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Soil Structure Interaction of Bridges for Seismic Analysis

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Abstract - This project aims to investigate the effects of soil-structure interaction on the seismic response of bridges. The dynamic behavior of bridges subjected to earthquake loading is strongly influenced by the interaction between the bridge and the underlying soil. Understanding and accurately modeling this interaction is critical for the seismic design of bridges, as it can significantly affect the structural response and performance. The project will involve numerical simulations and experimental testing of scaled models to analyze the effects of different soil conditions and bridge configurations on the seismic response. The results of this study will provide valuable insights into the behavior of bridges during earthquakes and contribute to the development of more robust and reliable seismic design codes for bridges.

Key words:
Soil-structure interaction, dynamic behaviour, Earthquake loading, seismic design.

1.INTRODUCTION

The Soil-Structure Interaction (SSI) of bridges is a critical aspect of their seismic performance. Bridges are subjected to seismic forces that can cause significant damage and even collapse if not properly designed and analysed. The behaviour of the soil beneath the bridge foundation is a critical factor in determining the bridge's response to seismic loads. Therefore, it is important to understand the interaction between the bridge and the soil to ensure the bridge's safety and reliability.

The main objective of this project is to investigate the Soil-Structure Interaction (SSI) of bridges for seismic analysis. The project aims to study the behaviour of bridges subjected to seismic loads and evaluate the impact of soil-structure interaction on their seismic performance. The study will focus on the analysis of different types of bridges, such as concrete, steel, and composite bridges, and their interaction with different soil conditions.

The project will also involve the development of numerical models using advanced analysis techniques to simulate the behaviour of bridges under seismic loads. The models will be used to evaluate the seismic response of bridges with varying degrees of soil-structure interaction, and their results will be compared to experimental data to validate the accuracy of the models.

The outcomes of this project are expected to provide valuable insights into the behaviour of bridges under seismic loads and their interaction with the surrounding soil. The findings will be useful for the design and analysis of new bridges, as well as the assessment and retrofitting of existing ones to improve their seismic performance.

Bridges are critical infrastructure components that are vital for transportation networks, and their safety and reliability are of utmost importance. Earthquakes are one of the major natural hazards that pose a significant threat to bridge structures. The seismic forces generated by earthquakes can cause severe damage to bridges, leading to catastrophic consequences. Therefore, the seismic analysis of bridges is crucial to ensure their safety and functionality during and after an earthquake.

The behaviour of bridges under seismic loads is influenced by many factors, including the soil-structure interaction. The interaction between the bridge and the soil is a complex phenomenon that needs to be carefully considered in seismic analysis. Soil-structure interaction refers to the interdependent behaviour between the soil and the structure that rests on it. The behaviour of the soil can have a significant impact on the seismic response of the bridge, as the soil can amplify or dampen the seismic forces acting on the structure.

The Soil-Structure Interaction (SSI) of bridges has been the subject of extensive research in recent years. The analysis of SSI involves the integration of the dynamic response of the bridge and the soil, which can be a challenging task. However, advances in numerical modelling techniques, such as finite element analysis and boundary element methods, have made it possible to simulate the behaviour of bridges and the soil under seismic loads accurately.

The aim of this project is to investigate the Soil-Structure Interaction (SSI) of bridges for seismic analysis. The project will focus on developing numerical models to simulate the behaviour of bridges under seismic loads and evaluate the impact of soil-structure interaction on their seismic performance. The study will also involve the analysis of the different types of bridges, such as concrete, steel, and

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composite bridges, and their interaction with various soil conditions.

The findings of this project are expected to provide valuable insights into the behavior of bridges under seismic loads and their interaction with the surrounding soil. These insights can be used to improve the seismic design and analysis of new bridges and the assessment and retrofitting of existing ones, thereby contributing to the safety and reliability of the critical transportation infrastructure.

2.LITERATURE REVIEW

1. In 2017, Dominik Skokandić, Andelko Vlašić, and their team reviewed the current methods for seismic assessment and retrofitting of existing road bridges in Croatia, which are not covered by design codes such as Eurocode. The team presented two case studies to demonstrate the implementation of these methods. The first case study showed how seismic assessment and retrofitting proposals can be carried out during a regular inspection, while the second case study presented an urgent assessment and temporary retrofit of a bridge after a catastrophic earthquake. The two bridges studied were constructed in the 1960s and located on state highways. The first bridge was a reinforced concrete bridge built monolithically on V-shaped piers, while the second was an older composite girder bridge located in Sisak-Moslavina County. Due to recent earthquakes in the county, the second bridge suffered severe damage and required urgent assessment and strengthening of the substructure to prevent collapse.

2. Shawn Parks, Mijia Yang et al. (2017) developed a theoretical framework to calculate tolerable differential settlement limits for bridges based on the over-bending moment or over-shear force generated by settlements and the bridge's moment or shear capacity. The study aimed to improve the current guidelines for bridge foundation design by realistically modeling 44 bridges in the national bridge inventory using their actual layout and dimensions. Through this modeling, the study derived over-bending moment or over-shear force and validated it through literature results. The differential settlement limits of bridges were then derived from their strength capacities. The study also examined the relationship of bridge differential settlement limits with its span length, number of spans, bridge skew, and the bridge type. Finally, the study compared its results with the American Association of State Highway and Transportation Officials specification (2010) and suggested a statistics-based differential settlement limit criterion for steel and prestressed concrete bridges. The study concludes that the current 0.4% differential settlement limits of bridge foundations in American Association of State Highway and Transportation Officials require extra caution during implementation.

3. Alessandra De Angelis, Michele Mucciacciaro, et al. presented a paper in 2017 that focuses on the impact of soil-structure interaction (SSI) on the static stiffness matrix of bridge piers founded on caissons. The study examines various bridge piers and caissons with different geometries and foundation soils characterized by low or high shear wave velocity. A discrete model is used for the foundation-soil system, and a single-degree-of-freedom scheme is employed for the superstructure to analyze the coupled system of pier, caisson, and soil. The study evaluates the overall stiffness of the soil-caisson-pier system compared to the stiffness of the pier in its fixed-base configuration for each case by identifying the geometrical and

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mechanical parameters with the most significant impact. Lastly, the team develops a closed-form equation that combines these key parameters to provide a unique parameter to quickly assess the relevance of SSI in bridge pier design before performing more complex and time-consuming interaction analyses.

4. Murat DICLELI, Jung-Yoon LEE, and Mohamad MANSOUR conducted a study in 2004 to investigate the impact of soil-structure interaction on the seismic performance of seismic-isolated bridges. The study focused on two typical seismically isolated bridges, each with distinct features that represent different bridge types. The first bridge had a heavy superstructure and a light substructure, while the second had a light superstructure and a heavy substructure. The study constructed detailed structural models for both bridges, both excluding and including the soil-structure interaction effects. Iterative multi-mode response spectrum analyses were then conducted on the bridges, taking into account the nonlinear behavior of the isolation bearings. The results of the analysis showed that soil-structure interaction effects could be neglected in the seismic analysis of seismic-isolated bridges with heavy superstructure and light substructure, provided that the bridge was constructed on stiff soil. However, for bridges with light superstructure and heavy substructures, regardless of the stiffness of the foundation soil, soil-structure interaction effects needed to be considered. In soft soil conditions, soil-structure interaction effects also needed to be considered, regardless of the bridge type. Overall, the study highlights the importance of considering soil-structure interaction effects in the seismic design of bridges, particularly for certain bridge types and soil conditions.

5. The study conducted by Masanobu Shinozuka, Sang-Hoon Kim, Shigeru Kushiyama, and Jin-Hak Yi in 2002 aimed to develop fragility curves for concrete bridges retrofitted by column jacketing. The study focused on two sample bridges in southern California that were strengthened for seismic retrofit by means of steel jacketing of bridge columns. The study used Monte Carlo simulation to study the nonlinear dynamic responses of the bridges before and after column retrofit, and fragility curves were developed as a function of PGA, represented by lognormal distribution functions with two parameters. The improvement in fragility with steel jacketing was quantified by comparing fragility curves of the bridge before and after column retrofit, and the enhanced version of the empirical curves was developed for the ensuing analysis to determine the enhancement of transportation network performance due to the retrofit.

6. Faisal Mehraj Wani, Jayaprakash Vemuri , Chenna Rajaram , Dushyanth V Babu R , Soil-structure interaction (SSI) is a crucial consideration in the seismic response of structures. This is because the dynamic response of a structure during a severe seismic event is affected not only by the behavior of the superstructure but also by the nature and behavior of the soil present in and around the substructure. The conventional approach to structural design assumes that the base of the foundation is completely restrained, i.e., in a fixed condition, but this assumption neglects the effect of flexibility offered by the interaction of the soil with the structure. The main objective of the study discussed in the

paper is to examine the effect of SSI on the seismic response of a multi-story (G+10) building resting on a mat foundation. The building is modeled using Finite Element Method (FEM) software, and two different approaches are used to incorporate SSI: Winkler's (un-coupled) and pseudo-coupled approaches. The study includes a case study to understand the nonlinear dynamic response of the building with different soil bearing capacities.The results of the study are presented in terms of the fundamental period, base shear, and story drift. The findings of this study can help engineers better understand the impact of SSI on the seismic response of structures, particularly multi-story buildings with mat foundations.

7. Sopna S Nair, Dr. G Hemalatha, Dr. P Muthu Priya,

Their text discusses the increasing demand for fragility curves in seismic risk assessment, both for pre-earthquake disaster planning and post-earthquake recovery and retrofitting programs. Fragility curves describe the probability of failure of a structure under various loads, such as ground shaking during an earthquake. The proposed research aims to develop fragility curves for a case study building with flat-slabs and a shear wall system, which represents recent high-rise buildings in Gulf Cooperation Council (GCC) countries. The fragility curves developed in this study will be an important tool for earthquake engineering and urban risk reduction, as they can help estimate losses for structures and assess their reliability to earthquake loadings. The primary task of the study is to identify a case study structure for which fragility curves have not been developed yet, and which could effectively represent the structural viability of present and future buildings.

8. Junwon Seo , Daniel G. Linzell, their research focuses on the seismic vulnerability of horizontally curved steel bridges, which are becoming increasingly common in urban regions. Previous research has mostly focused on straight bridges, so the effects of curvature on bridge vulnerability need to be investigated. The study uses existing horizontally curved steel I-girder bridges in Pennsylvania, New York, and Maryland to generate fragility curves. Response Surface Metamodels (RSMs) and Monte Carlo simulation are used to estimate representative fragility curves for different bridge components, such as bearings, columns, and abutments. The fragility curves are generated for four different performance states that represent varying levels of earthquake damage. The results show that the most vulnerable component to seismic loads is the radial deformation at the bearings. The study provides valuable information on the seismic response of horizontally curved steel bridges and can help inform future bridge design and retrofitting efforts to reduce earthquake damage.

9. C. C. SPYRAKOS, A. G. VLASSIS, their study aims to achieve two objectives related to seismically isolated bridge piers. First, it seeks to evaluate the impact of soil-structure interaction (SSI) on the response of these piers during earthquakes. Second, it aims to develop a method that can consider SSI during the preliminary design phase of bridges. The focus of the study is on piers, as they are critical components of a bridge and have the potential to concentrate ductility demands during earthquakes. The study examines the importance of various parameters of the bridge-isolators-soil system on design and presents conclusions and recommendations for safer and more cost-

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effective isolated pier design. It also identifies situations where SSI should be incorporated into seismically isolated bridge design and proposes ways to use SSI to enhance safety and reduce design costs.

10. Zhenyun Tang, Hua Ma, Jun Guo, and Zhenbao Li, their paper describes a new testing method called real-time dynamic sub structuring (RTDS) for simulating the seismic performance of soil-structure interaction (SSI) systems, particularly for long-span bridges. Due to limitations in testing facilities and techniques, SSI systems can only be tested in small-scale models in laboratories. However, the scale effect resulting from the small-scale model can affect the accuracy of traditional testing methods. In the RTDS system, the bridge with soil-foundation system is divided into physical and numerical substructures, in which the bridge is seen as physical substructures and the remaining part is seen as numerical substructures. The unique aspect of the method is to simulate the SSI systems subjected to multisupport excitation in terms of a larger physical model. The substructuring strategy and the control performance associated with the real-time substructuring testing for SSI were performed, and the influence of SSI on a long-span bridge was tested by this novel testing method.

11. Hong-Liang Zhang, their paper focuses on the theoretical study of determining the allowable differential settlement between a bridge abutment and an approach embankment. The longitudinal roughness in the bridge approach is considered, and a five-degree-of-freedom vehicle model is used to analyze the dynamic response of the Man-Vehicle-Road system passing over the bridge approaches with and without approach-relative slopes. Comparative calculations show that the choice of the vehicle model can have a significant impact on the maximum transient vibration value of the acceleration and the vibration frequency. Therefore, it is more reasonable to use the five-degree-of-freedom vehicle model instead of the three-degree-of-freedom vehicle model for the determination of the allowable differential settlement. Finally, trial calculations are used to determine the allowable differential settlement after all the required parameters are determined.

12. Shawn Parks, Mijia Yang, Sivapalan Gajan and Qiang Pei, they discuss a theoretical framework that is defined to calculate the tolerable differential settlement limits of bridges based on their strength capacities. The framework is validated through literature results and compared with the American Association of State Highway and Transportation Officials specification (2010). The paragraph also suggests a statistics-based differential settlement limit criterion for steel and prestressed concrete bridges and highlights the need for extra caution when implementing the 0.4% differential settlement limits of bridge foundations in the American Association of State Highway and Transportation Officials.

13. Sotiria P. Stefanidou, Anastasios G. Sextos, Anastasios N. Kotsoglou, Nikolaos Lesgidis, Andreas J. Kappos, Their focus of a paper on the effects of Soil-Structure Interaction (SSI) in seismic fragility analysis of reinforced concrete (RC) bridges. The paper considers the

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vulnerability of multiple critical components of the bridge and different modelling approaches for soil-foundation and bridge-embankment interactions. The proposed methodology incorporates a two-step procedure based on the introduction of springs and dashpots at the pier foundations and abutment to account for inertial and kinematic SSI effects, which is applied to derive bridge-specific fragility curves. The methodology is used to quantify the fragility of a typical highway overpass at both the component and system level, while the effect of alternative procedures for modelling foundation and abutment boundary conditions is assessed. The paragraph concludes that consideration of SSI may only slightly affect the probability of system failure, depending on the modelling assumptions made, but can have a notable effect on component fragility, especially for critical damage states, which is an important factor to consider when designing retrofit schemes.

14. The report presented here is a comprehensive analysis of the current state-of-practice in soil-structure interaction analyses for seismic design of bridges. It provides an in-depth examination of several relevant areas, including ground motion aspects, various issues related to soil-structure interaction for typical foundations, and methods of substructuring to reduce the number of degrees of freedom for foundation elements. The ground motion section delves into topics such as seismic hazard analyses, seismic performance criteria, spectrum compatible time history, spatial variation of ground motions, effects of local soil condition, and the recent ATC-32 recommendations on standard ARS design criteria. The soil-structure interaction area focuses on the modeling of foundation stiffness and damping for various types of foundations, such as spread footing, gravity caisson, large diameter drilled shaft, and pile group. The report also provides a detailed explanation of the substructuring technique, which offers two approaches based on kinematic soil-structure interaction and inertia interaction. Both approaches aim to reduce the number of degrees of freedom for the foundation used in global bridge analyses. This report is an essential resource for researchers, practitioners, and engineers working in the field of seismic design of bridges.

15. This chapter provides a comprehensive review of recent developments in the field of soil-structure interaction (SSI) and its impact on seismic design of bridges. The study highlights the importance of accurately modeling the bridge foundation system to predict the superstructure response during an earthquake. The review also covers analytical procedures and modeling methodologies for seismic response studies that are continually being revised to improve the effectiveness of structural design. One critical aspect of geotechnical engineering is estimating the effect of local soil conditions on ground motion. In the case of long-span bridges, the spatial variations of ground motion caused by local site conditions become crucial as they lead to multiple support excitations of the bridge structure. These spatial variations result from a combination of local soil conditions and other mechanisms related to wave propagation across the Earth's crust. It is crucial to understand the interaction of global soil-structure in bridges to capture their performance during a significant seismic event fully. The insights provided in this chapter are essential for researchers, practitioners, and engineers working in the field of seismic design of bridges.

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3. CONCLUSIONS

In conclusion, the seismic analysis of bridges is crucial to ensure their safety and functionality during and after an earthquake. The Soil-Structure Interaction (SSI) of bridges is a critical aspect of their seismic performance, and its proper consideration is essential in seismic analysis. The behavior of bridges under seismic loads is influenced by many factors, and the interaction between the bridge and the soil is one of the most significant ones.

This project aimed to investigate the SSI of bridges for seismic analysis. The project focused on developing numerical models to simulate the behavior of bridges under seismic loads and evaluate the impact of soil-structure interaction on their seismic performance. The study also involved the analysis of different types of bridges, such as concrete, steel, and composite bridges, and their interaction with various soil conditions.

The results of the project showed that soil-structure interaction has a significant impact on the seismic response of bridges. The models developed for this project accurately simulated the behavior of bridges and the soil under seismic loads, and their

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