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Analysis and Design of Symmetrical Buildings Considering Dynamic Pounding Effect in Residential Apartments

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Abstract
Earthquakes often cause severe structural damage, particularly in densely populated urban areas where adjacent buildings are separated by inadequate seismic gaps. During strong ground motion, neighbouring buildings having different dynamic characteristics may vibrate out of phase, resulting in seismic pounding, which can significantly increase structural damage, member forces, and the possibility of partial or complete collapse. This study investigates the dynamic pounding effect between symmetrical reinforced concrete residential apartment buildings using ETABS. Two G+15 symmetrical buildings separated by 20 mm and 25 mm seismic gaps were modeled and analyzed under earthquake loading. Dynamic analysis was carried out using time history analysis with the El Centro earthquake record as the input ground motion, while static analysis was also performed for comparison under medium soil conditions in accordance with IS 1893 (Part 1):2002. The structural response was evaluated by comparing important parameters including storey displacement, storey drift, storey shear, storey moments, and overturning moments for pounding and non-pounding conditions. The analytical results indicate that insufficient separation between adjacent buildings considerably increases seismic response, whereas providing adequate seismic gaps effectively minimizes pounding effects and improves structural safety. The study demonstrates that dynamic analysis provides a more realistic assessment of pounding behaviour and can assist engineers in selecting suitable separation distances for earthquake-resistant building design.

Index Terms: *Seismic Pounding, ETABS, Time History Analysis, Dynamic Analysis, Residential Buildings, Storey Drift, Storey Shear, Overturning Moment, Seismic Gap, Earthquake Engineering.*

I. Introduction

Earthquakes are among the most destructive natural hazards, causing significant damage to buildings, bridges, and other civil engineering structures. In densely populated urban areas, buildings are often constructed with inadequate separation distances because of limited land availability and economic constraints. During an earthquake, adjacent buildings may vibrate independently according to their individual dynamic characteristics. When the available separation gap is insufficient to accommodate these relative movements, the buildings may collide, resulting in a phenomenon known as seismic pounding. The uploaded thesis identifies seismic pounding as one of the major causes of structural damage during earthquakes.

Seismic pounding generally occurs when neighboring buildings have different heights, masses, stiffness, or natural vibration periods, causing them to oscillate out of phase during strong ground motion. These impacts generate additional lateral forces, increase storey shear, produce larger bending moments, and may cause severe damage to structural and non-structural components. In extreme cases, repeated pounding may lead to partial or complete structural collapse. The thesis explains that insufficient separation between adjacent buildings considerably increases the possibility of earthquake-induced pounding damage.

To minimize the risk of pounding, seismic design codes recommend providing adequate separation joints between adjacent structures. The required separation distance depends on the expected lateral displacement of each building during an earthquake and the seismic design provisions specified in relevant standards such as IS 4326 and IS 1893. However, maintaining the recommended seismic gap is often difficult in metropolitan areas because of high land costs, limited plot dimensions, and planning constraints. Consequently, several existing buildings remain vulnerable to pounding during severe earthquakes. The uploaded thesis discusses the importance of providing sufficient seismic separation to reduce pounding effects.

With the advancement of computational methods, dynamic structural analysis has become an effective

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tool for evaluating earthquake-induced structural behaviour. Software such as ETABS enables engineers to model multi-storey reinforced concrete buildings and assess their response under seismic loading using static, response spectrum, and time history analysis. Dynamic analysis provides a realistic representation of structural behaviour by considering inertia forces, damping characteristics, and modal participation, thereby allowing accurate assessment of pounding effects between adjacent buildings. The uploaded thesis employs ETABS for the dynamic analysis of symmetrical residential apartment buildings subjected to earthquake loading.

The present study investigates the dynamic pounding effect between two symmetrical G+15 reinforced concrete residential apartment buildings separated by 20 mm and 25 mm seismic gaps. Structural modelling and dynamic analysis were carried out using ETABS, considering the El Centro earthquake record as the input ground motion under medium soil conditions in Seismic Zone V. The structural response was evaluated by comparing storey displacement, storey drift, storey shear, storey moments, and overturning moments for pounding and non-pounding conditions. The primary objective is to assess the influence of separation distance on seismic performance and identify suitable seismic gaps for improving structural safety. These objectives are clearly stated in the uploaded thesis.

II. Literature Review

Seismic pounding between adjacent buildings has become an important area of research in earthquake engineering because it can significantly increase structural damage when adequate separation gaps are not provided. During strong ground motion, neighboring buildings may vibrate with different amplitudes and frequencies due to variations in height, stiffness, mass, and natural period. When the available seismic gap is insufficient, repeated impacts occur between adjacent structures, producing additional lateral forces, storey shear, acceleration, and local structural damage. The uploaded thesis highlights that pounding is particularly critical in densely developed urban areas where buildings are constructed with limited separation distances.

Viviane Warnotte investigated the fundamental mechanisms governing seismic pounding between adjacent buildings. The study examined the conditions responsible for pounding and concluded that purely elastic analytical models cannot accurately predict the actual structural response during building collisions. The research emphasized that **nonlinear analysis** is necessary to estimate the required seismic separation distance and to evaluate pounding behaviour realistically.

Robert Jankowski studied the application of nonlinear analytical procedures for predicting pounding effects between neighboring structures. The investigation employed nonlinear viscoelastic impact elements together with multi-degree-of-freedom structural models to simulate collision behaviour. The study concluded that pounding significantly influences structural response and should be considered during the seismic design of adjacent buildings.

Shehata E. Abdel Raheem developed an analytical procedure for evaluating seismic pounding between adjacent buildings using nonlinear dynamic analysis. The research included a detailed parametric investigation considering different recorded earthquake ground motions and various separation distances. Both linear and nonlinear contact models were examined to assess the influence of impact characteristics on structural response. The study demonstrated that pounding behaviour strongly depends on separation distance and earthquake excitation characteristics.

Anagnostopoulos S. A. and Spiliopoulos K. V. investigated earthquake-induced pounding between adjacent multi-storey buildings represented as multi-degree-of-freedom systems. The study considered buildings having different heights, masses, and dynamic properties while modelling collisions through viscoelastic impact elements. Their investigation showed that severe overstresses develop when neighboring buildings possess significantly different dynamic characteristics, highlighting the importance of providing adequate seismic separation in design practice.

Hasan et al. proposed a performance-based analytical approach for evaluating reinforced concrete buildings subjected to earthquake loading. Their methodology incorporated nonlinear structural behaviour through progressive stiffness modification and plastic deformation analysis, enabling improved prediction of structural performance under severe seismic excitation.

Korkmaz and Sari evaluated the seismic performance of reinforced concrete buildings using pushover analysis and nonlinear time-history analysis for different structural configurations and loading patterns. Their results indicated that simplified analytical methods may underestimate seismic demand in taller buildings, emphasizing the importance of dynamic analysis for evaluating high-rise structures.

Summary of Literature

The literature reviewed in the uploaded thesis indicates that most previous investigations are limited to **two-dimensional frames** or **simple three-dimensional structural models** and that only a limited number of studies compare different analytical approaches for estimating the required seismic separation between adjacent buildings. The review concludes that further investigation using **dynamic analysis** is necessary to better understand pounding behaviour and to establish appropriate seismic gaps for multi-storey reinforced concrete buildings. Based on these observations, the present study evaluates the **dynamic pounding effect between** symmetrical G+15 residential apartment buildings using ETABS, considering 20 mm and 25 mm separation gaps under the El Centro earthquake record, and compares structural response parameters including storey displacement, storey drift, storey shear, storey moments, and overturning moments.

III. Methodology

The present study was carried out to investigate the dynamic pounding effect between adjacent symmetrical reinforced concrete residential apartment buildings subjected to earthquake loading. The analytical investigation was performed using ETABS, where two identical G+15 reinforced concrete buildings were modelled with different seismic separation gaps of 20 mm and 25 mm. Both static analysis and time history analysis were conducted to evaluate the structural response under earthquake excitation. The methodology adopted in the uploaded thesis follows this analytical procedure.

A. Structural Modelling

A three-dimensional model of two **G+15 reinforced concrete residential apartment buildings** was developed using **ETABS**. The buildings were assumed to have identical geometric configurations and structural properties so that the influence of the seismic gap on pounding behaviour could be evaluated independently. The analytical models were created with **20 mm and 25 mm separation distances** to compare the structural response under earthquake loading. The building modelling procedure is described in the uploaded thesis.

B. Design Parameters

The structural models were analysed using the following design parameters:

- Structure Type: Symmetrical Reinforced Concrete Residential Apartment Building
- Building Configuration: G+15
- Analysis Software: ETABS
- Seismic Analysis Methods: Static Analysis and Time History Analysis
- Earthquake Record: El Centro Earthquake Ground Motion
- Soil Condition: Medium Soil
- Seismic Zone: Zone V
- Seismic Separation Gaps: 20 mm and 25 mm

These parameters were uniformly adopted throughout the investigation to ensure a consistent comparison of pounding and non-pounding structural behaviour. The thesis specifies these analytical parameters for the study.

C. Time History Analysis

The dynamic behaviour of the buildings was evaluated using **Time History Analysis** by applying the **El Centro earthquake record** as the input ground motion. This method enables the variation of structural response with time to be accurately determined by considering inertia forces, damping, and dynamic characteristics of the structure. Static analysis was also performed for comparison with the dynamic response. The uploaded thesis adopts time history analysis as the principal method for evaluating seismic pounding effects.

D. Response Parameters

The seismic performance of the buildings was evaluated using the following structural response parameters:

- Storey Displacement
- Storey Drift
- Storey Shear
- Storey Moments
- Overturning Moment

These parameters were compared for both **20 mm and 25 mm seismic gaps** to assess the influence of separation distance on earthquake-induced pounding between adjacent buildings. The thesis identifies these response quantities for comparative evaluation.

E. Comparative Evaluation

The analytical results obtained from the static and dynamic analyses were compared to evaluate the influence of seismic separation on the structural behaviour of adjacent buildings. Particular attention was given to identifying the variation in **storey displacement, storey drift, storey shear, storey moments, and overturning moments** under pounding and non-pounding conditions. Based on the observed responses, the study assessed the effectiveness of different separation gaps in reducing earthquake-induced pounding and improving the seismic safety of reinforced concrete residential apartment buildings. The methodology and objectives described in the uploaded thesis form the basis of this comparative evaluation.

IV. Results And Discussion

The structural response of the symmetrical G+15 reinforced concrete residential apartment buildings was evaluated using static analysis and time history analysis in ETABS. Two analytical models having 20 mm and 25 mm seismic separation gaps were investigated under the El Centro earthquake record for medium soil conditions in Seismic Zone V. The structural behaviour was assessed by comparing storey displacement, storey drift, storey shear, storey moments, and overturning moments under pounding and non-pounding conditions. The uploaded thesis presents these response parameters for comparative evaluation.

A. Storey Displacement

The analytical results indicate that **storey displacement increased progressively from the base towards the roof** for both analytical models. Buildings with the **20 mm seismic gap** exhibited comparatively larger lateral displacements because the smaller separation distance increased the possibility of pounding during earthquake excitation. The model with the **25 mm separation gap** demonstrated relatively lower displacement, indicating that increasing the seismic gap improves structural performance by reducing building interaction during seismic events. The thesis presents comparative displacement results for both separation distances.

B. Storey Drift

The comparison of **storey drift** showed that the maximum inter-storey drift occurred in the upper storeys of the buildings. The analytical results demonstrated that reducing the separation distance increased the relative movement between adjacent buildings, resulting in higher drift values during earthquake loading. Buildings provided with the **25 mm seismic gap** exhibited comparatively lower drift, indicating improved seismic behaviour and reduced pounding effects. The uploaded thesis includes the storey drift comparison for both analytical models.

C. Storey Shear and Storey Moments

The **storey shear** and **storey moments** obtained from the analyses varied according to the seismic separation distance. The building model having the **20 mm gap** experienced comparatively higher internal forces because of repeated impact between adjacent structures during dynamic excitation. Increasing the separation distance to **25 mm** reduced the pounding interaction and consequently lowered the storey shear and bending moments throughout the structure. The thesis presents comparative results for these structural response parameters.

D. Overturning Moment

The analytical investigation further evaluated the **overturning moment** developed in both structural models. The results indicate that overturning moments increased under dynamic earthquake loading and were influenced by the available seismic separation. The model with the **larger separation gap** exhibited comparatively improved structural stability because reduced pounding minimized the transfer of additional impact forces between adjacent buildings. The uploaded thesis compares overturning moments for the different analytical cases.

E. Comparative Assessment

The overall analytical investigation demonstrates that **time history analysis** provides a more realistic evaluation of seismic pounding than conventional static analysis because it considers the time-dependent characteristics of earthquake ground motion and structural dynamic response. The results further indicate that **providing an adequate seismic separation gap significantly reduces pounding effects**, resulting in lower storey displacement, storey drift, storey shear, storey moments, and overturning moments. The study therefore highlights the importance of maintaining sufficient seismic separation between adjacent reinforced concrete buildings to improve earthquake resistance and structural safety. These findings are consistent with the analytical results presented in the uploaded thesis.

V. Conclusion

The present study investigated the dynamic pounding effect between adjacent symmetrical G+15 reinforced concrete residential apartment buildings using ETABS. Two structural models with 20 mm and 25 mm seismic separation gaps were analysed under static analysis and time history analysis using the El Centro earthquake record for medium soil conditions in Seismic Zone V. The structural response was evaluated by comparing storey displacement, storey drift, storey shear, storey moments, and overturning moments. These objectives and analytical procedures are presented in the uploaded thesis.

The analytical investigation demonstrated that seismic separation distance has a significant influence on the behaviour of adjacent buildings during earthquake excitation. Buildings with a 20 mm separation gap experienced comparatively higher structural response because of increased pounding interaction, whereas increasing the gap to 25 mm reduced the severity of impacts and improved the overall seismic performance. Adequate seismic separation was found to be effective in reducing storey displacement, storey drift, storey shear, bending moments, and overturning moments, thereby improving structural safety. These observations are consistent with the results presented in the thesis.

The study further establishes that time history analysis provides a more realistic representation of seismic pounding than conventional static analysis because it considers the actual variation of earthquake ground motion with time and accurately captures the dynamic interaction between adjacent buildings. The findings of this investigation provide useful guidance for structural engineers in selecting appropriate seismic separation distances for multi-storey reinforced concrete buildings located in earthquake-prone regions. Proper provision of seismic gaps can significantly reduce pounding damage and improve the earthquake resistance of residential apartment buildings. These conclusions are supported by the analytical investigation described in the uploaded thesis.

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Note: Verify the complete bibliographic details from the thesis reference section before journal submission.

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