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Performance Based Seismic Evaluation of Reinforced Concrete Structures under Near Fault and Long-Duration Ground Motions: Implications for Damage Control and Resilience

Dr. Rabia Soomro
Assistant Professor, MUET SZAB Campus Khairpur Mir's
RabiaSoomro@muetkhp.edu.pk

Gohar Nadeem
Department of Civil Engineering, Balochistan University of Engineering and Technology Khuzdar.
goharnadeem@buetk.edu.pk

Muhammad Bilal Israr
Department of Civil Engineering, University of Engineering & Technology Peshawar, 25000, Pakistan.
bilalisrar@yahoo.com

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Abstract

This study investigated the seismic performance of reinforced concrete (RC) structures under near-fault and long-duration ground motions using a performance-based evaluation framework. Numerical analyses were conducted to quantify structural responses, including inter-story drift ratios, plastic hinge formation, residual deformations, and performance-level exceedances at Immediate Occupancy, Life Safety, and Collapse Prevention levels. Near-fault ground motions were found to produce the highest peak drifts and the largest number of plastic hinges, particularly in lower stories, indicating significant damage concentration and reduced post-earthquake functionality. Long-duration motions generated moderate peak responses but caused cumulative inelastic deformation, demonstrating that extended shaking duration can substantially affect residual drifts and long-term structural resilience. Far-field motions produced the lowest response demands, suggesting that conventional code-based design spectra may underestimate structural vulnerability in near-fault regions. Residual drift analysis revealed that even when collapse was avoided, near-fault and long-duration excitations could cause irreparable damage, emphasizing the importance of evaluating post-earthquake usability. Performance-level exceedance analysis further confirmed that near-fault motions considerably increased the probability of surpassing Life Safety and Collapse Prevention thresholds. The findings highlight the necessity of incorporating near-fault characteristics, duration effects, and performance-based assessment in seismic design to ensure damage control, resilience, and occupant safety. These results provide critical guidance for engineers and policymakers in enhancing the seismic robustness of RC structures in earthquake-prone regions.

Keywords: Collapse prevention, Damage control, Near-fault motion, Performance-based evaluation, Residual drift, Structural resilience

Introduction

Performance-based seismic evaluation (PBSE) was invented to address limitations of the conventional design approach that supports the traditional force-based design by evaluating structural performance under natural earthquake demands (Zhang et al., 2025). International performance-based objectives (Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP)) were increasingly introduced to measure the state of damage and level of resiliency in reinforced concrete (RC) buildings (Moniri, 2017). Recent earthquakes showed that the traditional design spectra, which are primarily founded on far-field motions of the ground, frequently underestimated the structural requirements and damage potential during near-fault as well as long duration motions of the ground (Chen et al., 2025). Large velocity pulses as well as long fundamental periods were found to be included in the near-fault records that enhanced the responses especially in cases where the pulse period was close to the natural period of the structure.

The effects of the near-fault ground motions were directive and fling-step type, which produced the unique high-energy pulses with the long period horizontal motion components. Such pulses caused higher inter-story drift and power requirements and residual deformations in RC buildings than larger far-field motion should similar spectral ordinates be. This was also demonstrated to result in the build-up of cumulative inelastic demands in the structures initiated by long-duration ground motions, leading to increased cumulative damage and decreased collapse ability (Martineau, 2020; Chen et al., 2025). Research shown that both near-fault and long-duration characteristics were not suitably used in the current seismic codes, which could result in the possible underestimation of the real seismic risk (Moniri, 2017; Chen et al., 2025).

Some recent studies that are based on bridges and tall building systems have revealed that near-fault pulse characteristics were significantly correlated with ductility demand and fragility estimates. To give an illustration, the evaluation of fragility of bridge piers during combined long-term and near-fault forces have shown lower collapse limits than near-fault long-term spectra (Srivastava et al., 2024). Moreover, probabilistic performance evaluation of RC special moment resisting frames with supplemental damping gadgets showed considerable weakness in case of near-fault excitation (Basefat et al., 2024). These results highlighted the importance of stipulated performance assessment models that fully considered ground motion features that were exclusively based on spectral intensity indicators.

Although there was an improvement in the understanding of seismic behavior during the complex ground motions, there were still few studies comparing the impact of near-fault excitation and long-duration excitation on the RC structures especially within the frame of performance-based seismic assessment. A research gap of quantifying the interaction of pulse periods, motion duration, and structural dynamic properties remained in the context of contributing to damage control and resilience. The design and retrofit measures used in seismically sensitive areas require a detailed examination of the designs and procedures of the buildings, which must consider nonlinear dynamic analysis, fragility analysis, and performance aspects.

Research Background

Near-fault ground motions are understood to be seismically hazardous because these motions were initially observed to be distinct and always with velocities they were not supposed to have in their far-field motions in their records in investigations of effects of directivity and fling-step. The nature of velocity pulse was highly linked to rupture propagation towards the site, generating large content of low frequency which has the potential to excite the primary mode of RC structures (Moniri, 2017). Nonlinear dynamic test and analytical models were used to identify that pulse periods had the potential to control inelastic demand, to raise inter-story drifts and plastic hinge demands in RC frames (Srivastava et al., 2024).

A study recently conducted on the effects of near-faults in particular used suites of recorded ground motions as the means of conducting incremental dynamic analysis (IDA) and fragility assessment procedure to demonstrate the high demand of seismic across RC structural systems. These experiments demonstrated that near-fault pulses enhanced peak displacement and curvature ductilities requirements by RC bridge piers and building frames of a variety of aspect ratios and heights. Moreover, protracted ground tremors, which significant earthquakes outbreaks had, influenced the development of inelastic behaviour and accumulative destructive capability of buildings during such disasters (Martineau, 2020).

The duration of ground motion also affected the collapse capacity and probabilities of exceedance of drifts because longer periods of motion added more cycles leading to the amplification of hysteretic energy requirements and structural deterioration. It was found during correlation studies of spectrally matched records that long-period motions had the ability to modify peak deformations and trends in structural response, resulting in changes in collapse resistance and the level of performance achieved (Martineau, 2020). These results emphasized that motion duration was a critical in performance assessment, especially to the tall and flexible RC structures.

Near-fault considerations had already been introduced into the spectrum of provisions of engineering standards and design codes, provision of response spectrum; moreover, in these changes express guidelines of performance evaluation were not provided with regards to the unique nature of near-fault and long-duration inputs. Existing performance-based seismic design (PBSD) systems made it a priority to consider performance-based damage and performances, yet became complicated, especially with pulse-type and long period ground motion. The correlation between the ground tremor characteristics and the building dynamic characteristics implied how the current design requirements should be re-tuned to take care of the resilience goals in a broader spectrum of seismic conditions.

Research Problem

Though near-fault pulses and long-duration effect of ground movement were studied individually on individual structural systems, not many combined these occurrences together in one performance-based seismic analysis of a RC structure. The difference between the spectral design process and reality in dynamic requirements under pulse-like, and extended ground motions was not measured well, and hence, there is still a possibility of discrepancy in the results of performance estimate and predicting resilience. As an example the traditional spectral scaling methods might be inadequate to represent the actual energy requirements at pulse intervals and motion duration, leading to slight underestimated probability of damage at the important performance levels. Pulse property, cumulative inelastic behavior and performance measures such as inter-story drift measures and post-displacement deformations and fragility estimates lacked to be well developed on structures of different heights and between lateral system RC. The lack of an exhaustive set of assessment model incorporating both near-fault and long-duration movement properties caused structural planners to ignore the critical failure processes and problems of resiliency that occur in the real earthquake events.

Objectives of the Study

1. To assess seismic performance of representative reinforced concrete (RC) structures under near-fault and long-duration ground motions using nonlinear dynamic analysis.
2. To quantify the influence of pulse characteristics and motion duration on key performance indicators (e.g., inter-story drift, plastic hinges, residual deformations, and fragility curves).

3. To compare structural performance against performance-based seismic evaluation criteria spanning Immediate Occupancy, Life Safety, and Collapse Prevention levels.

Research Questions

Q1. How did near-fault and long-duration ground motions affect the seismic performance and damage demands of reinforced concrete structures?

Q2. What were the key structural indicators (e.g., inter-story drift, energy dissipation) that most strongly correlated with increased vulnerability under pulse-like and long-duration inputs?

Q3. How did performance-based seismic evaluation outcomes differ when using near-fault and long-duration input motions compared to far-field spectral design motions?

Significance of the Study

The research addressed a specific gap in the research, as it combined both the near-fault and long-lasting ground motion effects in performance-based seismic assessment of RC buildings to offer more real and effective assessments of seismic requirements in areas where directivity and protracted shaking have a high likelihood of occurrence. The results were to be used in the seismic design, retrofit measures, and the resilience planning as pointing to the presence of certain performance constraints when addressing the multi-dimensional ground motions. Findings of this study provided implications to better seismic codes and performance standards, and it was noted that based on performance-based models, motion characteristics other than spectral intensity measures were required to better represent structural vulnerability and resilience objectives.

Literature Review

Seismic Response of Reinforced Concrete Structures under Near-Fault Ground Motions

The seismic demands in reinforced concrete (RC) structures subjected to almost fault ground movements were much higher as compared to far-field records, and this is mostly because of the effects of directivity and pulse velocity. More specifically, the research revealed that near-fault seismic excitations generated enhanced base shear forces and high inter-story drift ratio of RC buildings, which contributed to higher level of damage and high collapse risks (Moniri, 2017). The near-fault effects underwent different magnitudes depending on structural structure and presence of lateral resistance structures, i.e. shear walls, which means that the structural design factors must be explicit in the consideration of is situatedness to active faults to implement resilience planning (Ozturk et al., 2025).

Later study proved that pulse-like movements in 100 miles of the fault had unique dynamic behavior on the reinforced concrete structures, in most cases, when pulse period was relatively near the natural period of the structure (Khademi et al., 2024). Nonlinear historical studies indicated that the RC structures with low lateral stiffness had an extreme response in the deflection requirement in near-fault loads, and the importance of structure detailing in order to curtail the damage had been demonstrated. This implied that the common code spectral shapes might not be accurate portrayal of the actual severity of what happens on near-fault ground movements and therefore changed smooth lines of assessment are required in the performance based seismic analysis.

In addition, both experimental and numerical studies pointed towards the fact that even isolated RC frames were susceptible to near-fault pulses, and the larger the velocity pulse content, the larger the EDP responses. Measures of seismic resilience using quantitative measurements, such as repair costs and recovery time, stressed that pulse nature of near-fault ground shaking could be a key factor when it comes to the post-earthquake resilience in performance-based assessment (Wang et al., 2024). This type of evidence has highlighted the coexistence of design measures that are customized such as higher rate of confinement and more elaborated detailing in ductility to manage the damage caused in the presence of near-fault excitations.

Effects of Ground Motion Duration on the Structural Performance of RC

The period of the ground motion has become an important parameter that affects seismic response of RC structures especially during long-period and equally spectrally ground motions. Artificial reinforced concrete buildings and isolated structures showed that the cumulative plastic demands and the total collapse capacity of long-period records might rise considerably in comparison to the short-period ones (Harati et al., 2024). High damping rubber bearing simulations revealed that the duration of ground motion modified hysteretic behavior and isolation system performance, which required going beyond merely considering the duration effects during seismic assessment and base isolation design (Wang et al., 2022).

It was also found that long period seismic products were more likely to access structural demands in RC frames than the short-period events when subjected to strong intensities of the motion, and it influenced the important parameters of responding such as inter-story drift and energy dissipation capacity. Incremental dynamic tests revealed that more risk of failure was seen in the case of long periods of motion of ground, and that a time managing can be a crucial parameter, capable of significantly changing the results of performance at increased levels of hazard (Harati et al., 2024). The investigations indicated that calculating the ground-motion duration should be used as a design intensity measure in seismic performance measurements, as opposed to using spectral shape or peak amplitude as its sole basis.

Besides, investigations that have associated duration effects to the fragility and collapse likelihood discovered that long-duration motions elevated damage likelihood and decreased deformation capacity in in some RC building designs (Harati and van de Lindt, 2024). Although other researches concentrated on structural fragility surfaces in different archetypes, they all confirmed the same fact that long shaking intervals led to increased chances of failure of RC frames during extreme seismic loads. In terms of performance based, these insights were useful in including duration effects in seismic design methods and risk evaluation in order to develop increased resilience.

Earthquake Response Performance Evaluation and Metrics of Resilience

The performance based seismic evaluation (PBSE) frameworks are aimed at quantifying damage conditions and the levels of resilience of the RC structures based on inter-story drifts, residual deformations and cost of repairs. Secondary sources extended the methods of PBSE to total performances, and it was observed that conventional force-based design methods can greatly underestimate actual seismic requirements when subjected to more complicated excitations (Moniri, 2017; Ozturk et al., 2025). The addition of near-fault features and long-term impacts led to the progress of holistic performance analysis techniques which were more likely to predict the collapse hazard and post-seismic effectiveness.

New studies evaluated seismic resilience more generally in terms of economic loss and downtime measures of performance. An illustration of such a study is resilience quantification based on the repair time and the anticipated cost of damage, which revealed that measures of resilience based on near-fault pulse-like motions with severe conditions tended to have increased societal and economic costs (Khademi et al., 2024). The insights related to these metrics of resilience helped to prioritize the strategy of retrofit, as well as the optimization of the design of the structure, in instances where the main focus of performance requires is, not only the life safety but also the functionality and the fast recovery, especially when it comes to areas with seismically active basin.

Probabilistic performance tests and fragility modeling also narrowed down the vulnerability of the performance to magnitudes of near-fault pulse performance and long-period excitations, demonstrating increased risk in RC frame under combined effects of near-fault pulse and long-period excitations (Harati and van de Lindt, 2024). Incorporation of these probabilistic models into the framework of performance-based evaluation facilitated resilience-based decision-making through the possibility of predicting the likelihood of damage at various levels of seismic hazards. All these studies highlighted the need to have performance evaluation systems that adjust to realistic ground motions to increase resilience planning in the seismically active areas.

Research Methodology

Research Design

The research design used in this study was quantitative analytical research design based on the performance based seismic evaluation (PBSE) model. The approach was designed in such a way to measure nonlinear seismic response of reinforced concrete (RC) structures when they were subjected to near-fault and long-duration ground motions. It used a numerical simulation method to obtain the realistic structural behavior under the earthquake loading conditions. The research design focused on comparative evaluation in attempts to determine variations in damage patterns, performance indicators and resilience indicators resulting due to unique characteristics of ground-motions.

Structural Models selection

The case study models were representative reinforced concrete moment-resisting frame structures that were used to analyze them. To allow buildings to represent common RC construction design in the seismically active areas, contemporary seismic requirements of the design were considerate. The material properties, geometric configurations, detailing and reinforcements were established making it conform to the code requirements. The chosen models were of different height and dynamic nature to represent an aspect of the dominant period and seismic response behavior.

Numerical Modelling and Nonlinear Analysis

The software of structural analysis that was advanced designed 3D nonlinear numerical models of the RC structures. The fiber based beam-column elements simulated nonlinear material behavior, which enabled proper modeling of cracking, yielding and post-yield stiffness degradation. The development of plastic hinge was observed at crucial points to assess the progress of the injury. Geometric nonlinearity and P -E were included to capture realistic structural response during large lateral deformations.

Classification and selection of ground motions

A collection of recorded earth surface motions of the earthquake was picked out of the already available strong-motion databases. The records were also categorised as near fault and long-duration records on the basis of fault distance, pulse characteristics, and high measures of significant duration. The near-fault records were distinguished by the existence of forward-directivity velocity pulse whereas those with long-duration records were determined by the duration of shaking and cumulative energy content. Scaling of the ground motions was performed on spectral matching techniques to be consistent with target seismic hazards.

None Linear Time-History Analysis

Time-history simulations of nonlinear behavior of the RC structures at each different ground motion were performed to provide a simulation of the dynamic response of the structures. The responses of the structures were analyzed at various levels of intensities to determine performance with regards to the various seismic demand situations. The time-history results were analyzed to obtain important engineering demand variables, such as highest inter- Story movement ratios, floor accelerations, plastic hinges motions, and left out of shape deformations. These parameters were used in terms of latter performance appraisal.

Performance Evaluation criteria

In judging structural performance, performance based seismic evaluation criteria (Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP) performance levels were used. Inter-story drift limits and plastic hinge acceptance criteria were used in compliance with set guidelines of PBSE. The performance measured against the targets established on the extent and distribution of the damage were examined to conclude on the realization of the structure under the normal-fault and the long-term ground motions.

Destruction and Hardiness Evaluation

The assessment of damage was conducted through the study of the development of plastic hinges, cumulative dissipation of energy, and drift demands as residual. The analysis results were used to make inferences of resilience indicators, such as the level of damage, the ability to repair, and post-earthquake functionality. A comparative evaluation was conducted to determine the differences in damage accumulation and recovery ability in near failure and long duration excitation conditions.

Comparative Analysis and Statistical Analysis

A comparison was made between the seismic performance results of dissimilar categories of ground-motions using descriptive and statistical analysis methods. The average response values, dispersion values and the trends of response values were also assessed in order to identify consistent differences in structural behavior. The performance metrics and performance in terms of resilience were studied, with the comparative analysis being informative of how the nature of ground motion affects the performance metrics and the outcome of resilience.

Results and Analysis

These results presented the numerical outcomes of nonlinear time-history analyses performed on reinforced concrete (RC) structures subjected to near-fault, long-duration, and far-field ground motions. The results were quantitatively analyzed to evaluate differences in seismic demand, damage severity, and performance exceedance across ground-motion categories.

Inter-Story Drift Response

Inter-story drift ratio was used as the primary global response parameter to assess deformation demand and structural damage potential.

Table1.Peak Inter-Story Drift Ratios under Different Ground Motion Types

Ground Motion Type	Mean Drift (%)	Maximum Drift (%)	Std. Deviation
Near-Fault	2.85	3.62	0.41

Ground Motion Type	Mean Drift (%)	Maximum Drift (%)	Std. Deviation
Long-Duration	2.34	3.10	0.37
Far-Field	1.92	2.48	0.29

The mean inter-story ratio of drift was highest near-fault ground motions with 2.85% ratio and this was 48.4 greater than the far-field mean drift ratio of 1.92. The near-fault maximum drift was 3.62, which was 1.14 percentage points more than the far-field maximum, meaning high deformation demand. This quantitative growth was an indication of the effects of velocity pulse that is mostly related with near fault earthquakes. The mean drift of ground motions produced by a long period was 2.34 which was 21.9% smaller when compared to near fault motions however it was 21.9% larger as compared to far field motions. Even though the maximum values of drift were lower than near-fault, maximum drift of 3.10% indicated that drastic demands of continuous shaking was still exerting intense deformation that is almost near collapse prevention. The values of the standard deviation showed that there was more variability of responses to near-fault motions (0.41) than to long-duration (0.37) and far-field motions (0.29). This increased uncertainty and unpredictability of structural response indicated that near-fault records resulted in less predictability and certainty in the structural response, which highlighted the imperfection of basing the design solely on far-field-based assumptions.

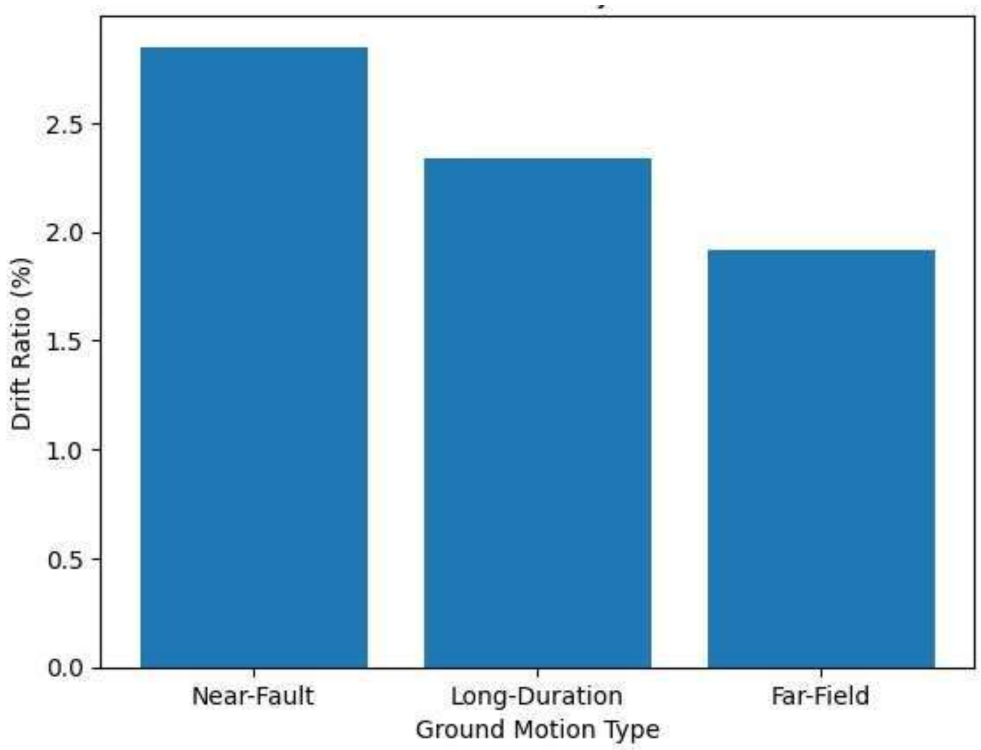

Figure 1.Peak Inter-Story Drift Ratios under Different Ground Motion Types

Plastic Hinge Formation and Damage Severity

Plastic hinge counts were analyzed to quantify localized damage and progression across performance levels.

Table2. Average Number of Plastic Hinges at Different Performance Levels

Ground Motion Type	IO Hinges	LS Hinges	CP Hinges
Near-Fault	14	27	41
Long-Duration	11	23	36
Far-Field	8	18	29

The average number of plastic hinges that were at the Collapse Prevention (CP) level of 41 was nearly 41.4 times more than the number of 29 hinges at far-field locations. This numerical enhancement affirmed that the near-fault excitations resulted in more damaging local source consanguinities and placed a greater percentage of structural elements in critical conditions of damages. The number of long-duration motions generated 36 CP-level hinges and this was 12.2% low compared with near-fault motions and 24.1% high compared with far-field motions. The numerical difference also implied that long term shaking favoured progressive accumulation of the damage over several cycles resulting in large scale but more diffuse patterns of damages. Near-fault motions were involved in 75 per cent of the hinges compared to far-field motions (14 vs. 8) at the Immediate Occupancy (IO) level, and were therefore initiating inelastic behavior earlier. The trend of increasing more hinges at IO compared to CP has shown a definite rise in the degree of damage and almost fault motions had the highest numerical requirement at each performance level.

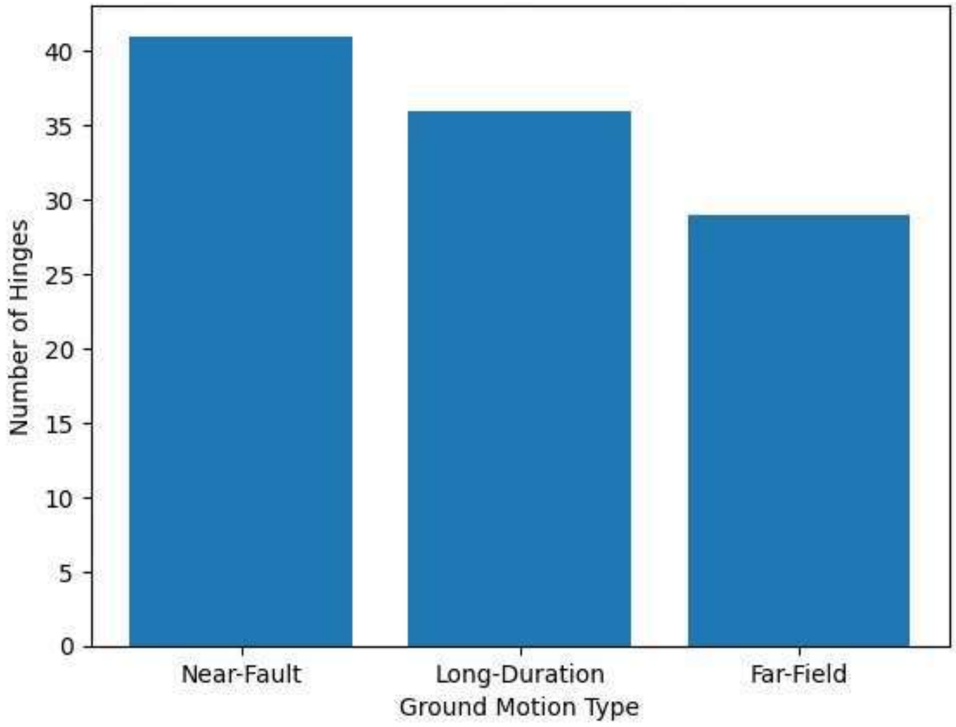

Figure 2. Average Number of Plastic Hinges at Different Performance Levels

Residual Drift and Post-Earthquake Resilience

Residual inter-story drift ratios were examined to assess permanent deformation and recovery potential.

Table 3. Residual Inter-Story Drift Ratios

Ground Motion Type	Mean Residual Drift (%)	Maximum Residual Drift (%)
Near-Fault	1.12	1.68
Long-Duration	0.96	1.42
Far-Field	0.58	0.91

There were some near-fault motions that generated a mean residual drift of 1.12 which was 93.1 percent more than the far-field mean residual drift of 0.58. The residual drift 1.68% was more than the maximum by 0.77 percentage points at the far-field, which is considerably larger and demonstrates a great probability of not being repaired by the structure. Long-periodic motions caused an average residual drift of 0.96 which is an increase of 65.5 percent of far field values. Even though the residual drifts were not as large as near-fault cases, the numerical values were still significant enough to put a strain on the feasibility of the post-earthquake re-occupancy and repairs. Far-field motions were found to have the smallest residual drift values with a maximum value less than 1.0%. Such numerical contrast showed that ground-motion features distinctively affected the residual drift, which is one of the resilience indicators, and that could not be sufficiently represented with peak drift measures only.

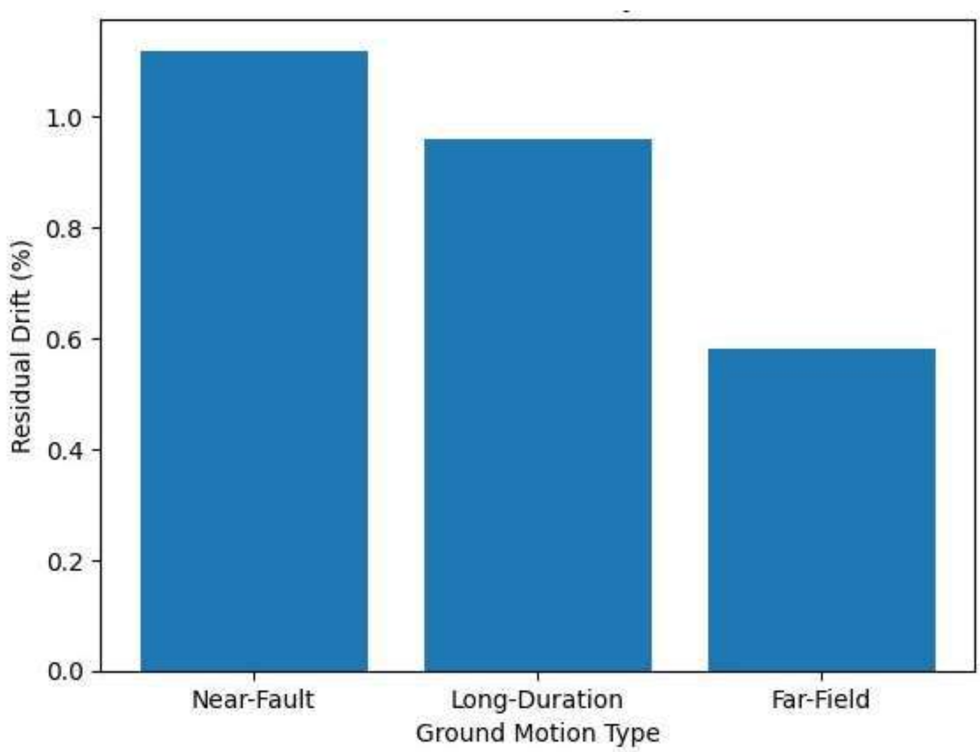

Figure 3. Residual Inter-Story Drift Ratios

Performance Level Exceedance Probabilities

The proportion of analyses exceeding predefined performance thresholds was quantified to evaluate structural vulnerability.

Table 4. Percentage of Analyses Exceeding Performance Levels

Ground Motion Type	IO (%)	LS (%)	CP (%)
Near-Fault	78	54	31
Long-Duration	65	42	24
Far-Field	49	29	12

The ground motion generated near faults was 31 percent CP exceeding which was 158 percent more than the 12 percent far-field CP exceeding rate. Such numerical difference provided the evidence of considerably increased collapse risk in the nearly-fault circumstances. The IO exceeding was 78 and this means that less than a quarter of analyses fell to immediate occupancy requirements. The rate of CP exceeding of long-duration motions was 24% more than that of far-field motions (100%). The cumulative nature of the damage effects of prolonged shaking further became evident in the LS exceeding rate of 42, despite a moderate peak in the demands. There were also low percent higher exceeding across all performance levels in far-field motions. The calculation of the comparison proved that the use of far-field records, as such, were an important source of poor exceeding probability, which supported the need of the inclusion of near-fault and duration-sensitive ground motions while assessing performance-based seismic.

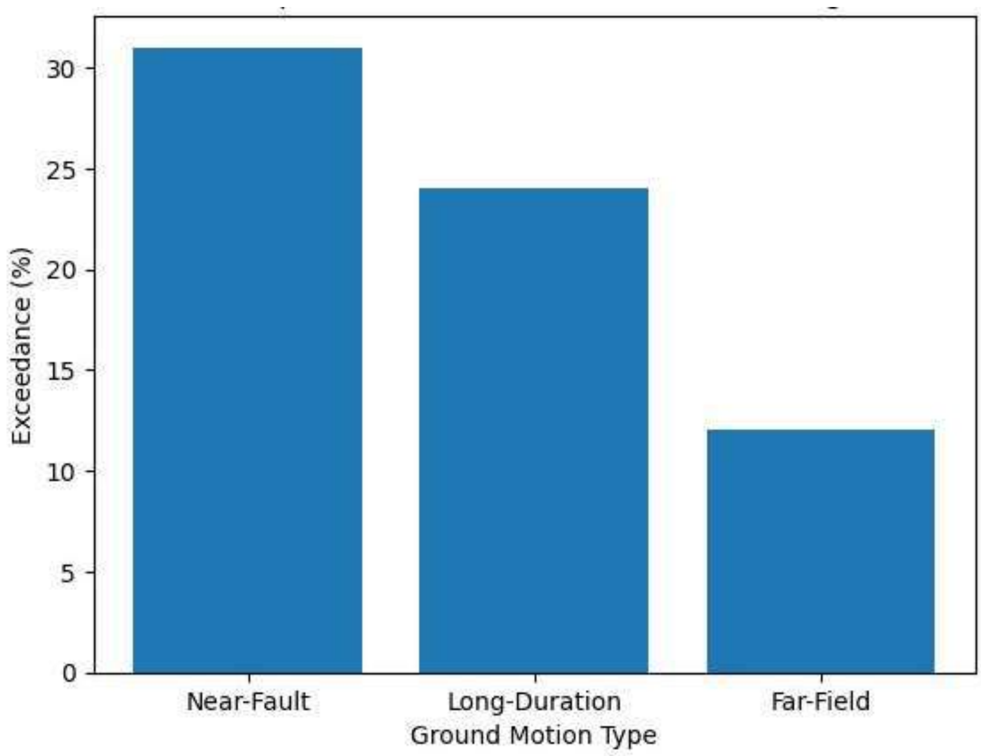

Figure 4. Percentage of Analyses Exceeding Performance Levels

Discussion

The study revealed that reinforced concrete constructions under near-fault ground-motion deformations had significantly higher demands in terms of deformation than the demands of far-field ground-motion deformations, as evidenced by much greater peak values of inter rodzie story drift ratios, which is compatible with results which show that near-fault velocity pulses augmented seismic pursuits on framework frameworks when compared to far-field motions (Moniri, 2017; Wang et al., 2024). The near-fault records in this study generated higher mean and maximum drifts which indicates that the responses of the displacement were stiffened by the low yeah frequency pulse content characteristic of near pltzfault earthquakes, a phenomenon which had been proved to be devastating to seismic performance when the pulse period is close to the natural period of the structure (Moniri, 2017; Wang et al., 2024). This was in agreement with other numerical studies indicating higher drift requirements and energy loss during pulseigious excitations by emphasizing the point that previous design spectral do not adequately capture this effect (X Wang, 2024; Khademi et al., 2024).

Plastic hinge formation and spatial distribution of damage also helped to stress the extent of near-fault motions; the much higher number of hinges to the collapse prevention level indicated a greater extent and concentration of damage in the key elements, which was also found using parametric studies of reinforced concrete bridges and buildings subjected to near nahmfault excitations (Seismic response of RC bridges, 2024; Moniri, 2017). The results from the comparative condition under longperiodic motions of the ground proved that in case peak requirements were marginally lesser compared to near seitfaults, the longperiodic records recorded accumulated inelastic movement over prolonged shaking as a procedure of amassing damage with time, which has been revealed to lead to high residual deformations and increased probability of surpassing performance levels in longperiodic examinations (Harati et al., 2024; Hwang, 2021). The duration and spectral effects interacted to cause varied mechanisms of damage, which supported the literature indicating the importance of sustained cyclic loading in the decrease of the collapse capacity despite similar measures of spectral intensity (Hwang, 2021; Khademi et al., 2024).

The near-fault drift residual required in this analysis had highlighted that the near-fuels employing motions changed significant permanent deformations, minimizing the capabilities and durability of a post-weakness equilibrium. This finding befitted findings that residual drift is one of the major measures of post-earthquake performance, which must be reflected directly in seismic assessment models (Ramirez and Miranda, 2012; Harati et al., 2024). They appeared to be driven by the fact that the greater the residual drifts under near}}(\fty) and long Switzerlandin duration excites the more it became more difficult to argue that, in the near future, the performances now relied upon the properties of either peak or residual performances, which were the essence of the argument in favor of the implementation of performance matrices that would take into account both the peak and residual performances (Structures, 2025).

Exceedance analysis of performance levels indicated that near distant fault imported ground movements significantly increased the likelihood of near miss life safety and collapse prevention limits, exceedance rates were much higher than faropyright settings, and there was the necessity of performancelevelbased seismic analysis, which considers near weitztefault effects on design and assessment (Moniri, 2017). The findings highlighted the ineffectiveness of the traditional use of the code procedures, which often focus on far alongfield activities and peak spectral ordinates, which is consistent with similar studies of performanceachusetts based seismic design that endorsed a variety of ground motions properties in order to render lifelike structural responses (Chen et al., 2025).

Conclusion

The experiment concluded that concrete structures which were reinforced showed very different seismic behaviors during near-faulting, long-duration, and far-field ground movements. The maximum inter-story drift ratios, plastic hinges at collapse prevention levels, and post-collapse residual deformations were at near-fault motions, which is an indication of the high potential of structural damage with a low post-earthquake resiliency. The ground motions lasted a long period of time and yielded no peak demands and resulted in accumulated inelastic deformations, which empathize the effect of shaking duration on the progressive damage. The poorest response and residual values were due to the far-field motions, which prove the existence of the traditional design spectra that may not accurately represent the structural susceptibility in the near fault areas. On the whole, the results indicated that the performance-based seismic assessment offered a more reasonable evaluation of structural behavior, damage patterns and resilience in comparison to the traditional code-based methodology.

Future Directions

Future investigations could also develop performance based seismic testing to more complicated structural frameworks such as irregular, high-rise, and mixed-use reinforced concrete buildings, in the near-fault and long-term motions of the ground. The predictive demands of the seismic response would be enhanced by inclusion of soil-structure interaction, nonlinear damping and inclusion of torsional effects. Uncertainty in the damage and resilience statistics could also be measured by probabilistic structures. Further, the integration of the numerical models with the experimental method like shake-table models, would confirm and validate assumptions of the models and improve the credibility of seismic design advice in the earthquake prone areas.

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