iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 12 **Issue:** V **Month of publication:** May 2024

DOI: https://doi.org/10.22214/ijraset.2024.62549

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue V May 2024- Available at www.ijraset.com

Behavioural Study of Beam-Column Joint for Seismic Loading

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***Abstract:** The seismic performance of Reinforced Concrete (RC) structures is a critical aspect of structural engineering, particularly in regions prone to seismic activity. This project presents a detailed study focusing on the behaviour of joints in RC structures following seismic events, utilizing the powerful computational tool ETABS. The primary objectives include understanding the response of joints under seismic loading, assessing their vulnerability, and proposing strategies for enhancing their seismic resilience. The study employs ETABS, a widely used software package for structural analysis and design, to simulate seismic actions on RC structures. Various types of joints, including beam-column joints and slab-column connections, are meticulously analysed under different seismic intensities and structural configurations. Through comprehensive analysis, the project aims to identify critical failure modes, such as shear failure, flexural failure, and joint sliding, and evaluate their impact on overall structural performance. Findings from this study contribute to the advancement of seismic design and retrofitting practices, offering insights into effective strategies for enhancing the seismic resistance of RC structures. The outcomes are valuable for engineers, researchers, and practitioners involved in earthquake engineering, providing essential knowledge for designing resilient structures capable of withstanding seismic hazards. This project underscores the importance of understanding joint behaviours in RC structures subjected to seismic loading, offering practical implications for improving structural safety and mitigating the impact of earthquakes on the built environment.*
***Keywords:** Seismic behaviour, Reinforced Concrete (RC) structures, Joints, ETABS, Structural analysis, Seismic resilience, Failure modes, Retrofitting, Seismic design, Earthquake engineering.*

I. INTRODUCTION

In the field of structural engineering, the concept of "strong column, weak beam" analysis is a fundamental design principle that has significant implications for the safety and resilience of buildings and other structures. This approach prioritizes the strength and stability of the columns, which serve as the vertical load-bearing elements, over the beams, which primarily support the horizontal loads. The rationale behind this strategy is to ensure that during a major structural event, such as an earthquake or explosion, the columns remain intact and capable of supporting the overall structure, even if the beams experience some level of damage or failure. By designing the columns to be stronger than the beams, engineers can create a system that is more likely to withstand the stresses and forces that can threaten a building's integrity, thereby enhancing the overall safety and stability of the structure.

In the realm of structural engineering, the term "moment capacity" is a crucial concept that refers to the maximum bending moment a structural element, such as a column or beam, can withstand before reaching its ultimate strength limit. This capacityis determined by the cross-sectional properties, material characteristics, and the loading conditions the element is subjected to Key terminology associated with moment capacity includes: 1. Bending Moment: The internal force that causes a structural element to bend, resulting in compressive and tensile stresses within the material. 2. Yield Strength: The stress at which the material transitions from elastic to plastic deformation, marking the point where permanent deformation begins. 3. Ultimate Strength: The maximum stress a material can withstand before it fails or fractures, representing the limit of the element's load-bearing capacity. 4. Neutral Axis: The imaginary line within a cross-section of a structural element where the stresses transition from compression to tension, or vice versa. 5. Moment of Inertia: A measure of a cross-section resistance to bending, which is directly related to the element's moment capacity.

Understanding these key definitions and terminology is essential for accurately analysing and designing structural elements to withstand the anticipated loading conditions and ensure the safety and integrity of the overall structure. The requirement for the moment capacity ratio between columns and beams is a critical design consideration in structural engineering. This ratio, often referred to as the "strong column-weak beam" principle, is essential for ensuring the safety and stability of a building or structure during seismic events or other extreme loading conditions. The general guideline is that the moment capacity of the column should be at least 1.4 times the moment capacity of the connected beam.

This requirement is based on the concept of ensuring a desired failure mechanism in the event of a major structural overload. By designing the columns to have a significantly higher moment capacity than the beams, it helps prevent a sudden and catastrophic collapse of the structure. Instead, the goal is to induce a controlled failure where the beams yield and deform first, allowing the columns to remain intact and maintain the overall stability of the system. This design approach is particularly important in seismic regions, where the structure needs to be able to dissipate energy through controlled inelastic deformations during an earthquake. By ensuring the columns are stronger than the beams, the structure is more likely to exhibit a "strong column-weak beam" behaviour, which is a desirable failure mechanism that can prevent a total collapse and minimize the risk to occupants. Reinforced concrete structures are commonly used in seismic regions due to their strength and durability.
However, during earthquakes, these structures are subjected to complex and dynamic forces that can lead to significant damage, particularly at beam-column joints. The behaviour of beam-column joints under seismic loading is influenced by various factors, including joint detailing, material properties, and structural configuration. The Strong Column Weak Base (SCWB) analysis approach, which prioritizes ensuring that columns remain strong relative to the base, is widely recognized for improving the seismic performance of structures. This paper focuses on analysing beam-column joints under seismic conditions using the SCWB analysis method implemented in the ETABS software.

II. OBJECTIVES

1) The primary objectives include understanding the response of joints under seismic loading, assessing their vulnerability, and proposing strategies for enhancing their seismic resilience.
2) To ensure the overall stability and safety of the structure.
3) To analyse the structural response and failure mechanisms of beam-column joints under different seismic loading scenarios.
4) To provide practical insights and recommendations for designing and detailing beam column joints to withstand seismic forces effectively.
5) To discuss design considerations and code provisions relevant to the seismic design of beam column joints.

III. METHODOLOGY

The methodology section outlines the procedures followed to analyse beam-column joints in ETABS under seismic conditions using the SCWB analysis approach. The study involves modelling representative structural frames with realistic beam column joint details and applying seismic loads based on specified design criteria. Key parameters considered in the analysis include joint geometry, reinforcement detailing, concrete strength, and ground motion characteristics. The analysis is done by using Clause 7.3 from IS 13920:2016.
The requirement for the moment capacity of a column to be at least 1.4 times the moment capacity of the connected beam is a key structural design principle. This ratio is intended to ensure that the column remains the stronger and more rigid element, preventing a scenario where the beam fails before the column. By maintaining this moment capacity ratio, the column is able to support the beam and transfer loads effectively, even if the beam experiences significant bending stresses. The 1.4 factor provides a safety margin, accounting for potential variations in material properties, construction tolerances, and other real- world conditions that could affect the relative strengths of the column and beam. This helps to ensure the overall structural integrity and stability of the building, reducing the risk of catastrophic failures where a beam collapse could lead to a progressive collapse of the entire system.
The ratio of moment capacity between the column and beam is a critical factor in ensuring the overall stability and safety of a structural system. This ratio, often referred to as the "1.4 times" requirement, is a fundamental design principle that helps prevent catastrophic failures and ensure a controlled, predictable response under load. By ensuring that the moment capacity of the column is at least 1.4 times greater than the moment capacity of the beam, the design promotes a desirable "strong column weak beam" mechanism. This means that in the event of a major load or seismic event, the beams will yield and dissipate energy first, while the columns remain elastic and maintain their load bearing capacity. This behaviour is essential for preventing a progressive collapse, as the columns provide the primary support for the structure.
The importance of this ratio lies in its ability to create a redundant and ductile system that can withstand unexpected loads or deformations. If the columns were to fail before the beams, the entire structure would be at risk of sudden and catastrophic failure. By prioritizing the moment capacity of the columns, the design ensures that the structure can undergo controlled inelastic deformations, giving occupants valuable time to evacuate and allowing for potential repair and reinforcement after an event. In the analysis of strong column-weak beam we have modelled a G+3 residential building by applying different load combinations along with the seismic loads by using IS:1893-2016 (Part 1) seismic load by using the Indian standard code IS:1893-2016 Part 1

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
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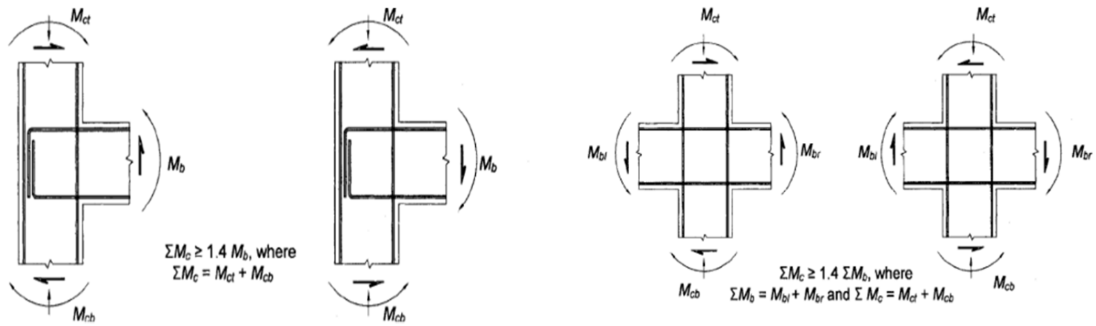

Fig 1: Strong Column Weak Beam IS Clause 7.2 (IS 13920-2016)

IV. SPECIFICATION

Specifications of G+3 Residential Building:

A) Properties of Materials:
- Grade of concrete= 25 MPa • Grade of steel= 415 MPa

B) Specifications of Beam:
- Primary Beam: 230mm X 325mm
- Plinth Beam: 230mm X 250mm
- Secondary Beam: 230mm X 250mm

C) Specifications of Column:
- Centre Columns: 375mm X 375mm
- Edge and Corner Columns: 350mm X 350m

D) Specifications of Slab:
- Floor Slab: 125mm
- Waist Slab: 250mm

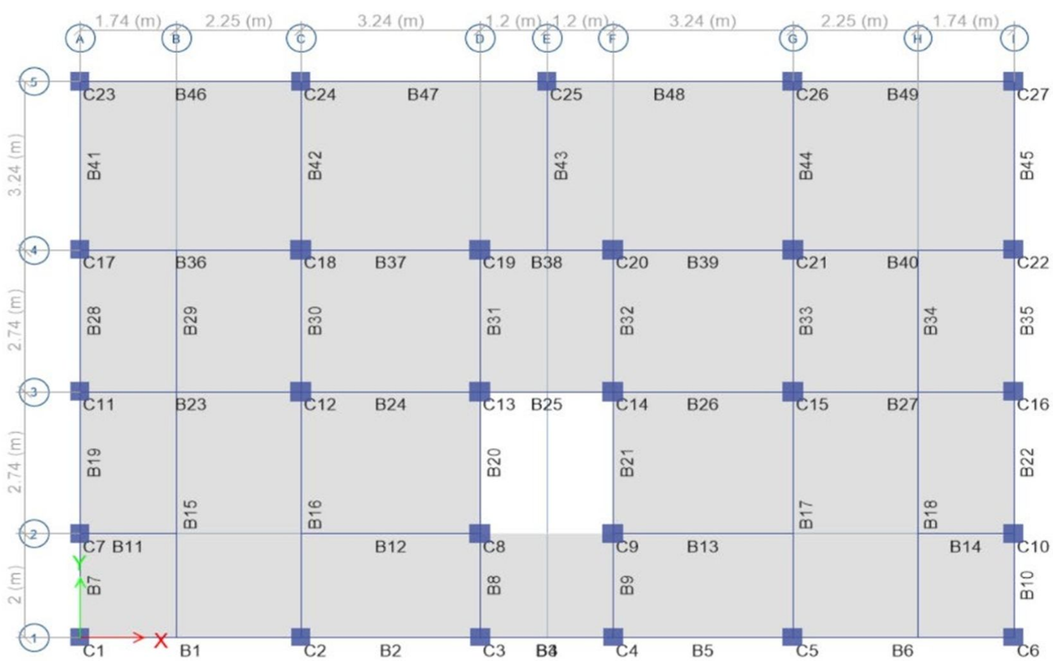

Fig 2: Plan

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V. RESULTS

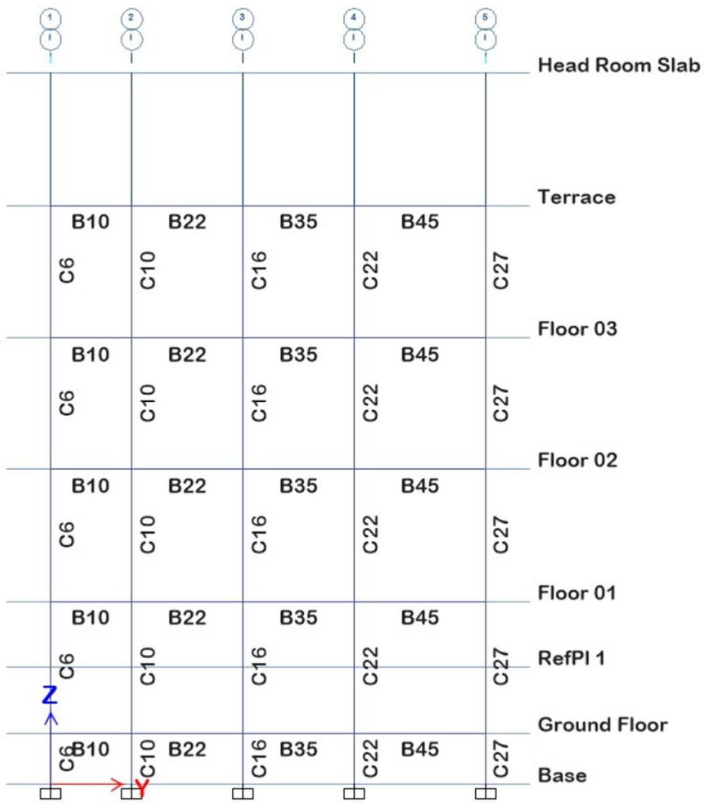

Fig 3: Grid I-I

Table 1: Moment Capacity of Grid I-I

Floor Level	Joint Type	Column Name	Moment of Upper Column	Moment of Lower Column	Total Moment (∑MC)	Left Beam	Right Beam	Moment of Left Beam	Moment of Right Beam	Total Moment (∑Mb)	∑Mc/∑Mb	Result
G.L	C0(I-1)	C6	75.03	85.75	160.78	NA	B10	0	37.75	37.75	4.25	OK
F.F	CO(I-1)	C6	75	75.03	150.03	NA	B10	0	95.48	95.48	1.57	OK
S.L	CO(I-1)	C6	53.59	75	128.59	NA	B10	0	95.48	95.48	1.34	REVISE
T.F	CO(I-1)	C6	42.88	53.59	96.47	NA	B10	0	95.48	95.48	1.01	REVISE
T	CO(I-1)	C6	0	42.88	42.88	NA	B10	0	95.48	95.48	0.44	REVISE
G.L	E (I-2)	C10	85.75	75.03	160.78	B10	B22	37.75	40.12	77.87	2.06	OK
F.F	E (I-2)	C10	75.03	85.75	160.78	B10	B22	95.48	82.69	178.17	0.90	REVISE
S.L	E (I-2)	C10	53.59	75.03	128.62	B10	B22	95.48	82.45	177.93	0.72	REVISE
T.F	E (I-2)	C10	85.75	53.59	139.34	B10	B22	95.48	82.8	178.28	0.78	REVISE
T	E (I-2)	C10	0	85.75	85.75	B10	B22	95.48	81.57	177.05	0.48	REVISE
G.L	E (I-3)	C16	85.75	75.03	160.78	B22	B35	40.12	43.57	83.69	1.92	OK
F.F	E (I-3)	C16	75.03	85.75	160.78	B22	B35	82.69	95.48	178.17	0.90	REVISE
S.L	E (I-3)	C16	53.59	75.03	128.62	B22	B35	82.45	95.48	177.93	0.72	REVISE
T.F	E (I-3)	C16	85.75	53.59	139.34	B22	B35	82.8	95.48	178.28	0.78	REVISE
T	E (I-3)	C16	0	85.75	85.75	B22	B35	81.57	95.48	177.05	0.48	REVISE

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G.L	E (I-4) C22	85.75	85.75	171.5	B35	B45	36.83	45.03	81.86	2.09	OK
F.F	E (I-4) C22	75.03	85.75	160.78	B35	B45	81.57	97.61	179.18	0.89	REVISE
S.L	E (I-4) C22	58.59	75.03	133.62	B35	B45	81.57	98.25	179.82	0.74	REVISE
T.F	E (I-4) C22	64.31	58.59	122.9	B35	B45	81.57	99.67	181.24	0.67	REVISE
T	E (I-4) C22	0	64.31	64.31	B35	B45	81.57	95.48	177.05	0.36	REVISE
G.L	CO(I-5)C27	101.83	85.75	187.58	B45	NA	36.83	0	36.83	5.09	OK
F.F	CO(I-5)C27	75.03	101.83	176.86	B45	NA	82.55	0	82.55	2.14	OK
S.L	CO(I-5)C27	64.31	75.03	139.34	B45	NA	82.84	0	82.84	1.68	OK
T.F	CO(I-5)C27	42.88	64.31	107.19	B45	NA	83.5	0	83.5	1.28	REVISE
T	CO(I-5)C27	0	42.88	42.88	B45	NA	81.57	0	81.57	0.52	REVISE

G.L: Ground Level, F.E: First Floor, S.L: Second Level, T.F: Third Floor, T: Terrace CO: Corner, E: Edge

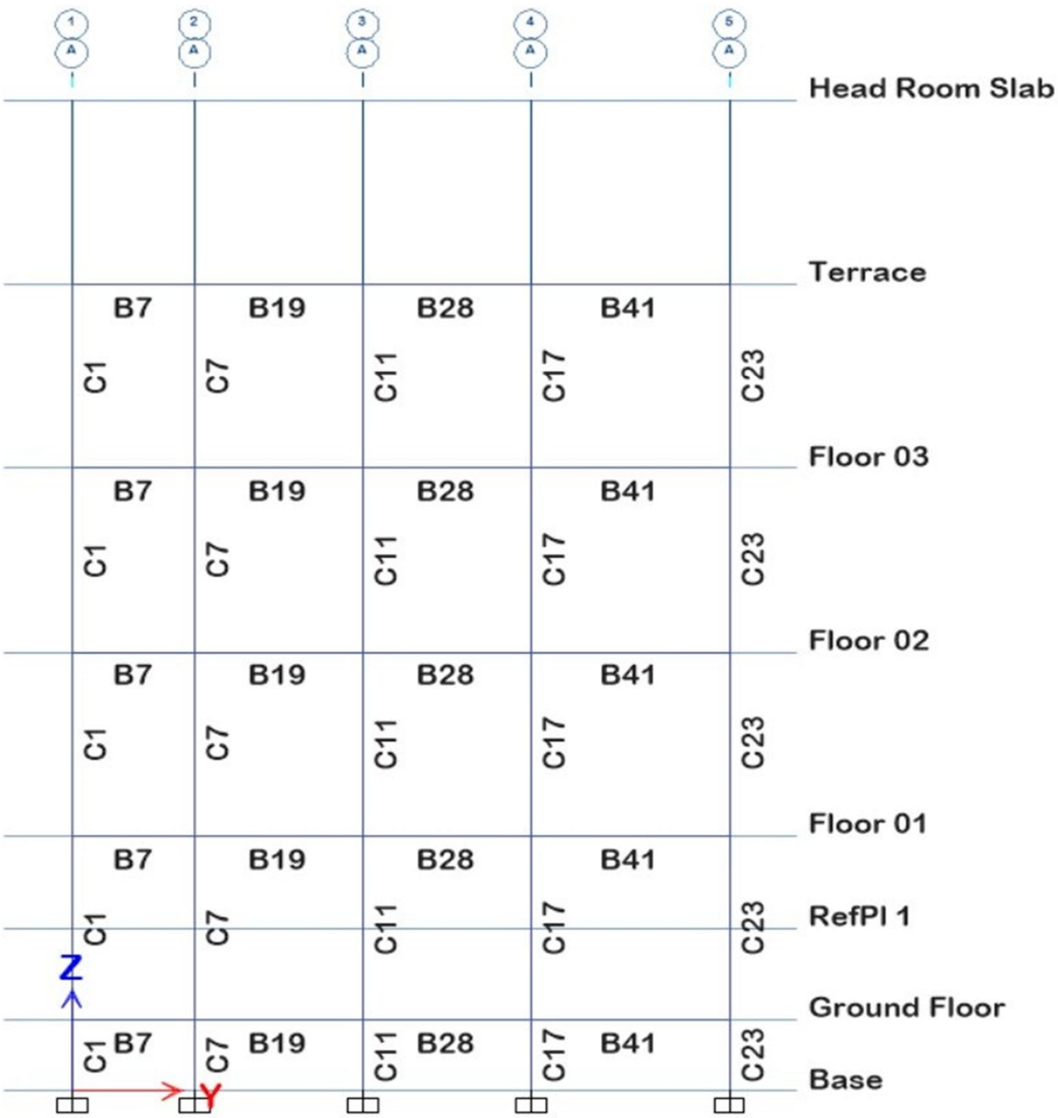

Fig 4: Grid A-A

Table 2: Moment Capacity of Grid A-A

Floor Level	Joint Type	Column Name	Moment of Upper Column	Moment of Lower Column	Total Moment (∑MC)	Left Beam	Right Beam	Moment of Left Beam	Moment of Right Beam	Total Moment (∑Mb)	∑Mc/∑Mb	Result
G.L	CO(A-5)	C23	101.83	85.75	187.58	B46	NA	36.83	0	36.83	5.09	OK
F.F	CO(A-5)	C23	75.03	101.83	176.86	B46	NA	82.55	0	82.55	2.14	OK
S.L	CO(A-5)	C23	64.31	75.03	139.34	B46	NA	82.84	0	82.84	1.68	OK
T.F	CO(A-5)	C23	42.88	64.31	107.19	B46	NA	83.5	0	83.5	1.28	REVISE
T	CO(A-5)	C23	0	42.88	42.88	B46	NA	81.57	0	81.57	0.53	REVISE
G.L	CO(A-1)	C1	75.03	85.75	160.78	NA	B7	0	37.75	37.75	4.26	OK
F.F	CO(A-1)	C1	75	75.03	150.03	NA	B7	0	95.48	95.48	1.57	OK
S.L	CO(A-1)	C1	53.59	75	128.59	NA	B7	0	95.48	95.48	1.35	REVISE
T.F	CO(A-1)	C1	42.88	53.59	96.47	NA	B7	0	95.48	95.48	1.01	REVISE
T	CO(A-1)	C1	0	42.88	42.88	NA	B7	0	95.48	95.48	0.45	REVISE
G.L	E (A-4)	C17	85.75	85.75	171.5	B28	B41	45.03	36.83	81.86	2.10	OK
F.F	E (A-4)	C17	75.03	85.75	160.78	B28	B41	97.61	81.57	179.18	0.90	REVISE
S.L	E (A-4)	C17	58.59	75.03	133.62	B28	B41	98.25	81.57	179.82	0.74	REVISE
T.F	E (A-4)	C17	64.31	58.59	122.9	B28	B41	99.67	81.57	181.24	0.68	REVISE
T	E (A-4)	C17	0	64.31	64.31	B28	B41	95.48	81.57	177.05	0.36	REVISE
G.L	E (A-3)	C11	85.75	75.03	160.78	B19	B28	43.57	40.12	83.69	1.92	OK
F.F	E (A-3)	C11	75.03	85.75	160.78	B19	B28	95.48	82.69	178.17	0.90	REVISE
S.L	E (A-3)	C11	53.59	75.03	128.62	B19	B28	95.48	82.45	177.93	0.72	REVISE
T.F	E (A-3)	C11	85.75	53.59	139.34	B19	B28	95.48	82.8	178.28	0.78	REVISE
T	E (A-3)	C11	0	85.75	85.75	B19	B28	95.48	81.57	177.05	0.48	REVISE
G.L	E (A-2)	C7	85.75	75.03	160.78	B7	B19	40.12	37.75	77.87	2.06	OK
F.F	E (A-2)	C7	75.03	85.75	160.78	B7	B19	82.69	95.48	178.17	0.90	REVISE
S.L	E (A-2)	C7	53.59	75.03	128.62	B7	B19	82.45	95.48	177.93	0.72	REVISE
T.F	E (A-2)	C7	85.75	53.59	139.34	B7	B19	82.8	95.48	178.28	0.78	REVISE

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T	E (A-2)	C7	0	85.75	85.75	B7	B19	81.57	95.48	177.05	0.48	REVISE

G.L: Ground Level, F.E: First Floor, S.L: Second Level, T.F: Third Floor, T: Terrace CO: Corner, E: Edge

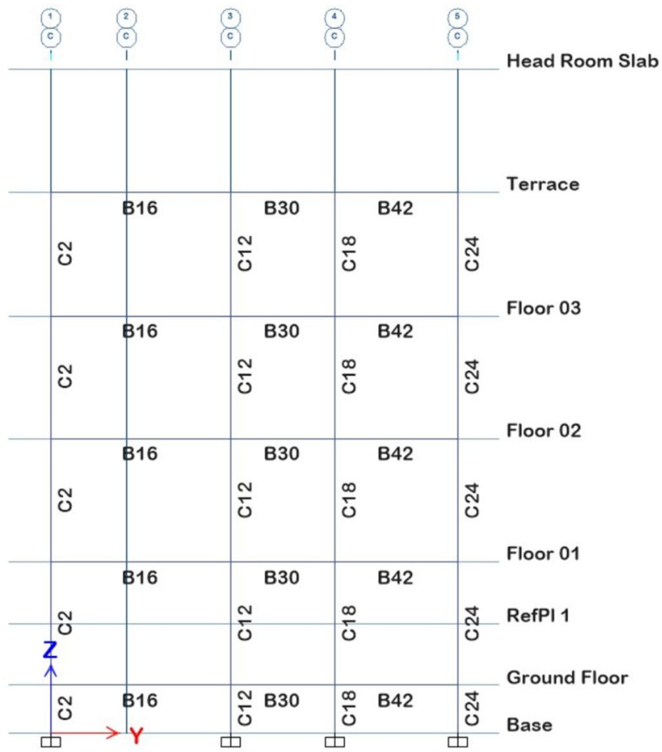

Fig 5: Grid C-C

Table 3: Moment Capacity of Grid C-C

Floor Level	Joint Type	Column Name	Moment of Upper Column	Moment of Lower Column	Total Moment (∑MC)	Left Beam	Right Beam	Moment of Left Beam	Moment of Right Beam	Total Moment (∑Mb)	∑Mc/∑Mb	Result
G.L	CE(C-4)	C18	96.47	85.75	182.22	B30	B42	43.57	40.12	83.69	2.18	OK
F.F	CE(C-4)	C18	131.84	96.47	228.31	B30	B42	67.38	49.17	116.55	1.96	OK
S.L	CE(C-4)	C18	92.29	131.84	224.13	B30	B42	86.28	73.62	159.9	1.40	OK
T.F	CE(C-4)	C18	65.92	92.29	158.21	B30	B42	98.48	82.8	181.28	0.87	REVISE
T	CE(C-4)	C18	0	65.92	65.92	B30	B42	95.48	81.57	177.05	0.37	REVISE
						0						
G.L	CE(C-3)	C12	131.84	105.47	237.31	B16	B30	43.57	49.15	92.72	2.56	OK
F.F	CE(C-3)	C12	105.47	131.84	237.31	B16	B30	97.67	92.31	189.98	1.25	REVISE
S.L	CE(C-3)	C12	92.29	105.47	197.76	B16	B30	97.69	82.62	180.31	1.10	REVISE
T.F	CE(C-3)	C12	65.92	92.29	158.21	B16	B30	98.17	92.67	190.84	0.83	REVISE
T	CE(C-3)	C12	0	65.92	65.92	B16	B30	95.48	84.44	179.92	0.37	REVISE
G.L	E(C-5)	C24	139.34	85.75	225.09	NA	B42	0	43.57	43.57	5.17	OK
F.F	E(C-5)	C24	85.75	139.34	225.09	NA	B42	0	95.48	95.48	2.36	OK

S.L	E(C-5)	C24	75.03	85.75	160.78	NA	B42	0	95.48	95.48	1.68	OK
T.F	E(C-5)	C24	85.75	75.03	160.78	NA	B42	0	95.48	95.48	1.68	OK
T	E(C-5)	C24	0	85.75	85.75	NA	B42	0	95.48	95.48	0.90	REVISE

G.L: Ground Level, F.E: First Floor, S.L: Second Level, T.F: Third Floor, T: Terrace, CE: Centre, E:Edge

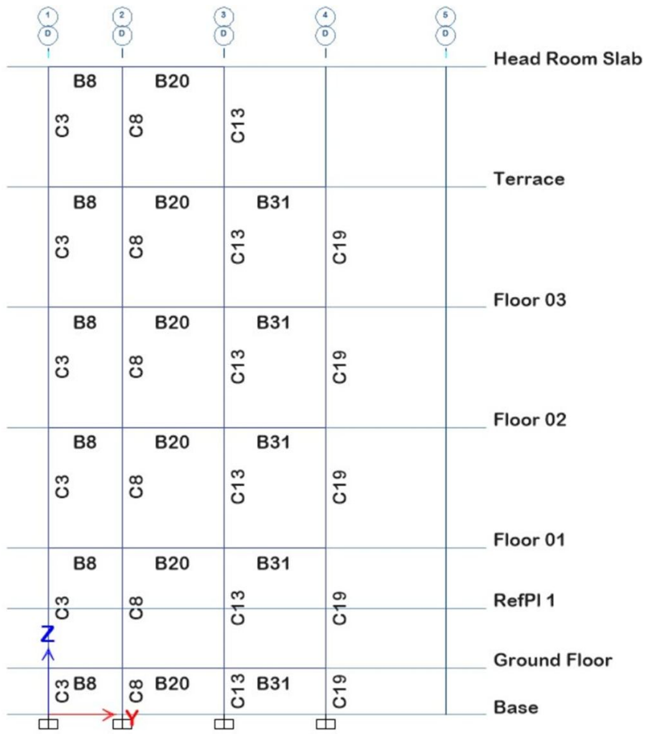

Fig 6: Grid D-D

Table 4: Moment Capacity of Grid D-D

Floor Level	Joint Type	Column Name	Moment of Upper Column	Moment of Lower Column	Total Moment (∑MC)	Left Beam	Right Beam	Moment of Left Beam	Moment of Right Beam	Total Moment (∑Mb)	∑Mc/∑Mb	Result
G.L	CE(D-2)	C19	131.84	129.4	261.24	B8	B20	43.44	43.57	87.01	3.00	OK
F.F	CE(D-2)	C19	52.73	131.84	184.57	B8	B20	81.57	95.48	177.05	1.04	REVISE
S.L	CE(D-2)	C19	98.88	52.73	151.61	B8	B20	81.57	95.48	177.05	0.85	REVISE
T.F	CE(D-2)	C19	65.92	98.88	197.76	B8	B20	81.57	95.48	177.05	1.11	REVISE
T	CE(D-2)	C19	0	65.92	65.92	B8	B20	81.57	95.48	177.05	0.37	REVISE
G.L	CE(D-3)	C19	118.65	158.2	276.85	B20	B31	40.12	43.57	83.69	3.31	OK
F.F	CE(D-3)	C19	79.1	118.65	197.75	B20	B31	81.57	97.93	179.5	1.10	REVISE
S.L	CE(D-3)	C19	65.92	79.1	145.02	B20	B31	81.57	101.96	183.53	0.79	REVISE
T.F	CE(D-3)	C19	65.92	65.92	131.84	B20	B31	81.57	102.44	184.01	0.72	REVISE
T	CE(D-3)	C19	0	65.92	65.92	B20	B31	81.57	100.07	181.64	0.36	REVISE
G.L	CE(D-4)	C19	158.2	105.48	263.68	B31	NA	40.12	0	40.12	6.57	OK

F.F	CE(D-4)	C19	105.48	158.2	263.68	B31	NA	82.69	0	82.69	3.19	OK
S.L	CE(D-4)	C19	105.47	105.48	210.95	B31	NA	84.44	0	84.44	2.50	OK
T.F	CE(D-4)	C19	65.92	105.47	171.39	B31	NA	86.64	0	86.64	1.98	OK
T	CE(D-4)	C19	0	65.92	65.92	B31	NA	83.64	0	83.64	0.79	REVISE

G.L: Ground Level, F.E: First Floor, S.L: Second Level, T.F: Third Floor, T: Terrace, CE: Centre, E:Edge

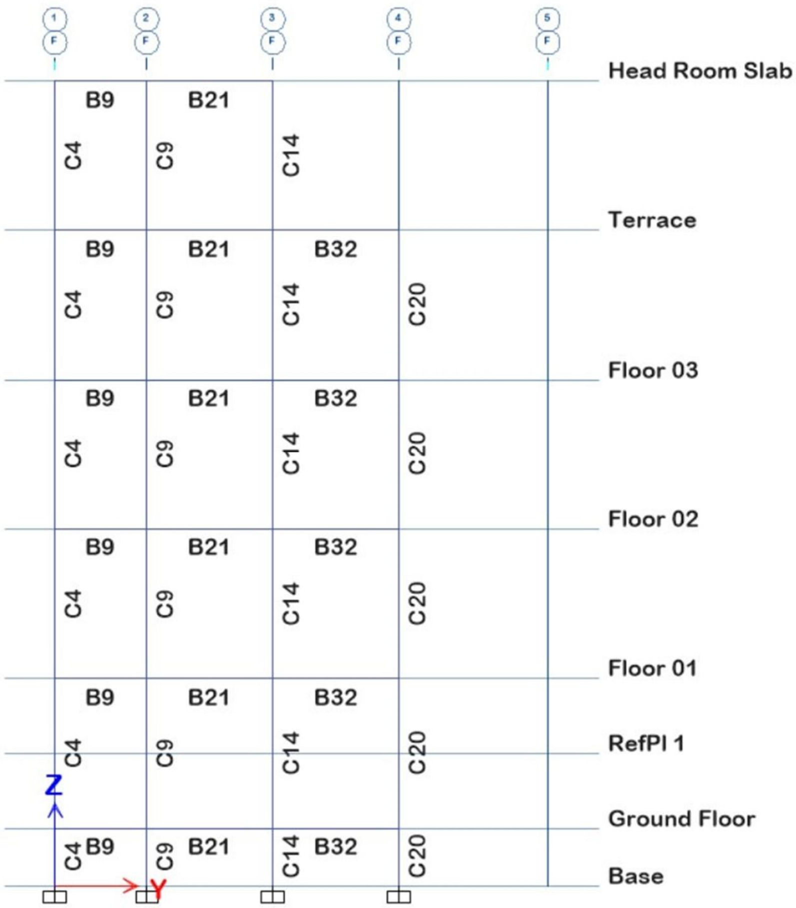

Fig 7: Grid F-F

Table 5: Moment Capacity of Grid F-F

Floor Level	Joint Type	Column Name	Moment of Upper Column	Moment of Lower Column	Total Moment (∑MC)	Left Beam	Right Beam	Moment of Left Beam	Moment of Right Beam	Total Moment (∑Mb)	∑Mc/∑Mb	Result
G.L	CE(F-2)	C20	131.84	129.4	261.24	B9	B21	43.57	43.44	87.01	3.00	OK
F.F	CE(F-2)	C20	52.73	131.84	184.57	B9	B21	95.48	81.57	177.05	1.04	REVISE
S.L	CE(F-2)	C20	98.88	52.73	151.61	B9	B21	95.48	81.57	177.05	0.86	REVISE
T.F	CE(F-2)	C20	65.92	98.88	164.8	B9	B21	95.48	81.57	177.05	0.93	REVISE
T	CE(F-2)	C20	0	65.92	65.92	B9	B21	95.48	81.57	177.05	0.37	REVISE
G.L	CE(F-3)	C20	118.65	158.2	276.85	B21	B32	43.57	40.12	83.69	3.31	OK
F.F	CE(F-3)	C20	79.1	118.65	197.75	B21	B32	97.93	81.57	179.5	1.10	REVISE
S.L	CE(F-3)	C20	65.92	79.1	145.02	B21	B32	101.96	81.57	183.53	0.79	REVISE

T.F	CE(F-3)	C20	65.92	65.92	131.84	B21	B32	102.44	81.57	184.01	0.72	REVISE
T	CE(F-3)	C20	0	65.92	65.92	B21	B32	100.07	81.57	181.64	0.36	REVISE
G. L	CE(F-4)	C20	158.2	105.48	263.68	B32	NA	40.12	0	40.12	6.57	OK
F.F	CE(F-4)	C20	105.48	158.2	263.68	B32	NA	82.69	0	82.69	3.19	OK
S.L	CE(F-4)	C20	105.47	105.48	210.95	B32	NA	84.44	0	84.44	2.50	OK
T.F	CE(F-4)	C20	65.92	105.47	171.39	B32	NA	86.64	0	86.64	1.98	OK
T	CE(F-4)	C20	0	65.92	65.92	B32	NA	83.64	0	83.64	0.79	REVISE

G.L: Ground Level, F.E: First Floor, S.L: Second Level, T.F: Third Floor, T: Terrace, CE: Centre, E:Edge

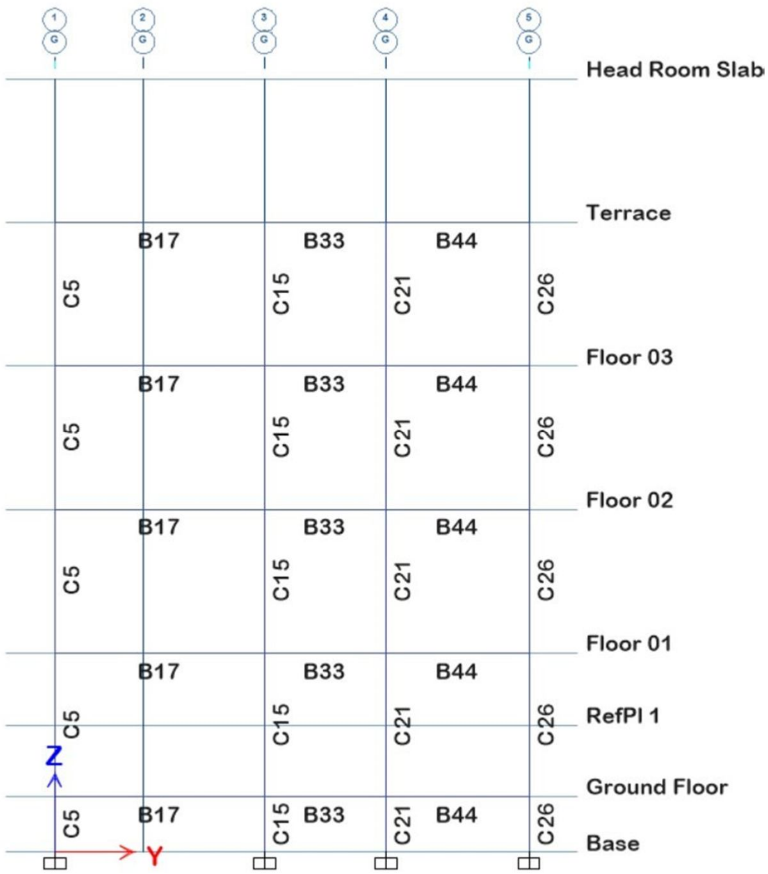

Fig 8: Grid G-G

Table 6: Moment Capacity of Grid G-G

Floor Level	Joint Type	Column Name	Moment of Upper Column	Moment of Lower Column	Total Moment (∑MC)	Left Beam	Right Beam	Moment of Left Beam	Moment of Right Beam	Total Moment (∑Mb)	∑Mc/∑Mb	Result
G.L	CE(G-3)	C15	131.84	105.47	237.31	B17	B33	49.15	43.57	92.72	2.56	OK
F.F	CE(G-3)	C15	105.47	131.84	237.31	B17	B33	83.54	81.57	165.11	1.44	OK
S.L	CE(G-3)	C15	92.29	105.47	197.76	B17	B33	82.62	97.69	180.31	1.10	REVISE
T.F	CE(G-3)	C15	65.92	92.29	158.21	B17	B33	92.67	98.17	190.84	0.83	REVISE
T	CE(G-3)	C15	0	65.92	65.92	B17	B33	84.44	95.48	179.92	0.37	REVISE
G.L	CE(G-4)	C21	96.47	85.75	182.22	B33	B44	40.12	43.57	83.69	2.18	OK

F.F	CE(G-4)	C21	131.84	96.47	228.31	B33	B44	49.17	67.38	116.55	1.96	OK
S.L	CE(G-4)	C21	92.29	131.84	224.13	B33	B44	76.62	82.48	159.1	1.41	OK
T.F	CE(G-4)	C21	65.92	92.29	158.21	B33	B44	82.8	98.48	181.28	0.87	REVISE
T	CE(G-4)	C21	0	65.92	65.92	B33	B44	81.57	95.48	177.05	0.37	REVISE
G. L	E (G-5)	C26	139.34	85.75	225.09	B44	NA	43.57	0	43.57	5.17	OK
F.F	E (G-5)	C26	85.75	139.34	225.09	B44	NA	95.48	0	95.48	2.36	OK
S.L	E (G-5)	C26	75.03	85.75	160.78	B44	NA	95.48	0	95.48	1.68	OK
T.F	E (G-5)	C26	85.75	75.03	160.78	B44	NA	95.48	0	95.48	1.68	OK
T	E (G-5)	C26	0	85.75	85.75	B44	NA	95.48	0	95.48	0.90	REVISE

G.L: Ground Level , F.E: First Floor, S.L: Second Level, T.F: Third Floor, T: Terrace, CE: Centre, E:Edge

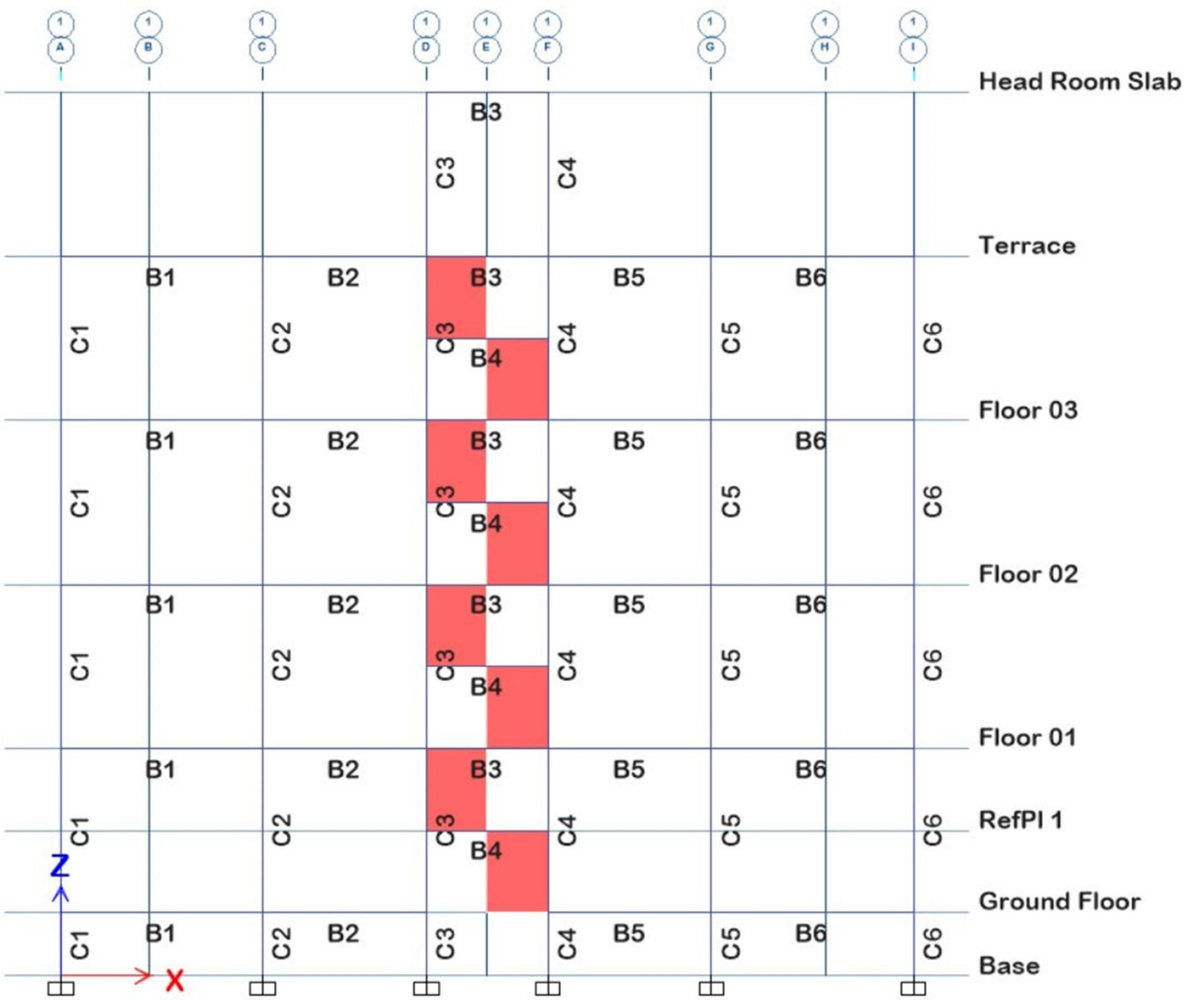

Fig 9: Grid 1-1

Table 7: Moment Capacity of Grid 1-1

Floor Level	Joint Type	Column Name	Moment of Upper Column	Moment of Lower Column	Total Moment (∑MC)	Left Beam	Right Beam	Moment of Left Beam	Moment of Right Beam	Total Moment (∑Mb)	∑Mc/∑Mb	Result

G.L	CO(1-A)	C1	75.03	85.75	160.78	NA	B1	0	70	70	2.296857143	OK
F.F	CO(1-A)	C1	75	75.03	150.03	NA	B1	0	77.78	77.78	1.928902031	OK
S.L	CO(1-A)	C1	53.59	75	128.59	NA	B1	0	81	81	1.587530864	OK
T.F	CO(1-A)	C1	42.88	53.59	96.47	NA	B1	0	96.11	96.11	1.003745708	REVISE
T	CO(1-A)	C1	0	42.88	42.88	NA	B1	0	101.5	101.5	0.422463054	REVISE
G.L	CO(1-I)	C6	75.03	85.75	160.78	B6	NA	49.85	0	49.85	3.225275827	OK
F.F	CO(1-I)	C6	75	75.03	150.03	B6	NA	82.12	0	82.12	1.826960546	OK
S.L	CO(1-I)	C6	53.59	75	128.59	B6	NA	81.86	0	81.86	1.570852675	OK
T.F	CO(1-I)	C6	42.88	53.59	96.47	B6	NA	86.53	0	86.53	1.114873454	REVISE
T	CO(1-I)	C6	0	42.88	42.88	B6	NA	75.39	0	75.39	0.5687757	REVISE

G.L: Ground Level, F.E: First Floor, S.L: Second Level, T.F: Third Floor, T: Terrace CO: Corner, E: Edge

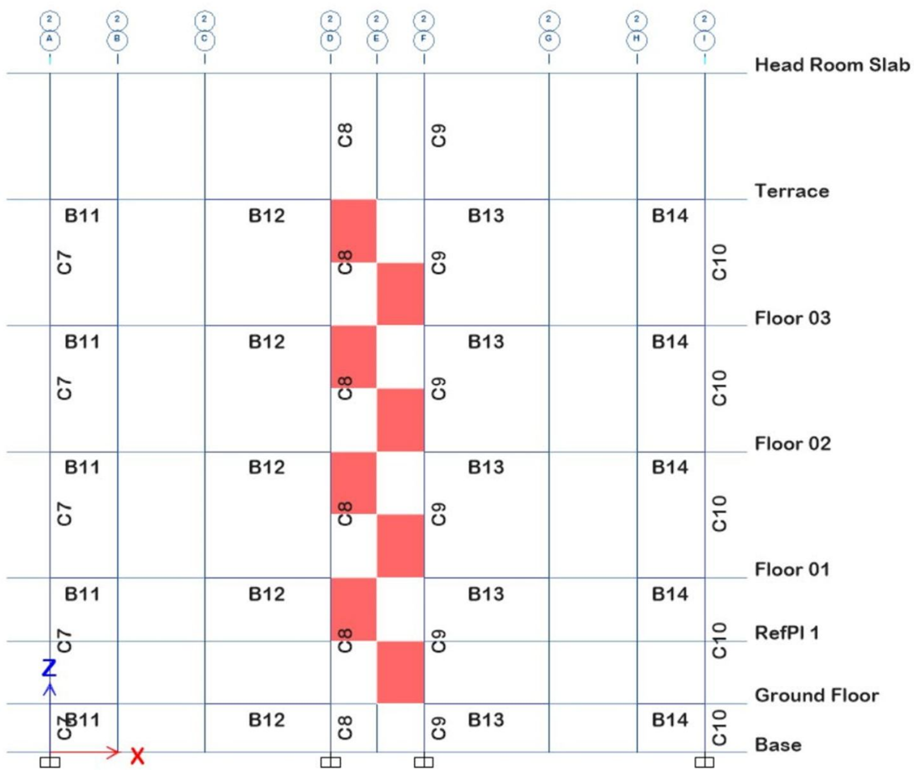

Fig 10: Grid 2-2

Table 8: Moment Capacity of Grid 2-2

Floor Level	Joint Type	Column Name	Moment of Upper Column	Moment of Lower Column	Total Moment (∑MC)	Left Beam	Right Beam	Moment of Left Beam	Moment of Right Beam	Total Moment (∑Mb)	∑Mc/∑Mb	Result
G.L	CE(2-D)	C8	131.84	129.4	261.24	B12	NA	46.56	0	46.56	5.61	OK
F.F	CE(2-D)	C8	52.73	131.84	184.57	B12	NA	67.54	0	67.54	2.73	OK
S.L	CE(2-D)	C8	98.88	52.73	151.61	B12	NA	67.54	0	67.54	2.24	OK
T.F	CE(2-D)	C8	65.92	98.88	164.8	B12	NA	67.54	0	67.54	2.44	OK

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ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
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T	CE(2-D)	C8	0	65.92	65.92	B12	NA	67.54	0	67.54	0.97	REVISE
G.L	CE(2-F)	C9	131.84	129.4	261.24	NA	B13	0	46.56	46.56	5.61	OK
F.F	CE(2-F)	C9	52.73	131.84	184.57	NA	B13	0	67.54	67.54	2.73	OK
S.L	CE(2-F)	C9	98.88	52.73	151.61	NA	B13	0	67.54	67.54	2.24	OK
T.F	CE(2-F)	C9	65.92	98.88	164.8	NA	B13	0	67.54	67.54	2.44	OK
T	CE(2-F)	C9	0	65.92	65.92	NA	B13	0	67.54	67.54	0.97	REVISE
G. L	E (2-I)	C10	85.75	75.03	160.78	NA	B14	46.72	0	46.72	3.44	OK
F.F	E (2-I)	C10	75.03	85.75	160.78	NA	B14	37.79	0	37.79	4.25	OK
S.L	E (2-I)	C10	53.59	75.03	128.62	NA	B14	37.79	0	37.79	3.40	OK
T.F	E (2-I)	C10	85.75	53.59	139.34	NA	B14	37.79	0	37.79	3.68	OK
T	E (2-I)	C10	0	85.75	85.75	NA	B14	37.79	0	37.79	2.26	OK
G. L	E (2-A)	C7	85.75	75.03	160.78	B11	NA	0	46.72	46.72	3.44	OK
F.F	E (2-A)	C7	75.03	85.75	160.78	B11	NA	0	37.79	37.79	4.25	OK
S.L	E (2-A)	C7	53.59	75.03	128.62	B11	NA	0	37.79	37.79	3.40	OK
T.F	E (2-A)	C7	85.75	53.59	139.34	B11	NA	0	37.79	37.79	3.68	OK
T	E (2-A)	C7	0	85.75	85.75	B11	NA	0	37.79	37.79	2.26	OK

G.L: Ground Level, F.E: First Floor, S.L: Second Level, T.F: Third Floor, T: Terrace CE: Centre, E: Edge

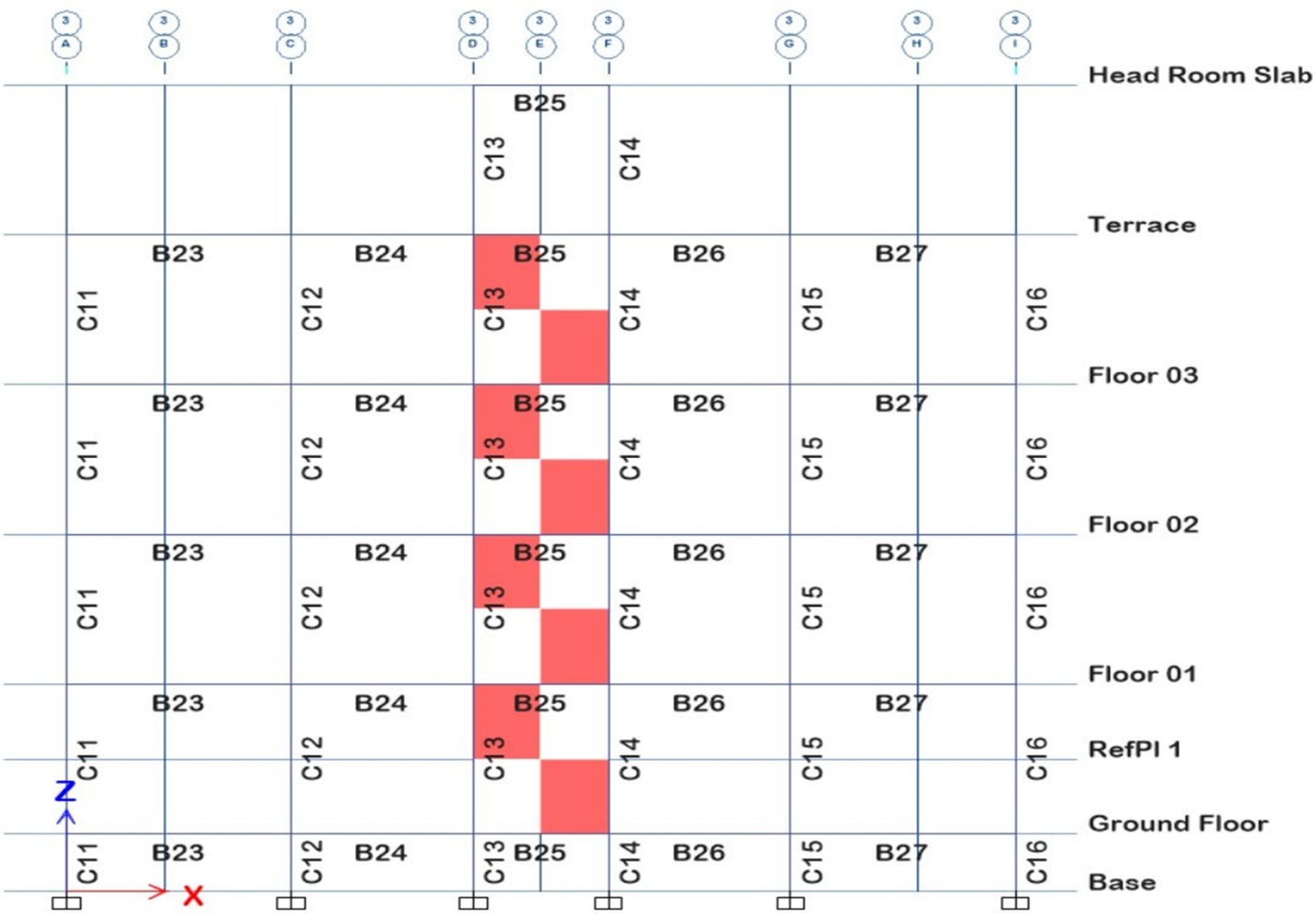

Fig 11: Grid 3-3

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ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
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Table 9: Moment Capacity of Grid 3-3

Floor Level	Joint Type	Column Name	Moment of Upper Column	Moment of Lower Column	Total Moment (∑MC)	Left Beam	Right Beam	Moment of Left Beam	Moment of Right Beam	Total Moment (∑Mb)	∑Mc/∑Mb	Result
G.L	CE(3-G)	C15	131.84	105.47	237.31	B26	B27	48.29	115	163.29	1.453303938	OK
F.F	CE(3-G)	C15	105.47	131.84	237.31	B26	B27	75.39	91.05	166.44	1.425799087	OK
S.L	CE(3-G)	C15	92.29	105.47	197.76	B26	B27	65.42	74.27	139.69	1.415706207	OK
T.F	CE(3-G)	C15	65.92	92.29	158.21	B26	B27	76.8	92.4	169.2	0.935047281	REVISE
T	CE(3-G)	C15	0	65.92	65.92	B26	B27	75.39	83.54	158.93	0.4147738	REVISE
G.L	CE(3-C)	C12	131.84	105.47	237.31	B23	B24	48.29	115	163.29	1.453303938	OK
F.F	CE(3-C)	C12	105.47	131.84	237.31	B23	B24	91.05	75.39	166.44	1.425799087	OK
S.L	CE(3-C)	C12	92.29	105.47	197.76	B23	B24	78.55	62.57	141.12	1.401360544	OK
T.F	CE(3-C)	C12	65.92	92.29	158.21	B23	B24	92.4	76.8	169.2	0.935047281	REVISE
T	CE(3-C)	C12	0	65.92	65.92	B23	B24	83.54	75.39	158.93	0.4147738	REVISE
G. L	CE(3-D)	C13	118.65	158.2	276.85	B24	B25	88.96	12.5	101.46	2.728661541	OK
F.F	CE(3-D)	C13	79.1	118.65	197.75	B24	B25	83.54	81.57	165.11	1.197686391	REVISE
S.L	CE(3-D)	C13	65.92	79.1	145.02	B24	B25	85.75	81.57	167.32	0.866722448	REVISE
T.F	CE(3-D)	C13	65.92	65.92	131.84	B24	B25	86.07	81.57	167.64	0.786447149	REVISE
T	CE(3-D)	C13	0	65.92	65.92	B24	B25	83.54	81.57	165.11	0.399248986	REVISE
G. L	CE(3-F)	C14	118.65	158.2	276.85	B25	B26	12.5	88.96	101.46	2.728661541	OK
F.F	CE(3-F)	C14	79.1	118.65	197.75	B25	B26	81.57	83.54	165.11	1.197686391	REVISE
S.L	CE(3-F)	C14	65.92	79.1	145.02	B25	B26	81.57	85.75	167.32	0.866722448	REVISE
T.F	CE(3-F)	C14	65.92	65.92	131.84	B25	B26	81.57	86.07	167.64	0.786447149	REVISE
T	CE(3-F)	C14	0	65.92	65.92	B25	B26	81.57	83.54	165.11	0.399248986	REVISE
G. L	E (3-I)	C16	85.75	75.03	160.78	B27	NA	27.65	0	27.65	5.81482821	OK
F.F	E (3-I)	C16	75.03	85.75	160.78	B27	NA	79.41	0	79.41	2.02468203	OK
S.L	E (3-I)	C16	53.59	75.03	128.62	B27	NA	80.16	0	80.16	1.604540918	OK
T.F	E (3-I)	C16	85.75	53.59	139.34	B27	NA	80.09	0	80.09	1.739792733	OK
T	E (3-I)	C16	0	85.75	85.75	B27	NA	75.39	0	75.39	1.137418756	REVISE
G. L	E (3-A)	C11	85.75	75.03	160.78	NA	B23	0	27.65	27.65	5.81482821	OK
F.F	E (3-A)	C11	75.03	85.75	160.78	NA	B23	0	79.41	79.41	2.02468203	OK
S.L	E (3-A)	C11	53.59	75.03	128.62	NA	B23	0	80.16	80.16	1.604540918	OK
T.F	E (3-A)	C11	85.75	53.59	139.34	NA	B23	0	80.09	80.09	1.739792733	OK
T	E (3-A)	C11	0	85.75	85.75	NA	B23	0	75.39	75.39	1.137418756	REVISE

G.L: Ground Level, F.E: First Floor, S.L: Second Level, T.F: Third Floor, T: Terrace CE:Centre, E: Edge

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
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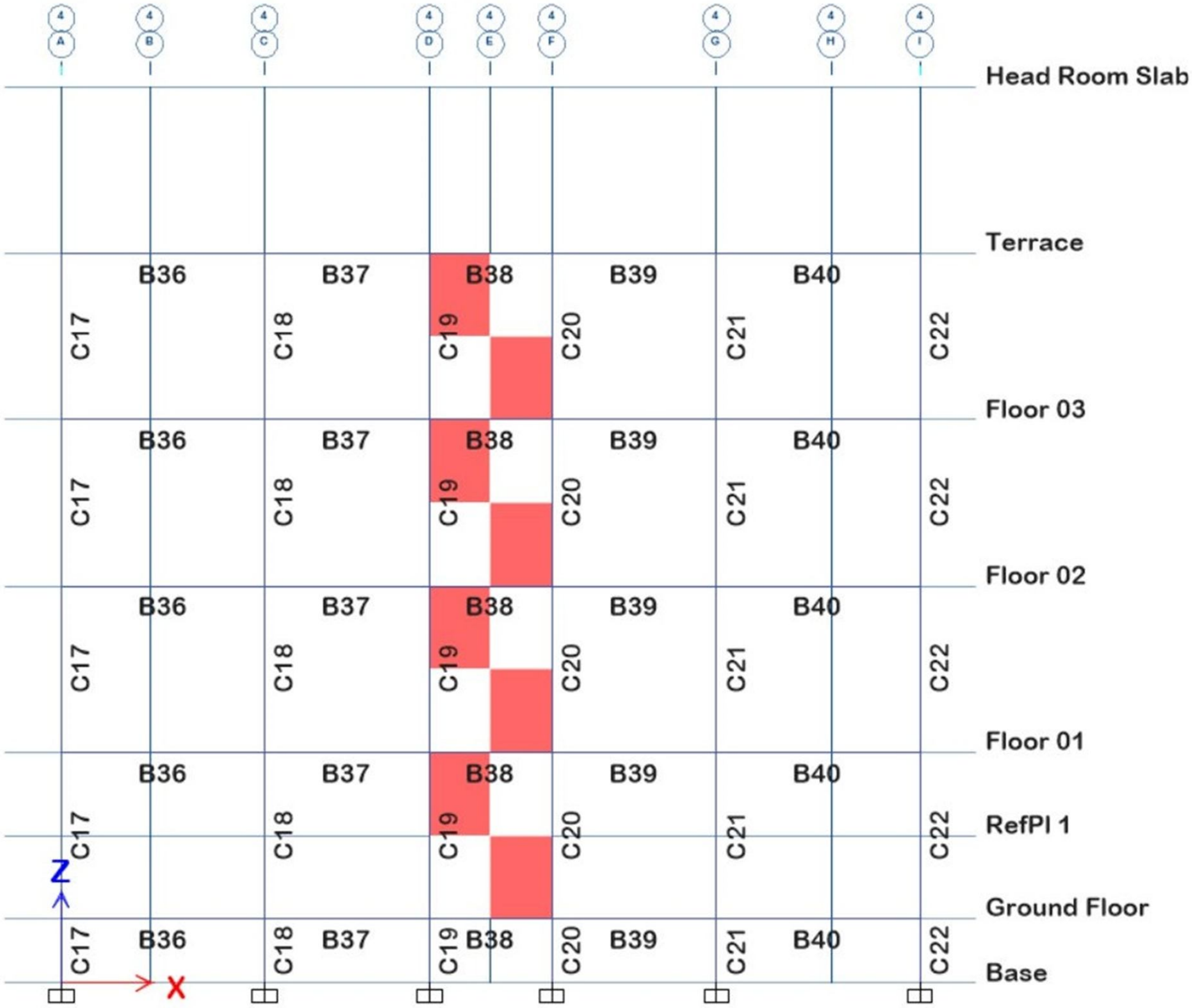

Fig 12: Grid 4-4

Table 10: Moment Capacity of Grid 4-4

Floor Level	Joint Type	Column Name	Moment of Upper Column	Moment of Lower Column	Total Moment (∑MC)	Left Beam	Right Beam	Moment of Left Beam	Moment of Right Beam	Total Moment (∑Mb)	∑Mc/∑Mb	Result
G.L	CE(4-G)	C21	96.47	85.75	182.22	B39	B40	43.83	65.14	108.97	1.67	OK
F.F	CE(4-G)	C21	131.84	96.47	228.31	B39	B40	70.39	90.89	161.28	1.42	OK
S.L	CE(4-G)	C21	92.29	131.84	224.13	B39	B40	59.03	89.63	148.66	1.51	OK
T.F	CE(4-G)	C21	65.92	92.29	158.21	B39	B40	59.04	95.87	154.91	1.02	REVISE
T	CE(4-G)	C21	0	65.92	65.92	B39	B40	75.39	83.54	158.93	0.41	REVISE
G.L	CE(4-C)	C18	96.47	85.75	182.22	B36	B37	65.14	43.83	108.97	1.67	OK
F.F	CE(4-C)	C18	131.84	96.47	228.31	B36	B37	90.89	70.39	161.28	1.42	OK
S.L	CE(4-C)	C18	92.29	131.84	224.13	B36	B37	89.63	59.03	148.66	1.51	OK
T.F	CE(4-C)	C18	65.92	92.29	158.21	B36	B37	95.87	59.04	154.91	1.02	REVISE
T	CE(4-C)	C18	0	65.92	65.92	B36	B37	83.54	75.39	158.93	0.41	REVISE

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G. L	CE(4-D)	C19	158.2	105.48	263.68	B37	B38	41.28	50.3	91.58	2.88	OK
F.F	CE(4-D)	C19	105.48	158.2	263.68	B37	B38	81.57	83.54	165.11	1.60	OK
S.L	CE(4-D)	C19	105.47	105.48	210.95	B37	B38	89.63	59.03	148.66	1.42	OK
T.F	CE(4-D)	C19	65.92	105.47	171.39	B37	B38	81.57	95.48	177.05	0.97	REVISE
T	CE(4-D)	C19	0	65.92	65.92	B37	B38	81.57	95.48	177.05	0.37	REVISE
G. L	CE(4-F)	C20	158.2	105.48	263.68	B38	B39	50.3	41.28	91.58	2.88	OK
F.F	CE(4-F)	C20	105.48	158.2	263.68	B38	B39	83.54	81.57	165.11	1.60	OK
S.L	CE(4-F)	C20	105.47	105.48	210.95	B38	B39	80.48	69.27	149.75	1.41	OK
T.F	CE(4-F)	C20	65.92	105.47	171.39	B38	B39	95.48	81.57	177.05	0.97	REVISE
T	CE(4-F)	C20	0	65.92	65.92	B38	B39	95.48	81.57	177.05	0.37	REVISE
G. L	E (4-I)	C22	85.75	85.75	171.5	B40	NA	48.82	0	48.82	3.51	OK
F.F	E (4-I)	C22	75.03	85.75	160.78	B40	NA	48.25	0	48.25	3.33	OK
S.L	E (4-I)	C22	58.59	75.03	133.62	B40	NA	48.04	0	48.04	2.78	OK
T.F	E (4-I)	C22	64.31	58.59	122.9	B40	NA	48.1	0	48.1	2.56	OK
T	E (4-I)	C22	0	64.31	64.31	B40	NA	46.83	0	46.83	1.37	REVISE
G. L	E (4-A)	C17	85.75	85.75	171.5		B36	0	48.82	48.82	3.51	OK
F.F	E (4-A)	C17	75.03	85.75	160.78		B36	0	48.25	48.25	3.33	OK
S.L	E (4-A)	C17	58.59	75.03	133.62		B36	0	48.04	48.04	2.78	OK
T.F	E (4-A)	C17	64.31	58.59	122.9		B36	0	48.1	48.1	2.56	OK
T	E (4-A)	C17	0	64.31	64.31		B36	0	46.83	46.83	1.37	REVISE

G.L: Ground Level, F.E: First Floor, S.L: Second Level, T.F: Third Floor, T: Terrace CE: Centre, E: Edge

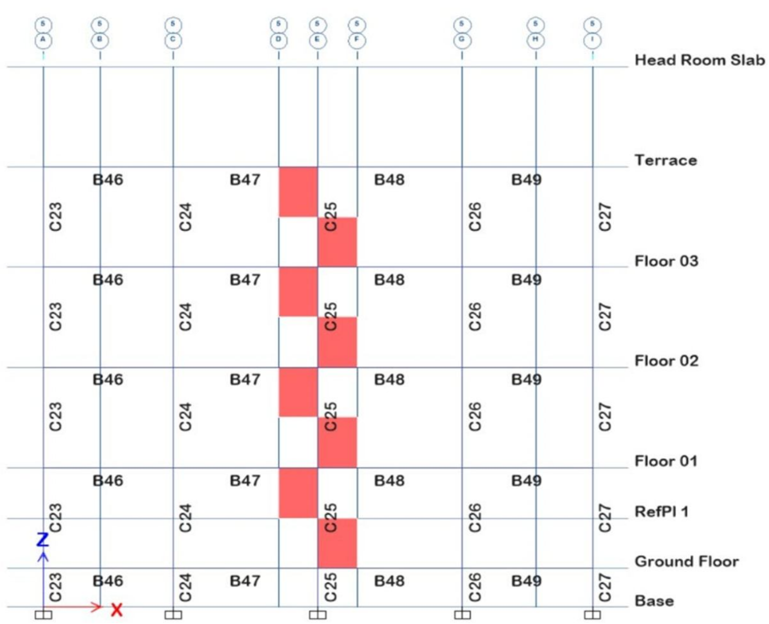

Fig 13: Grid 5-5

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
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Table 11: Moment Capacity of Grid 5-5

Floor Level	JointType	Column Name	Moment of Upper Column	Moment of Lower Column	Total Moment (∑MC)	Left Beam	Right Beam	Moment of Left Beam	Moment of Right Beam	Total Moment (∑Mb)	∑Mc/∑Mb	Result
G.L	CO(5-I)	C27	101.83	85.75	187.58	B49	NA	48.75	0	48.75	3.85	OK
F.F	CO(5-I)	C27	75.03	101.83	176.86	B49	NA	79.45	0	79.45	2.23	OK
S.L	CO(5-I)	C27	64.31	75.03	139.34	B49	NA	78.89	0	78.89	1.77	OK
T.F	CO(5-I)	C27	42.88	64.31	107.19	B49	NA	79	0	79	1.36	REVISE
T	CO(5-I)	C27	0	42.88	42.88	B49	NA	75.39	0	75.39	0.57	REVISE
G.L	CO(5-A)	C23	101.83	85.75	187.58	B41	NA	48.75	0	48.75	3.85	OK
F.F	CO(5-A)	C23	75.03	101.83	176.86	B41	NA	79.45	0	79.45	2.23	OK
S.L	CO(5-A)	C23	64.31	75.03	139.34	B41	NA	78.89	0	78.89	1.77	OK
T.F	CO(5-A)	C23	42.88	64.31	107.19	B41	NA	79	0	79	1.36	REVISE
T	CO(5-A)	C23	0	42.88	42.88	B41	NA	75.39	0	75.39	0.57	REVISE
G. L	E (5-G)	C26	139.34	85.75	225.09	B48	B49	46.57	57.81	104.38	2.16	OK
F.F	E (5-G)	C26	85.75	139.34	225.09	B48	B49	48.29	58.44	106.73	2.11	OK
S.L	E (5-G)	C26	75.03	85.75	160.78	B48	B49	48.1	58.44	106.54	1.51	OK
T.F	E (5-G)	C26	85.75	75.03	160.78	B48	B49	48.1	58.44	106.54	1.51	OK
T	E (5-G)	C26	0	85.75	85.75	B48	B49	46.81	58.44	105.25	0.81	REVISE
G. L	E (5-C)	C24	139.34	85.75	225.09	B46	B47	57.81	46.57	104.38	2.16	OK
F.F	E (5-C)	C24	85.75	139.34	225.09	B46	B47	58.44	48.29	106.73	2.11	OK
S.L	E (5-C)	C24	75.03	85.75	160.78	B46	B47	58.44	48.1	106.54	1.51	OK
T.F	E (5-C)	C24	85.75	75.03	160.78	B46	B47	58.44	48.1	106.54	1.51	OK
T	E (5-C)	C24	0	85.75	85.75	B46	B47	58.44	46.81	105.25	0.81	REVISE

G.L: Groun Level, F.E: First Floor, S.L: Second Level, T.F: Third Floor, T: Terrace CO: Corner, E: Edge

VI. CONCLUSION

The requirement that the moment capacity of a column should be at least 1.4 times the moment capacity of the connected beam is a critical design consideration in structural engineering. This ratio ensures that the column is stronger and more robust thanthe beam, preventing the catastrophic failure of the column and promoting the desired collapse mechanism where the beam yields first before the column.

By prioritizing column strength over beam strength, structural integrity and occupant safety are enhanced, as the column actsas the backbone of the building and must be able to withstand extreme loading conditions without buckling or failing.

1) It is observed that with the increase in height of the building, the column is more susceptible to damage caused by seismic forces.
2) It is observed that the column situated near to the staircase failed from the first floor itself, which means that the columns supporting to the staircase should have more stiffness.
3) The columns situated at the edges and at corner are likely to fail earlier than the interior columns.
4) This design philosophy is essential for the construction of tall buildings, bridges, and other critical infrastructure that must be able to safely endure a wide range of loading scenarios over their lifetime.

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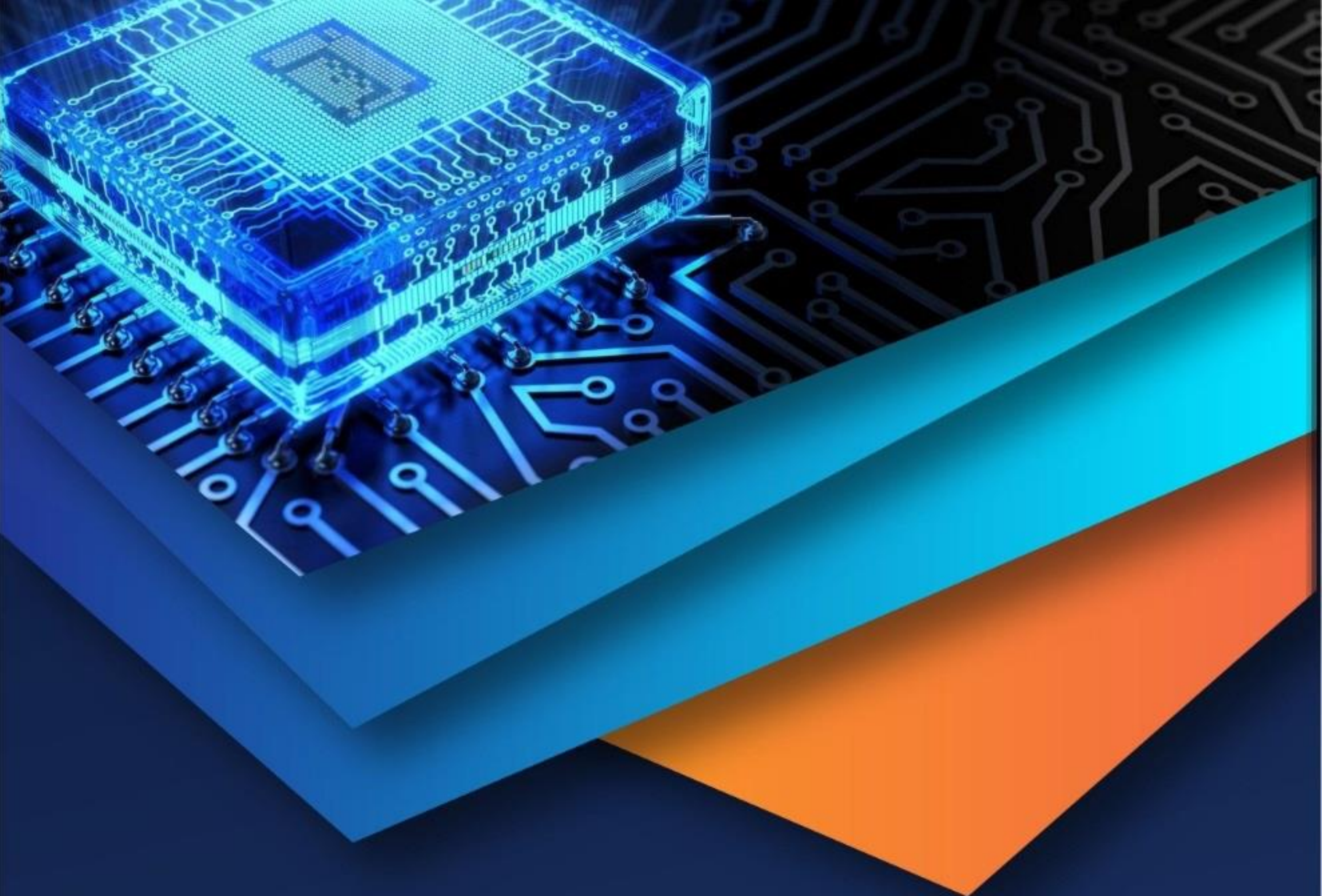

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