_D(t) + \mathbf{F}_s(t) = \mathbf{F}(t), \quad (1)$$

in which the force vectors at time t are: $\mathbf{F}_I(t)$ is a vector of inertia forces acting on the node masses; $\mathbf{F}_D(t)$ is a vector of viscous damping, or strength dissipation, forces; $\mathbf{F}_s(t)$ is a vector of inner forces carried with the aid of the shape; $\mathbf{F}(t)$ is a vector of externally carried out hundreds.

Equation (1) is based totally on bodily legal guidelines and is valid for each linear and non-linear system if equilibrium is formulated with recognizing to the deformed geometry of the structure. For lots of structural systems, the approximation of linear structural behavior is made to convert the physical equilibrium statement, Eq. (1) to the subsequent set of 2nd-order, linear, differential equations:

$$\mathbf{M}\ddot{\mathbf{u}}_a(t) + \mathbf{C}\dot{\mathbf{u}}_a(t) + \mathbf{K}\mathbf{u}_a(t) = \mathbf{F}(t), \quad (2)$$

where \mathbf{M} is the mass matrix (lumped or constant); \mathbf{C} is a viscous damping matrix (which is normally decided on to approximate electricity dissipation inside the real shape) and \mathbf{K} is the static stiffness matrix for the device of structural elements. The time-structured vectors $\mathbf{u}_a(t)$, $\dot{\mathbf{u}}_a(t)$ and $\ddot{\mathbf{u}}_a(t)$ are absolutely the node displacements, velocities and accelerations, respectively.

For seismic loading, the outside loading $\mathbf{F}(t)$ is equal to $\mathbf{0}$. The simple seismic motions are the 3 additives of free-subject ground displacements $\mathbf{u}(t)$ which are acknowledged at some point beneath the foundation level of the structure. Therefore, equations can be written in terms of the displacements $\mathbf{u}(t)$, $\dot{\mathbf{u}}(t)$ velocities and accelerations $\ddot{\mathbf{u}}(t)$, which can be relative to the 3 components of free-discipline ground displacements [8].

2.2. Analysis in frequency domain

Analysis in the time domain does not provide any information about the frequency or system damping effect. Consequently, every other evaluation can be performed, particularly reaction spectra. Basically, this evaluation will deliver an outline of the most reaction (acceleration, velocity or displacement) of a single degree of freedom system with a described damping and various frequencies of the system. This is a completely crucial device in earthquake engineering. Response spectra are useful in quantifying the demands of earthquake floor movement on the ability of bridges to resist earthquakes. records on beyond earthquake floor

movement is normally inside the form of time-records recordings obtained from instruments located at numerous sites, which might be activated by sensing the preliminary ground motion of an earthquake. The amplitudes of motion can be expressed in terms of acceleration, velocity and displacement. The first data reported from an earthquake record is generally the peak ground acceleration, which expresses the tip of the maximum spike of the acceleration ground motion [9].

The amount of acceleration a structure undergoes during an earthquake is a critical factor in determining how much damage it will suffer. The spectra in parent five provide some indication of the way acceleration is associated with frequency traits, which suggests one manner wherein response spectra can be beneficial, seeing that identifying the resonant frequencies at which a structure will undergo height acceleration is a completely important step in designing a structure to resist earthquakes. Response spectra plot maximum dynamic responses as displacement, velocity, and acceleration of a range natural frequency of single degree of freedom system under a certain earthquake loading. In other words, response spectra do not describe the response of the actual ground motion, but show the response of a single degree of freedom system connected to the ground and showing only the peak response [10].

By definition, the response spectra analysis procedure involves the evaluation of the maximum value of structure responses as displacements and member forces for each mode of vibration, using a spectrum of earthquake records. The response spectrum provides the required information for design purposes and at the same time, simplifies the analysis by reducing the problem to a static problem of the estimated maximum responses. The response spectrum is

defined, based on a single degree of freedom system of varying frequency excited by a specific earthquake, as the maximum response of the system, ignoring the particular time of its occurrence. If the response is the displacement of the system then the displacement spectrum is formed. For velocity and acceleration, they are pseudo spectra and derived by multiplying displacement spectra by ω and ω^2 respectively, where ω is the natural frequency of a single degree of freedom system.

Spectral acceleration, S_a , is the maximum generally used depth degree in exercise nowadays for evaluation of systems. This price represents the maximum acceleration that a ground motion will purpose in a linear oscillator with a certain natural duration and damping level. In truth, the actual degree is pseudo-spectral acceleration, that is equal to spectral displacement times the rectangular of the natural frequency, but the distinction is often negligible and the call is frequently shortened to “spectral acceleration” [11].

Figure 2 gives the simple form of a reaction spectrum in acceleration and duration base. T_0 is a factor in which spectral acceleration is regular until T_s , where the acceleration starts to decrease considerably. These conditions are inside the peak responses of a single degree of freedom system of the structure, due to ground motion acceleration.

3. NONLINEAR MODEL OF BEHAVIOR OF THE GROUND

The MPii model accounts for the nonlinear hysteretic behavior of the soil considering a hardening elastic-plastic approach through a series of plasticity surfaces [12]. For a one-dimensional model, one considers a series of rheological cells combining a linear spring and a friction unit (Fig. 3). The friction unit remains locked until the stress reaches the value Y_i . The spring constants, G_i , are chosen in order to recover the stress-strain behavior observed in the laboratory.

The implementation of this model could be finished by counting on the paintings of Joyner. This version makes use of only the general curves of reduction of the initial shear modulus, G/G_0 . It is miles an elasto-plastic model with hardening, which is tailored to the modeling of the linear responses (for small deformations) and nonlinear (for massive deformations) of the soil. The nonlinear dynamic

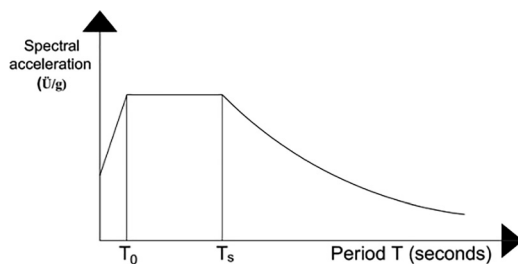


Fig. 2. Idealization of response spectrum

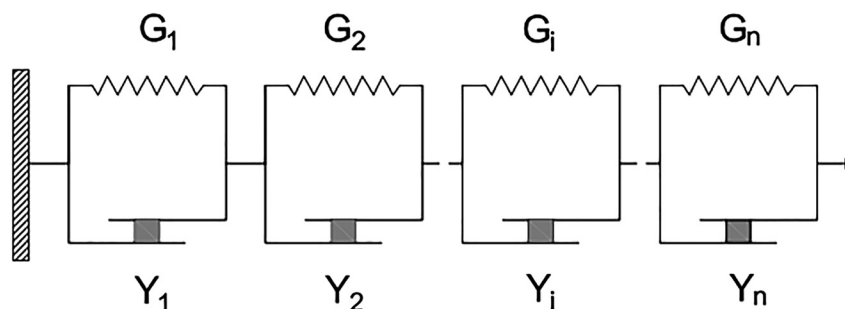


Fig. 3. Rheological model 1D of Iwan

Table 1. Mechanical characteristic soil

	Physical characteristics of the soil		
	Young's moduls E_s (MPa)	Density (kg/m^3)	Poisson module (ν)
Soil type	1000	2200	0.3
	800	1800	
	400	1200	

Table 2. Bridge model for various soil types

Modes	Frequency (Hz)			Rigid soil
	Soil 1 ($E = 1000$ MPa)	Soil 2 ($E = 800$ MPa)	Soil 3 ($E = 400$ MPa)	
1	1.4835	1.3269	0.9382	5.9
2	2.6804	2.3974	1.6965	10.1
3	2.8532	2.5532	1.8046	10.5
4	3.4792	3.1419	2.2004	13.1
5	3.6183	3.2363	2.2884	13.9

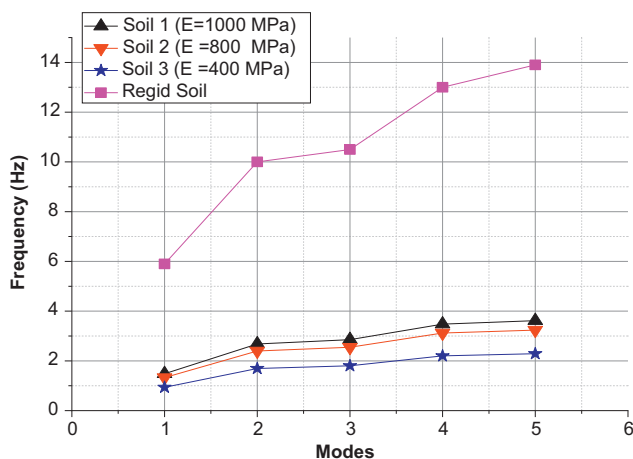


Fig. 4. Varying frequency variation according to the rigidity of the soil

evaluation has continually been considered as the most well-known and herbal technique to predict the dynamic structural response, however, due to high demand computing, its implementation in the seismic analysis and layout is growing to be well-known practice. Requirements around the dynamic analysis, summarized via Elnashai [13], with admire to the static pushover evaluation, is appreciably higher in number and complexity.

4. RESULTS AND DISCUSSION

4.1. Modal analysis

Three types of sites are defined in Table 1 as soil characteristics (the density and Poisson module). Once the various classified sites are used, Table 1 gives the values and physical characteristics (density, ν Poisson coefficient and Young's modulus E_s) of supposedly homogeneous soil.

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 1,000 MPa (very firm ground) to 800, 400. The results are defined in Table 2.

With the increase of the rigidity of the foundation, periods of vibrations converge to the natural periods for the case of a considered bridge (Fig. 4).

4.2. Dynamic analysis

4.2.1. Seismic record. Morocco is a country regularly shaken by earthquakes, and has already suffered deadly earthquakes, as example those of Agadir in 1960, Rissani in 1992 and Al Hoceima in 1994 [14].

The acceleration of the seismic loading has a great influence on the dynamic response of the pile, that is why is chosen to submit the structure to the Al Hoceima earthquake (Fig. 5), which occurred in 2004 with a magnitude of 6.3 [14].

4.2.2. Analysis results. The seismic response of the studied structure using numerical modeling was simulated with the ANSYS programs. The variation of the maximum shear force in the head is related to the variation of the inertial

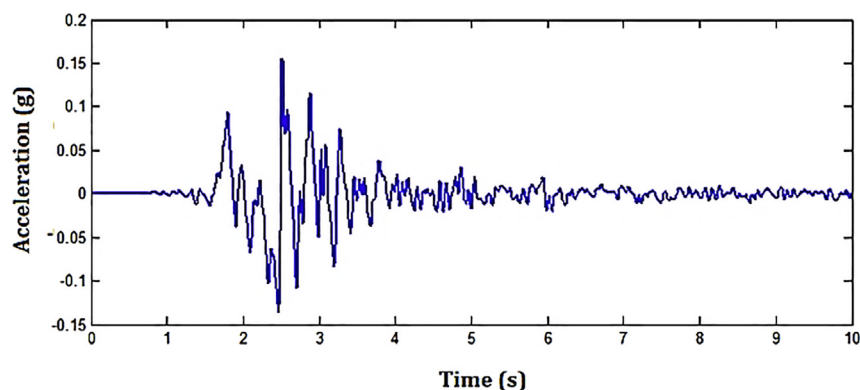


Fig. 5. AL HOCEIMA earthquake's record: Acceleration

force in the superstructure, which decreases due to the extension of the plasticity of the soil. The flickering moment does not show a steady trend. The setting of the plasticity of the soil does not necessarily lead to a reduction of the maximum effort. In fact, this moment is not only controlled by the acceleration of the mass of the superstructure but also by the state of the soil surrounding the pile, particularly at the surface. For example, when the cohesion decreases by 100 kPa at 25 kPa, the results show significant attenuation of the acceleration at the head of the superstructure, however, a minimal decrease in the maximum momentum is obtained. This is due to the extension of the soil plasticity to the surface for $C = 25$ kPa as it is shown in Figs 6 and 7. This plasticization favors a strong increase of the bending due to the absence of the ground stop in the head of the stakes. Several post-seismic observations on damaged piles led to the formation of a void between the pile head and the ground.

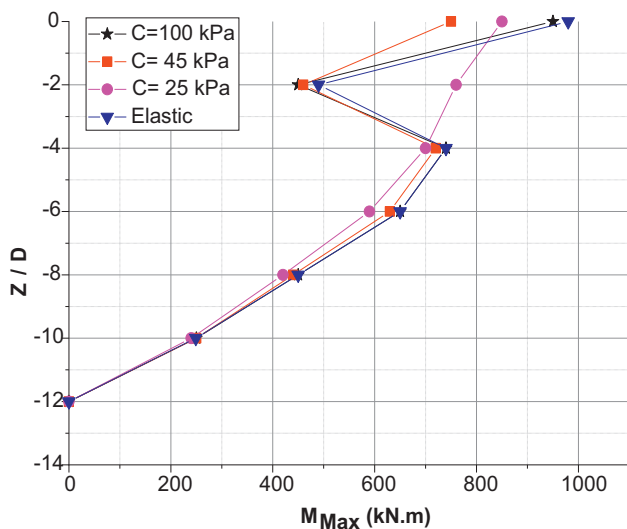


Fig. 6. Influence of the coherent soil plasticity on the seismic forces induced in the corner stake (maximum bending moment)

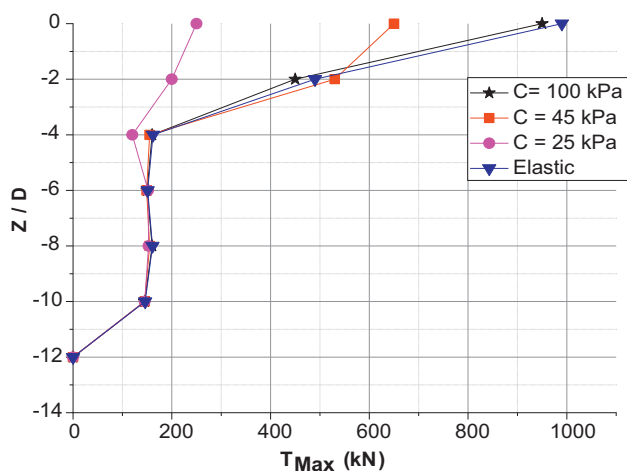


Fig. 7. Influence of the coherent soil plasticity on the seismic forces induced in the corner stake (maximum shearing effort)

5. CONCLUSION

This article includes an evaluation of the impact of linear and nonlinear conduct of the soil on the reaction of the dynamic overall performance of the bridge. The plasticity of the soil can notably have an effect on a dynamic machine reaction. For a cohesive soil, plasticity propagates from the base of the mass, which dampens the transmission of power to the floor and to the superstructure. The three-dimensional analysis of the dynamic behavior of the structure of the soil-foundation machine showed that the dynamic reaction of the structure relies upon appreciably on soil-structure interaction. It entails complex mechanisms, which depend upon the burden frequency content material, the natural frequencies of the strong ground and the structure and the linear conduct of the soil. They have an effect on of these frequencies can be low if they are a ways from the dominant frequencies of the weight. The examine of the effect of the plasticity of the soil on the soil-structure interaction confirmed that soil plasticity induces effects, particularly an extra damping due to dissipation with the aid of plastic deformation and a discount within the soil device basis “herbal frequency” due to the discount of the “stiffness” of the brought about plasticity. The value of the impact of plasticity depends on its extension into the strong floor, which relies upon on the amplitude of the load, the frequency content material and the natural frequencies of the structure of the floor basis device.

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