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The Influence of Moment Redistribution on the Optimization of Beam Reinforcement in Multistorey Structures

Chaitali Bangar, Roshni John

***Abstract:** The redistribution of design bending moments in continuous reinforced concrete beams is widely acknowledged as a valuable resource for designers of reinforced concrete structures. Moment redistribution is beneficial for practical design, as it provides flexibility in reinforcement arrangement. According to IS 13920:2016, the minimum reinforcement at the bottom face of the beam at support locations must be 50% of the top reinforcement at the same point. At the same time, it should be no less than 25% of the support reinforcement at midspan to meet ductility requirements. In detailing the junctions between columns and beams, the author has noted that congestion of reinforcement at the column faces of the beams poses practical challenges when placing both longitudinal and transverse rebars for the columns. This congestion can lead to inadequate concrete compaction, increasing the risk of honeycombing. By redistributing the top moment in the beam at the support location to the bottom face at midspan, it becomes possible to reduce both the top and bottom reinforcement at the supports, thus optimizing the reinforcement allocation in beams. This study examines a three-dimensional G+20-storey building, which includes both laterally stiffened and unstiffened designs with symmetrical plans. The entire structure is situated in zone III on medium soil conditions, incorporating partial moment releases. The percentages of moment redistributed in the beams were determined at 10%, 20%, and 30% for the laterally unstiffened structure, and 10% for the laterally stiffened structure. Following this, a response spectrum analysis was performed using STAAD Pro. By IS 13920:2016, comparisons were made between the beams' top and bottom-face longitudinal reinforcement across various moment redistribution values.*

***Keywords:** Building With and Without a Shear Wall, Moment Redistribution in Beams, Longitudinal Reinforcement in Beam*

I. INTRODUCTION

We know that for fixed or continuous beams subjected to uniformly distributed loads, it is typical to observe larger moments in the support regions than in the spans. When designing a reinforced concrete (RCC) section, this results in a congested arrangement of reinforcement bars at the supports, which can complicate the pouring and compaction of concrete. To address this issue, a portion of the moment at the support is redistributed to the span region. Moment redistribution entails reducing the moment in areas where it is higher and correspondingly increasing it in regions where it is lower [1].

In the limit state of collapse method, Cl.37.1 of IS 456:2000 recommends the redistribution of the calculated moment in continuous beams and frames satisfying the following conditions:

1. Equilibrium between the internal forces and the external loads should be maintained.
2. The elastic moment at any cross-section in a member due to a particular combination of loads shall not be reduced by more than 30 per cent of the numerically largest moment given anywhere by the elastic maximum moment diagram for the particular member, covering all appropriate combinations of loads.
3. A 30% reduction in the moment is permitted in several stories of four or fewer and above shall be restricted to 10% for structures where the structural frames provide lateral stability.
4. Cross-sections having moment capacity after redistribution less than that of the elastic maximum moment shall satisfy the relationship:

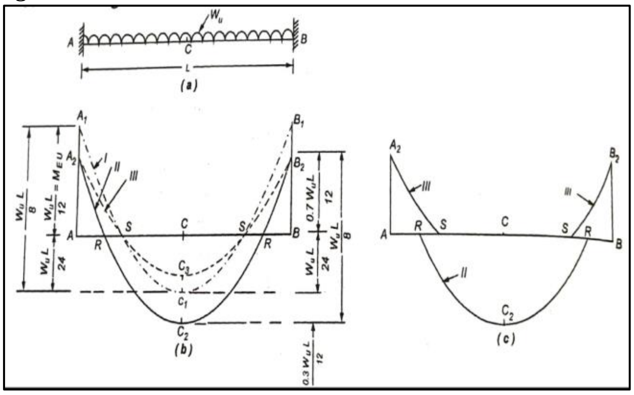
$(X_u / d) + (\delta M / 100) \leq 0.6$ (I)

Where, X_u = depth of the neutral axis,

d = effective depth, and

δM = percentage reduction at the moment.

The subtle meaning of all these provisions made regarding redistribution of the moment will be easily understood from the following illustration of a fixed beam carrying a uniformly distributed load over its entire span as shown in Fig. 1



[Fig.1: Moment Redistribution B.M.D (from Shaha and Karve's Book)][1]

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***Correspondence Author(s)**

Chaitali Bangar*, Department of Civil Engineering, Mumbai University, Pune (Maharashtra), India. Email ID: chaitali.bangar22me@civil.sce.edu.in, ORCID ID: 0009-0008-6220-3854

Prof. Roshni John, Associate Professor, Department of Civil Engineering, Saraswati College of Engineering, Navi Mumbai (Maharashtra), India. Email ID: roshni.john@civil.sce.edu.in

Curve-I i.e. A1C1B1 shows the elastic moment diagram at ultimate load.

Curve-II i.e., A2C2B2 represents the bending moment diagram after reducing the numerically largest support moment by 30% as per condition 3.

Curve - III is obtained by reducing each ordinate of the curve - 1 by 30% to satisfy condition 3.

II. LITERATURE REVIEW AND OBJECTIVE

A. Literature Review

A brief review of previous studies focuses on finding out the behaviour of the structure under different moment release percentages as compared to that when no moment release is available.

1. Ling Li., et al (2024) The research focused on the investigation of two-stage moment redistribution: elastic and plastic moment redistribution. Using ABAQUS finite element software, a numerical analysis of two-span UHPC (Ultra High-Performance Concrete) beams with high-strength reinforcement was conducted. The study involved a detailed examination of nine simulated two-span UHPC continuous beams, focusing on failure modes, load-displacement curves, changes in support reaction forces, tensile strains of steel bars, and the entire process of moment redistribution. Parameters studied included neutral axis depth factor, concrete strength, yielding strength of reinforcement, beam depth, span-depth ratio, reinforcement ratio between mid-span and intermediate support section, and various load forms [1].

2. Tiejiong Lou., et al (2021) This study evaluates the influence of substituting steel rebars with carbon- or glass-fibre-reinforced polymer (CFRP or GFRP) on moment redistribution in prestressed concrete beams (PCBs) with external CFRP tendons. A numerical model is introduced, and simulations are conducted on two-span continuous beams with steel, CFRP, or GFRP rebars of varying areas (Ar2 = 360–3560 mm2), maintaining a ratio Ar1/Ar2 = 1.5, where Ar1 and Ar2 denote the areas of tensile rebars over positive and negative moment zones, respectively. Findings indicate that moment redistribution is primarily influenced by concrete cracking in beams with fibre-reinforced polymer (FRP) rebars, while in beams with steel rebars, it is affected by both concrete cracking and steel yielding. Consequently, the use of FRP rebars results in significantly lower moment redistribution compared to steel rebars [2].

3. Hesham M. A. Diab., et al. (2020) This study experimentally examines the correlation between tensile reinforcement in the sagging and hogging regions and its impact on the performance and moment redistribution of reinforced concrete continuous T-beams. Four two-span RC (Reinforcement Concrete) continuous beams were fabricated and subjected to failure testing, with three featuring a loaded central concrete column. The research offers a detailed analysis of the load-carrying capacity, deformation, ductility index, and moment redistribution of continuous beams with varying steel reinforcement ratios in critical zones. Findings reveal that the load-carrying capacity of continuous beams is primarily influenced by longitudinal reinforcement in the sagging region rather than the hogging region. Reinforcement in the sagging region enhances the ductility and serviceability of continuous beams within allowable deflection and permissible crack width limits [3].

4. Gandhi, et al (2017) In this study, a symmetrical steel model with three floors (G+3) is analyzed using STAAD Pro. Various percentages of moment release, ranging from 20% to 100%, are applied. The analysis calculates the reduction in member forces and the corresponding required cross-sectional areas for each section. The aim is to determine the optimal percentage of moment release for achieving structural economy. Results indicate that beams experience the highest reduction in bending moment, reaching 7.09% at 40% moment release. Therefore, the most economically viable moment release percentage is found to be 40% [4].

5. A V Vasiliev, et al (2017) Compare the computed data for continuous beams using both elastic and moment redistribution systems [5]. Assess the potential reinforcement savings based on these computations. Develop a design model capable of initial elastic system calculations and subsequent transformation to accommodate moment redistribution [6]. Identify the locations of plastic hinge formation and determine the corresponding permanent moment values [7]. Evaluate the likelihood of fracturing in these sections [8]. It has been demonstrated that employing the design model for continuous beams considering moment redistribution leads to significant reinforcement savings [9]. For instance, with 17.31% moment redistribution, there is a 13% reduction in primary reinforcement in the central spans compared to calculations based solely on elastic principles [10].

B. Objectives

1. To study stiffened and unstiffened structures after the Redistribution of bending moment in the beam.
2. To analyze and design a beam before and after the percentage of moment redistribution in the beam.
3. Calculate the reinforcement quantity and compare it with a regular structure
4. Find out the most economical percentage of moment redistribution in the beam.

III. MATERIALS AND METHODS

Here the study is carried out for the effect of moment redistribution in beam of G+20 storied R.C frame buildings in symmetric plans. The floor height provided is 3.2m. Two regular models are created in STAAD Pro i.e. one is laterally unstiffened (without a shear wall) and the other is laterally stiffened (with the shear wall). Each model is analyzed with 10%, 20%, and 30% moment redistribution by giving the partial moment releases in STAAD Pro.

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Table 1: Load Data

Member	Area Load
Slab	3.75kN/sqm
Floor Finish	1.00kN/sqm
Live Load	2.00kN/sqm
Column & Beams	Applied by Self-weight Command

Table 2: Member Properties

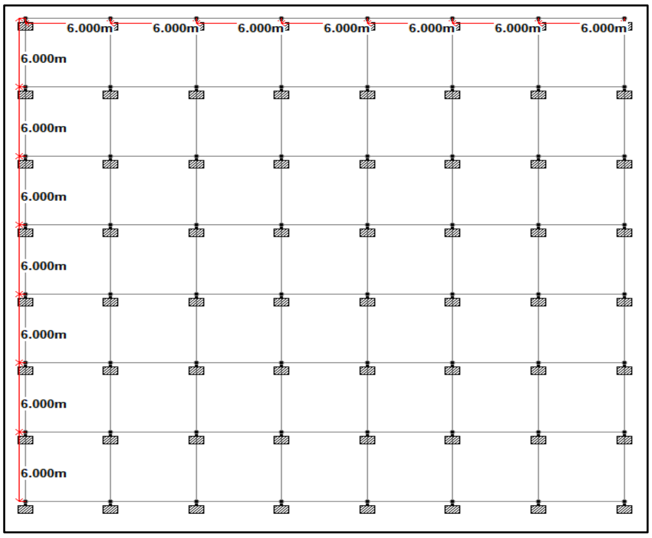
Member	Size	Concrete Grade
Thickness of Slab	150 mm	M30
Beam size	230x600 mm	M30
Column sizes	300x750 mm	
300x900 mm		
300x1000 mm		
400x1000 mm	M40	
Shear wall size	230x1200mm	M40

Table 3: Seismic Force Parameters

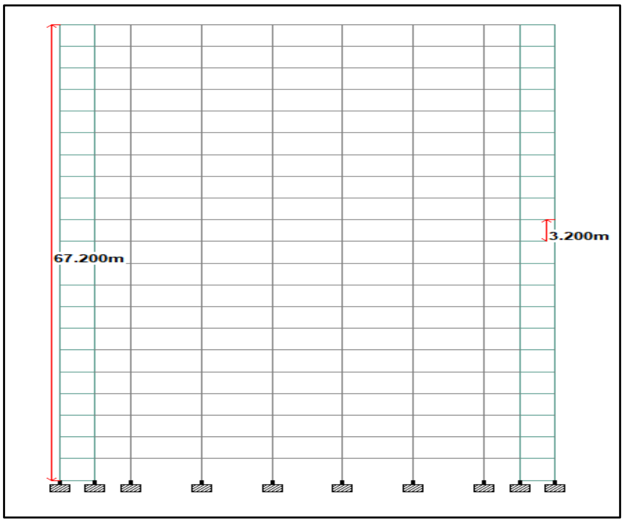
Seismic zone	III
Zone factor	0.16
Importance factor	1.2
Type of soil	II (medium)
Response reduction factor	5

Table 4: Description of Models

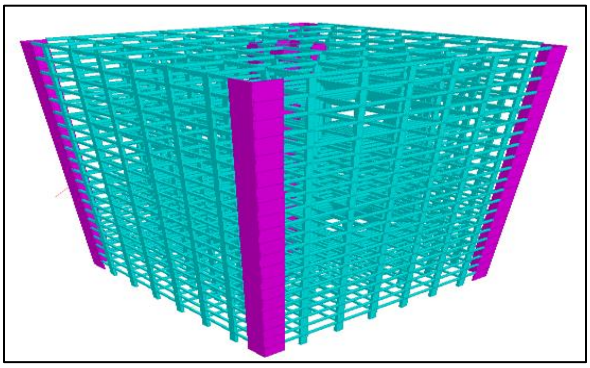
Models	Description
1	Laterally unstiffened (without shear wall) without a partial moment of redistribution.
2	Laterally unstiffened (without shear wall) with a 10% partial moment of redistribution.
3	Laterally unstiffened (without shear wall) with 20% partial moment of redistribution.
4	Laterally unstiffened (without shear wall) with a 30% partial moment of redistribution.
5	Laterally stiffened (with the shear wall) without a partial moment of redistribution.
6	Laterally stiffened (with the shear wall) with a 10% partial moment of redistribution.



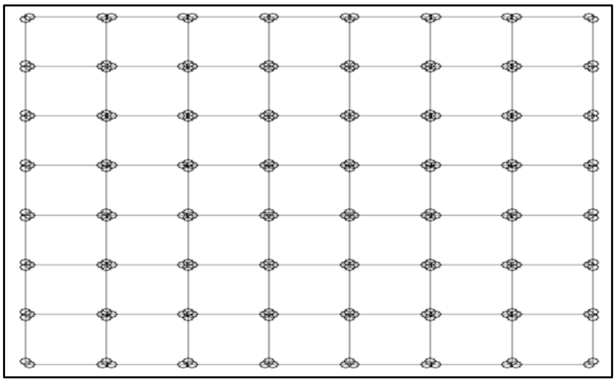
[Fig.2: Plan of G+20 Storey Ordinary Structure]



[Fig.3: Elevation of G+20 Storey Ordinary Laterally Stiffened Structure]



[Fig.4: 3D View of G+20 Storey Laterally Stiffened Structure]



[Fig.5: Plan View of G+20 Storey Ordinary Structure with 10%, 20% & 30% of Moment Redistribution in the Beam]

IV. RESULTS AND DISCUSSION

A. Longitudinal Reinforcement Quantity

As per IS 13920: 2016 clause 6.2.3 “Longitudinal steel on the bottom face of a beam framing into a column (at the face of the column) shall be at least half the steel on its top face at the same section.” Below are calculations showing R/F consumption for beam numbers 8009, 8024, 8039, 8056, 8073, 8088 & 8103 for different moment redistribution values.

Sample R/F calculation for Beam No. 8009 for Laterally

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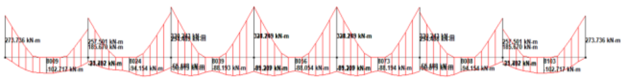
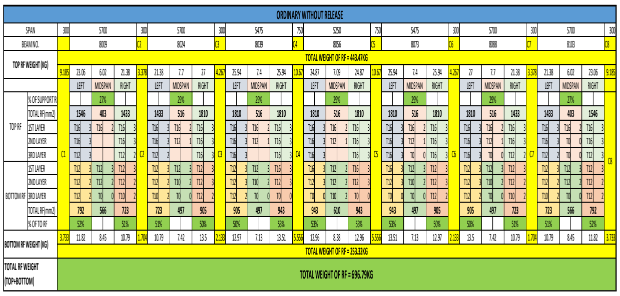
Unstiffened structure without moment redistribution:

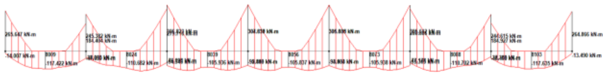
Beam Number =	8009						
DATA :							
Concrete Grade =		M30		Beam Width(b)	230mm		
Concrete Clear Cover =		35mm		Beam Depth(D)	600mm		
Main R/F Grade =		Fe500		Beam Span(L)	6000mm		
Stirrups R/F Grade =		Fe415		Spacer Bar	16mm		
BEAM TO BE DESIGNED FOR DUCTALITY							
Torsional Moment =		**3kN.m**					
Max. Negative BM =		**274kN.m**		**Max. Positive BM =**			**103kN.m**
Effective depth =	533mm			Effective depth =	549mm		
Mu_{lim} =	261kN.m	<	280kN.m	Mu_{lim} =	277kN.m	>	109kN.m
Section to be design as doubly beam				**Section is Under reinforced**			
Mu1	=	261kN.m		Mu1	=	109kN.m	
Mu2	=	19kN.m		Mu2	=	0kN.m	
Ast1	=	1387mm^2		Ast1	=	506	
Ast2	=	85mm^2		Ast2	=	0	
(Ensure min Ast2 R/F at opposite face.)				(Ensure min Ast2 R/F at opposite face.)			
Ast Required =		**1472mm^2**		**Ast Required =**		**506mm^2**	
Number of Layers :		3		**Number of Layers :**		2	
	Bar Dia.	**Nos.**			**Bar Dia.**	**Nos.**	
1st layer	16	3	Streight	**1st layer**	12	3	Streight
2nd layer	16	3	Curtail	**2nd layer**	12	2	Curtail
3rd layer	12	3	Curtail	**3rd layer**	12	0	Curtail
Total R/F Area provided =			**1546mm^2**	**Total R/F Area provided =**			**566mm^2**
			1.27%				0.47%
Maximum % allowed =			2.50%	**Maximum % allowed =**			2.50%
Minimum % allowed =			0.26%	**Minimum % allowed =**			0.32%
			SAFE				**SAFE**



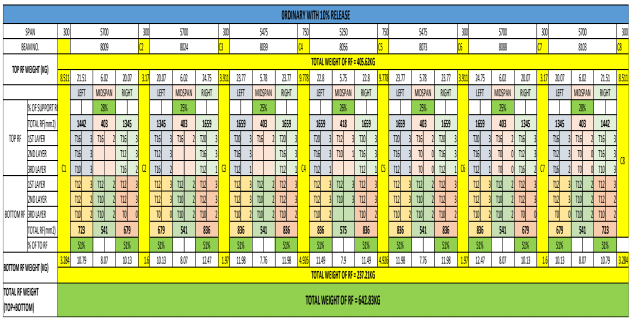
[Fig.6: Bending Moment Diagram for Ordinary Structure without Moment Redistribution]



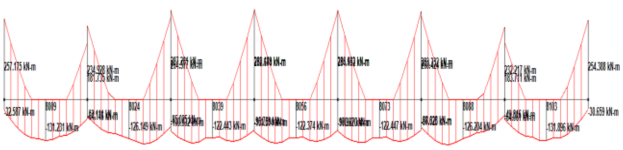
[Fig.7: Longitudinal R/F Quantity for Ordinary Structure without Moment Redistribution]



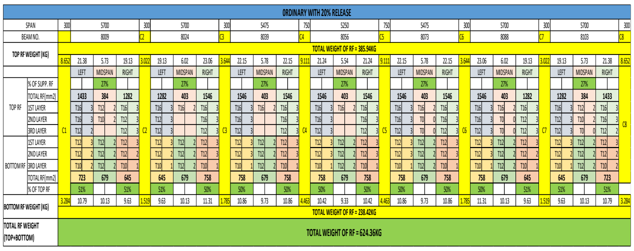
[Fig.8: Bending Moment Diagram for Ordinary Structure with 10% Moment Redistribution]



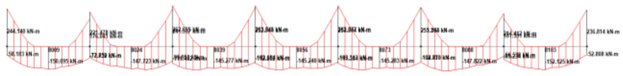
[Fig.9: Longitudinal R/F Quantity for Ordinary Structure with 10% Moment Redistribution]



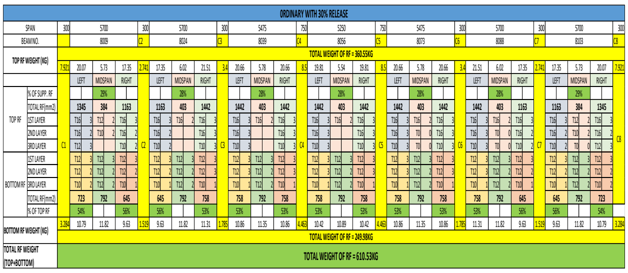
[Fig.10: Bending Moment Diagram for Ordinary Structure with 20% Moment Redistribution]



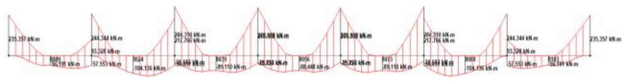
[Fig.11: Longitudinal R/F Quantity for Ordinary Structure with 20% Moment Redistribution]



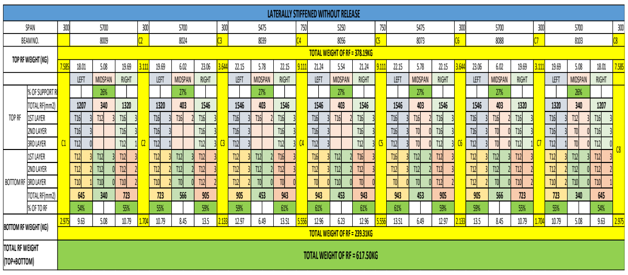
[Fig.12: Bending Moment Diagram for Ordinary Structure with 30% Moment Redistribution]



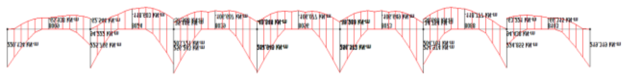
[Fig.13: Longitudinal R/F Quantity for Ordinary Structure with 30% Moment Redistribution]



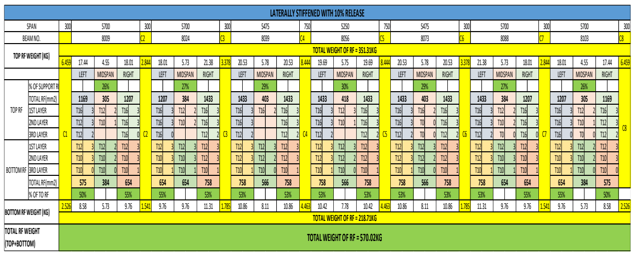
[Fig.14: Bending Moment Diagram for Laterally Stable Structure without Moment Redistribution]



[Fig.15: Longitudinal R/F Quantity for Laterally Stable Structure without Moment Redistribution]



[Fig.16: Bending Moment Diagram for Laterally Stable Structure with 10% Moment Redistribution]



[Fig.17: Longitudinal R/F Quantity for Laterally Stable Structure with 10% Moment Redistribution]

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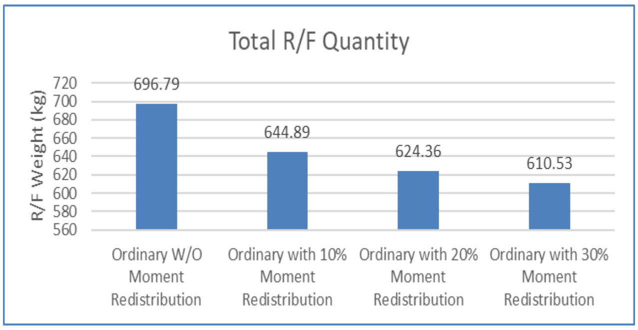
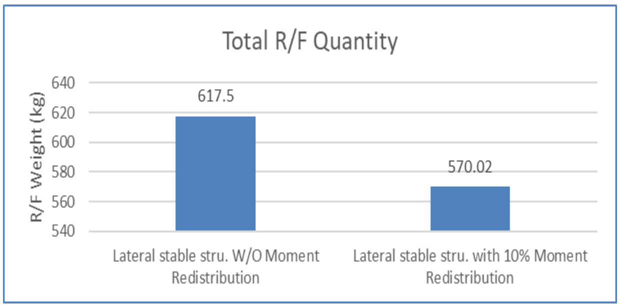


[Fig.18: Graphical Representation Longitudinal R/F Quantity for Ordinary Structure without & with 10%, 20% & 30% of Moment Redistribution]



[Fig.19: Graphical Representation Longitudinal R/F Quantity for a Lateral Stable Structure without & with 10% Moment Redistribution]

V. CONCLUSIONS

The above study shows that for laterally unstiffened structure; the reduction in reinforcement quantity is 7.44% for 10% moment redistribution, 10.39% for 20% moment redistribution, and 12.38% for 30% moment redistribution.

Also, it can be observed that for a laterally stiffened structure; the reduction in reinforcement quantity is 7.68% for a 10% moment redistribution.

From the results and discussions, it can be concluded that 10%, 20% & 30% moment redistribution in the beam for laterally unstiffened structure and 10% of moment redistribution in the beam for laterally stiffened structure is economical.

VI. FUTURE SCOPE

In this research paper, the author compares optimization in longitudinal reinforcement of the beam. As per IS 13920: 2016, the Column shall have 1.4 times the moment capacity of connecting beams. One can research optimization in longitudinal reinforcement in columns due to the redistribution of bending moments in beams.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been sponsored or funded by any organization or agency. The independence of this research is a crucial factor in affirming its impartiality, as it has been conducted without any external sway.
- **Ethical Approval and Consent to Participate:** The data provided in this article is exempt from the requirement for ethical approval or participant consent.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Authors Contributions:** The authorship of this article is contributed equally to all participating individuals.

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AUTHORS PROFILE

Chaitali Bangar, obtained her B.E. degree in Civil Engineering from Samarth Group of Institute College of Engineering (formerly affiliated with Savitribai Phule Pune University), Pune, Maharashtra India, in 2017. She is pursuing her M.E. in the Department of Civil Engineering at Mumbai University. Her current research interests include structural analysis of buildings and the optimization of structures after moment redistribution in the beam. She has extensive experience in the field of Oil & Gas structures, as well as in high-rise multistorey residential and commercial building designs. She has expertise in Indian Codes such as IS 456: 2000, IS 13920: 2016, IS 1893: 2016 (Part-1) etc.

Prof. Roshni John, B. Tech (Civil Engg.) M.E(Structural Engg.) is working as an Associate Professor in the Department of Civil Engineering at Saraswati College of Engineering, Navi Mumbai. Dedicated and passionate faculty with a proven record of fostering academic excellence and personal development in students. I strive to create an inspiring and supportive learning environment. My teaching philosophy revolves around nurturing curiosity, creativity, and critical thinking. My expertise is in structural engineering with research publications in the field of dynamic analysis of multistoried buildings, structural dynamics, earthquake engineering, concrete technology, and design of concrete structures.

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