



A probabilistic framework for seismic resilience assessment of steel diagrid structures using machine learning approach

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ABSTRACT

Assessing the seismic performance of diagrid structures is critical for performance-based design, particularly in high-rise buildings. This study presents a novel surrogate modeling framework using supervised Machine Learning (ML) algorithms to predict two key performance indicators—resilience index and total loss—under seismic loading. The primary contribution is reducing the dependence on computationally demanding simulations by developing accurate ML-based predictors trained on a large dataset. A total of 1,350,000 data points were generated from 135 Incremental Dynamic Analyses (IDA) performed on diagrid models with varying heights (4–24 stories), angles (50°, 67°, 78°), and bay configurations (3, 5, 7), using OpenSees. Twenty supervised ML models were trained in Python using input features such as spectral acceleration at the fundamental period ($S_a(T_1)$), recovery time (TRec), inter-story drift (δ_i), time between investment and event (T_i), and recovery time ratio. Influential features were selected through iterative trial and error. Model robustness and generalization were ensured using 10-fold cross-validation. Among all models, CatBoost, Extra Trees Regressor (ETR), Bayesian Ridge (BReg), Random Forest (RF), Support Vector Regression (SReg), and K-Nearest Neighbors (KNN) showed superior performance (correlation of the determination (R^2) > 0.95, low mean square error (MSE)). In contrast, Gaussian Process Regression (GPReg), Partial Least Squares Regression (PLSReg), and Generalized Regression (GReg) performed poorly (R^2 < 0.5). The results confirm that ML-based surrogate models can provide fast, reliable, and scalable alternatives to traditional methods, offering practical tools for early-stage seismic vulnerability assessment and resilience-based decision-making in diagrid systems.

1. Introduction

Seismic vulnerability assessment is critical to modern structural engineering, particularly as urban development increasingly involves high-rise buildings in earthquake-prone regions (Hejazi and Jalaeefar, 2021; Rezaei Ranjbar and Naderpour, 2020). Seismic vulnerability refers to the degree to which a structure is likely to experience damage or functional failure during an earthquake, influenced by its design, materials, geometry, and construction quality (Nguyen et al., 2022a, 2022b). Accurate evaluation of this vulnerability is essential to ensure occupant safety, minimize economic losses, and promote the rapid recovery of urban infrastructure following seismic events (Hu et al., 2022a, 2022b).

Traditionally, seismic vulnerability assessments have relied on computationally intensive methods, such as Incremental Dynamic

Analysis (IDA), which involves subjecting detailed structural models to multiple ground-motion records scaled to various intensities (Liu and Fang, 2020; Baker et al., 2010). While IDA provides in-depth insights into structural performance, it is impractical for large-scale or rapid evaluations due to its high computational demand. This limitation becomes more pronounced when assessing complex structural systems such as diagrids, a modern structural form characterized by an external framework of diagonal members that replace conventional vertical columns (Fu et al., 2021; Cascone et al., 2021).

Diagrid systems have gained popularity in high-rise construction due to their architectural appeal and superior structural efficiency under lateral and gravity loads (Kim and Lee, 2012; Heshmati et al., 2022). The triangulated geometry of diagrids provides enhanced stiffness and redundancy, making them suitable for resisting seismic forces. Several studies have focused on optimizing diagrid parameters, such as angle

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