Modeling the impact of railway traffic vibrations on surrounding structures

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Abstract -Railway traffic induces vibrations that propagate in the ground and in the structures, these vibrations lead to displacements and settlements that can affect the stability of the structures throughout their life. The case of study is the Regional Express Train which will connect Dakar to Blaise Diagne Airport where the soil presents geological constraints due to compressible soils, slopes, voids and cavities. This research aims to study the impact of the vibrations induced by the trains on the surrounding structures involved. A literature review showed that the use of FEM (Finite Element Method) can be difficult and must take into account the use of absorbant boundaries. Since that, the coupling between FEM and BEM (Boundary Element Method) may be necessary in order to adapt the choice of the method to the various components of the problem including the nature of the domain, the type of material behavior, the heterogeneities and the frequency range.

Keywords – Modeling - Impact - Vibrations - Rail Traffic –FEM – BEM.

I. Introduction

In recent years, rail and road transport have expanded considerably, with the result that traffic becomes much faster and more dense. However, the observed phenomenon is that the higher the speed of vehicles, the greater the dynamic movement of rail and infrastructure (Mostefa, 2008) [1] . The same observation can be made for roadways. Therefore, the transmission of vibrations is a complex phenomenon that involves several factors: the rail-ground coupling; the ground-building coupling; the transmission and dissipation in the building and the radiation efficiency of the walls. The measurements show that the dynamic overloads are random signals whose dispersion increases with the speed and which depend on the state of the rail and also of the vehicle. Moreover, by analyzing acceleration spectra, three frequency bands can be distinguished as indicated in (Alias, 1984) [2] : from 0 Hz to 20 Hz corresponding to the oscillation of the suspended masses of the vehicle, from 20 Hz to 125 Hz corresponding to the oscillation of the unsprung masses of the vehicle and the masses linked to the track on the elastic support of the track and from 200 Hz to 2000 Hz corresponding to the natural vibrations of the intermediate elastic links of the track. Due to the importance of the moving and dynamic loads, several studies have been dealt with this problem, especially for high-speed railway trains (Sharhraki et al., 2014) [3]. In the case of the numerical simulation, Correia et al. (2007) [4] accomplished a preliminary study of comparative suitability of 2D modeling with different numerical tools, including PLAXIS 2D, DIANA and ANSYS. The studies showed that the reliability of the models depends largely on the accuracy of the model, the input data and the choice of an appropriate underlying theory. This study aims to present the projet involved and a literature review of vibrations impact modeling studies on soils and structures as well as the research methodology.

II. PROJECT PRESENTATION

The line of the TER extends over 55 km for 180km in terms of linear. The train has a speed of 160km/h and will connect Dakar to the AIBD in 45 minutes with an axle load of 225 kN and a track spacing with a value of 1.435 m. The project is located in the Senegal-Mauritania-Guinean sedimentary basin, a vast coastal basin of the West African passive continental margin. The geological formations are represented by mainly sedimentary terrains, from Cretaceous to Quaternary recent. The main constraints and problems related to the geological environment of the project are: the presence of compressible soils (sands as well as superficial clays on the first meters) with primary consolidation settlements reaching amplitudes of more than 10 cm; the stability of slopes and slopes (sandy facies have zero or very weak cohesion so that they are susceptible to erosion, clay and marl clay facies are evolutionary (circulation of water) and may be subject to instability phenomena in cuttings slopes, presence of formations sensitive to swelling phenomena and presence of voids or cavities (marly and marl-limestone clays). The hydrogeological resources present on the project are organized into 3 major aquifer systems: the aquifer present in the quaternary marine sands which surmount the Eocene marls and clays of the Dakar seahorst, the present Thiaroye aquifer system within the dune sands of the littoral cord which also surmount Eocene marls and clays; at the level of the coastline, this layer is in relation with the ocean and the horst of Ndiass, whose framework is formed by the sandstones of the Upper Cretaceous and the zoogenic limestones of the Paleocene, constitutes a body of water present at depth. in the most permeable facies (SETEC, 2017) [5] .

III. VIBRATIONS IMPACTS MODELING ON SOIL AND STRUCTURES

Various works allow us to see how the waves propagate in the ground and in the structures in order to evaluate their impacts on the environment traversed.

A. Propagation of seismic waves in sedimentary basin-

In the case of the study of the propagation of seismic waves in a 2D sedimentary basin, the effect of seismic sites leads to a significant local amplification of the seismic movement (Bouchon, 1985) [6] . This amplification of the movement occurs mainly in alluvial filling zones whose characteristics (geometry, mechanical properties) govern the magnitude of the phenomenon (Pitilaki, 1999) [7] . In the case of Nice, Figure 1 gives the isovalues of the amplification factor in the fill and the substratum for different frequency values by considering an SH wave with vertical incidence (weak movements).

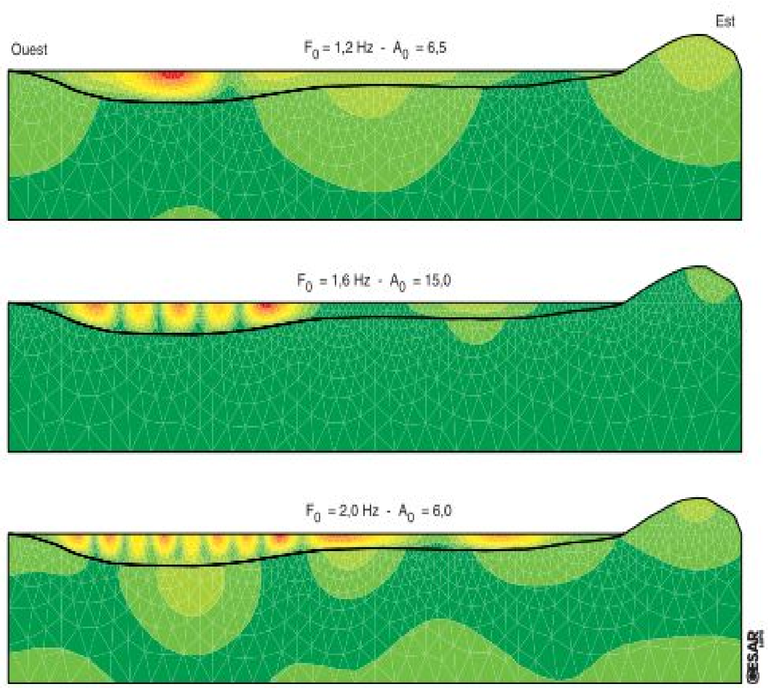

Figure 1- Border element modeling of the amplification of seismic waves in the center of Nice: amplification factor A_0 at different frequencies F_0 (Semblat et al, 2000) [8].

The amplification appears clearly on the surface of the filling and it takes a maximum value of 15.0 for a frequency of 1.6 Hz. It is in the thickest part of the filling that the amplification is the strongest. However, for the highest frequency (f = 2.0 Hz), the amplification factor in the thinnest fill zone increases substantially (lower wave lengths at higher frequency). Using the boundary element method, it is also possible to simulate three-dimensional seismic wave propagation. Figure 2 corresponds to the case of a hemispherical sedimentary basin resting on a more rigid bedrock. The boundary elements are surface elements arranged at the interface between the different three-dimensional environments. In the case of a vertical plane P wave, the results obtained at different frequencies are represented (Figure 3). It can be seen that the amplitude of the seismic waves is greater inside the sedimentary basin. This is due to the contrast of mechanical characteristics between the basin and the bedrock, which leads to an amplification of the waves on the surface of the basin. In addition, the geometry of the basin also influences the amplitude of the waves on the surface since it can cause a focusing of the waves in the basin.

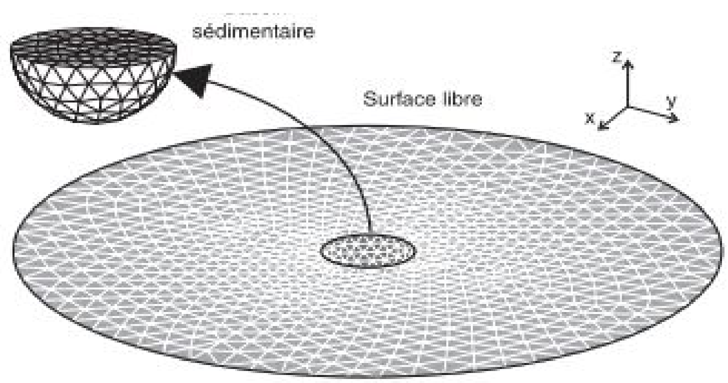

Figure 2.- Border Element Modeling of 3D Seismic Wave Propagation: Hemispheric Sedimentary Basin Model (Dangla et al., 2005) [9].

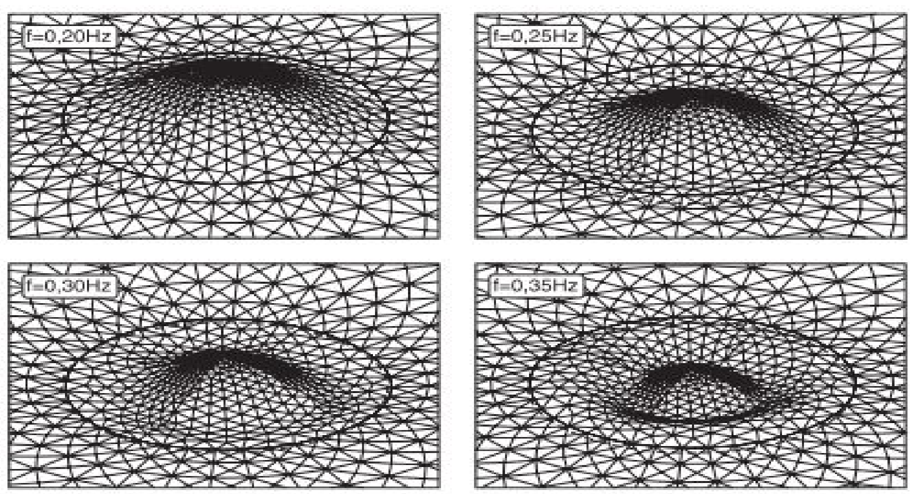

Figure 3.- Border element modeling of three-dimensional seismic wave propagation: deformation of the sedimentary basin at different frequencies (Dangla et al., 2005) [9].

B. Seismic response of buildings-

A building of 50 m high and 30 m wide rests on the ground surface. The ground and the building are subjected to an incident harmonic wave SH. The building and the soil are assumed to be elastic, homogeneous and isotropic. Figure 4 shows the movement of the base and top of the building calculated as a function of frequency for an SH of vertical incidence and unit amplitude. We note characteristic frequencies for which the displacement of the base is canceled. They correspond to the resonant frequencies of the building with its built-in base. For the very low frequencies (long wave lengths), the waves do not perceive the presence of the building and one thus obtains the amplitude of the free field (sum of the incident wave and the reflected wave). Figure 5 shows the zones of iso-displacement in the ground and allows to appreciate qualitatively the zones of reinforcement of the movement by interference. Due to the soil-structure interaction, high and low amplitude zones are thus obtained both in the soil and in the structure. In the same figure (bottom), the case of three buildings separated by 100 m is also treated. It is thus possible to visualize the most stressed buildings according to the frequency and the mutual interactions between buildings via the ground.

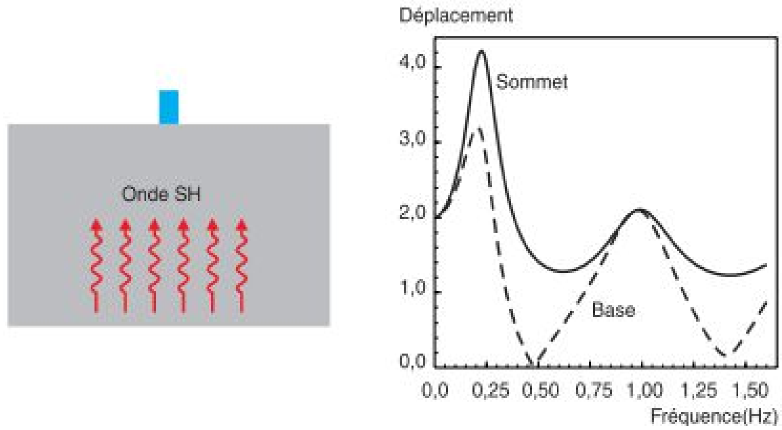

Figure 4.- Soil-structure interaction model considered (left); dimensionless displacements at the base and at the top of the structure as a function of frequency (right) (Semblat et al, 2005) [10].

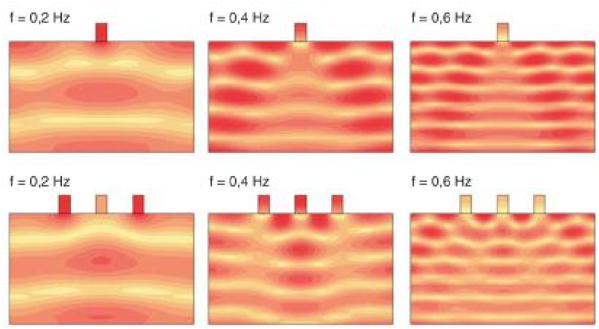

Figure 5.- Movement of soil and structures at different frequencies (Semblat et al, 2005) [10].

C. Vibrations of a railway tunnel-

A railway tunnel subjected to seismic loading is shown in Figure 6. The concrete liner has a thickness of 50 cm. The tunnel is first subjected to seismic loading on the SH wave (left). Figure 7 shows the areas of iso-displacement for vertical incidence and incidence of 60 degrees to the horizontal and for three different frequencies. The interference patterns, due to the diffraction of the wave by the tunnel, make it possible to locate the strongest movements of the ground and in particular those of the surface. In addition, areas of low amplitude (shadow areas) can be noticed downstream of the tunnel (relative to the direction of propagation). Figure 9 shows the areas of iso-displacement obtained. In addition, wall stress values are also influenced by the characteristics of the problem. This type of calculation has been compared with the results of a full-scale vibration experiment on a tunnel of the Paris-Strasbourg line (Dangla, 1989) [11]. Ground movements were recorded on the surface and at the vertical of the tunnel.

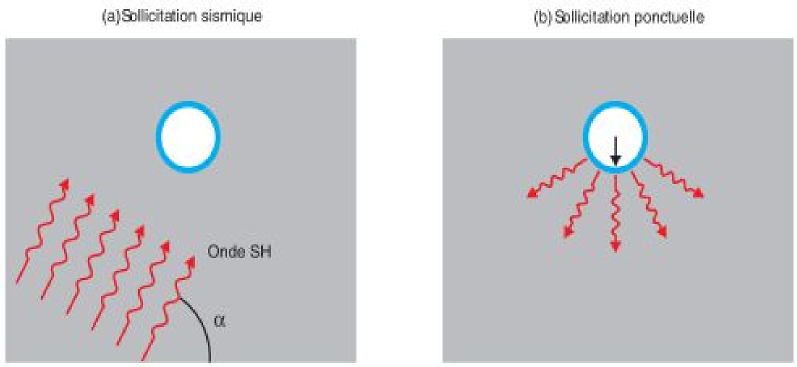

Figure 7.- Tunnel subjected to an SH (a) seismic wave or to a point excitation (b) (Semblat et al, 2005) [10].

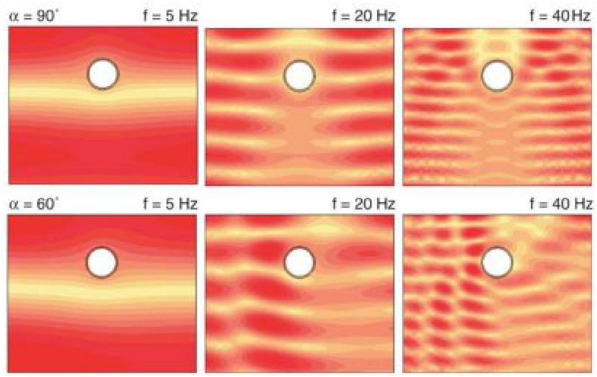

Figure 8.- Iso-displacements areas for vertical incidence and incidence of 60 degrees to the horizontal and for three different frequencies. (Semblat et al, 2005) [10].

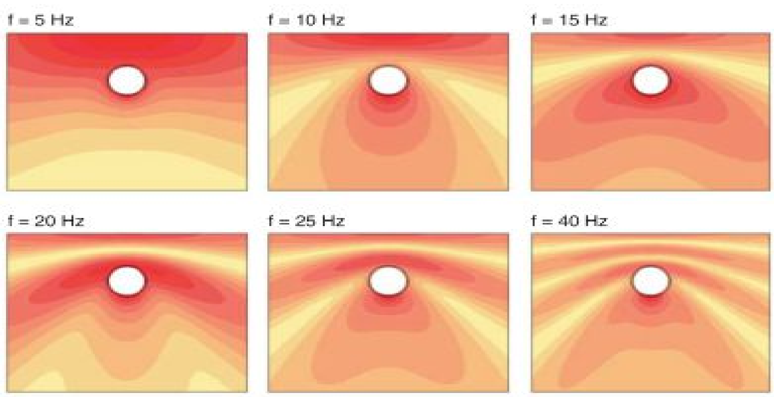

Figure 9.- Zones d'iso-déplacement pour une excitation ponctuelle (Semblat et al, 2005) [10].

D.Embankment modeling of a railroad track of a high-speed train-

A study by Shahkraki et al. (2014) [3] proposed to simulate the mobile loads of high-speed trains with the PLAXIS software. A comparison was made in order to justify the reliability of the results with other software especially made by other authors on different software like (Correia et al, 2007) [4] who worked on Diana and ANSYS. The results of simulations of the mobile loads of the two 2D and 3D models on PLAXIS showed different displacements variations. Displacements are higher in 2D than in 3D. Figure 11 and 12 present the 2D model.

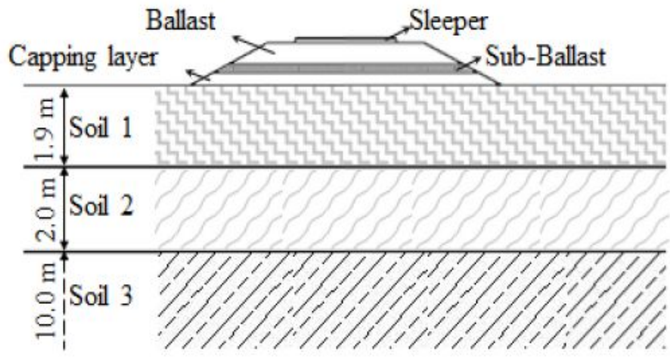

Figure 11.- Model geometry in 2D modeling (Shahraki et al, 2014) [3].

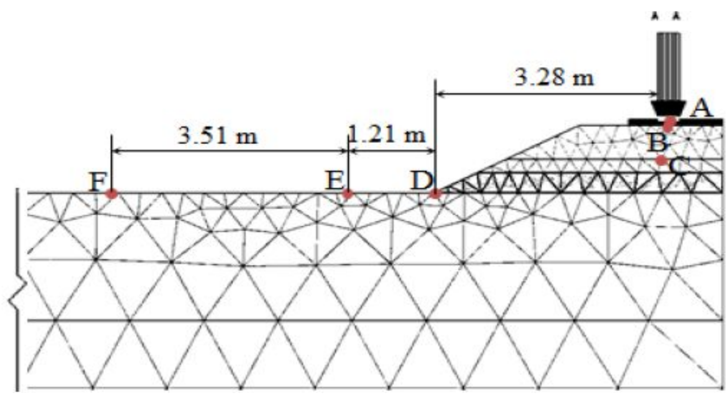

Figure 12.- Finite element mesh and points considered for the 2D PLAXIS model (Shahraki et al, 2014) [3]

The presented studies (foundation, amplification of seismic waves, soil-structure interaction, tunnel) showed the variety of wave propagation problems that can be modeled digitally. It should be noted that the use of these numerical methods in the case of dynamic analysis is not trivial. In the case of FEM, the use of absorbent boundaries has been necessary, however the use of the boundary element method is more suitable for soils. Since each method has different advantages and disadvantages, their coupling may be necessary in order to adapt the choice of the method to the various components of the problem (near field, far field, type of behavior, heterogeneities, frequency range, etc.).

IV. RESEARCH METHODOLOGY

This research project is conducted to evaluate the impact of railway trafic vibrations on surrounding structures. The case study is the TER Dakar-AIBD. The train has a speed of 160km /h and will connect Dakar to the AIBD in 45 minutes. The study will start with a comparative and validation study using dynamic scenarios in order to eliminate sources of errors in the FEM. Also, an analysis of the wave propagation will be an important issue for better understanding the soil behavior. The ground model will consist in a multilayered massif when we have to consider the most elaborate representation (rails, sleepers, footings and ballast). Also a parametric study will allow to highlight the influence of the characteristics of the soil and the constituents of the pavement in particular the rail on the vibratory behavior of the medium. In order to model rail traffic the presence of the railway has to be taken into account. The 'Dynamic analysis' module of PLAXIS software makes it possible to model the dynamic loads in particular harmonic conditions. The geometry of the model and the boundary conditions of the domain ("standard fixities" and "absorbent boundaries") are defined as well as the materials and their parameters (the Young's modulus, the Poisson's ratio, the damping coefficients α and β, etc.) as well as the behavior laws (linear elastic, Mohr Coulomb, etc.) The calculation phase must take into account the time t, the frequency f, the amplitude A and the pulse w. The simulation is to be taken in a sandy and clay context relatively to the geological configuration of the site. Therefore, the results of the simulations have to be discussed and the comparison made for both media.

V. CONCLUSION

The railway traffic vibration analysis presents an important issue for the prediction and anticipation of disorders in the structures involved. The distance between the track and the structures but also the attenuation of the noise plays an important role in the prevention of these disorders. The expected results should make it possible to evaluate the various risks related to the vibrations of rail traffic. In addition, in order to study the phenomena related to the emission and propagation of waves and vibrations due to the traffic, it is essential to carry out measurement campaigns in the field. They make it possible to apprehend reality in all its complexity, but at the same time they combine all the uncertainties concerning the characteristics of the source (wheel-lane interaction, structure of the railway, etc.), the different soils crossed and the possible heterogeneities, the presence on the propagation path of the waves including cavities, particular geological formations and topographical irregularities.

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