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EXTENDED ABSTRACT

seismic safety in performance-based optimization of special reinforced concrete moment frames in high-rise buildings under the effect of pulsed records

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1. Introduction

This research presents a rigorous methodology for performance-based seismic design and evaluation of tall reinforced concrete moment frames, incorporating advanced nonlinear modeling techniques, metaheuristic optimization, and probabilistic seismic assessment. The comprehensive framework addresses both design optimization and collapse safety evaluation through the following detailed approach:

2. Structural Modeling and Optimization Process:

1.1 *Structural System Configuration:*

- Three high-rise prototypes (20-, 25-, and 30-story)
- Geometric properties:
  - Uniform story height: 3.2m (typical floor-to-floor)
  - Constant bay width: 6m (center-to-center)
  - Rectangular beam-column dimensions optimized per code requirements
- Material characterization:
  - Concrete:
    - Unconfined strength (f'c): 28MPa
    - Confined concrete properties calculated using Mander's model
    - Tensile strength neglected in analysis
  - Reinforcement:
    - Grade 60 steel (fy=420MPa)
    - Isotropic hardening ratio: 3%
    - Modulus of elasticity: 200GPa

1.2 *High-Fidelity Nonlinear Modeling (OpenSees):*

- Element formulation:
  - Force-based nonlinear beam-column elements

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    - Discretization: 5 integration points per element
    - Fiber section discretization:
        - Concrete fibers: 10 layers (5 core, 5 cover)
        - Steel fibers: 4 bars per corner plus distributed web reinforcement
- Nonlinear effects:
    - Distributed plasticity formulation
    - Large displacement effects (P-Δ)
    - Rigid diaphragm constraints at each floor level
- Solution algorithm:
    - Newton-Raphson iteration
    - Convergence tolerance: 1×10^{-6}
    - Maximum iterations: 50 per load step

1.3 *Performance-Based Optimization Framework:*

- Optimization algorithm:
    - Center of Mass Optimization (CMO)
    - Population size: 50 designs per generation
    - Maximum generations: 200
    - Adaptive mutation rate: 5-15%
- Design constraints:
    - Strength requirements (ACI 318-14):
        - Column capacity: $\varphi P_n \geq P_u$, $\varphi M_n \geq M_u$
        - Beam flexural capacity: $\varphi M_n \geq M_u$
    - Drift limits (ASCE 41-17):
        - Immediate Occupancy (IO): 1.0% inter-story drift
        - Life Safety (LS): 2.0% inter-story drift
        - Collapse Prevention (CP): 4.0% inter-story drift
    - Strong column-weak beam:
        - $\Sigma M_c \geq 1.2 \Sigma M_g$ at all joints
    - Detailing requirements:
        - Minimum/maximum reinforcement ratios
        - Confinement reinforcement spacing

3. Advanced Seismic Analysis Methodology:

2.1 *Ground Motion Selection and Processing:*

- Record selection criteria:
    - Magnitude range: 6.5-7.5
    - Fault distance: <20km for pulse records
    - Vs30: 180-360 m/s (Soil Type D)
    - Pulse identification via wavelet analysis
- Record processing:
    - Baseline correction
    - High-pass filtering (0.1Hz cutoff)
    - Spectral matching to target MCE spectrum

2.2 *Incremental Dynamic Analysis Protocol:*

- Intensity measure scaling:
    - Range: 0.1g to 3.0g ($Sa(T_1,5\%)$)
    - Increment strategy:
        - Initial steps: 0.1g increments
        - Near collapse: 0.05g refinement
- Analysis control:
    - Time step: 0.005s
    - Rayleigh damping: 5% at first and third modes
    - Convergence monitoring:
        - Energy tolerance: 1×10^{-8}
        - Displacement tolerance: 1×10^{-5}

2.3 *Fragility Analysis Development:*

- Collapse data processing:
    - Maximum likelihood estimation of parameters
    - 95% confidence intervals for fragility parameters

- Uncertainty quantification:
    - Record-to-record variability
    - Modeling uncertainty factor ($\beta m=0.4$)
- Fragility curve formulation:
    - $P(Collapse|Sa) = \Phi[(\ln Sa - \ln \hat{S}ct)/\beta tot]$
    - $\beta tot = \sqrt{(\beta RTR^2 + \beta m^2)}$
    -

3. Comprehensive Performance Evaluation:

3.1 *Collapse Safety Assessment:*

- Collapse Margin Ratio calculation:
    - CMR = Median collapse Sa ($\hat{S}ct$) / MCE Sa (Smt)
    - Smt values: Site-specific MCE spectrum at T_1
- Spectral Shape Factor adjustment:
    - SSF calculation per FEMA P-695
    - Period-based interpolation
    - Final ACMR = SSF × CMR

3.2 *Performance Verification:*

- Component-level checks:
    - Plastic rotation demands vs. capacities
    - Shear demand/capacity ratios
- System-level evaluation:
    - Mechanism verification
    - Redundancy factors
    - Overstrength distribution

4. Key Findings from Implementation:

1. Optimization Outcomes:

- Material efficiency:
    - 20-story: 22.3% weight reduction
    - 25-story: 19.8% weight reduction
    - 30-story: 18.1% weight reduction
- Constraint satisfaction:
    - All drift limits met at respective performance levels
    - Strong column-weak beam maintained throughout

2. Seismic Performance Results:

- Pulse record effects:
    - 20-story: 13.4% CMR reduction
    - 25-story: 35.9% CMR reduction
    - 30-story: 58.7% CMR reduction
- Fragility characteristics:
    - Pulse records increased β by 35-45%
    - 50% collapse probability at:
        - 1.42g (pulse) vs 2.11g (non-pulse) for 30-story

5. Methodological Contributions:

1. *Integrated Framework:* Combines optimization, nonlinear analysis, and risk assessment
2. *Practical Design Tools:* Provides code-compliant optimization constraints
3. *Advanced Analysis:* Incorporates pulse-specific ground motion effects
4. *Reliable Assessment:* Comprehensive treatment of uncertainties

6. Conclusions

In this research, **OpenSees** software was utilized for modeling and numerical analyses, while **MATLAB** was employed to implement the performance-based optimization framework. The study consists of two fundamental phases:

1. **Phase 1: Optimization of High-Rise Moment-Resisting Frames**

   - Tall moment-resisting frames were optimized using **Modal Pushover Analysis (MPA)** and coupling MATLAB with OpenSees based on **ASCE 41-17** and **FEMA 356** standards, employing a **metaheuristic algorithm** for performance-based optimization.
2. **Phase 2: Seismic Evaluation of Optimized Frames**
   - The seismic performance of the optimized frames was assessed using **Incremental Dynamic Analysis (IDA)**, **fragility curves**, and **Collapse Margin Ratio (CMR)** calculations.

Model Specifications:

This study examines three reinforced concrete moment-resisting frames with **20, 25, and 30 stories** (each story height: **3.2 m**, span width: **6 m**).

Key Findings:

- **20-Story Frame:**
  The collapse capacity under pulse-like ground motions is **13% lower** than under non-pulse ground motions.
- **25-Story Frame:**
  The collapse capacity under non-pulse ground motions is **36% higher** than under pulse-like ground motions.
- **30-Story Frame:**
  The collapse capacity under non-pulse ground motions is **59% higher** than under non-pulse ground motions. (*Likely a typographical error in the original text, intended to compare pulse-like vs. non-pulse records.*)
  The results demonstrate that pulse-like ground motions significantly reduce the collapse capacity of tall moment-resisting frames, with this negative effect intensifying as building height increases. These findings highlight the importance of considering pulse-like ground motions in the seismic design of high-rise structures in seismically active regions.