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"SEISMIC ZONE-BASED DYNAMIC ANALYSIS OF TUNNEL STRUCTURES USING ADVANCED MATERIALS AND SIMULATION TECHNIQUES"

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Abstract: The tunnel structures are subjected to heavy seismic excitations which may cause damage to tunnel linings and its wall. The objective of current research is to evaluate the structural characteristics of tunnel structure subjected to seismic excitations. The seismic excitation is applied to the structure using harmonic response analysis system. The modelling and seismic analysis of tunnel structure is conducted using ANSYS software. Frequencies with significantly elevated response amplitudes, such as 30 Hz and 90 Hz, indicate potential resonance points where the tunnel structure may experience heightened stress concentrations, increasing the risk of failure and crack initiation.

Keywords: *Tunnel, Seismic Analysis*

INTRODUCTION:

Seismic analysis involves evaluating how the tunnel reacts to the shaking caused by an earthquake. This study focuses on the transmission of seismic disturbances through the earth and the interaction between tunnel construction and the surrounding soil. Often, in order to predict the displacement, acceleration, and velocity of a tunnel structure over time, dynamic response analysis involves solving differential equations of motion. Seismic events have a significant impact on the behavior of the tunnel, which is influenced by the characteristics of the neighboring sediment. The theory of soil-structure interaction explores the effects of the tunnel's dynamic behavior on the properties of the soil, including inertial, damping, and stiffness properties. The complex interactions between different factors, such as lateral spreading, soil liquefaction, and ground motion amplification, can lead to intricate mechanisms that impact the performance of tunnel construction.

2. LITERATURE REVIEW

Karakus et. al. [1] investigated different strategies for building the Semmering Base Tunnel in Austria using FLAC2D. The study aimed to develop a construction approach and auxiliary infrastructure that would minimize tunnel displacements while ensuring compatibility with the fault system. To assess the geological characteristics of the Graßberg-Schlagl fault system, which played a crucial role in the construction of this tunnel, core samples underwent triaxial compression analyses. The results of a single specimen's triaxial compression test were examined using the finite element program ZSoil. The study utilized both the M-C constitutive law and the Hardening Soil (HS) – Small Strain constitutive law to determine the suitability of a nonlinear analysis.

Cigla et. al. [2] After a thorough examination of the advantages of using the HS model in ZSoil compared to the M-C model, reached the conclusion that, within the realm of finite element analysis, the HS model provides superior accuracy. The soil exhibits complete elasticity only under very low stresses. As a result, the linear-elastic M-C model may not always provide accurate and practical predictions when used in finite element analysis. The HSStandard Model accurately reproduces key macroscopic phenomena observed in soils, including plastic yielding, densification, stress-dependent rigidity, soil stress history, and dilatancy. In addition, the soil's non-linear behavior before failure is taken into account. In addition, the HS-Small Strain model, an enhanced version of the previous model, considers significant variations in rigidity and the hysteresis, which refers to the non-linear elastic stress-strain relationship of the soil.

Ghee et. al. [3] conducted a finite element analysis using ABAQUS software to assess the impact of fault dislocation on a tunnel. The model consisted of bedrock, a concrete liner, and fault-fractured zones. A simulation was conducted using ABAQUS to model the vertical movement of the upper plate (representing the suspended wall) and lower plate (representing the foot wall) in a thrust fault with reverse thrusting. The displacement used in the simulation was 0.5 meters. To replicate the vertical displacement of the fault, a displacement was applied to the upper plate while keeping the lower plate stationary. The upper and lower plates, soil, and tunnel lining were all equipped with surfaces designed to create frictional contact. In the context of this research model, it was determined that both the tunnel and the sediment were ideal elastic-plastic materials. The research utilized the relevant flow rule and the Drucker-Prager yield criterion to evaluate the impact of hydrostatic pressure and primary stresses on soil yielding.

Hejazi et. al. [4] utilized the MASW component to gain a clearer understanding of the soil layer characteristics at various depths. MASW is used to analyze the behavior of soil and embankments. This paper presents the methodology used to analyze soil characteristics in various soil strata in and around Bangalore. The study focuses on parameters such as density, Poisson's ratio, and Young's modulus, and utilizes Multichannel Analysis of Surface Waves. The SURFSEIS software is used to digitize the Rayleigh surface waves generated in the area, which helps determine the soil characteristics of the site.

Hitoshi et. Al. [5] provided a comprehensive analysis of the topography, groundwater level, hard rock depth, and tunnel alignment for the east-west segment of the metro train project. The article examines the potential impact of the aquifer system on the proposed metro conduit. Based on the study's findings, it has been determined that the groundwater table is located approximately five meters below the surface. The factor mentioned above will have a significant impact on the strain experienced by the underground conduit.

Mollon et. al. [6] An exploratory approach, based on probability, was utilized to investigate the integrity of the tunnel's active front. The investigation utilized the collocation-based random response surface technique (RSM) along with a two-dimensional (2D) multiblock failure mechanism. The Face Overburden Reinforcement Method (FORM) was implemented in the design of the circular tunnel to ensure the integrity of the tunnel face. The procedure should include additional stochastic input components such as soil shear resistance, unit mass, depth of covering, and pressure of support.

Wang et al. [7] conducted an investigation into the fault crossing theories that are applicable to twin shield tunnels in Turkey. The main objective of these tunnels is to facilitate the construction of the Bolu Tunnel, which passes through the Bakacak and Zekidai faults. A comprehensive seismic investigation was conducted in the vicinity of the Bolu Tunnel project in response to the 1999 Düzce earthquake (MW = 7.2). The evaluation of the two issues under investigation was enhanced through the implementation of this research. The tunnel descends at an inclination of nearly 90 degrees, crossing the two channels of the Zekidai Fault. It covers a distance ranging from 25 to 30 meters (82 to 98 ft). The expected horizontal displacement of the fault due to a seismic event with a magnitude of 6.25 to 6.25 is estimated to range from 0.15 to 0.25 meters (5.91 to 9.84 inches). However, the probability of the fissure experiencing another rupture in the future is considered extremely low. The Bakacak Fault is traversed by a tunnel that has a length of 100 meters (328 feet) and a slope of 40 degrees. The expected outcome of an earthquake with a magnitude ranging from 6.25 to 6.5 on the moment magnitude scale is the displacement of the fault line by no more than 0.5 meters (19.69 inches). The Zekidai Fault was expected to cause a higher number of unexpected displacements, while the Bakacak Fault was predicted to mainly cause scattered horizontal displacements. As a result, it has been proven that this hypothesis is indeed accurate. The shear strain in the soil fault was calculated by dividing the anticipated offset by the width of the fault at the tunnel level, as per the previously mentioned initial assumption. The soil contact elements and tunnel lining were utilized in combination with Mohr Coulomb (M C) compressive springs in order to replicate the behavior of the soil.

Pan et. al. [8] The objective of the investigation was to determine the most effective construction method and support structure for the Austrian Semmering Base Tunnel. The goal was to achieve tunnel displacements that are consistent with faults. The FLAC2D software is widely used in the investigation. A series of triaxial compression experiments were performed on core samples in order to determine the geological characteristics of the Graßberg-Schlagl fault system, which was chosen as the location for the construction of the tunnel. The ZSoil finite element software was utilized to retrospectively calculate the outcomes of a triaxial compression test performed on a solitary sample to determine the suitability of a nonlinear analysis. The calculations utilized both the M-C and the Hardening Soil (HS) - Small Strain constitutive models.

Zuo et. al. [9] The HS model has been identified as the most accurate method for conducting finite element analysis. The linear-elastic M-C model, commonly used in Finite Element Analysis (FEA), often lacks accuracy and realism due to the limited elasticity of the Earth under minimal loads. The HS Standard Model accurately replicates essential physical soil processes, such as dilatancy, stress-dependent rigidity, antecedent soil stress, and plastic yielding. The technique incorporates the consideration of non-linearities in soil dynamics that manifest before collapse. The revised HS-Small Strain model includes the mentioned procedures to consider substantial variations in soil rigidity and the corresponding non-linear, hysteretic, elastic stress-strain correlation.

Cape et al. [10] employ the Multichannel Analysis of Surface Waves (MASW) technique to analyze the variations in the soil stratum at various depths. Researchers employ the Multichannel Analysis of Surface Waves (MASW) technique to investigate the properties and behavior of banks and soil. This article presents a methodology for evaluating the density, Poisson's ratio, and Young's modulus of different soil layers in and around Bangalore. The assessment is conducted through a thorough analysis of surface waves using multiple channels

3. OBJECTIVES

The objective of current research is to evaluate the structural characteristics of tunnel structure subjected to seismic excitations. The seismic excitation is applied to the structure using harmonic response analysis system. The modelling and seismic analysis of tunnel structure is conducted using ANSYS software.

4. METHODOLOGY

The seismic analysis is conducted on tunnel structure developed in design modeller of ANSYS software. The developed model of tunnel structure is shown in figure 1:

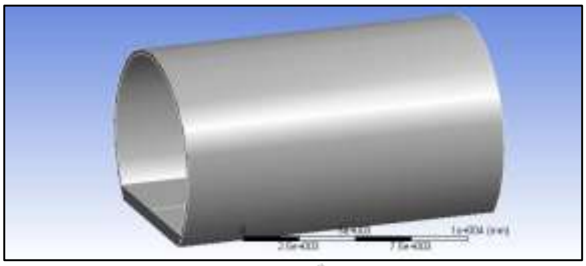

Figure 1: Tunnel design

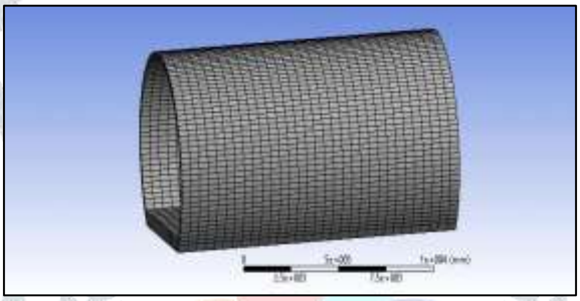

Figure 2: Tunnel meshed model

After modelling, the tunnel design is meshed using hexahedral element type. The hexahedral element type has 8 nodes with 3DOF/node. The tunnel model is meshed using fine element sizing and normal inflation. The meshed model of tunnel is shown in figure 2.

Figure 3: Boundary condition

The structural boundary condition is applied on the tunnel. This base of the tunnel is applied with the fixed support and base excitation of 0.1g is applied to it. After applying boundary conditions, the simulation is run at different excitation frequencies ranging up to 100Hz.

5. RESULTS AND DISCUSSION

From the FEA simulation, the total deformation plot and equivalent stress plot is generated. The deformation plot in figure 4 shows zones of maximum deformation with magnitude of more than .000465m as represented by red colored zone. Some of the zones have lower deformation in the magnitude of 0.0031826m.

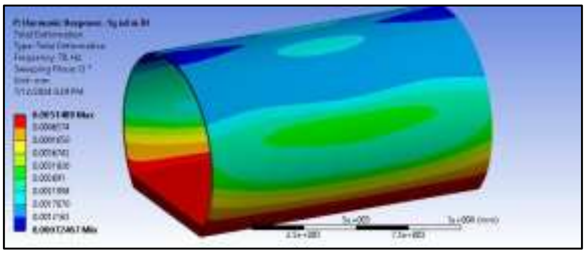

Figure 4: Deformation plot of tunnel

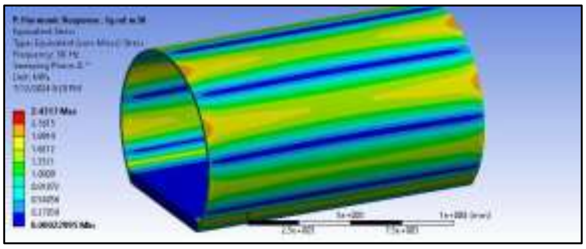

Figure 5: Equivalent stress plot on tunnel

The equivalent stress distribution plot is generated for tunnel as shown in figure 5 above. The maximum stress induced on the tunnel is 2.1615MPa at the corner and top roof of the tunnel which is represented by yellow and dark orange colored zones.

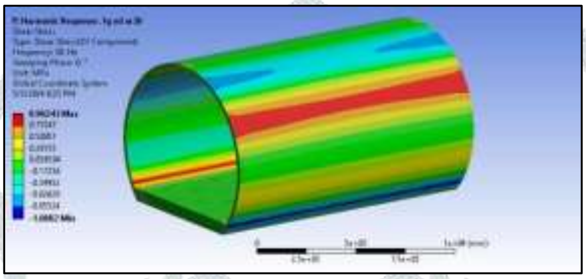

Figure 6: Shear stress plot on tunnel

The shear stress distribution plot of tunnel is generated as shown in figure 6 above. The plot shows zones of high shear stress at the bottom corner edge and at the roof of the tunnel which is represented by red colored zones. The magnitude of maximum shear stress induced in tunnel structure is 0.73547MPa.

6. CONCLUSION

The seismic response data, obtained through harmonic response analysis of the tunnel, provides crucial insights into its dynamic behavior under seismic loading conditions. The numerical values represent the amplitude of response at various frequencies, ranging from 1 to 100 Hertz. These values, expressed in scientific notation, illustrate the magnitude of vibration experienced by the tunnel structure at each frequency interval. Analyzing this data enables engineers to assess the tunnel's susceptibility to seismic forces and design appropriate mitigation measures to enhance its resilience and structural integrity.

1. Frequencies with significantly elevated response amplitudes, such as 30 Hz and 90 Hz, indicate potential resonance points where the tunnel structure may experience heightened stress concentrations, increasing the risk of failure and crack initiation.
2. Regions where the response amplitudes exhibit sudden spikes or peaks, particularly at frequencies corresponding to soil or structural resonances, suggest areas of localized vulnerability where cracks may propagate more readily.
3. Comparative analysis of response amplitudes across different regions of the tunnel can help identify sections that are disproportionately affected by seismic forces, guiding targeted reinforcement and monitoring efforts to mitigate the risk of failure and crack formation.
4. Understanding the frequency-dependent behavior of the tunnel structure enables engineers to prioritize maintenance and retrofitting strategies in regions with heightened susceptibility to failure and crack propagation, thereby enhancing overall safety and resilience.

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