

Ministerul Educației și Cercetării
Universitatea Tehnică de Construcții București
Facultatea de Căi Ferate, Drumuri și Poduri



*THE EFFECTS OF SPATIAL VARIATION OF THE
SEISMIC GROUND MOTION ON BRIDGE
STRUCTURES*

PHD THESIS - SUMMARY

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The study makes an introduction to the state-of-the-art approaches to seismic soil-structure interaction (SSI) which were developed for the nuclear industry and are applied to a bridge structure with deep foundations.

In the first chapter, the effects of three major earthquakes where not considering SSI effects had devastating consequences are described and explained:

- Vrancea 1977 (Romania);
- Michoacan 1985 (Mexico City);
- Kobe 1995 (Japan).



Fig. 1 Collapse of bridge nr. 3 on the Hanshin Motorway (Kobe 1995)

After a short presentation on the history of soil-structure interaction, a description of the SSI methodology through substructuring as developed by the team from Berkeley University, California coordinated by J. Lysmer in the 70's is made.

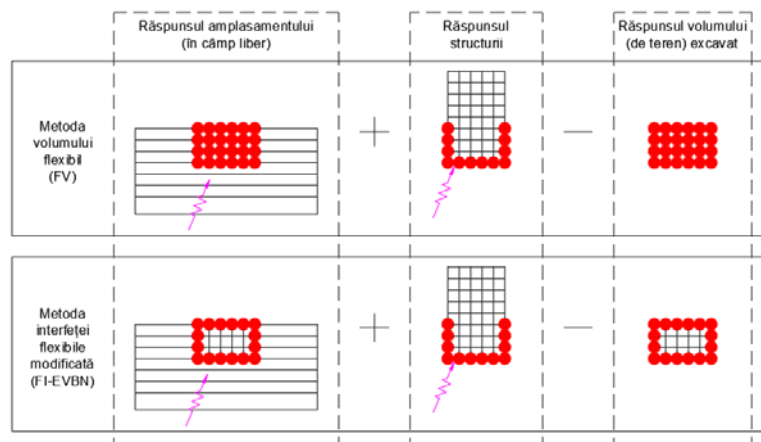


Fig. 2 Abordările de împărțire în substructuri

All three components of the analysis are covered:

- Free-field response;

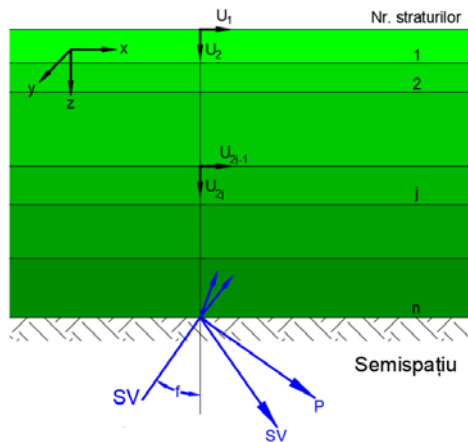


Fig. 3 Plan model for SV wave propagation

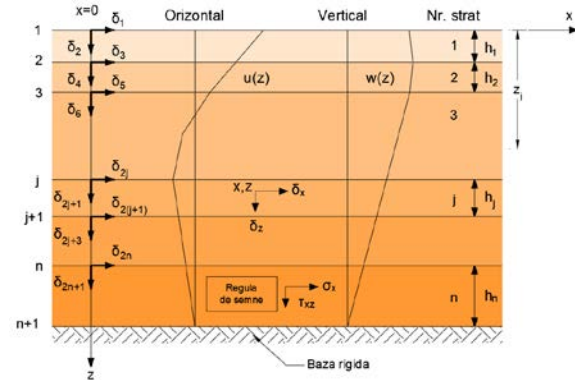


Fig. 4 Typical vibration modes for Rayleigh waves on site with horizontal

- Impedance calculation;

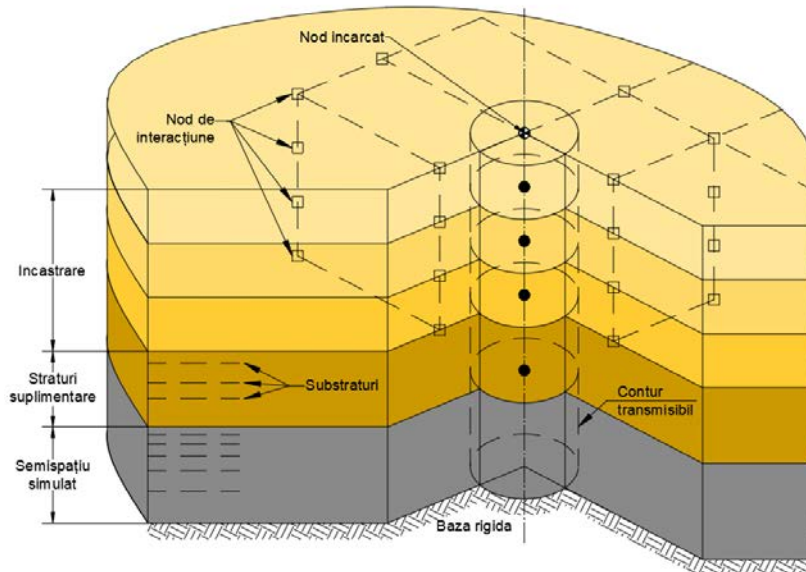


Fig. 5 Axisymmetric and 3D model of free-field used for the determination of the impedance matrix

- Structural analysis with the finite element method.

The paper continues with the definition and description of the spatial variation of the seismic ground motion, along with the main reasons of appearance:

- Attenuation due to different distances from fault;
- Spatial incoherency, which can be divided into 3 categories:
 - Wave passage effect, due to wave propagation along a horizontal direction;
 - Extended source effect, due to the mix of various waves originating in different places along the fault;
 - Ray path incoherency, due to the dispersion and scattering of the waves along their 3-dimensional propagation path;
- Local soil conditions

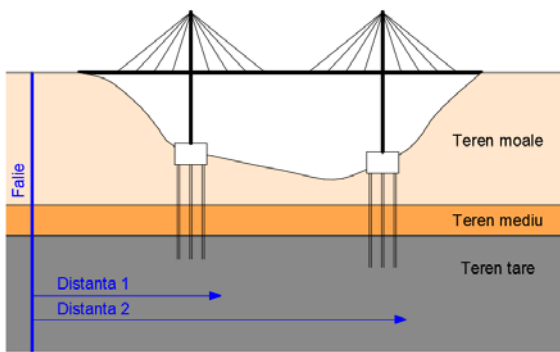


Fig. 6 Attenuation effect

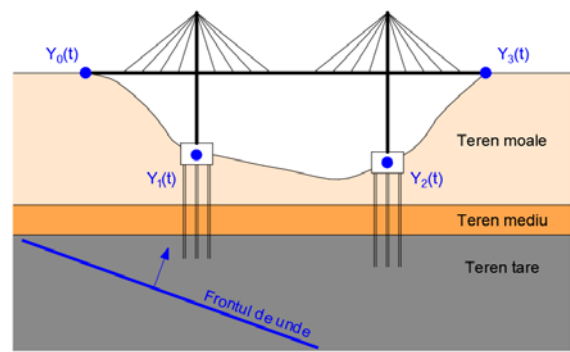


Fig. 7 Wave passage effect

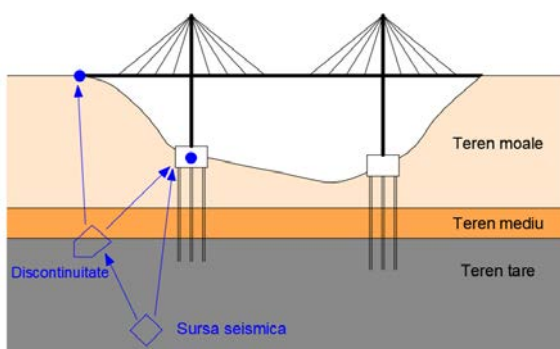


Fig. 8 Ray path incoherency effect

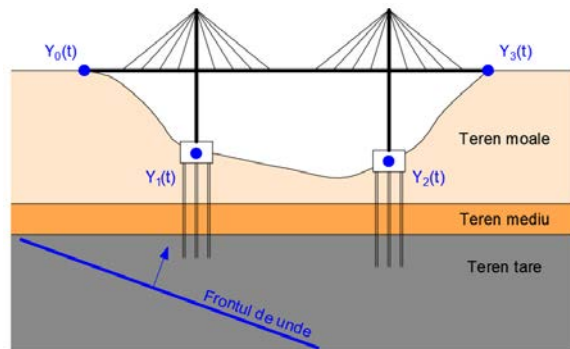


Fig. 9 Extended source effect

The theoretical part ends with a description of the incoherency models developed by Abrahamson through processing of the measurements obtained from dense or extended arrays, with a short presentation of the mathematical formulation and an example of a coherency function generated based on the models.

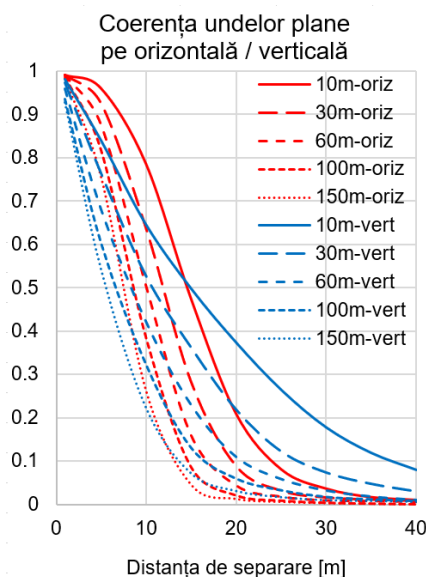


Fig. 10 The evolution of the coherency function with an increase in separation distance – Abrahamson 2006

The analyses are done in ACS SASSI, a software specialized in soil-structure interaction, which has a leading position in the field. It started from the original version which was developed at Berkeley University in the 70's.

In the case study, the state-of-the-art methods that have been described up until now are applied to a concrete bridge, that is quite common in Romania. The SSI analysis results are then compared with the typical design approach according to european and national norms. The main differences between the two approaches are highlighted, especially regarding the inchoerent seismic input, which can be both on the safe side or on the vulnerability side.

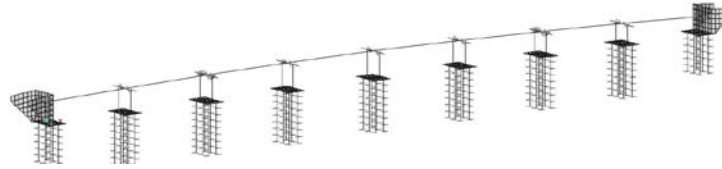


Fig. 11 Design model of the bridge

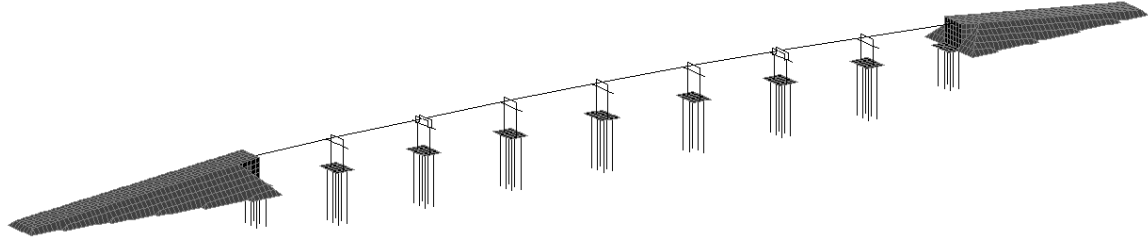


Fig. 12 SSI model of the bridge

The study proves that the simplified method of accounting for the spatial variability of the seismic ground motion according to Eurocode misses the essential: the dynamic and highly random character of the wave field that travels through the soil.

In the beam and shell model of the whole bridge a problem regarding extremely large axial forces in the piles which are not physically possible is discovered. Because the site of future nuclear power-plants is carefully chosen for its good soil or rock quality, deep foundations were never necessary and, therefore, never studied. There are very few papers where SSI specialists use their techniques on bridge structures, but they never go into full detail with their analyses. This is the reason, the current paper develops and proposes its own modelling methodology.

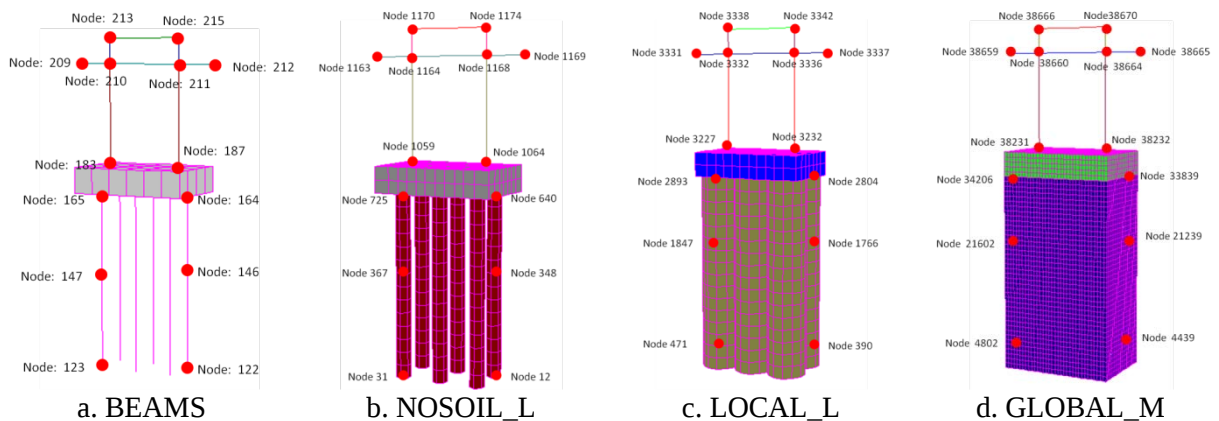


Fig. 13 Pier foundation models

In the detailed foundation analysis, the stick models (with beams and shells) did not behave correctly. For the rest of the study, the foundation (piles and pile cap) has been modeled with 3D solid elements. This is consistent with the experience from the nuclear field, where all models (even stick models) have the foundation slab modeled with 3D solid elements.

The next stage was to consider the near-field soil as part of the structural model, with the same nonlinear behaviour as the soil in free-field. The nonlinearity in the near-field soil is more pronounced, due to the displacements of the foundations and the reflexion and refraction of the seismic waves from the concrete surface

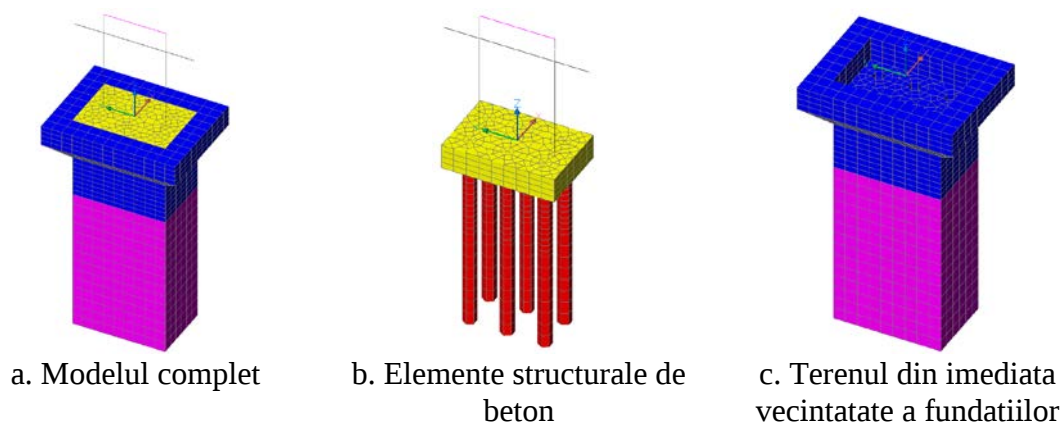


Fig. 14 Pier model for nonlinear analysis

Even now, after the nonlinear behaviour of the near-field soil, the variation of axial forces in the piles is still too large and above the usual soil-pile friction capability. Due to the lack of a specific pile-soil interface solution for the SSI approach, the study focused on developing a pile-soil interaction model at the interface, which has been done by adjusting a model from the usual bridge design practice.

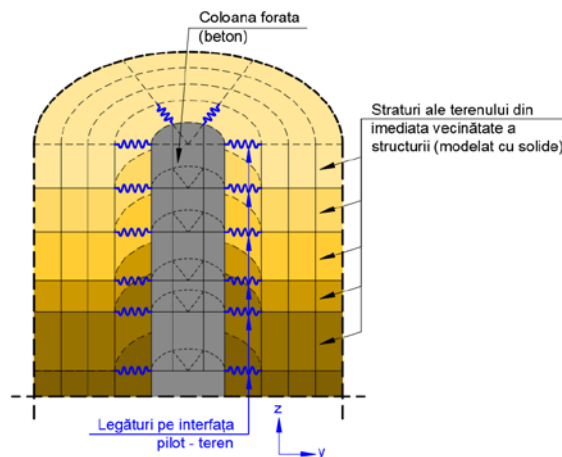


Fig. 15 Use of springs on the pile-soil interface

After finishing this stage, the methodology for SSI analysis of bridges with deep foundations is considered finished.

The last step of the study was a probabilistic SSI analysis. This approach is the newest and most modern procedure. It has been included in nuclear facilities design norms only in recent years and even in that field is not widely spread. Through such an analysis, weak points of the structure can be highlighted due to variations in the seismic action, soil parameters (p- and S-waves velocity, nonlinear behaviour curves $G-\gamma$ și $D-\gamma$) and structural behaviour (modulus of elasticity).

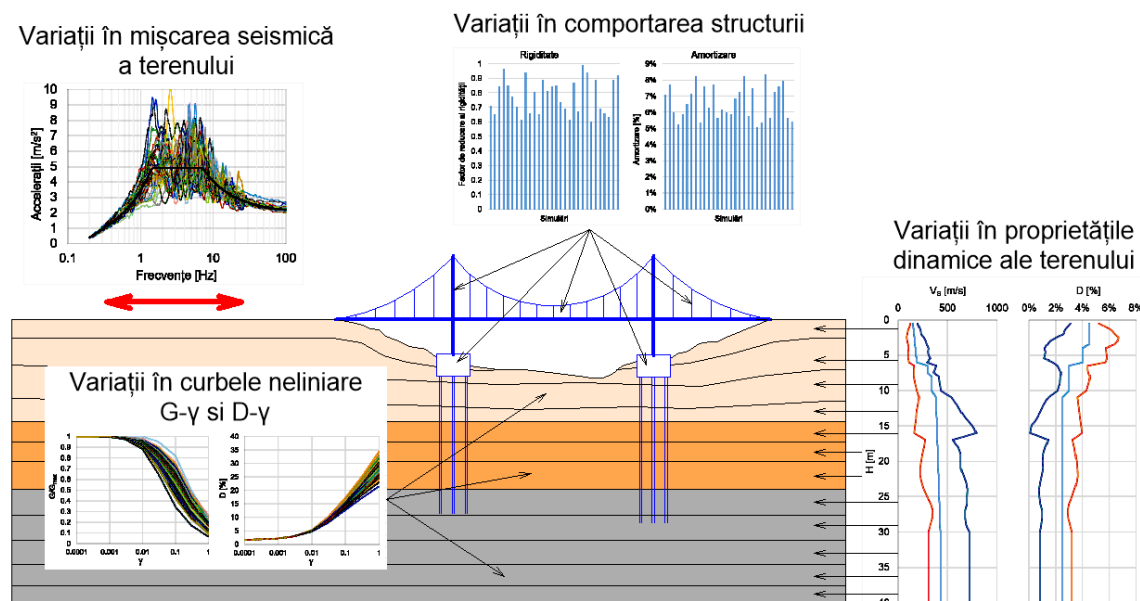


Fig. 16 Steps of a complete probabilistic SSI analysis

Through such an analysis, differences in behaviour and structural response intensity between the classic design model, the deterministic and probabilistic SSI analysis. These differences are highly variable and cannot be accounted for by a simple procedure, like additional safety coefficients.

The most important conclusion of the present study is that the current design approaches for the seismic design of bridges do not manage to simulate the correct behaviour of the structure during the earthquake.

The most advanced approaches which are currently used for very large structures that require a higher level of safety are, usually, a mix between the free-field wave propagation and then calculation of the ground motion / impedances for each foundation. Still this

approach fails to capture one essential aspect: the interdependency of the behaviour of the structure and that of the soil.

The thesis provides the methodology to be applied to bridges for a rigorous, safe and economical design.

Moreover, a first step in the perfecting of deep foundation models in SSI analyses has been made, which are being studied in the nuclear field also, for sites with weaker soils or for small, modular and deep buried reactors.