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Seismic Response of Reinforced Concrete Columns: Damage Evolution and Failure Mechanisms in Biaxial Bending

Vijay Kumar Pandit
Department of Civil Engineering, Graduate School of Engineering, Mid-West University, Surkhet, 21700, Nepal.
vijaykpst@gmail.com

Abstract-This paper studies the seismic response of reinforced concrete (RC) columns, focusing on how damage develops and the failure mechanisms during biaxial bending. The behavior of RC columns is crucial for the reliability and safety of buildings, especially during unpredictable events like earthquakes. The research looks at the geometric and displacement features of RC columns under both uniaxial and biaxial cyclic loading. It discusses various confinement models for axial compression in column design, covering area-based, strength, and ductility analyses. The paper explores the reasons behind RC building failures, such as inadequate confinement, bond splitting or slipping, insufficient shear and flexural capacity, and irregularities in the design structure. It presents an experimental study on the behavior of RC columns under different failure scenarios, including earthquakes and heavy loads. The effects of biaxial loading on columns and 3D characteristics are assessed through evaluations of inelasticity and damage concentration. The study also looks at the shapes of columns and their displacement patterns when subjected to biaxial bending forces from two orthogonal directions. The findings enhance understanding of RC column behavior under extreme loads and offer insights for better design and construction practices to prevent structural failures during seismic events.

Keywords-RC Column, Earthquake, Biaxial Bending, Confinement Models, Failure Mechanisms, Structural Deficiencies, Shear Capacity.

I. INTRODUCTION

When designing structural components, columns are considered the most critical elements. Safe considerations and specifications are taken into account to generate the structure design. These considerations include specifying different materials, and analyzing environmental and stress vectors. A key part of column-based design is loading case analysis, which addresses safety and reliability from a behavioral perspective. One such aspect is confinement, which evaluates the column's ductility and capacity. A predictive mathematical analysis assesses the degree of confinement across different vectors. However, there is currently only one new tool available for this type of analysis, and its usage is limited. Eccentric load conditions are examined alongside axially loaded design components. Additionally, the effects of misalignment and tolerance are analyzed to ensure effective column design within the overall structure[1][2].

Various confinement models exist for concentric axial compression in column design. These models consider area-based, strength, and ductility analyses. Structural response analysis during stress or safety evaluations encompasses the earthquake effect based on horizontal loads and related damage scenarios. Axially loaded members are also assessed under critical events, such as biaxial bending history analysis. Uncertainty analysis regarding bending moments includes orthogonal direction analysis with complications. Knowledge-based behavior analysis occurs under biaxial cyclic moments alongside uniaxial loads and bending load assessments. These models also adopt a fiber-based approach for analytical behavior analysis against global specifications. Analytic models integrate code standards, helping to reduce design deficiencies[3][4].

Performance analysis of column designs evaluates earthquake performance. The causes of RC building failures include:

- Lack of Confinement
- Bond Splitting or Slipping
- Inadequate Shear Capacity
- Inadequate Flexural Capacity
- Joint-Based Shear Strength Analysis
- Influence of Infill Masonry
- Design Structure Irregularities
- Mode Effects
- Weak Column Mechanism
- Structural Deficiencies

When it comes to design and construction deficiencies, extensive structural damage can occur. To address these potential issues, columns must be systematically designed based on load considerations. Load considerations should prevent failure and support ductile behavior analysis. RC column failures often relate to flexural capacity, requiring attention to confinement deficiencies and eventual analysis[5][6].

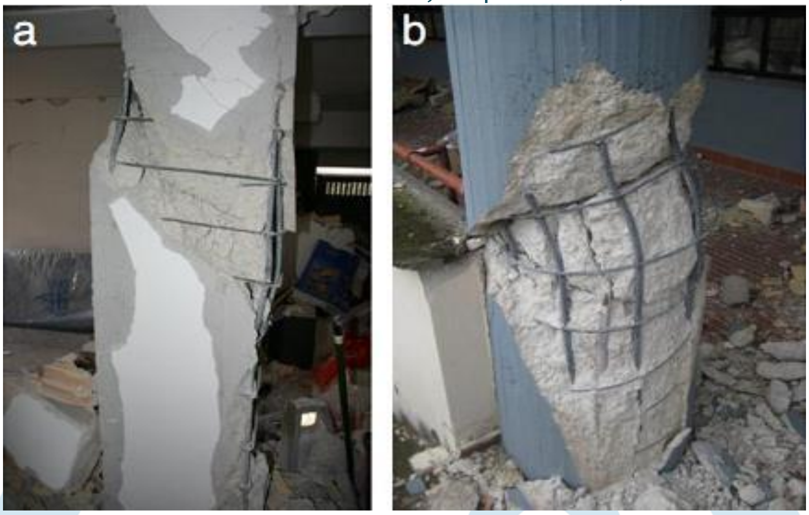

Figure 1: Shear and Circular Column in Earthquake Situation

Another problem for columns is shear or diagonal cracking. Examples of such problems can be seen in Figure 1 These failures occur when the section of a beam/ column does not have the capacity to support locally. Fractures are also more likely to occur with gapping and defects. Improper lengths can also cause bends in the reinforcing bars. Beam columns hold significant importance in RC buildings. However, poor behavior at column joints can lead to rapid collapse and damage during heavy loads or earthquakes[7].

This paper discusses the RC column and beam points in relation to failures and earthquakes. It includes a case study on RC column behavior, specifically examining their performance under biaxial and uniaxial conditions. Section II covers the analysis of column specimens under various damage or failure scenarios.

II. COLUMN SPECIMEN ANALYSIS

Structural engineering involves designing and testing under various load and failure scenarios. Earthquake analysis represents one such test category. RC columns in bridges and buildings experience cyclic loading in horizontal orientations. This study aims to analyze the behavior of RC columns under biaxial cyclic loading. Different RC column designs reflect various geometric characteristics and reinforcement adjustments, tested under multiple load histories. These column types undergo evaluations in uniaxial and biaxial loading, applying axial forms and displacements under controlled conditions. The column specimens are robust, fixed with concrete foundation blocks to ensure effective construction plans[8][9].

Column designs are also analyzed within reaction frames and store analysis. Prestressed steel bars prevent sliding and overturning, creating an effective frame. Axial loads impact column specimen deflections, using sliding devices to minimize friction. Specimens are tested under a constant axial force to apply absolute axial loads. Characterization of column specimens with cyclic lateral displacements occurs at specified levels, enabling the behavior analysis and comparisons between tests and numerical models. Cyclic repetitions for each displacement demand capture essential data for column strength analysis, aiming to prevent fractures. To further analyze the load on these columns, shear drift curves are derived from uniaxial and biaxial loading tests. These curves show strength reductions with biaxial loading in both directions. Analysis includes weak points and maximum strength observations, ensuring comprehensive load evaluations. While assessing load cases, attention is given to damage evolution[10].

a. Damage Evolution

Another crucial consideration in examining biaxial loading effects on columns is damage control or damage effect analysis. Various specimens are studied through different stages for crack and reinforcement analyses. This analysis incorporates effects under varying conditions, such as spalling and longitudinal reinforcement fractures, helping to identify potential column failure situations. It is essential to locate the maximum strength point to discern effective damage in columns. Biaxial loading can lead to damage in columns, especially at corners, while uniaxial columns are assessed for rupture and bar fractures.

III. EXPERIMENTAL STUDY ON BEHAVIOR ON RC COLUMNS

This section details the experimental study of RC columns in scenarios involving failure, earthquakes, or heavy loads. Observational analyses and performance measurements occur across different components of RC columns, with examinations conducted with or without axial loads. Axial forces are defined in conjunction with associated beams to clarify uniaxial behaviors. The study includes behavioral cross-section analysis under shear span ratios to assess flexure and shear mechanisms. Experiments focus on rectangular columns under horizontal loads applicable in biaxial behavior. The building structures are analyzed for earthquake conditions, acknowledging three-dimensional responses with random values and various structural irregularities. This analysis evaluates bending under moment ratios for structural capacity assessments. Strength and acceleration analyses occur under successive load conditions, addressing frame deterioration and vertical behavior. Biaxial loading's impact on columns and 3D features is tested through inelasticity and damage concentration evaluations. Performance analyses of RC frame structures occur under various load situations, focusing on bending load responses to manage uncertainties. Experimental setups are informed by responses to biaxial cyclic moments. Test results contrast biaxial bending under constant loads with uniaxial bending, enhancing understanding of cyclic loads. Increased complexity in testing designs amplifies risk levels, especially when applying biaxial bending with constant forces. These directional forces and dimensional considerations shape the strength and stiffness of RC columns, necessitating focused analysis on biaxial lateral loading with fluctuating axial forces. Tests occur on bare frame structures to achieve effective evaluations.

a. Column Geometrics

In cyclic biaxial tests, two primary column types are used. These columns, fixed against rotational ends, require effective test configurations and flexibility. Curvature specimens are applied from top to bottom in rigid zones to assure building stability. Feature factors undergo analysis across various configuration vectors for optimal column placement. The cantilever model includes inflection points during column alterations.

b. Displacement Patterns

The behavior of RC columns is shaped by geometric and mechanical characteristics. They are designed via cross-section analysis and axial load assessments. Displacement patterns reflect overall behavior in response to biaxial bending forces applied in two orthogonal directions. Such patterns are effective for biaxial tests, ensuring clarity in uniaxial and biaxial load paths.

IV. CONCLUSIONS

This paper looks at how reinforced concrete (RC) columns respond to earthquakes, focusing on how damage develops and how failures happen under biaxial bending. It reviews different confinement models used in column design and examines the reasons behind RC building failures. An experimental study highlights the behavior of RC columns during various failure scenarios, including earthquakes and heavy loads. The paper assesses the impact of biaxial loading on columns and their three-dimensional features by evaluating inelasticity and damage concentration. It also explores the shapes of columns and their movement patterns when exposed to bending forces from two different directions. The findings offer insights for improved design and construction practices to avoid structural failures during seismic events.

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