Abstract of Research Project
XXXVI Cycle (A.Y. 2020-2021)

Name of fellow: DAVIDE PAUSELLI

Name of UNIPG Supervisor: DIANA SALCIARINI

Name of UNIPG Co-Supervisor (if any): FILIPPO UBERTINI

International Partner Institution: Grenoble University

Name of International Co-Supervisor: To be defined

Start Date: 1.11.2020 **End Date: 31.10.2023**

RESEARCH PROJECT (max 3 pages):

Introduction and state of the art

The growing need to verify and increase the safety of infrastructures requires and has required over the years the development of engineering models that are increasingly consistent with real behavior. The construction of reliable behavioral models of linear infrastructures such as bridges or viaducts is the fulcrum of both the design of new infrastructures and the safety assessment of existing ones. The influence of soil-foundation structure interaction phenomena on the dynamic response of relatively flexible structures characterized by isolated foundations or foundations like bridges and viaducts is the object of several studies. The correct schematization of the ground-structure interaction phenomena (SSI) conditions both the interpretation of the state of health of the bridges (field of Structural Health Monitoring) and the prediction of the dynamic response to the occurrence of medium / high intensity seismic phenomena. The problems of soil-structure interaction in general show a high level of complexity: by definition they arise as coupled problems in which the action strongly depends on the reaction of the structural system. This research project aims to improve the current state of knowledge on the main techniques modeling of the soil-structure interaction phenomenon applied to the foundation of bridges and on the evaluation of the capabilities and shortcomings of each technique applied to a case study.

Most of the structural design of bridge foundations is developed with the assumption that the structural elements are perfectly clamped to the ground with respect to translations, settlements and rotations. In reality, the static and above all dynamic response of bridges is strongly conditioned by the stiffness relationships between the superstructure, the foundation and the ground. Ignoring the effects of interaction phenomena can lead to gross errors in the analysis and assessment of the response under dynamic loads. Many studies, formalization and schematization methods of the interaction between soil-foundation and bridge piers under seismic loads are due to Gazetas (1991) and Mylonakis et al. (1997-2006), who have classified and detailed many of the most common techniques. The general methods by which the soil-structure interaction analysis is conducted are divided in literature into direct methods and indirect methods, according to the approach of substructures or macro-elements. In the direct approach, the significant volume of soil and the structure are part of the same engineering model that is analyzed in a single solution using a numerical method of continuum discretization (typically finite element method or finite difference method). For example, in the finite element method (FEM), the ground can be schematized using 3D solid elements and the bridge structure using linear elements (beam) or plate. The biggest drawback of direct methods is for sure the computational burden. To obtain accurate results, the model needs to take into account a large foundation soil significant volume; in addition, in order to get the response of the system for a wide range of frequencies, it’s necessary to refine the discretization of the model, especially for 3D analysis and in non-linear field. Among the indirect methods, the most widespread (reference for example in the design notebooks of the road society ANAS s.p.a.) is the substructure method. The ground-structure interaction problem is solved by decomposing the system into two subsystems whose response is determined independently by separating the effects caused by the kinematic interaction from those caused by inertial interaction. The response of the overall system is obtained through the application of the principle of superposition of effects (Kausel). The literature shows how the application of the superposition principle of the effects and therefore of the substructure method is an engineering approximation acceptable in the case of linear or at most moderately non-linear systems (CALTRANS 1999). The non-linearities in soil-structure interaction problems may lie in several aspects: geometric non-linearities, for example at the soil-foundation interface, non-linear hydromechanical response of the soil, constitutive laws of non-linear materials rather than the occurrence of uplift phenomena. An alternative and innovative approach to correctly take into account the effects of non-linearities in soil-structure interaction problems is that linked to the notion of macro-element where the entire foundation soil system is schematized through a single element at the base of the superstructure having general three or six degrees of freedom (respectively for three-dimensional or two-dimensional problems). The first application of the macro element concept in geotechnical engineering is due to the contribution of Nova and Montrasio (1991) in the formulation of a new method for assessing the settlements of a strip foundation on cohesionless soils and quasi-static monotonic loading. Recent developments and applications of the concept of macroelements applied to bridge shallow foundations are due to Salciarini et al. (2010) Grange (2013). The models briefly mentioned above are also useful for to issues of dynamic identification of bridge structures and contextual monitoring of conservation and safety conditions. The model updating developed by the experimental or operational modal analysis have to take into account the schematization of the ground-structure interaction phenomena both in the static and seismic phases.

Research objectives

A proper evaluation of the static and seismic response of a bridge can strongly depend on a proper schematization of the soil-structure interaction phenomenon. The general purpose of this research is the comparison of the main SSI schematization techniques applied to a real and sufficiently representative / widespread bridge case, pointing out pros and cons both in static and seismic conditions. In particular, the application of the macro-elements technique on a real case is innovative and a relevant progress in the state of the art.

Therefore, the objectives to be pursued in this PhD project, identified by a careful analysis of the aspects for which the state of the art is not yet exhaustive, are the following:

Numerical modeling of the response in static conditions of a bridge pile founded on the surface or on piles. Comparison of the dynamic characteristics obtained on the basis of the different schematizations (perfect fit, substructure method, macroelements method), typically modal characteristics (frequencies, damping and modal forms). Analysis of the influence of the main parameters that affect each schematization.

1. <u>Numerical modeling of the response in static conditions of a bridge pile on shallow or piled foundations</u>. Comparison of the dynamic characteristics obtained by different schematizations (perfect fixed, substructure method, macroelements method), typically modal characteristics (frequencies, damping and modal shapes). Analysis of the influence of the main parameters that affect each schematization.

2. <u>Numerical modeling of the response in seismic conditions of a bridge pile on shallow or piled foundations</u>. Comparison of the structural response according to the application of a history of seismic displacements / accelerations with the application of different models of soil / structure interaction phenomenon. Analysis of the influence of the main parameters that affect each schematization.

3. <u>Application of dynamic identification techniques on the real case to compare which schematization of the SSI is closest to the experimental data.</u> Comparison of the main modal parameters obtained from each schematization with the results of an in situ dynamic identification campaign using velocimeters / accelerometers installed on site (model updating).

Methodology

In order to pursue the objectives, the methodology used will be the following:

1. Selecting a real or realistic case study of a bridge. It must necessarily be, at least from the point of view of the structural scheme, a type of diffused bridge in order to be able to generalize results as much as possible. Analysis and reconstruction of the main geometric, structural, geological and geotechnical characteristics of the case study. Of fundamental importance in the choice of the case study is the stiffness relationship between superstructure / foundation and ground in order to focus on both recurring and relevant cases for the soil-structure interaction problems.

Ph.D. Program Secretariat (Mrs. Teresa Nocera, teresa.nocera@unipg.it)
Ph.D. Program Coordinator (Prof. Filippo Ubertini, filippo.ubertini@unipg.it)

2. Modeling of the bridge structure in static condition (Pile-foundation-soil) using finite element software (Abaqus for 3D modeling) considering three hypotheses: structure fixed at the ground, structure that takes into account the SSI by means of the substructures method and structure that takes into account the SSI by means of the macroelements method. An experimental dynamic identification campaign of the bridge determines which of the methods is closest to the experimental conditions.

3. Modeling of the bridge structure in seismic conditions (Pile-foundation-soil) using finite element software (Abaqus for 3D modeling) considering three hypotheses: structure fixed at the ground, structure that takes into account the SSI by means of the substructures method and structure that takes into account the SSI by means of the macroelements method. Spectrum-compatible accelerometric stories with different frequency content will be selected.

Expected results

1. From the analysis of the main methods of schematization of the soil-structure interaction on a real case, we want to draw out and emphasize the main differences, capabilities and shortcomings. In static field these differences can guide the model updating process for the purposes of Structural Health Monitoring.

2. From the in situ experimental tests of dynamic monitoring using accelerometers / velocimeters and from the subsequent dynamic identification process (environmental vibrations) we expect to understand which of the tested schematizations best approximates the experimental behavior of the structure and if more onerous schematizations from a computational point of view are actually always necessary.

3. From the analysis of the main methods of schematization of the soil-structure interaction on a real case subjected to seismic stresses, we want to draw out and underline the main differences, capabilities and shortcomings to guide the technical / scientific community in the design phase of new bridges or the assessmnet of the existing ones.

Therefore, the doctoral research project aims to test, with particular reference to the method of macro-elements, the techniques of schematization of the ground-structure interaction of bridges on a real / realistic and diffused case. The results of the research can represent a valid support for the structural health monitoring, design and assessment of the vulnerability of bridge structures.

Bibliography

Salciarini D., Tamagnini C., Grange S., Kotronis P., 2010. La modellazione dei fenomeni di interazione Terreno struttura mediante macroelementi:elastoplasticità vs. ipoplasticità. Rivista Italiana di Geotecnica.

Lai C.G., Martinelli M., 2013. Soil-structure interaction under earthquake loading: Theoretical framework. ALERT Doctoral School 2013.

Gueguen P., 2013. Using strong and weak motion to identify the dynamic characteristics and the response of buildings considering soil-structure interaction. ALERT Doctoral School.

Martinelli M., Tamagnini C., 2013. Modeling SSI on piled foundations: The effects of kinematic interaction. ALERT Doctoral School.

Kotronis P., 2013. Simplified modeling strategies for soil-structure interaction problems: The multifiber beam concept. ALERT Doctoral School.

Grange.S., 2013. Simplified modeling strategies for soil-structure interaction problems: The macro–element concept . ALERT Doctoral School.

Mylonakis G., Nikolau S., Gazetas G., 2006. Footings under seismic loading: Analysis and design issues with emphasis on bridge foundations. Soil Dynamics and Earthquake Engineering.

Mylonakis G., Nikolau S.., 1997. Soil-Pile-Bridge Seismic Interaction: Kinematic and Inertial Effects. Soil Dynamics and Earthquake Engineering.

Mylonakis G., Gazetas G., 2000. Seismic Soil-Structure Interaction: Beneficial Or Detrimental?. Journal of Earthquake Engineering.

Po Lam I., Law H. 2000. Soil Structure Interaction of Bridges for Seismic Analysis. MCEER Technical Report.

Mylonakis G., Gazetas G., 1998. Seismic Soil-Structure Interaction: New Evidence and Emerging Issues. Geotechnical Earthquake Engineering and Soil Dynamics.

Ph.D. Program Secretariat (Mrs. Teresa Nocera, teresa.nocera@unipg.it)
Ph.D. Program Coordinator (Prof. Filippo Ubertini, filippo.ubertini@unipg.it)