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Analysis of the Seismic Performance of Various Irregularly Shaped Concrete Columns on Residential Buildings

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Abstract

The shape of the columns can affect a structure's seismic resistance. A building's important structural and architectural components are columns. Seismic resistance requires lateral strength and stiffness. Architects and engineers commonly use L-shaped, T-shaped, and plus-shape for composite columns. The researchers assessed the capacity of irregular concrete columns under seismic stress circumstances, which may help structural designers for future designs. In order to accomplish this, the researchers investigated and analyzed the seismic strength of the columns using STAAD, as well as the finite element approach, which were used to validate the STAAD results. The results showed that using square columns for a three (3)-story building resists seismic waves better than other columns, while the irregular-shaped columns resist seismic waves better for five (5) and seven (7)-story residential buildings. Compared to rectangular and irregularly shaped columns, square columns are more ideal for low-rise residential buildings. For residential buildings over three floors, irregular-shaped columns are recommended to be able to withstand seismic waves.

Keywords: Seismic capabilities, storey drift, irregularly shaped columns, finite-element method

1.0 INTRODUCTION

Columns are structurally and architecturally critical elements of a building. The book De Architectura, published in the 1400s, established column measurements based on the number and type of columns to be utilized, as well as the temple style required. The height of the column was determined as a multiple of the diameter.

During the Elizabethan and Jacobean periods, large columns were brought to the greatest homes, although their proportions did not necessarily complement the property. Symmetry became increasingly essential during this period, and homes were designed to face outward rather than inside into courtyards.

In terms of structural behavior, a column is identical to a wall. In a perfect world, the column would be loaded axially rather than eccentrically, which would cause a moment and weaken the column (Smith, 2016). One of the challenges that structural engineers typically confront is balancing the architectural design with the seismic design of the project. Engineers are in charge of choosing a material that can withstand lateral forces operating on the system as well as gravity forces adding additional stress to the structure.

The basic criteria for a structural part to be seismically sound is that it be made of concrete. Its lateral strength and stiffness are resistant. All lateral loads resisting in the structure's components must be stiff to make the structural system more seismically resistant. Tremors have a complicated effect on the structure. The duration of a structure's shaking, the type of soil it's built on, and the frequency of earthquakes are all instances of this. To avoid the effects of tremors, a structure should be constructed to adapt to an earthquake. Design economy is achieved by allowing the structural part to flex beyond its elastic limit.

A composite structure is a steel-reinforced concrete frame with uneven sections. The steel will be shaped to meet the uneven column's section, with a transverse stirrup providing longitudinal support. T, L,

+, and enclosed steel constructed of solid and lattice steel are the most common composite forms utilized by architects and engineers. Because the irregular steel reinforced concrete (SRC) column has equal width between its column limbs and infilled walls, it can withstand the swellings of the

rectangular column and maximize the internal space consumption of the building. Furthermore, because to their bearing capacity and seismic performance, SRC structures can withstand seismic motion even if they are in a high seismic zone. The bearing strength and ductility of reinforced concrete irregular columns are unsatisfactory, according to the results of many models and studies.

The paper will focus on the effects of seismic behavior onto various irregularly shaped plain concrete columns, specifically the L-shaped column, T-shaped column, and plus-shaped column on a 3-storey, 5-storey, and 7-storey residential structure. The researchers compared the mechanical behavior and shear performance of the columns to solid rectangular and square columns. The use of STAAD PRo V8i and finite element analysis will be applied to determine the seismic capabilities of the columns on a 30 m by 10 m residential building and compare them.

The researchers aim to assess the various irregularly shaped columns and generate suggested design methods. The following are the objectives of this research:

(1) Incur a Threshold table on the seismic capabilities for specific irregularly shaped concrete columns, (2). Identify the storey drift of each irregularly shaped concrete column, (3) Incorporate the irregularly shaped concrete column in 3 - 5 - 7 Storey structure (4) Validate the experimental result of irregularly shaped concrete columns through the use of finite element method, and

(5) Make a comparison of STAAD results and finite element method for the 3 - 5 - 7 storey structure with regular and irregular columns.

2.0 METHODOLOGY

This chapter details the researchers' methodology and procedures for the analysis of the seismic performance of various irregularly shaped concrete columns on residential buildings. The methodology section is a critical component of the research paper; thus, the researchers will detail each phase and step. The methodology clarifies all of the research's fundamental questions, including why, who, how, and where. The methodology section contains an in-depth examination of the study's methodological framework. The methodology section discusses the research design, the research setting, the data collection procedures, the data collection instruments, and the statistical treatment.

The use of programs are applied to conduct the experiments. Both STAAD and ABAQUS were used to determine the displacement of the storey drift and seismic capabilities of the structure. These were used since they show accurate results in the measurement of shear forces and lateral displacement; it is particularly well-suited for simulating material and structural problems. It includes numerous constitutive models for analyzing the nonlinear behavior of steel, concrete, and soil, among other materials.

Methodological Framework

The Methodological Framework depicts the workflow for achieving the goals of this research article. The sequence of developing the study's development is considerably clearer when using the methodological framework. The research study followed the experimental research design to discuss and evaluate the strength of the different column shapes of the structure against seismic forces. The researchers chose this since an experiment will be conducted regarding the seismic capabilities of the columns.Data Analysis

The researchers compared the results obtained from STAAD and ABAQUS. The data consists of the displacement of the storey drift and the strength of the columns. The structure was considered more resistant to earthquakes if its storey drift displacement is low and its seismic capabilities to be high. After comparing the results from the two programs, the researchers generated a conclusion if the usage of irregular columns positively affects the seismic capabilities of s structure or not. The final output of the strength of each structure was put to the Threshold Table to be more presentable and for ease of comparison of column strength in the structure subjected to earthquakes.

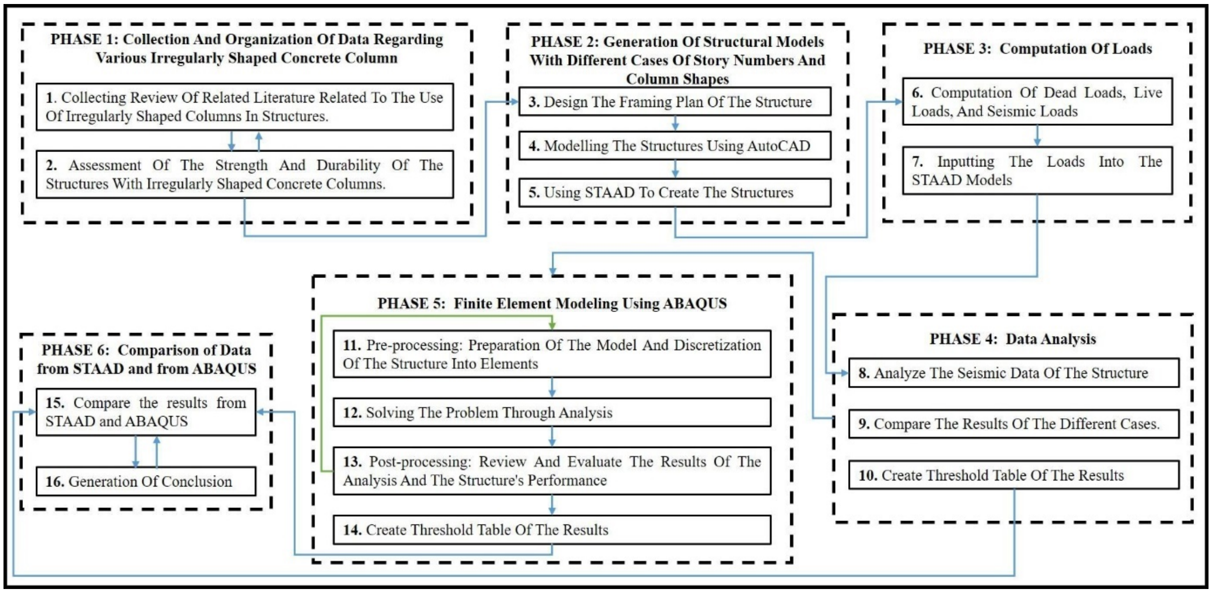

Figure 1. Methodological Framework

STAAD Data Analysis

In analyzing the seismic analysis of the structure in STAAD Pro V8i, the researchers used the static check, static loads analysis, and story drift analysis from STAAD Pro V8i to further analyze the strength and behavior of the structures. Other analysis in STAAD Pro V8i like buckling shapes, Diaphragm Center of Rigidity (Dia. CR in STAAD) were used since the study is focused on the seismic behavior of the structure.

ABAQUS Data Analysis

There are several ABAQUS programs that the researchers used for the different steps. In total, the researchers will use three programs to solve and generate the final model. These programs are ABAQUS preprocessor, ABAQUS solver, and ABAQUS postprocessor.

3.0 RESULTS AND DISCUSSION

Floor Framing Plan for STAAD Pro V8i and ABAQUS

A basic floor framing layout as shown in Figs. 2, 3, and 4. They were used for the analysis and will be typical to all floors. The floor framing is a two-way slab system supported by girders. Columns were spaced six meters on X- direction and five meters on Z- direction.

As shown in Fig. 4, the L-shaped columns were located in the corners of the structure. The T-shaped columns were put on the sides of the structures, and the plus-shaped columns were put in the middle of the structure.

Drift Comparison

Drift limits were based on the resulting period of the structure, drift should not be greater than 2.5% for the period of less than 0.7Sec and 2.0% for the period of more than 0.7Sec. For the 3 Level Structure, the period is 0.38 Sec therefore drift should not be greater than 2.5% of story height. For the 5 Level Structure the period is 0.56 Sec therefore drift should not be greater than 2.5% of story height. For the 7 Level Structure the period is 0.72 Sec therefore drift should not be greater than 2.0% of story height.

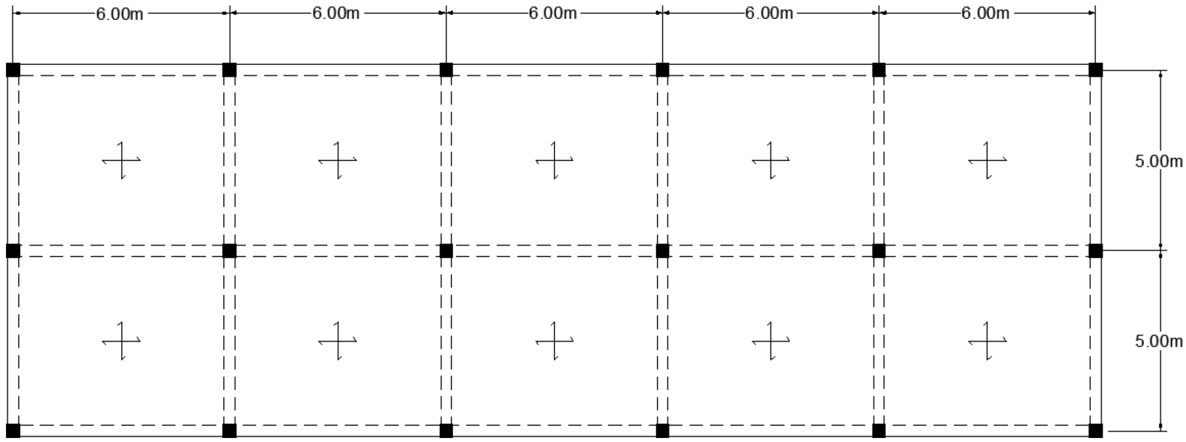

Figure 2. General Frame Plan of Structure with Square Columns

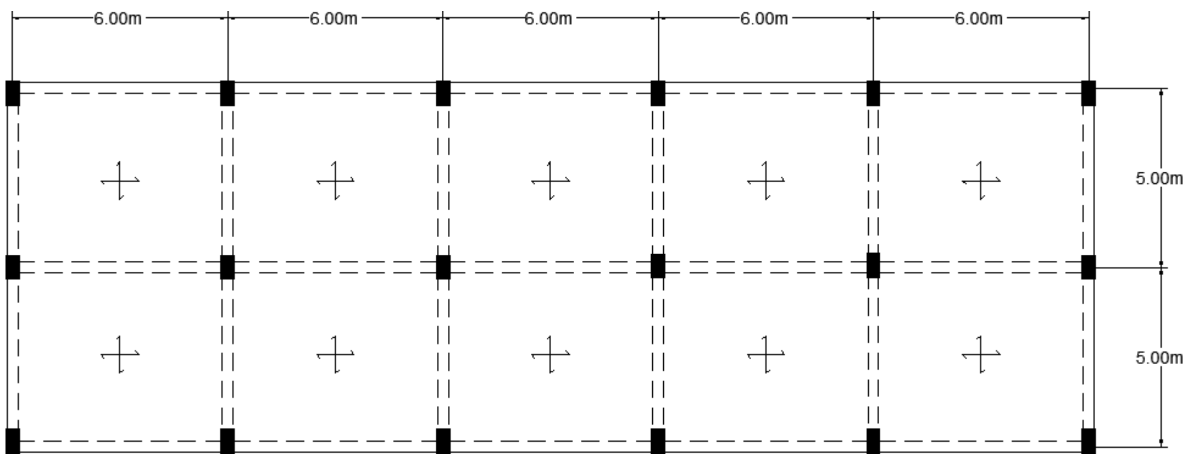

Figure 3. General Frame Plan of Structure with Rectangular Columns

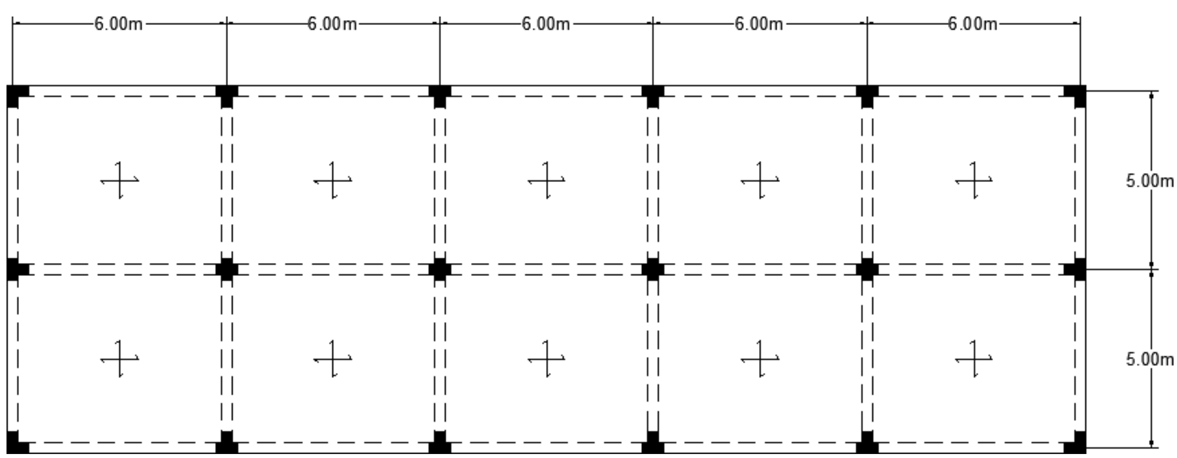

Figure 4. General Frame Plan of Structure with Irregularly-Shaped Columns

As shown in Fig. 4, the L-shaped columns were located in the corners of the structure. The T-shaped columns were put on the sides of the structures, and the plus-shaped columns were put in the middle of the structure.

Threshold Table

Results from STAAD and from finite element analysis using ABAQUS differ in the results of the accumulated data. The table below shows the summary of the data collected from the analysis made using STAAD Pro V8i and a finite element analysis made using ABAQUS. The researchers compiled the results of the maximum values of the drift ratio, axial, shear, and bending moment of the columns of the different levels of structures.

For the drift ratio, it was found out in the results for both STAAD Pro V8i and ABAQUS in the 3 - 5 - 7 level structure, the square columns produced a low story drift compared to the other two columns for both X and Z directions. For the X drift direction, the average percentage of change between STAAD Pro V8i and ABAQUS in square column for 3 -5 level structure is an increase of 2.37% and 0.45%, while a decrease of 1.60% in level 7 structure.

On the other hand, for the Z direction drift, there is an increase of 5.02% in level 3 structure and decrease of 6.38% and 5.61% in 5 and 7 level structure. There are little discrepancies in the ratio for the square column in the Z directions between the three columns, but for the overall results, the square column produces the lowest drift ratio. Using the square column in 3 - 5 -7 level structure, the structure can be stiff enough to comply with the NSCP 2015 drift limit of 2.5% with periods of 0.38, 056, and 0.72 respectively.

The column with the least value of its maximum shear and axial forces is the irregularly shaped columns for the 5-7 level structures. This requires lesser rebar requirements for the column when designing it. The square column has the least value of its maximum shear and axial forces when the structure only has 3 levels. It can be recommended to use irregularly shaped columns for structures that are greater than 3 levels, and square columns for structures less than 3 levels. For the bending moment, the finite element analysis showed that the column with the least bending moment is the irregularly shaped columns for the 5-7 level structures. While the 3 level structure with rectangular columns has the least amount of bending moment.

4.0 CONCLUSION AND RECOMMENDATIONS

Conclusion

The shape of the columns may impact the structural integrity of a structure against seismic forces. Columns are important structural and architectural elements of a building. A structural element's lateral strength and stiffness are required for seismic resistance. The L-shaped, T-shaped, and plus shaped columns are the most common composite column shapes utilized by architects and engineers. Once the researchers have determined the capacity of irregular concrete columns, structural designers will have a better understanding of the capacity of various irregular shaped concrete columns under seismic loading conditions than they did in the past.

The researchers successfully created threshold tables containing the summary of the story drift, axial, shear, and moment bending of the different columns of different stories shown in tables 1, 2, and 3. In the 3 - 5 - 7 level structure, the square columns produced a low story drift compared to the other two columns for both X and Z directions. Based from the tables, for the irregular column structures, it can be observed that there is an increase of 2.61%, 1.3%, and 6.28% from the results using STAAD and the results using ABAQUS for the story drift in the X-direction in the 3-story, 5-story, and 7-story structures, respectively. There is also an increase of story drift of 7.17% in the Z-direction for the 3-story structure.

For the 5-story and 7-story structures, there is a decrease of story drift of 4.6% and 2.04% in the z-direction. The axial loads of the 3-5-7 story structures have close values, decreasing by an average of 50%. There is also a decrease of 17.19%, 22.16%, and 32.81% for the shear force of the 3-story, 5-story, and 7-story structures, respectively.

For the bending moment, there is a decrease of 26.78%, 45.53%, and 47.25% for the 3-story, 5-story, and 7-story structures, respectively. The incorporation of the irregularly shaped shaped concrete column into the structures is shown in a frame plan in figure 4. The seismic performance of the different irregularly shaped columns, particularly the L-shaped, T-shaped, and plus shaped columns, was analyzed in comparison to the square and rectangular columns on a 3-storey, 5-storey, and 7-storey residential structure.

Recommendations

Based on the conclusions made and the process on how the researchers conducted the study, this study offers the following:

For any research-related problem, consider the research in a high-rise structure since the h paper focuses only on the low to mid rise structure. Furthermore, consider also applying reinforcement into the column and to further analyze the strength of irregularly shaped columns, particularly the L-shaped, T-shaped, and plus-shaped columns. This is because almost all the structures nowadays use reinforced concrete columns in their structure.

In addition, the size of the columns, especially the L-shaped, T-shaped, and plus-shaped columns, should be prioritized to avoid further high storey drift of the structure. The size of the columns should not compromise the seismic design of the structure; that is why adding the different materials or strengthening products that could avoid high storey drift and inelastic deformation to accompany the damage and residual deformation in the elements.

For the following researchers, they must be considerate when creating research questions. They need to make technical questions, and it has to be directly connected to the themes of the review of related literature and to the test results of the experiment if the research design is experimental. Considering also different applications like ETABS for analysis of the structures and ANSYS for the finite element model analysis, this would greatly help other researchers to gather more data in their paper.

Lastly, people in charge of the development of infrastructures should look at this study to impart knowledge not just in their field but also to everyone capable of improving the development of infrastructures. These studies would enlighten the engineers and individuals on the importance of the column's strength and behavior when applying seismic loads, especially for the structures near the fault line.

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