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Investigating the Performance of Nonlinear Dynamic Analysis mechanisms of the Dam-Reservoir-Foundation System based on the Seismic Damage Level

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ABSTRACT: The purpose of the present research is to investigate the damage analysis mechanisms of the Dam-Reservoir-Foundation system using the Finite Element Method (FEM). The study focuses on the Koyna dam-reservoir-foundation system, which is a two-dimensional model that has been subjected to the horizontal and vertical components of ground acceleration in the Koyna earthquake using ABAQUS software and the Concrete Damage Plasticity (CDP) model. The comparison of models in linear and linear analysis shows that considering the bottom of the foundation for applying the load increases the seismic damage compared to applying the bottom of the dam. The results indicate that applying foundation excitation at the contact surface of the dam foundation in the condition of foundation without mass, as well as applying foundation excitation at the level of the rock foundation in the condition of massed foundation can lead to a more accurate prediction of the response of the structure during an earthquake. However, the level of seismic damage in the dam is greatly affected by how the base excitation is applied and the mechanism of the modeling Dam-Reservoir-Foundation system. Therefore, it is crucial to consider the correct application of base excitation and the modeling mechanism while analyzing the damage analysis of the Dam-Reservoir-Foundation system.

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1- Introduction

The construction of a complex operational dam is a time-consuming and expensive process, and the failure of this strategic structure can pose significant risks to both human life and the economy. Therefore, it is crucial to exercise extreme caution in the design and computer simulation of the dam both before and after construction.

This research aims to compare different computer models for nonlinear seismic analysis of concrete dams. By doing so, it seeks to identify the most accurate and reliable model for predicting the behavior of the dam under seismic loads.

In 2019, Kalateh and Gamtalo investigated the effect of near and far earthquakes on weighted concrete dams in terms of dam-reservoir-foundation-sediment interaction using Abaqus software. In 2022, Tarinejad *et al* applied the effects of alluvium and reservoir bottom sediments in the stress analysis of the dam, in addition to the dynamic effects of the reservoir. In 2021, Zainab *et al* studied the effect of reservoir height and level on the seismic response of weighted concrete dams using incremental dynamic analysis (IDA).

In another study conducted in 2022, Biju and Joseph estimated the maximum principal tensile stress, compressive stress, displacement, and acceleration for the analysis of concrete dam response functions under the load of the Koyna earthquake, considering different levels of the water reservoir.

The present research has three main goals. Firstly, to compare numerical models for estimating the level of seismic damage. Secondly, to investigate the impact of different dam modeling approaches, such as non-linear and linear models, considering massed or non-massed foundation, and the location of acceleration mapping, on the level of damage. Thirdly, to determine the closest numerical model to the physical model in terms of the damage level of the body and compare it with the results of the laboratory model and technical reports of the actual conditions of the Koyna.

Previous research has compared the effects of dynamic analysis type (linear-nonlinear) and foundation type (rigid foundation, massed or massless foundation), as well as the directions of foundation stimulation (horizontal, vertical, or a combination of the two) on the level of seismic damage of the weighted concrete dam. In this study, the effects of four components, including analysis type, foundation type, level of the applied load, and the direction of loading in different combinations on the damaged surface of the dam, have been studied.

2- Methodology

One of the fundamental parameters in the analysis of gravity dams is the appropriate definition of the numerical model for the dam body and foundation. In the current

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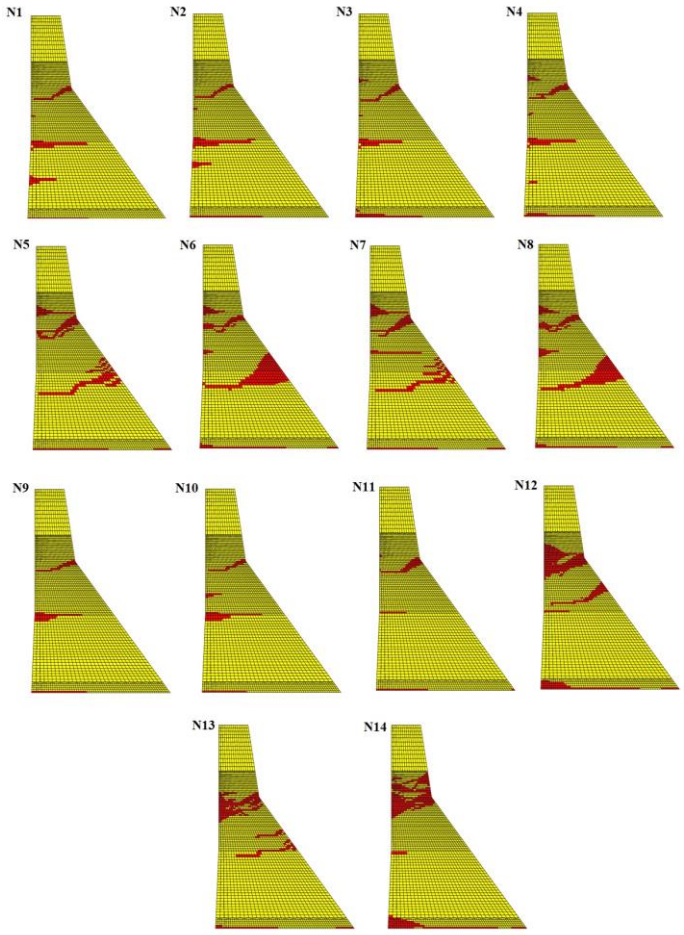

Fig. 1. Comparison of the level of damage and crack development in the concrete dam body in different earthquake action mechanisms resulting from the nonlinear dynamic analysis of the dam-reservoir-foundation system.

analysis, the dam body is assumed to have plane stress, and the plane strain conditions that are typically used in the dynamic analysis of concrete dam-reservoir-foundation systems have been applied to the foundation. This type of modeling, which considers the three-dimensional structure in a two-dimensional form, is applicable in gravity dam structures and foundations where the length of the dam crest is significant compared to the height of the dam.

In the Koyna Dam, the width of the valley is 853 meters, and the ratio of the height to the width of the valley is 8.28 and the foundation is rectangular with dimensions of 379.2 x 103 meters. The Koyna dam has a length of 923 meters and a height of 103 meters compared to the river bed. In the design, an earthquake coefficient of 0.02 was used uniformly in the height. Due to the poor-quality materials and unusual shape, the Koyna Dam is highly vulnerable to earthquakes.

3- Discussion and Results

In all models, damage is observed in three areas, N, M, and B, and by comparing the result with the validation model, it can be concluded that all models of nonlinear FE analysis are successful in detecting damage in the N region but have errors in estimating the damage in the M and B regions.

Among the mechanisms studied in the current research, model number N11 is more matches with the validation results compared to other outputs, as shown in Figure 1. In this model, nonlinear face analysis, simulation of the dam as a mass foundation, and the application of acceleration mapping at the lower level of the foundation, which is only subjected to an earthquake with a horizontal component, have been applied. This model provides the closest estimate to the model obtained from field and laboratory reports, and it is the mechanism that is closest to reality.

4- Conclusions

The results of the research indicate that in all three conditions of rigid foundation, without mass, and with mass, the difference in simultaneous application of the horizontal-vertical component is significant compared to the application of the horizontal component alone. The assumption of simplifying the earthquake frequency to the horizontal component creates a high error in the output of the model.

Comparing the application of the input load at the foundation level and the lower level of the dam shows that considering the lower part of the foundation to apply the load causes an increase in the damaged elements, and this effect can be observed in both the foundations without mass and with mass.

The comparison of the mechanisms obtained from the present study indicates that the failure in the N and M regions is more than in other parts. In general, the model that is most similar to the actual Koyna dam cracks is the nonlinear model with a massless foundation under an earthquake with a horizontal component and with the acceleration mapping location of the side level and the bottom level of the foundation. This model is in good agreement with reality.

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