MODELING OF SOIL-STRUCTURE INTERACTION FOR ITS INFLUENCE INVESTIGATION ON THE DYNAMIC RESPONSE OF RAILWAY VIADUCT

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1. INTRODUCTION

With the development of railway infrastructure systems all over the world, railway viaducts have become essential components of this system. These structures are subjected to various dynamic loads like train-induced vibrations, earthquake shaking, etc. With the increase of fractional share of viaducts and bridges in the railways systems, the probability of a train passing over the viaduct during an earthquake is also more likely, which renders the safety of the viaduct critical for structural & vehicular stability and passenger safety. The vibrations and deformations of the bridge structure, foundation, and soil are interactive and, to a considerable extent, influenced by one other. However, the study of train-bridge-soil dynamic interaction is a complex problem due to various complicated parameters involved such as the bridge or foundation geometry, material stiffness, damping, moving load's (train) interaction with rails, rail-track-bridge interaction, soil-bridge dynamic interaction, boundary conditions, etc.

The interaction between substructure and soil had been seldom considered in numerical models during the dynamic analysis and design of such structures due to a large number of aforementioned uncertain parameters involved and the limited computational power. In most of the design codes for railway bridges and viaducts, Soil Structure Interaction (SSI) is simulated by modeling a series of equivalent linear springs along the depth of the bridge pile, calculated using a coefficient of horizontal subgrade reaction increasing linearly with depth of the pile. This simplification can result in over-estimation of vertical bridge accelerations and under-estimation of critical speed. Large vertical deck accelerations can cause displacement of the ballast, undermining the support for rails, and leading to misalignment and excessive fatigue. This consequently leads to higher maintenance costs or in the worst case, derailment (Albright et al. 2022). Previous studies have highlighted the influence of the SSI on the dynamic response of railway viaducts. For instance, the response of railway bridges is strongly affected by SSI, particularly under resonance conditions (Romero et al. 2013). Anand et al. (2022) concluded that neglecting the SSI effects while analyzing the seismic response of a continuous bridge leads to an underestimation of displacement and acceleration at the pier top and an overestimation of shear force and bending moments at the pier bottom. The bridge fundamental periods and damping ratios also tend to increase when SSI is considered. Studies have also highlighted the importance of SSI effects in the assessment of the Serviceability Limit State (SLS) associated with traffic safety. Therefore, incorporating SSI can lead to optimized bridge design, performance, and monitoring during challenging situations of operation and natural disasters.

2. OBJECTIVES

1. To investigate the influence of Soil-Structure Interaction (SSI) on the structural response (in terms of vibrations) of a coupled dynamic response of a railway viaduct-soil system.
2. To compare the efficiency of simulating the model by soil continuum and soil springs for dynamic analyses.

3. METHODOLOGY

The subject research is a simulation-based parametric study to study the influence of soil properties on the viaduct response. A coupled bridge viaduct foundation and soil continuum system model is simulated under seismic excitation. The viaduct under consideration is the Okuda viaduct, which is a Shinkansen RC viaduct near Nagoya consisting of 18 24m double track concrete bridges with a radius of curvature around 3000m and resting on a piled foundation. The model is prepared in Abaqus. Since the model involves multiple uncertain and varying parameters for the soil continuum, structure, and ground motion. Therefore, before full-scale modeling of the complete span of the viaduct altogether with soil, a small-scale parameter setting model has been used to adjust the most appropriate and realistic parameters for the study. The parameter setting model consists of a single viaduct pier resting on grouped piled foundation embedded in a stratified soil continuum consisting of alternate layers of sand, silty sand, and silt. Initially, the part geometry, properties, and element type are defined, and assembly is generated. Next, the boundary condition, loads, and interactions are introduced. Different layers of soil are connected using tie constraint while the soil-pile interaction is developed by defining friction using the tangential and normal behavior.

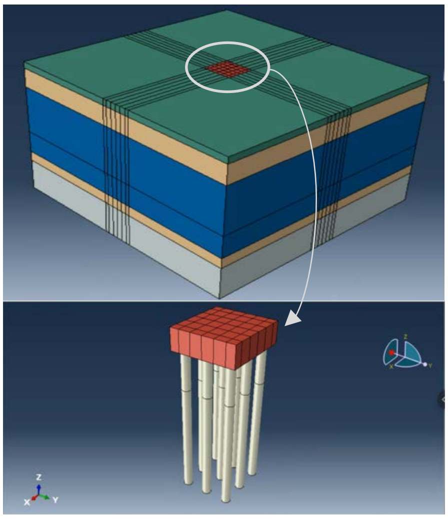

Fig. 1 Parameter Setting Model Assembly

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Table. 1 Material Properties of Soil & Foundation

Material	Density (kg/m3)	Young's Modulus (Pa)	Poisson's Ratio	Friction Angle	Dilation Angle
Silt (Layer 5)	1,500	20	0.3	32	8
Silty Sand (Layer 2 & 4)	1,650	25	0.3	35	10
Sand (Layer 3)	1,750	35	0.35	38	12
Earth fill (Layer 1)	1,900	30	0.3	36	10
Pile	2,450	30	0.1667	-	-
Pile-cap	2,700	30	0.1667	-	-

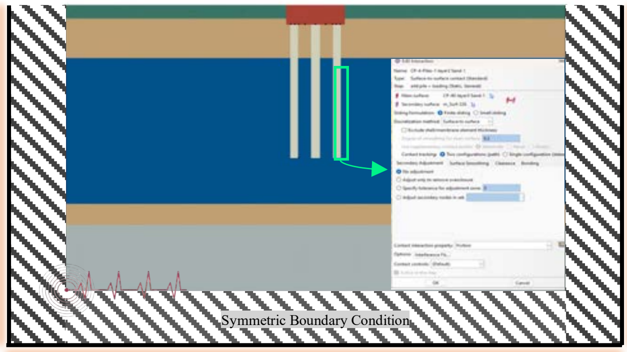

Fig. 2 Interaction & Boundary Conditions schematic

5. ANALYSIS & DISCUSSION

The first step is to perform the geostatic analysis of the soil. It is the steady-state equilibrium configuration of the undisturbed soil under geostatic loading. The equilibrium state usually includes both horizontal and vertical stress components. Establishing these initial conditions correctly is important so that the problem begins from an equilibrium state. In Abaqus, geostatic stress is applied by defining a pre-defined field. This analysis should ideally produce zero deformation in the soil continuum; however, deformations in soil continuum of the range 0.15 – 1.2 mm (Fig. 3a) are small and acceptable for further analysis. After establishing the equilibrium, static analysis is carried out, firstly considering the materials, particularly soil in the elastic range (Fig. 3b) and later in the plastic range (Fig. 3c). Mohr Coulomb plasticity model is used to introduce the plasticity of the soil continuum. After static analysis, dynamic analysis is carried out. Truncated Kobe-Takatori ground motion is applied to the model base. The ground-motion is truncated by area intensity method to account for 95% concentration of the ground acceleration i.e., which turns out to be around 15 seconds. Special attention needs to be paid to the boundary conditions to prevent the reflection of seismic waves. Symmetric conditions are used for this analysis. In contrast, for modelling the soil using soil springs, they are calculated by American Petroleum Institute (API) 1993 for sand / silty sand, modelling beams as Winkler piles on elastic foundation. The soil continuum consists of multiple layers, and the springs are calculated for each one by using the experimental and laboratory testing fetched properties. The first tangent of soil reaction vs. pile deformation equals the elastic soil spring stiffness in kN/m^3.

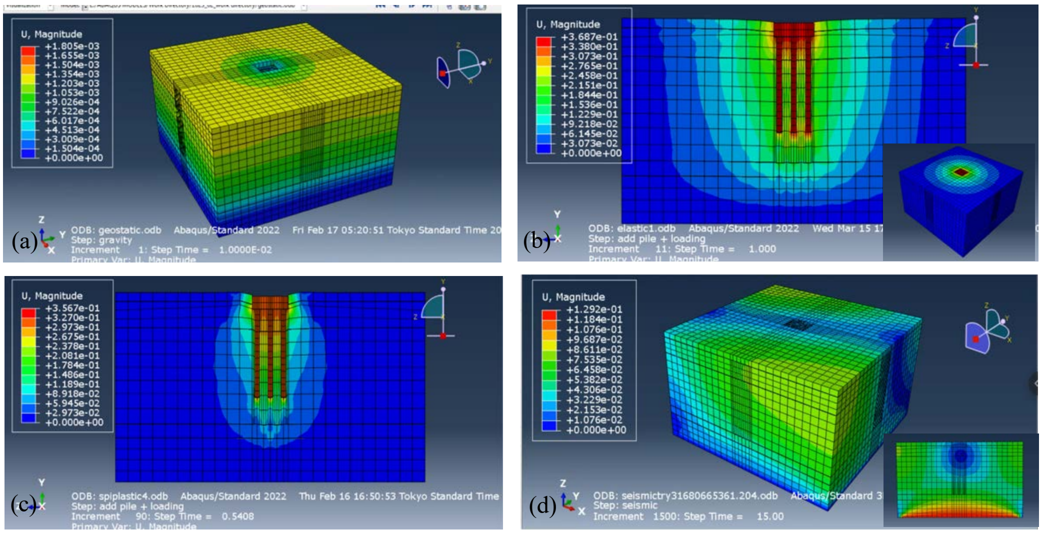

Fig. 3 Displacement Response of the Coupled Soil-structure system under (a) Geostatic Loading (b) Static Analysis in Elastic Range (c) Static Analysis in Plastic Range (d) Dynamic Analysis in Elastic Range

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