Behaviour of buildings with coupled Reinforced Concrete columns

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Abstract. Columns play a very crucial role in transferring forces to the foundation. This study aims to compare the influence of Coupled columns in place of Regular (conventional) columns in Reinforced concrete framed structures. A Coupled column is one with two individual parallel members connected at their ends with deep beams so that it behaves as a single member. The parallel members are also some times connected at intermediate levels. A six-storey parking structure is considered for the study with three alternatives of different column configurations. They are analysed for gravity loads, seismic (Zone-II) and wind (basic speed of 50m/s) loads. The configurations are Regular Column with Regular Beam (RCRB), Coupled Column with End Connecting Beam (CCEB) and Coupled Column with End and Intermediate Connecting Beams (CCIB). The cross-sectional area of the Coupled column is maintained equal to that of conventional Regular column. Linear Dynamic analysis of the structure is performed for load combinations as per IS 456: 2000. It is observed from the results that the lateral sway is reduced in CCIB by 7%, while quantities of concrete and steel reinforcement are 7% and 13% less respectively compared to RCRB. Considering the advantages of strength and serviceability, apart from the economy, it was concluded that the structure with Coupled columns performs better than conventional column structure.

1. Introduction

The configuration of any building structure is generally decided based on functional aspects. For high-rise buildings, the effect of wind and earthquake forces are predominant on the lateral load resisting system of a structure. As the columns are primary lateral load resisting elements, the size and spacing of columns depend upon functional requirements duly following the prescriptive guidelines laid down in respective codes of practice. Alternatively, shear walls and bracing systems need to be introduced to satisfy the lateral load capacity of buildings which may have an impact on the economy of the building. Aditya and Prakash [1] made a comparison between the buildings with specially shaped RC columns and rectangular-shaped RC columns of 6 storeys, 9 storeys, 12 storeys and 15 storeys. The authors reported that seismic performance of the building with specially shaped columns behaves better compared to the building with rectangular shaped columns. The authors reported that the stiffness of the frame with a rectangular column of the same area is inferior to the frame of a specially shaped column. Atickur et al. [2] studied the effect of the special-shaped column on lateral load resistance capacity of Reinforced Concrete building. The authors have considered four different buildings (6 storeys, 10
storeys, 15 storeys and 20 storeys) which were analyzed with conventional rectangular columns and specially shaped columns of L, Tee and Cross. They reported that the maximum storey displacements in building with rectangular shaped columns increased by 11.78%, 8.83%, 34.84 and 5.51% respectively for 6, 10, 15 and 20 storey buildings. Yang et al. [3] carried out a comparative study of seismic behaviour between specially shaped column frame structure and rectangular column frame structure as per Chinese code and technical specifications. Yang and Tang [4] investigated seismic behaviour of specially shaped columns with a cross-section of L, T, + and compared with rectangular columns. The authors reported that the cross-section shape of a column, axial compression ratio and reinforcement are the main parameters sensitive to seismic behaviour of these specially shaped columns. Zhou et al. [5] investigated the behaviour of a specially shaped column composed of concrete-filled steel tubes (SCFST column) experimentally subjected to a constant axial load and a cyclically varying flexural load. They concluded that mono columns of SCFST worked together well and behaves effectively when subjected to lateral loads.

2. Aim, Objective and Scope

2.1. Aim
To study the influence of Coupled Columns vis-a-vis Regular columns in a normal Reinforced Concrete framed structure.

2.2. Objective
1) To assess the variations in the Stiffness and Member forces in columns.
2) To study Lateral sway, Inter-Storey Drift behaviour.
3) To compare the concrete and reinforcement requirements.
4) To report the influence of Coupled Column.

2.3. Scope
The study conducted on a six-storey Parking structure accommodating 80 cars in each floor is considered in seismic Zone-II (Visakhapatnam). Accordingly, the basic wind speed of 50 m/s is considered. ETABS Evaluation version software was adopted for the analysis and design. The Equivalent Static method and Linear dynamic analysis (Response Spectrum Method) of the structure are performed for seismic design. The pressure coefficient method is adopted for wind load analysis.

3. Details of building considered for the study
A six-storey parking structure is planned as per the National Building Code of India 2016 (Volume-1) [6] and considered for the study. The size of the building is 72m × 35m excluding ramps and the building is assumed to be located in Visakhapatnam. The ramps are provided on either end of the building to access the structure for parking and also climbing to different storey levels. The ends of the parking structure block are not integrated with the ramps provided on either end to study the behaviour of parking structure independently. The height of the structure is about 20 m with a storey height of 3.3 m each. Plan of the parking structure is shown in figure 1. The parking structure beam layouts with Rectangular and Coupled columns are shown in figure 2. Figure 3 shows Rendered view of the parking structure.

![Figure 1. Parking plan of the structure](image-url)
3.1. Aim

In this study, coupled columns are introduced as a replacement to Regular rectangular columns to behave structurally better and providing large column-free space, particularly in parking structures. Since it is a new concept that is being introduced, the definition of the Coupled column is explained as follows.

A Coupled column is one with two individual parallel members connected at their ends with deep beams so that it behaves as a single member. The parallel members are also connected at intermediate levels if necessary. The vertical configurations of the alternatives considered are presented in figure 4. The cross-sections of both rectangular and coupled columns are shown in figure 5. The sizes of elements in a Coupled column is fixed in such a way that the area of cross-section is constant with that of a Regular column. However, the sizes of individual elements may not be equal and will be decided based on adjoining spans. Clear distance between the two elements of the Coupled column is computed based on the trial and error method to meet the Coupled behaviour (Deep beam).
The member dimensions and material properties are shown in Table 1 and Table 2 respectively and load cases considered are shown in Table 3.

### Table 1. Member Dimensions (mm)

| Type                  | RCRB | CCEB | CCIB |
|-----------------------|------|------|------|
|                       | C1   | C2   | C1   | C2   |
| Columns               |      |      |      |      |
| 1-3 storey (Columns)  | 300 x 800 | 300 x 300 | 300 x 500 | 300 x 300 |
| 4-6 storey (Columns)  | 300 x 600 | 300 x 250 | 300 x 350 | 300 x 250 |
| Beam - X direction    | 300 x 450 | 230 x 350 | 230 x 350 |      |
| Beam – Y direction    | 300 x 650 | 300 x 650 | 300 x 650 |      |
| Plinth Beam          | 300 x 500 | 300 x 500 | 300 x 500 |      |
| End Connection        | -NA- | 300 x 900 | 300 x 300 |      |
| Intermediate Connection | -NA- | -NA- |      | 300 x 300 |
| Slab                 |      |      |      |      |
| S1                   | 180  | 160  | 160  |      |
| S2                   | 180  | 160  | 160  |      |
| S3                   | 130  | 130  | 130  |      |

### Table 2. Material Properties

| Parameter                        | Detail |
|----------------------------------|--------|
| Grade of concrete for all RCC structural elements | M30    |
| Grade of concrete for Parapet wall | M25    |
| Grade of steel                   | Fe415  |
Table 3. Design load parameters

| Type           | Description                                                                 | Reference                                      |
|----------------|-----------------------------------------------------------------------------|------------------------------------------------|
| Dead           | Self-weight of the structure to be considered by the software (Density of Reinforced Concrete = 25 kN/m³) | Table-1 of IS 875 (Part 1): 1987 [7]           |
|                | Floor finish = 1.5 kN/m²                                                     |                                                |
| Live load      | Live load = 4 kN/m² (Fixed based on the gross weight of the vehicle)         | IS 875 (Part 2): 1987 [8]                     |
| Earthquake load| Importance load parameters:                                                 | IS 1893 (Part-1): 2016 [9]                    |
|                | Zone = II                                                                   |                                                |
|                | Importance factor = 1                                                        |                                                |
|                | Soil type = Medium (II)                                                      |                                                |
|                | Response reduction factor = 3                                                |                                                |
| Wind load      | Wind load parameters:                                                       | IS 875 (Part-3): 2015 [10]                    |
|                | Basic wind speed, V₉ = 50 m/s                                                |                                                |
|                | Risk factor, K₁ = 1                                                          |                                                |
|                | Terrain Category = 3 (K₂ varies with the height of the building)             |                                                |
|                | Topography factor, K₃ = 1                                                    |                                                |
|                | Importance factor for Cyclone region K₄ = 1                                  |                                                |

3.1.1. End connections. Effective span, l = 1 m; Overall depth of beam, D = 0.9 m

\[
\frac{l}{D} = \frac{1}{0.9} = 1.11 < 2.5
\]

Hence, as per Clause 29.1 of IS 456: 2000 [11], the End Connection is designed as a deep beam.

4. Analysis and design of the structure
The three alternatives, viz., Regular columns and Regular beams (RCRB), Coupled column structure with End connecting beam (CCEB), Coupled column structure with End and Intermediate connecting beams (CCIB) were analyzed for gravity and lateral loads as indicated in Table 3. The load combinations are taken as per IS 456: 2000 [11].
The analysis was carried out using ETABS Evolution version software. The wind analysis of the alternatives is performed using Equivalent Static pressure coefficient method. The seismic design of the alternatives is carried out based on results of Linear Dynamic analysis (Response Spectrum Method).

5. Results and discussion
The results of the analysis and design for all the three alternatives considered are presented. The parameters such as stiffness, lateral sway, storey drift and quantity of materials (concrete and steel reinforcement) are compared among the alternatives for the whole building.
The flexural behaviour of three typical columns i.e., Intermediate column (IC), Edge column (EC), Corner column (CC) as marked in figure 2 is also presented.

5.1. Lateral sway
According to Cl. 20.5 of IS 456: 2000 [11] the lateral sway at the top of the structure should not exceed (H/500), where H is the total height of the building. Accordingly, the permissible lateral sway is 40 mm for a 20 m total building height. The lateral sway along the principal direction (Y-axis) of the structure for all the three alternatives is shown in figure 6. The alternative with CCIB has less lateral sway than RCRB followed by CCEB. When compared with RCRB, the sway in CCIB is less by 7%. However, it is 15% more in the case of CCEB. The sway in CCEB and CCIB followed a similar pattern whereas a regular trend is observed in RCRB. However, the lateral sway is within the permissible limits in all the three alternatives.
5.2. Inter-storey drift
According to Clause 7.11.1 of IS 1893 (Part 1): 2016 [9], the Inter-storey drift shall not exceed 0.004 times the storey height. Accordingly, permissible storey drift is 13.2 mm for a storey height of 3.3 m.

5.3. Storey stiffness
Variation in storey stiffness along the principal direction (Y-axis) of the structure for all the three alternatives is shown in figure 8. It is observed that the storey stiffness is higher in CCIB almost throughout the height of the building compared to RCRB and CCEB. The stiffness of RCRB and CCEB is almost similar up to 3rd storey. Thereafter the stiffness of CCEB is gradually reduced compared to RCRB.

The Axial force in the Intermediate column for the three alternatives are shown in figure 9. Reduction of Axial force is noticed in CCEB and CCIB in the order of about 13% compared to RCRB. This may be due to reduction in self-weight of the structure.

The bending moment for the three alternatives in the Intermediate column, Edge column and Corner column for the total height of the structure is shown in figure 10. When compared with RCRB, the bending moment in the Intermediate column is less in CCIB and followed by CCEB. A maximum reduction of 70% in CCIB and CCEB compared to RCRB at plinth level is observed in the load combination (1.5 Dead loads +1.5 R.S.M).
Figure 8. Variation of Storey Stiffness in principle direction (Y-axis)

Member forces

Figure 9. Axial Force in Intermediate column

Figure 10. Bending Moments along with IC, EC and CC
5.4. **Longitudinal rebar percentage (LRP)**

Longitudinal rebar percentage in an Intermediate column, Edge column and Corner column is shown in figure 11 for the three alternatives. The LRP in CCEB and CCIB was reduced to 21% compared to RCRB at plinth level in respect of Intermediate column.

![Figure 11. Longitudinal Rebar Percentage along with IC, EC and CC](image)

In the case of the Edge column, the LRP is also less for CCIB and CCEB compared to RCRB. The maximum reduction is found to be 48% and 20% for CCIB and CCEB respectively at 5th storey level. LRP is less in RCRB compared to CCEB and CCIB up to 4th storey in case of Corner column. At 4th storey level, LRP reduction is 24%.

The longitudinal reinforcement in a typical beam along Y-axis is shown in figure 12. The LRP at Top (support) of the beam is less for CCEB and CCIB compared to RCRB and the reduction was up to 22% at supports. Similarly, the LRP at the Bottom (mid-span) was up to 35%.
5.5. Quantity of materials

The total material quantity for all the three alternatives is presented in figure 13. When compared to RCRB, the concrete quantity is less by 8% and 7% in CCEB and CCIB respectively. Similarly, total steel quantity in CCEB and CCIB is less by 16% and 13% respectively compared to RCRB.

6. Conclusions and recommendations

After a comparative study, as per engineering knowledge and best practices, it has been established that the building with Coupled columns with End and Intermediate connecting beams (CCIB) performs better under seismic and wind load conditions than building with Regular rectangular columns (RCRB) under same loadings. The following conclusions are derived based on results and discussion.

6.1. Conclusions based on serviceability aspects

1. The structure with CCIB has less lateral sway (7%) compared to RCRB. However, it is more in CCEB (15%) when compared with RCRB.
2. The maximum inter-storey drift is more (45%) in CCEB compared to RCRB. However, in the case of CCIB, it is marginally less (2%). In all the three cases maximum storey drift occurs at the fourth storey. However, the storey drift in all three cases is within the maximum permissible limit.
3. The structure with CCIB provides more storey stiffness than CCEB and RCRB.
6.2. Conclusions based on collapse behaviour

1. The axial force in intermediate columns is less by about 13% in both CCEB and CCIB compared to RCRB.
2. The bending moments in Intermediate, Edge and Corner columns in CCEB and CCIB structures are less compared to RCRB structure throughout their height.
3. The span and support bending moments in beams along Y-axis are less in CCIB and CCEB structures compared to RCRB.
4. Coupled column structure with “End connecting beam” (CCEB) and with “End and Intermediate connecting beams” (CCIB) require less quantity of concrete (by 8% and 7% respectively) than the structure with “Regular columns” (RCRB). In respect of steel reinforcement also, CCEB and CCIB need less quantity than RCRB by 16% and 13% respectively.

6.3. Recommendations

To bring Coupled column behaviour, Deep beams are required to be introduced at the column ends as Connecting beams instead of Regular beams.

1. An advantage of using Coupled columns is demonstrated through a case study on a Parking structure. It is recommended to introduce such columns to improve the economy in construction and safety in serviceability parameters.
2. Coupled column arrangement would facilitate the running of various common services such as pipelines, fire lines, and plumbing, etc., in multi-storied buildings.

References

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