SEISMIC DAMAGE EVALUATION OF REINFORCED CONCRETE TALL PIERS WITH CIRCULAR CROSS SECTION USING 3D LATTICE MODEL

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1. Introduction

Advances in concrete technology have enabled the development of more slender and efficient bridge designs, particularly those involving tall piers. However, the dynamic behavior of these tall piers under seismic loading differs significantly from that of shorter piers due to their increased flexibility and longer fundamental periods, which result in lower seismic spectral accelerations [1]. This can diminish the effectiveness of seismic isolation or high-ductility designs. This study introduces a 3D lattice model to simulate the nonlinear behavior of tall, reinforced concrete (RC) piers under earthquake loads, accounting for cracking, spalling, and reinforcement yielding. The model incorporates both arch and truss actions to represent the shear-resisting mechanism, using an orthogonal coordinate system and compressive struts to analyze dynamic loads [2].

2. Analytical program

For the analysis, the two hollowed circular cross-section tall piers were modeled in the 3D Lattice Model and then compared with a Finite Element Model (FEM) software. In the 3D Lattice Model, the two piers were modeled with a cross-section with the mass distributed along the height and the deck weight concentrated on the nodes on the top of the column. The first pier has a height (H) of 40 m and a circular hollow cross-section, with an external radius of 4.0 m and an internal radius of 3.2 m, deck mass of 1,180tons and the fundamental period for the first mode is 4.19 s. The second one was modeled from a squared cross section hollowed pier H of 60 m and a hollow square cross-section with dimensions 8.60 m×8.60 m, thickness of 2.55 m, but in this study, it was converted to a hollowed circular cross section pier with 9.20 m of diameter.

Based on the properties of the lattice model, where the truss and arch analogies are fundamental to the structural response, a more precise discretization of the target structure is modeled using 16 peripheral nodes arranged in a circular pattern, with a shared central core node for each given layer. The analytical diameters were made considering the equivalent moment of inertia for each pier as shown in **Fig. 1**.

A 3D dynamic analysis was performed to the understanding of the RC structure's behavior under cyclic loading by accounting for the actual input ground motion. The ground motion used input is the Kobe Earthquake E-Takatori ground motion, considering both 100% of it in the North-South (NS) and East-West (EW) load directions.

Furthermore, the 3D lattice model offers distinct advantages for understanding structural behavior at the material level. Its discrete characteristics, composed of truss and arch members, allow for the evaluation of each material individually, making it particularly useful for assessing damage propagation across the structure. A damage analysis was conducted for both piers under the aforementioned ground motion by applying an energy-based index. In addition, the first pier was evaluated under seven scale long ground motions.

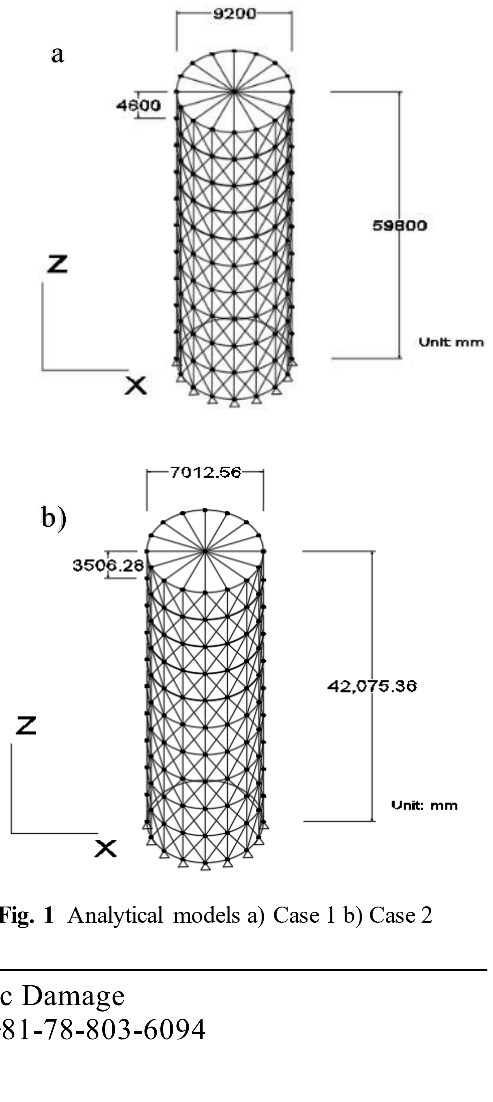

Fig. 1 Analytical models a) Case 1 b) Case 2

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3. Results

The discretization has been shown to satisfy the initial requirements for geometric identity between the analytical model and the actual target column compared to the FEM model by applying the Kobe Earthquake E-Takatori input motion. The differences between the two models can be explained mainly by the bigger mesh size in the FEM, that influences the responses, especially post-cracking (Fig. 2).

In the damage analysis, there was the observation that, under the given conditions, the damage potential is significantly higher in concrete than in steel reinforcement. Furthermore, they support the idea that the energy dissipation capacity of steel reinforcement plays a much more dominant role in the damage resistance of the column, owing to the higher ductility of the steel reinforcement.

For Case 1, the concrete presented a Seismic Performance II (SP-II), which means it suffered severe damage under the E-Takatori earthquake. On the other hand, the reinforcement ratio had a Seismic Performance I (SP-I), meaning moderate damage. Case 2 had SP-I for both materials, as illustrated in Table 1. Moreover, in Case 1, the base of the column plays a dominant role in absorbing and dissipating energy during seismic events, potentially leading to more localized damage at the pier's base. In contrast, Case 2 may exhibit a more distributed energy dissipation throughout the structure, with less concentration at the base.

For the scaled earthquake analysis, for the 7 scaled ground motions, the damage was distributed along the height of the pier, and that the degree of damage was more related to the earthquake velocity and displacement than to the acceleration.

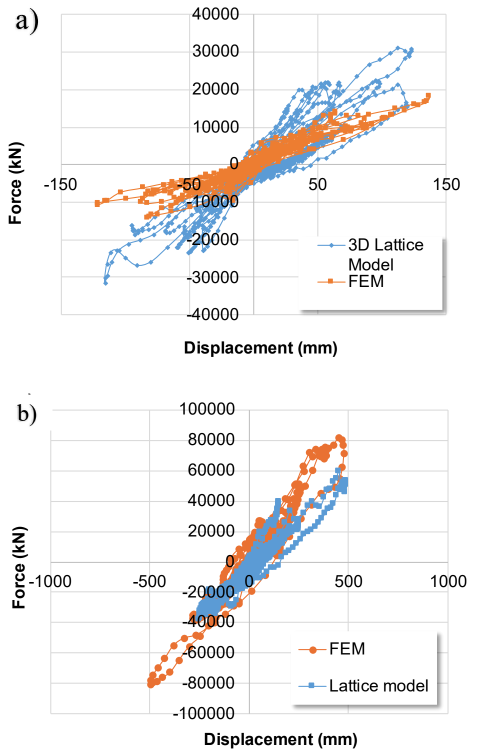

Fig. 2 Load-displacement relationship for a) Case 1 and b) Case 2 for E-Takatori ground motion at NS directions.

Table 1 Seismic performance verification

		Concrete		Steel	
		Case 1	Case 2	Case 1	Case 2
Energy dissipation kN.m	Accumulated	5,543	9,803.27	7.87	23.02
	Ultimate	14,160.34	65,298.13	539.08	2,844.6
CDP		0.2304	0.471	0.471	0.0145
Damage index		0.391	0.1501	0.1501	0.008
Seismic performance		SP-II	SP-I	SP-I	SP-I

4. Conclusions

In this study, the 3D lattice model was validated through a comparison with a FEM model, revealing discrepancies in load-displacement responses due to differences in discretization methods. Dynamic analysis, incorporating scaled ground motions, further explores the seismic response of these structures. Damage assessment, based on strain energy, identifies critical damage zones, with the highest dissipation observed at the bottom of the pier, though damage can extend along the height depending on the ground motion scaling. The study highlights the vulnerability of both concrete and reinforcement in tall RC piers under strong seismic events, emphasizing the need for robust seismic design to enhance resilience and reduce potential damage. The 3D lattice model proves effective in predicting seismic behavior and provides valuable insights for the design and retrofitting of RC tall piers in earthquake-prone regions.

References

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