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Earthquake-Induced Structural Response of Railway Steel Plate Girder Bridges Crossing Deep Conduits

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Abstract

This study investigated the structural behavior of a railway bridge that could be constructed in a seismically active zone. The definition of these bridges' primary components is discussed first. A three-span bridge with varying pier heights is proposed to cross a deep conduit in a proposed plate girder bridge. A detailed design is provided here, taking into account the train track's live load and following the AREMA specifications. A finite element model is provided, which uses the SAP2000 software program to simulate the behavior of the bridge under moving load in a quasi-static condition. Two methods are used to simulate the bridge's behavior during an earthquake, with the influence of soil type being investigated using response spectrum analysis. Furthermore, the bridge is subject to a recorded earthquake acceleration in the time domain (El Centro Earthquake). The stress and deformation limits are determined under all loading conditions. It was discovered that soil of Type C has the greatest influence on these limits, increasing stresses by approximately 27.40% and deformation by 40.73%. In addition, the bridge is earthquake-safe. Furthermore, the ballast layer may improve foundation performance by increasing load distribution and minimizing the danger of liquefaction, which happens when damp soil loses strength during shaking. The ballast layer improves drainage, reducing water gathering, which is critical for soil stability during an earthquake.

Keywords: Earthquake acceleration, Multi-span bridge, Railway bridge, Response spectrum analysis, Steel Plate Girder

1. Introduction

Steel plate girder bridges in railways are essential elements of transportation infrastructure, enabling effective mobility and economic interconnectivity. In seismically active areas, these constructions have considerable obstacles, especially when traversing deep conduits. These bridges exhibit complicated structural dynamics, characterized by intricate interactions among components such as girders, piers, and bearings under seismic stresses. Examining these dynamics yields insights into stress distribution and probable failure mechanisms, crucial for formulating predictive models and improving engineering designs. Comprehending the behavior of steel and other building materials during seismic occurrences is essential. This involves analyzing their reactions to elevated stress and strain rates, resulting in advancements in material science and the creation of more durable building materials. Examining the distribution of seismic forces across the structure aids in optimizing load routes, ensuring that essential components endure these stresses, which is crucial for improving overall structural integrity and safety.

These bridges often cross a wide range of geological conditions, and soil-structure interaction has a substantial impact on seismic response. Studying these interactions improves models and design solutions for accommodating unique soil types, particularly in areas with diverse topography. Analyzing the bridge's reaction to transient seismic waves offers a better knowledge of dynamic loading effects, which leads to better safety measures like expansion joints and energy dissipation devices that are specifically designed to limit seismic impacts. Scientific research also fuels the creation of novel technical solutions, such as seismic isolation systems and enhanced dampening mechanisms. These technologies improve bridge performance during earthquakes, lowering damage and increasing infrastructure longevity. Insights from these investigations contribute to growing engineering standards and building regulations, ensuring that new buildings reflect the most current scientific knowledge and best practices.

By concentrating on these scientific factors, research into the seismic response of steel plate girder bridges in railroads promotes structural engineering and guarantees that infrastructure is better prepared to resist seismic disasters, thereby saving lives and supporting economic activity. The most popular railway bridges that cross terranes or other barriers in rural areas are composed of deep piers of various heights that support steel plate girders. The dynamic behavior due to earthquakes of such bridges is the main problem and the goal of this study

1.1 Bridge dynamics

Bridge dynamics is the study of deflections and stresses in bridges caused by high-speed moving wheel loads and other dynamic loads. The most important factors that affect dynamic stresses in bridges are listed below.

1. Bridge structure fundamental frequency characteristics (i.e., Individual member length, mass, and stiffness);
2. Frequency characteristics of vehicles (e.g., sprung and unsprung masses, spring stiffness), damping in bridges and vehicles, vehicle speed, and so on.

3. The vehicles affect the bridges not only in terms of vertical forces but also in terms of longitudinally horizontal shear forces.
4. These effects are represented in design practice by the dynamic coefficient or dynamic impact factor, which only shows how many times the static effects must be multiplied to cover the additional dynamic loads.

$$I = \frac{\alpha}{\beta + L} \quad (1)$$

Where α and β are factors depending on the main bridge element flexure stiffness and the material and type of bridges (Deng et al, 2014),(ÜNAL et al, 2014). The dynamic impacts for moving loads are included as part of the static analysis in this study, especially because the truck speed is normal.

1.2 Earthquake Loads

Seismic loading is a concept used in earthquake engineering to describe how seismic vibrations affect a structure. It happens when a structure's contact surfaces with the ground or neighboring structures come into contact. Seismic loading is mainly determined by the seismic hazard, site geotechnical parameters, and natural frequency of the structure, among other factors. While earthquake ground motions have both horizontal and vertical components, the horizontal component is the primary cause of bridge damage.

Because the railway is an international line, all categories show in the seismic zone map in Turkey that the train is most designed for the worst place to pass through.

2. Review of Literature

The structural behavior of railway steel plate girder bridges spanning deep conduits under seismic stress is a complicated and essential issue in bridge engineering. Several researches have looked at the seismic response and collapse processes of such bridges, utilizing analytical, experimental, and numerical methodologies. One research simulated seismic-induced bridge collapse, taking into account nonlinear and discontinuous characteristics such as material yielding, cracking, member damage, separation, and bridge element impact response. The analytical approach was able to recreate the in-situ collapse of the Matsurube Bridge during the 2008 Japan Iwate-Miyagi inland earthquake, which was caused by both significant ground excitations and the sliding of the rock mass under the bridge. Another research examined the performance of short-span bridges with pile foundations in the Christchurch, New Zealand earthquakes [?]. The researchers discovered that these bridges' stiff superstructure caused a specific deformation process comprising lateral spreading, deck pinning, and abutment backrotation, resulting in abutment pile damage and approach slumping.

The effect of near-fault vertical ground movements on the seismic response of highway overpasses has also been investigated. The seismic effectiveness of railway bridges has been intensively researched in the aftermath of significant earthquakes such as the Kobe earthquake in Japan. Railway bridges are studied and improved by engineers from all over the world. Along with the bridge's construction codes and specifications, the seismic tolerant design criteria are specified (Michel, 1998).

Trains passing over earthquake-prone bridges were studied to determine their dynamic stability. For the earthquake analysis of railway bridges, both of the components of ground motion’s acceleration and those for the velocity and displacement are needed. The results of the seismic analysis, using recorded earthquake data as input excitation, illustrate that the train and the bridge structures remain safe during the earthquake, as long as the bridge and train structures are not exposed to plastic or large deformations. The impact of the vertical component of ground motions on the train-rail-bridge system's stability is significant. (Yang & Wu, 2002).

Longitudinal interactions (Biondi et al., 2005), (König & Christoph, 2023), and vertical (Battini & Ülker-Kaustell, 2011) force between the bridge and railroad tracks have been studied in several studies. Bridge movements are limited by the track structure, which acts as a stiff layer over railway bridges. Track Bridge Interaction (TBI) has the potential to limit bridge movement and, as a result, harm railway bridges.

(kim et al, 2013) Dynamic reactions of steel monorail bridges to significant earthquakes were explored, including train-bridge interaction. The research looked at two kinds of steel monorail bridges: traditional ones with steel track girders and advanced ones with composite track girders and a simplified lateral bracing system. During significant earthquakes, monorail trains were considered to be standing on the track girders of monorail bridges. The analytical investigation revealed that treating the monorail train as extra mass rather than a dynamic system in numerical modeling overstated the influence of train load on seismic performance of monorail bridges. Previously, plastic deformations at the end bracing of the girder system absorbed seismic energy and decreased stress at the pier base.

(Yang et al, 2016), Investigated the dynamic reaction of a train-bridge system to earthquakes. Additionally, the operating safety indices of the train on the bridge during an earthquake were investigated. Consider a long span cable-stayed bridge spanning the Huangpu River. A comprehensive three-dimensional finite element model of the train-bridge system was created, taking into account the interactions between soil, bridge, and train. Parallel computing based on contact balancing was used to solve this large-scale numerical simulation challenge. The dynamic nonlinear analysis was done on a supercomputer using the finite element package LS-DYNA 971.

The study of the impacts of a ballast layer, whether present or missing, is critical for understanding how it affects railway system stability and performance. A ballast layer, often made of gravel or similar materials, offers critical support by spreading train loads more uniformly over the underlying soil, reducing structural damage and uneven settling. Furthermore, the ballast layer helps with drainage, decreasing erosion, and managing water-related difficulties that might jeopardize the track's integrity. Its presence may also aid in reducing vibrations and noise caused by moving trains, resulting in a more sustainable and pleasant railway environment. By investigating the mechanical characteristics of several ballast materials and their behavior under diverse environmental situations, this study aims to evaluate the overall effectiveness of the earthquake effect and of using a ballast layer in railway construction and maintenance.

3. Research Approach

First, a definition of the bridges and their types has been presented, whereby the expected load on the bridge is mentioned. The main components of the railway bridges are designed according to AREMA specifications, and their structural idealization and the appropriate finite element model for each component are mentioned. The stress level for each component is the main objective of the study to predict the expected failure during and after earthquakes.

4. Research Purpose

This project aims to investigate the behavior of earthquake bridges passing deep conducts when they are subjected to seismic loads. A literature review was conducted to learn more about how the railroad bridge reacts during earthquakes. The analysis of the superstructure of a railway bridge exposed to severe loading (moving live loads and earthquake loading) conditions is performed numerically using a finite element analysis implemented in the SAP2000 software package. The main objective of this project is to simulate this structure and make an assessment of the critical component of the bridge.

5. Proposed Bridge

The most popular type of railway bridge is made from single or multi-span simply supported plate girders. Here a proposed bridge is assumed to pass over conduit or valley as shown in Fig.1. the main bridge elements are shown in section Fig. 2 and 3D-view Fig. 3.

Figure 1: Proposed Railway Multi-Span Bridge

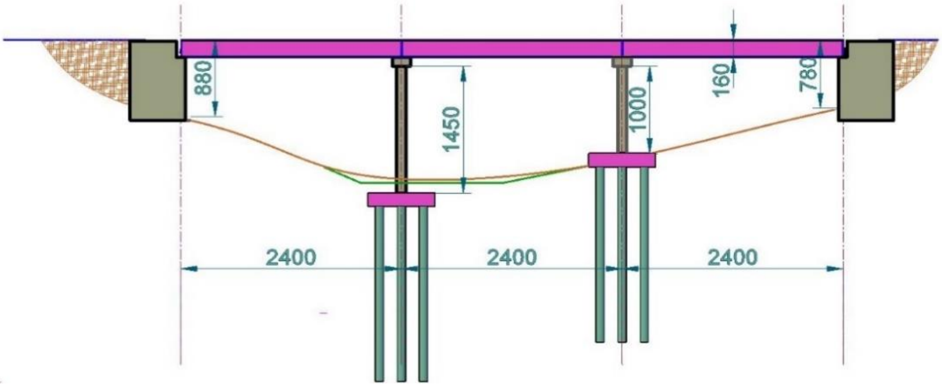


Figure 2: Bridge Cross Section (without Ballast Layer)

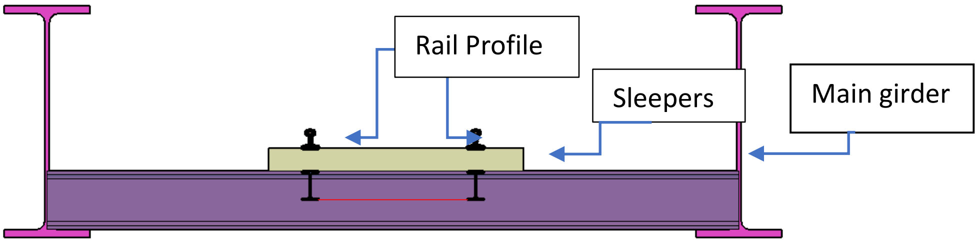
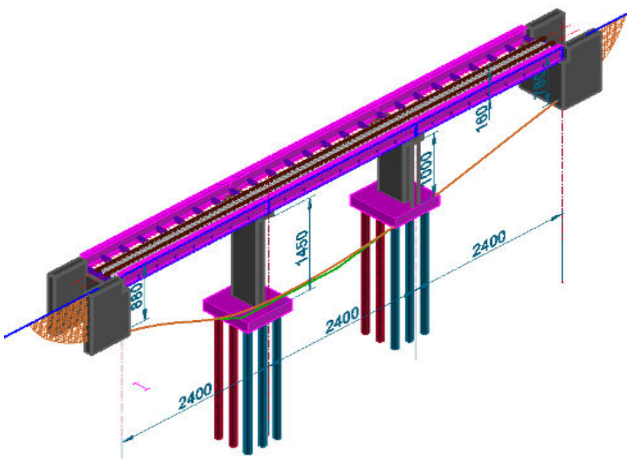


Figure 3: Three-dimensional view of bridge and girder



6. Finite element modeling

The proposed bridge, designed by SAP2000 software (SAP2000 V22, 2020), is used to create a three-dimensional finite element model of a steel bridge. Main girders, stringers, and floor Beams are modeled by 3d frame elements having three translational degrees of freedom (DOFs) and three rotational DOFs at each node. Ballaster casing is modeled by shell elements. Also, concrete piers and cross beams are modeled by solid elements. Expansion joints between multi-span are modeled utilizing rigid springs and constrained boundary conditions. To reflect the different sections of the longitudinal Main girders and transverse floor beams, grid lines are constructed and insertion point options with rigid bodies are considered (Altunisik & Bayraktar, 2014).

6.1 Material properties

The material properties are assumed according to the available materials at the construction markets. These properties are given in Tab.1.

Table 1: SAP2000 material properties for finite element analysis (Altunisik & Bayraktar, 2014)

Member	Modulus of elasticity, kN/mm^2	Failure stress limit, N/mm^2	Poisson's ratio	Mass density, kg/m^3
Main Girder	210	$F_y = 350$	0.3	7850
Floor beams	210	$F_y=275$	0.3	7850
Stringers	210	$F_y=275$	0.3	7850
cross beams	26	$f_c' = 30$	0.2	2400
Piers (columns)	26	$f_c' = 30$	0.2	2400

To make the study easier, a finite element model of the bridge with one simple span was presented first. The full model of a multi-span bridge would be presented later for earthquake analysis.

6.2 Geometry and section properties.

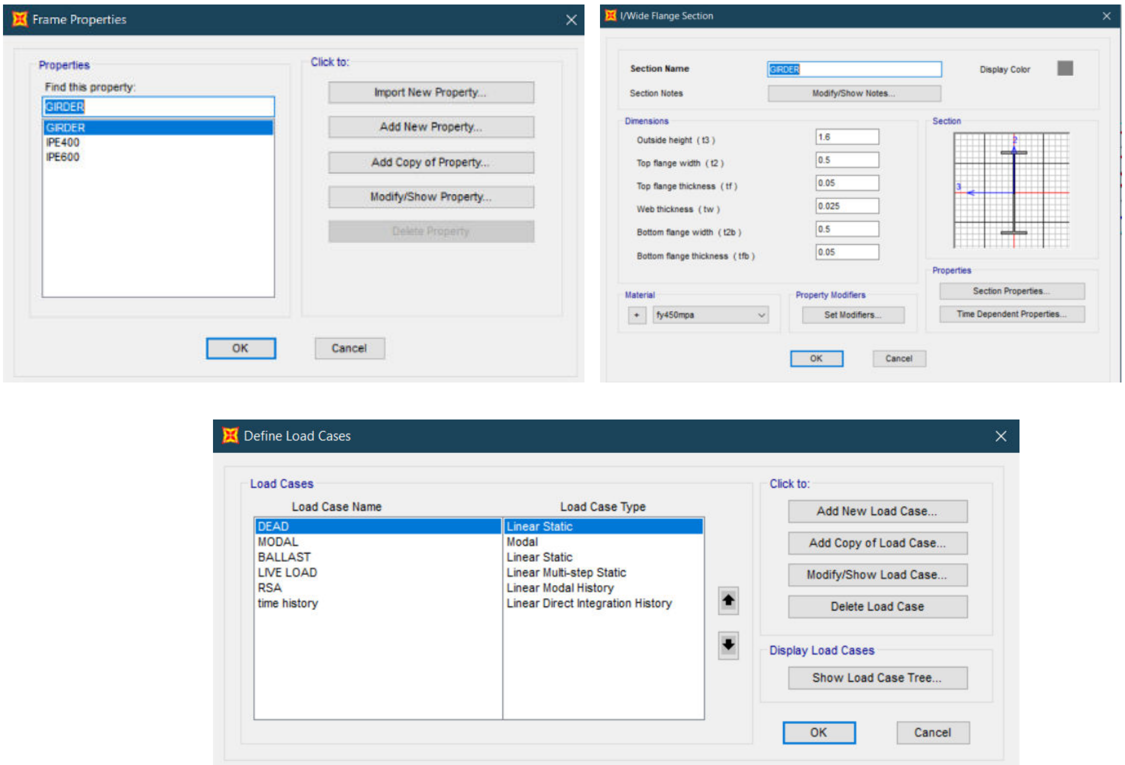
The geometry and section properties of the main bridge components are listed in Tab.2 and Fig. 4.

Table 2: Geometry and section properties

Member	**Section**	**Element**
Main Girder	Plate Girder	3D Frame Element
	$b_f = 500mm, t_f = 50mm$	
	$h = 1600mm, t_w = 25mm$	
Floor beams	IPE 600	Beam Element
Stringers	IPE 400	Beam Element

cross beams	$2 \times 1 \times 6$	Solid Element
Piers (columns)	$1 \times 4 \times (14.5,10)$	Solid Element
Pile cup	$7.2 \times 7.2 \times 1.5$	Solid Element
Abutment	$1 \times 6 \times (8.8,7.8)$	Solid Element

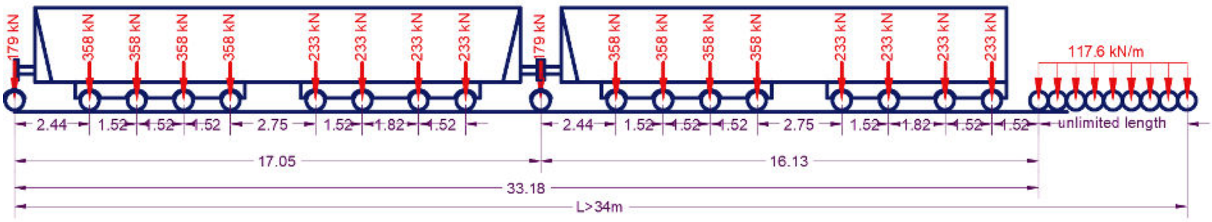
Figure 4: Material properties, such as the grades of concrete and steel & load cases



6.3 Design Live Load Trucks

For studies depending on field investigations, information about the train passing through the bridge could be measured through the wheel weight and lateral pressure measuring device installed on the rail. While the theoretical studies or for design purposes, the live load information of the truck has been presented by many international specifications. Here, the following idealization of truck loading will be adopted from AREMA specifications, this live load is presented in SI units as shown in Fig. 5 (Rakoczy & Nowak, 2018).

Figure 5: Live load on Railway Bridge according to AREMA (AREMA, 2006)

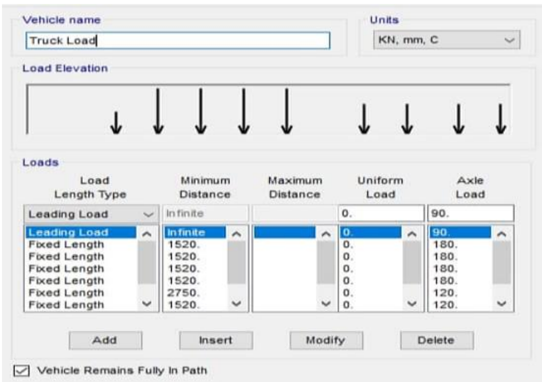


This truckload is simulated in SAP2000 as a moving load passing through the pathways of two rail profile sections. Fig.6 depicts one path with 50% of the axile live load. In this study, the speed of the train is limited to be not more than 250 km/hrs. In order to simulate the live load as quasi-static load.

Load cases were then created in line with applicable design rules, taking into account dead loads, live loads, and environmental conditions like as wind and seismic pressures. To guarantee accuracy in the study, we created a revised mesh and chose element types and sizes depending on convergence criteria. The study was carried out using linear static with a focus on damping parameters for dynamic assessment.

Following the study, we confirmed the results by comparing them to existing literature and experimental data, assuring the correctness and trustworthiness of our conclusions. This complete method not only satisfies the study goals, but it also provides useful insights into the structural behavior of railway bridges under certain situations.

Figure 6: Presenting half the Truck Live load in SAP2000



6.4 Earthquake Simulation

As a result, in bridge design and study, only horizontal earthquake ground motion is taken into account. The model earthquake in sap 2000 (ASCE7-16) is taken into account throughout the analysis (Yılmaz & Çaglayan, 2017).

6.4.1 Seismic Analysis Methodology

Several structural, dynamic equations can be addressed through many methods, that are suitable for SDOF, and MDOF as well as for separate, and continuous systems. These methods are classified as follows:

I. Analyses of Time Domain
   a. An exact solution to the differential equation. (For simple problems)
   b. Duhamel Integral.
   c. Methods of direct integration.
   d. Modal overlay.
II. Analyses of Frequency Domain
   a. FFT (Fast Fourier transform) is using for the analysis of the frequency field.
   b. The principle of random vibration is using to analyze the frequency field spectrum.
   c. Spectral response analysis.
III. Methods of approximate
   a. The equivalent static side loads are based on spectral response analysis.
   b. Equivalent basal shearing method.

7. Results of analysis

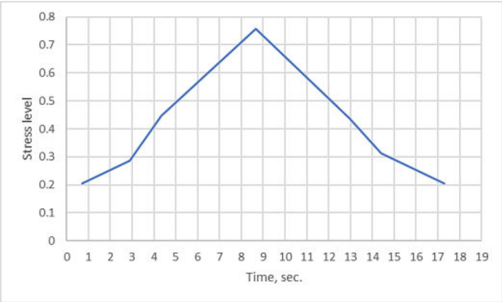
7.1 Static Moving Load Analysis

After conducting the finite element analysis implemented in the SAP2000 software package including the effect of moving load of a train track with a speed of 120km/hr (33.3 m/s), the following results were obtained.

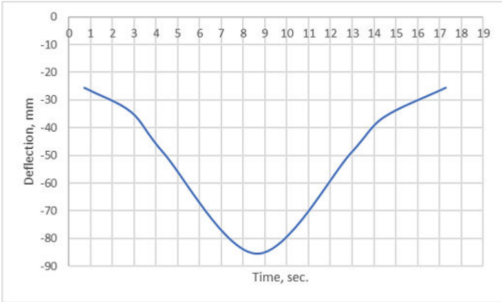
7.1.1 Stresses and deformed shapes of the main girder

A step-by-step finite element result displays the state of stresses and deformations for each component of the bridge during the passage of a vehicle on the proposed girder. Fig.7.a, Fig.7.b, and Fig.8, depicts the maximum stresses and deflection for each phase, which are listed in Tab.3 below. As a result of these findings, it can be concluded that the maximum deflection will grow as the truck passes over the bridge. Maximum deflection occurs towards the mid-span.

Figure 7.The variation with time due to the passage of the train



a: The variation of stress level with time



b : The variation of deflection with time

Table 3: maximum stress variation with a time step of track loading

Load step	Time, sec.	Maximum stress in girder due to ultimate load, N/mm^2.	Stress Level, $\left(\frac{\sigma_{11}}{F_y}\right)$	Maximum deflection due to serves load, mm
1	0.721	71.637	0.205	25.686
4	2.883	100.15	0.286	34.516
6	4.326	156.539	0.447	48.866
12	8.652	264.968	0.757	85.416
18	12.978	152.75	0.436	48.946
20	14.42	109.51	0.313	36.512
24	17.304	71.64	0.205	25.679

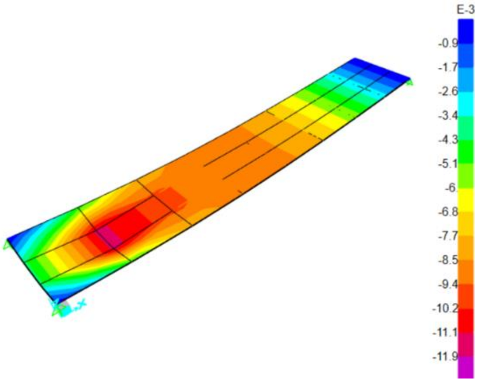
7.1.2 Mode shapes

One of the advantages of the finite element approach is that it can be used to determine the mode shapes of a structure by addressing the eigenvalue problem.

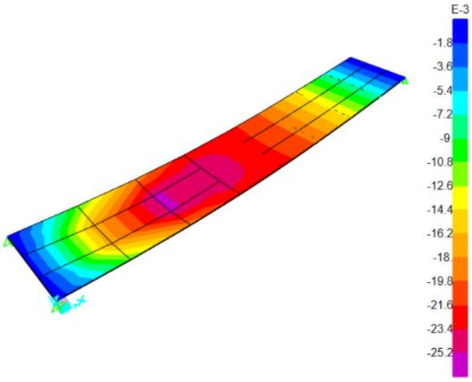
$$[K] - \omega^2[M] = 0 \quad (2)$$

Here the superstructure of the bridge comprising the main girder, floor beams, and strangers has the following mode shapes listed in Tab.4, and their mode shapes are shown in Fig.9. notes that the lowest value is the most dominant frequency which is known as the fundamental frequency.

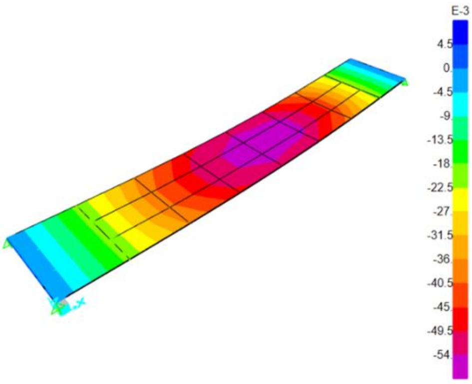
Figure 8: 3D Deformed Shape due to Ultimate Load



Step 4 3D deflection



Step 6 3D deflection

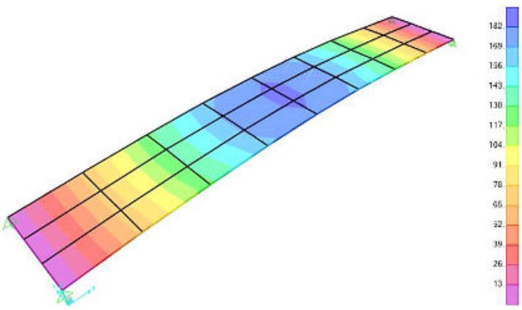


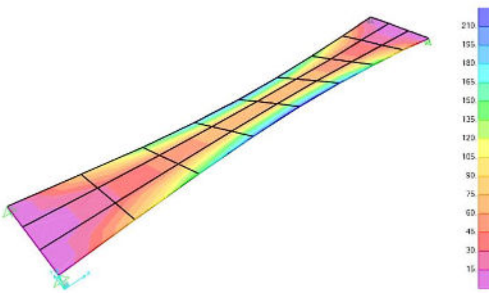
Step 12 3D deflection

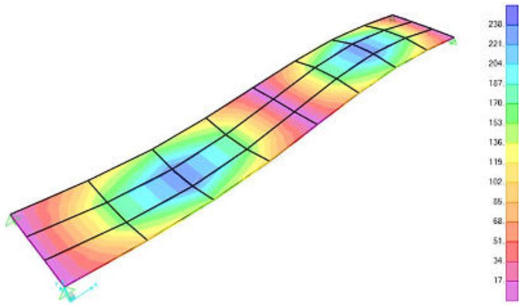
Table 4: mode shapes and frequencies of the bridge superstructure

Mode shape	Natural period, sec. (T)	Frequency, Hz.
1	0.172	5.797
2	0.145	6.907
3	0.049	20.367
4	0.038	26.18
5	0.033	29.985

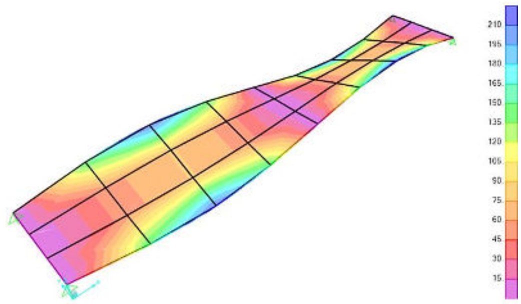
Figure 9: Mode shapes with time and frequency


Mode 1


Mode 2



Mode 3



Mode 4

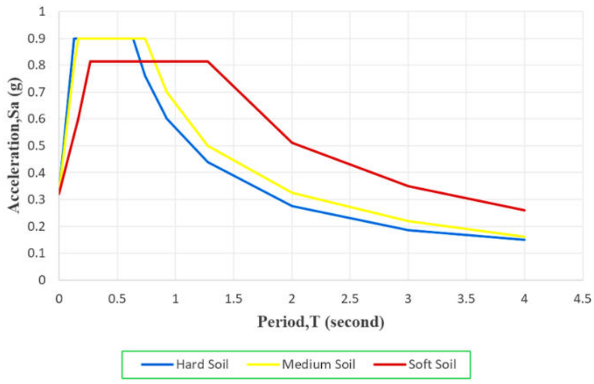
7.2 Seismic analysis

The SAP2000 software package has the ability to analyze structures subjected to the earthquake by one of the following analysis methods, the following results were obtained.

7.2.1 Response Spectrum

The responses of the bridge structural models were determined using a modal response spectrum analysis (displacement, velocity, and acceleration). To represent seismic loading, a seismic response spectrum was utilized, which depicts the relationship between the design value of Structure Acceleration (Sa) and the period of free vibration (T) of the structure. Depending on the type of soil and the location of the earthquake. The variations in the Sa vs. T plot are depicted in Fig.10 (Suryanita et al, 2017). Also, the seismic properties of different soil types are listed in Tab.5.

Figure 10: seismic response spectrum structure acceleration vs free vibration

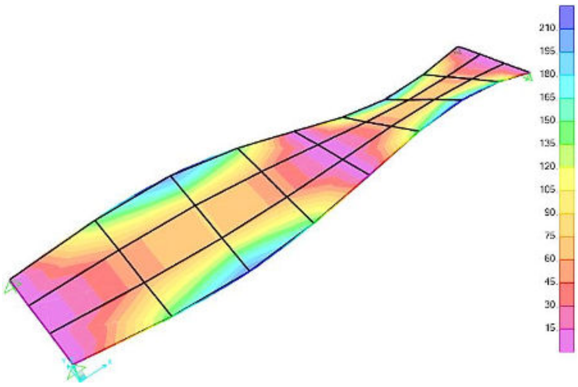


The influence of site location and soil type is first investigated, with the results presented in Tab.6 It may be observed from this Table that soil C has a greater effect. Also, the stress level gives an indication of the safety of the bridge during an earthquake here it is not exceeded one (≤ 1). Fig.11 depicts the spectrum analysis mode shape.

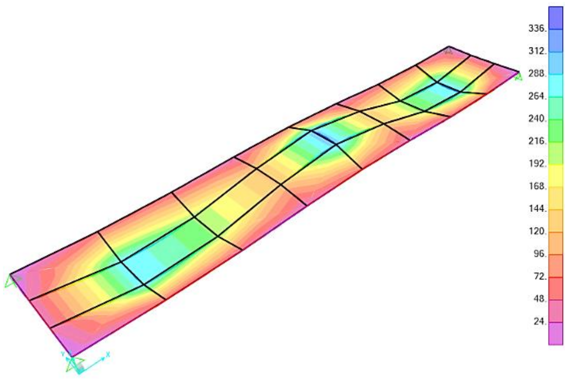
Table 5: Classification of soil profile types for seismic amplification (ASCE 7-22, 2022), (Thitimakorn & Raenak, 2016)

Soil type	Soil Designation	shear wave velocity V_{s30}, (m/s) *
A	Hard rock	> 1500
B	Rock	$760 < V_s \leq 1500$
C	Very dense soil and soft rock	$360 < V_s \leq 760$
D	Stiff soil	$180 < V_s \leq 360$
E	Soft clay	$V_s \leq 180$
F	Soils that need to be evaluated on a site basis	
* The top 30 m of a site's soil profile's average shear wave velocity.		

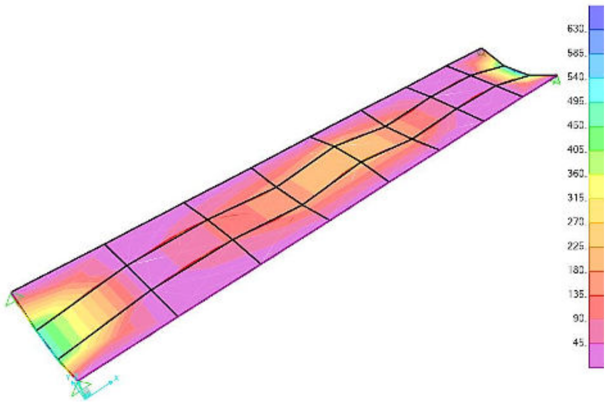
Figure 11: Spectrum Analysis Mode Shape



Mode 4 spectrum analysis at 0.05 sec



Mode 6 spectrum analysis at 0.04 sec



Mode 12 spectrum analysis at 0.03 sec

Typically, the structural designer assumes the intermediate piers to be of comparable stiffness and bases the bridge design on the main spans. However, because of the haphazard nature of the terrain, these piers have bases of different soil types. Because earthquakes travel through these piers, the rigidity of the piers bases affects how strong the earthquake is. These waves may disperse via piers rested on soft soil or move swiftly through piers on stiff soil. The multi-span bridge will react differently as a result, which calls for careful investigation. To illustrate the magnitude of the impact of this difference of soil type on the bases of the bridge piers, one of these cases is used in this study. Three types of soil have been studied herein.

Table 6: spectrum analysis results for soil type

Soil type	Max stress	Stress level	Max deflection	Total deflection	percentage increase in deflection	percentage increase in stress
	264.968	0.757	85.416	85.416	0	0%
A	48.41	0.895	23.19	108.606	27.15%	18.27%
B	54.47	0.913	26.09	111.506	30.54%	20.56%
C	72.59	0.964	34.79	120.206	**40.73%**	**27.40%**

There are a number of significant ramifications if soil type C has a greater percentage increase in stress. Because of its increased density, lesser stiffness, or greater compaction, which alters the way forces are transferred from the structure into the soil, this soil probably has properties that cause larger stress concentrations in the bridge piers during seismic events. Elevated stress levels may compromise the bridge's structural soundness, resulting in possible collapse or damage like cracking or buckling, which would raise safety issues. Engineers must also take these increased stress levels into consideration while designing, which may include the use of stronger materials, the reinforcement of piers and connections, or the modification of foundation geometry to better distribute loads. Additionally, since engineers would need to keep an eye out for indications of distress over time, the increased stress may call for more regular inspections and maintenance procedures. This situation could also point to poor seismic performance, necessitating the inclusion of safety precautions or the use of retrofitting techniques. It is crucial to accurately calculate the structural reaction to seismic stress, which calls for sophisticated analytical techniques to forecast the bridge's behavior in soil C. It could be essential to investigate mitigation strategies, such as installing base isolation devices to lessen pressures communicated to the building or improving foundation designs to better control loads, if this soil regularly causes greater stress. A greater percentage rise in stress in soil C highlights the vital need of giving bridge design and analysis considerable thought in order to preserve structural integrity and guarantee safety in seismically active places.

A number of important ramifications and factors come into play if soil type C has a larger percentage increase in deflection. Soil C probably has characteristics like lesser stiffness, higher compressibility, or increased liquefaction susceptibility that lead to more deflection under seismic stress. This means that during an earthquake, bridge piers on this kind of soil will move more than those on tougher soils. This larger deflection suggests that the bridge would react to seismic forces more strongly, which might put more strain on structural components and raise the possibility of damage or collapse if these circumstances are not sufficiently taken into consideration in the design. The effects of soil C must be taken into account by engineers when designing bridges. This may entail making the piers larger or more reinforced, using flexible design techniques or expansion joints to allow for more movement, and taking base isolation methods into account to lessen the seismic forces that are transferred to the superstructure. The bridge's serviceability and safety may also be jeopardized by the increased deflection, requiring more regular maintenance and inspections or maybe modification to guarantee continued safety. In order to anticipate performance during earthquakes, it may be necessary to use sophisticated simulation methods to accurately analyze the behavior of the bridge under seismic stresses, taking into account the unique characteristics of soil C. It could be essential to investigate mitigating options, such as soil stabilization procedures or alternate foundation designs that can better withstand seismic demands, if soil C routinely results in larger deflections. A greater percentage increase in deflection in soil C highlights the need of giving careful thought to bridge design and analytical procedures, especially in seismically active regions, as resolving these issues is essential to guaranteeing structural integrity and safety.

7.2.2 Time History Assessments

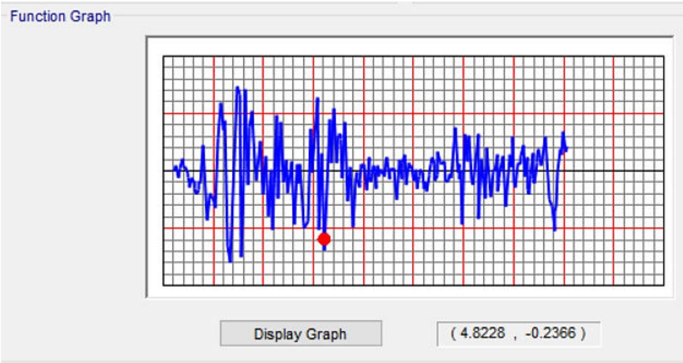
The dynamic behavior of the railway bridge has been investigated, primarily in response to seismic activities, as well as time histories of the soil-structure models. A simplified model of a railway bridge is used to organize the analysis. Now, the proposed Railway Bridge is utilized to set up the finite element model by taking into consideration the suitable boundary conditions for the multi-span bridge considered in this study. In seismic analysis, an earthquake is defined as input motion or acceleration randomly varied with time. the well-known El Centro earthquake response as shown in Fig.12 has been considered. The damping factor for steel bridge constructions may be considered to be 5% of the mass matrix, see Tab.7.

Table 7: Damping factor for bridge constructions (Xia & Zhang, 2005)

Type of bridge	ζ Lower percentage Damping ratio [%]	
	$When$ span $L < 20$	Span $L \geq 20$
Steel and steel-concrete (composite) structures	$\zeta = 0.5 + 0.125\ (20 - L)$	$\zeta = 0.5$

The analysis starts from zero initial conditions with an unstressed state (no initial displacement and velocity). Linear analyses with trainset history (i.e., damping is neglected for the worst condition). Direct integration numerical method with a number of time steps (N= 600), and time increment of 0.02 seconds. Only the vertical and lateral excitations are considered here. the stiffness and mass matrices of all elements are considered.

Figure 12: El Centro Earthquake



Now, the displacement, velocity, and acceleration in the time domain can be presented to any part of the bridge, also the forces and the corresponding stresses (Fig.13 and Fig.14). Here the structure mass (self-weight) is the main part of the mass matrix. As a parametric study, the influence of the ballast layer is studied. Fig.15 shows the effect of this layer. From this study, the excitation response of the bridge is affected mainly by the supper structure mass rather than the secondary parts such as the ballast layer. That is mean this layer has a small effect on the frequencies of the bridge. These results underscore the importance of considering soil-structure interaction in seismic design. By understanding how different soil types influence bridge behavior, engineers can better anticipate potential failures and implement effective mitigation strategies. This research contributes to the field by providing empirical data that can inform future design guidelines and enhance the resilience of bridge infrastructures in earthquake-prone regions. By proving that the bridge remains safe under earthquake circumstances, the research reassures engineers and stakeholders about the proposed design's feasibility in seismically prone locations. Furthermore, the density and angularity of the materials used in the ballast layer may impact the layer's capacity to sustain seismic forces. Overall, studying the role of the ballast layer in earthquake scenarios should provide significant insights into design concepts for enhancing infrastructure resilience in seismically active place.

Figure 13: Plot function trace time history & modal damping (Yang et al, 2016), (Faizan & Kirtel, 2016)

Figure 14: multi-span bridge

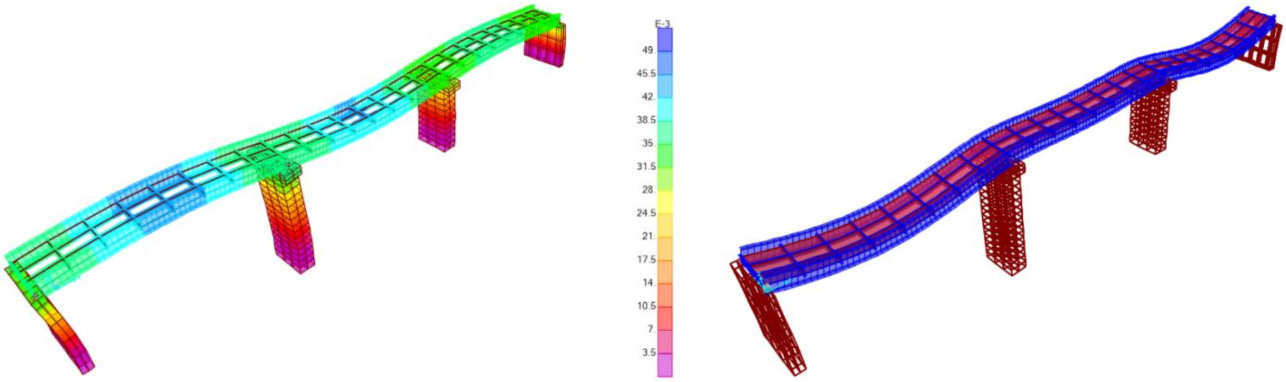
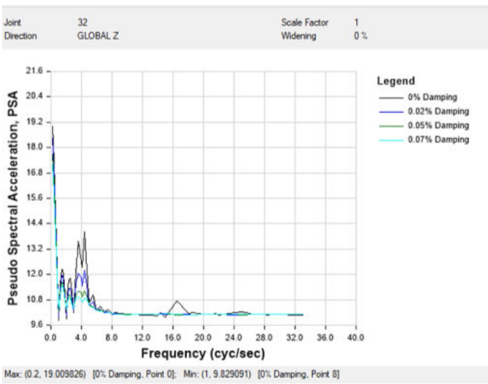
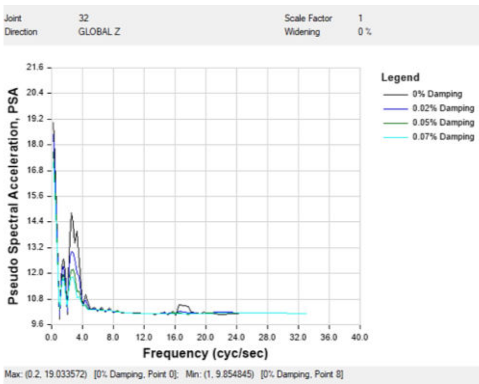


Figure 15: Response spectrum curves considering the effect of the ballast layer (Ling-kun et al, 2014)



Time history with ballast



Time history without ballast

8. Conclusion

This research delves deeply into the structural behavior of a railway bridge constructed for seismically active zones, adding to our knowledge of how such bridges may be properly manufactured to resist seismic stresses. The study starts with a detailed characterization of the key components of the proposed railway bridge, which provides a clear foundation for comprehending the structural elements involved in the design. A three-span bridge design with different pier heights is offered, demonstrating a customized way to bridging deep conduits. This design not only meets the AREMA criteria, but it also prioritizes realistic technical solutions for difficult terrains. The use of SAP2000 software for finite element modeling makes a major methodological advance by simulating the bridge's behavior under changing loads and during seismic occurrences.

Important information about structural design and safety may be gained by examining the effects of various soil types on bridge pier behavior during seismic events. When subjected to seismic loads, piers built on soft soil show more deformation and less stiffness, which increases energy dissipation but may also cause more substantial movement of the structure. Piers on medium-soil, on the other hand, provide a compromise between rigidity and pliability, efficiently transferring seismic forces while allowing some movement to lessen stress concentrations. Because piers on stiff terrain are more rigid and move less when subjected to seismic pressures, seismic waves travel faster and apply more stresses to the structure. Overall stability is impacted by differential settlement and lateral movement of the bridge piers caused by variations in soil stiffness. Uneven reactions may cause torsional effects in bridges with diverse soil types, and design assumptions that assume all piers as having the same stiffness may understate the seismic demands on those constructed on soft soil, which might result in failures. Therefore, to manage greater displacements and stresses during an earthquake, bridges with piers on soft soil would need more reinforcing or other design techniques. The research highlights the need of including soil variability into seismic design codes and conducting site-specific soil studies. The performance of piers on soft soil may be improved by using dampers or base isolation methods, and structural engineers should do dynamic studies that take into consideration the particular qualities of each kind of soil. All things considered, the results demonstrate how crucial soil conditions are to the seismic performance of bridge structures, emphasizing how crucial it is to comprehend these relationships in order to guarantee the durability and safety of multi-span bridges in seismically active regions. In order to increase resistance against seismic pressures, future research should concentrate on improving prediction models and investigating creative design options. The reaction of bridge piers to earthquakes is greatly influenced by the kinds of soil, which calls for meticulous design considerations and assessments to guarantee structural integrity and safety.

1. Future studies could compare the proposed design with other bridge configurations (e.g., arch bridges or cable-stayed bridges) to evaluate their relative seismic performance and practicality in similar contexts.

2. Investigating the application of new materials or advanced construction techniques (e.g., fiber-reinforced polymers or smart materials) could enhance the seismic resilience and lifespan of railway bridges.
3. Future research could utilize real-time monitoring technologies to assess the immediate response of railway bridges during seismic events, facilitating the development of adaptive design strategies based on live data.

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