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RCC Beam Design by Redistibution Method

KEYWORDS: RCC Beam Design, Redistribution of Moment, shear force, bending moment, Elastic curve

CHETAN ALKUNTE
Sinhgad Academy of Engineering Khondhwa, Pune (MS)

Dinesh W. Gawatre
Sinhgad Academy of Engineering Khondhwa, Pune (MS)

ABSTRACT *Concrete is the most important building material, playing part in building structures. Its ability to be molded to take up the shapes required for the various structural forms. It is also very durable and fire resistance when specification and construction procedure are correct. Concrete can be used for all standard buildings single storey, multi storey and containment, retaining structures and bridges. Structural design is a science and art of designing, with economy and elegance, a durable structure which can safely carry the design forces and can serve the desired function satisfactorily in working environment during its intended service life span.*

1. Design philosophies

Since the inception of the concept of reinforced concrete in the last twenties of the nineteenth century, the following design philosophies have been evolved for design of reinforced concrete structures:

a) Working stress method (WSM),b)Ultimate load method (ULM) c)Limit state method (LSM)

2. Analytical Theories

2.1 Macaulay's Method	2.2Moment Area Method
2.3 Influence Line Theory	2.4 The Three Moment Equation (Clapeyron's Theorem)
2.5 Stiffness& Flexibility Methods	2.6 Slope Deflection Method
2.7 The Moment Distribution Method	

3. Redistribution of Moment

In the current practices of structural design, the concept of moment redistribution in conjunction with linear analysis is well known and widely accepted. There are numerous studies and various references that deal with the issue and different codes propose various provisions for the amount of permissible redistribution. Despite numerous advantages, there are some limitations in the available work about this subject. In reality, continuous beams lie in the structural frames, symmetric configuration may not happen, and more importantly, lateral load also exist. Linear analysis with moment redistribution is one of the prominent and ordinary methods used in continuous structures design. This approach is to use a linear elastic analysis for calculating the bending moment and shear force distributions in a reinforced concrete structure, and then moment redistribution is performed under code provisions

The phenomenon of transferring additional moment to any other section which has reserved load carrying capacity is called redistribution of moment.

4 Concept of Redistribution

Consider a beam AB which is fixed at A and simply supported at B carrying a point load W at its center as shown in fig 2.The maximum bending moment will occur at fixed end A rather than the point load C.

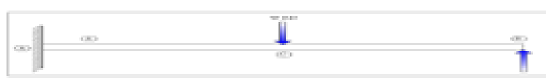

FIGURE NO. 2

Now the load is increased from zero to a certain value the maximum moment at A attains a value equal to ultimate moment of resistance (Mu) the behavior of beam is elastic since the bending moment at A is greater than the span moment the yield stress is first reached at end A. the support section yields and plastic hinge is formed at A. the beam now acts like a statistical determinate beam hinge at A and carrying a constant moment Mu at A let this stage called STAGE – 1.

However by formation of just one hinge at A the mechanism is not formed and the beam does not fail at this stage. The load is therefore increased from W to W1 the additional load is carried by the span portion of the beam. As the load increased bending moment at A does not change but the moment in the span region increases till the mid span moment reaches its ultimate moment capacity (Mur) with the formation of second hinge at C. at this stage mechanism is formed which leads to collapse of the beam.

4.1 plastic hinge

It is define as a yielded section of the beam which acts as if it were hinged with constant restraining ultimate moment acting at the section.

4.2 Plastic hinge in R. C. member

It is define as that section of the beam where the plasticization of concrete in compression and the yielding of steel in tension zone have occurred causing rotation of the section under constant ultimate moment.

4.3. I. S. provision for Redistribution of moments [clause no. 37.1.1-IS 456-2000]

I. All structure may be analyzed by the linear elastic theory to calculate internal action produced by design loads.
II. In case of limit state design loads are ultimate loads

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thus the structure should be analyzed by elastic theory to calculate the internal forces. (i.e. BM , SF , torsion etc)

III. Equilibrium between the internal forces and external loads is maintained.

IV. The ultimate moment of resistance provided at any section of a member is not less than 70 percent of the moment at that section obtained from an elastic maximum moment diagram covering all appropriate combinations of loads.

V. The elastic moment at any section in a member due to particular combination of loads shall not be reduced by more than 30 percent of the numerically largest moment diagram for the particular member covering all appropriate combination of loads.

VI. At sections where the moment capacity after redistribution is less than that from the elastic maximum moment diagram the following relationship shall be satisfied.

VII. $\frac{x_u}{d} + \frac{\delta_M}{100} \leq 0.6$

Where, Xu – depth of neutral axis, d - effective depth, dm –percentage reduction in moment

VIII. In structures in which the structural frame provides the lateral stability the reduction in moment allowed by condition (37.1.1 -4) shall be restricted to 10 percent for structure over 4 stories in height.

4.4 Purpose of Redistribution of Moments

I. It gives a more realistic picture of the actual load carrying capacity of the indeterminate structure.

II. Structures designed considering the redistribution of moment would result in economy as the actual load capacity is higher than that we determine from any elastic analysis.

III. The designer enjoys the freedom of modifying the design bending moments within limits. These adjustments are sometimes helpful in reducing the reinforcing bars, which are crowded, especially at location of high bending moment.

5. Design of beam by limit state method

The design of beam can be carried out as per the step given below

I. Span – Determine the effective span (L). This can be approximately taken equal to center to center distance between the supports provided supports are not too wide.

II. Loads and Trial section – Calculate the super imposed load transferred from slab, wall load and load from secondary beam if any. Assume width and depth of beam. Assume effective cover between 35mm to 70mm decide whether the beam is acting as a flange section or rectangular section calculate self weight of the beam and ultimate load on the beam per meter length.

III. Design moments – Using appropriate method of analysis calculate design moments and shearing forces at various critical sections. If redistribution of moments to be done then consider various loading arrangements to arrive at maximum positive moment, maximum negative moment and maximum shear. Carry out the redistribution of moments in case of indeterminate structures, if desired, limiting the percentage of redistribution of moment to 30%.

IV. Calculate depth from bending moment consideration –

a) For rectangular section calculate the required depth of the beam for maximum sagging moment assuming balanced section and revised the assumed depth if necessary.

b) For flange section calculate the flange width, $bf = (\frac{l_0}{(\frac{l_0}{b})+4} + b_w)$ Moment of resistance of the section for Xu = using $M_{uf} = 0.36 f_{ck} b_f D_f (d - 0.42 D_f)$ And decide whether the neutral axis lies inside the flange or outside the flange and accordingly calculate using appropriate equation. for continuous beam calculate maximum span moment and point of contra flexures.

V. Main steel –

a) Depending on the type of beam calculate area of steel at mid span.

$$A_{st} = \frac{0.5 f_{ck}}{f_y}\left[1 - \sqrt{1 - \frac{4.6 M_u}{f_{ck} b d^2}}\right] bd$$

For flange section if Xu≤ D_f , substitute b_f in place of b in above equation.

For continuous beams design the support section as doubly reinforced section or rarely as a singly reinforced section and obtain the area of tension and compression steel if required. Decide whether the bars are to be curtained or to be bent-up and accordingly ensure that appropriate provisions of the code are adhered to.

b) Maximum area of tension or compression steel = 0.04bD

VI. Design of Shear reinforcement –If the reaction at the ends of the beam is not the same design the shear reinforcement at the both ends.

a) Spacing of stirrups for design shear reinforcement

$S = \frac{0.87 f_y A_{sv} d}{V_{us}}$ < lesser of (0.75d or 300mm)

b) Spacing of stirrups for minimum shear reinforcement

$$S = \frac{0.87 f_y A_{sv}}{0.4 b}$$

VII. Check for deflection – calculate the allowable L/d ratio as per details given in

Table no.1 basic values of span to effective depth ratio

End condition	Basic L/d ratio
Cantilever	7
Simply supported member	20
Fixed or continuous member	26

Check that $d_{reqd.} < d_{provided}$ else increase the depth.

VIII. Check for bond – Bond is not very critical in beams. If required check for development length may be carried out at the end of simple support, at the end of point of contra flexure and at the end of cantilever beam.

$$L_d = \frac{0.87 f_y}{4 \tau_{bd}} . \Phi$$

Where is design bond strength at ultimate load given table.

Table no.2 Design Bond stress in limit state method for plain bars in Tension

Grade of concrete	M20	M25	M30	M35	M40
Design bond stressin N/	1.2	1.4	1.5	1.7	1.9

5.1 Problem statement

A five story residential building is located in seismic zone 3 and a site with medium soil. Analyzed and load on each beam is found out. Out of the entire plan two span continuous beam is referred to elaborate the moment redistribution method. Two span continuous beams is supported

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and loaded as shown in figure no1. Beam AB is loaded with uniformly distributed load of 45.15 kN/m and Point load of 101.89 kN at distance 0.83 m from support A. Span BC is loaded with uniformly distributed load of 27.77 kN/m.

6.2 Redistribution of moment

4.2.1 Case –I Entire Span is loaded with 1.5(DL+LL)

Table no.3 Distribution Factor Table for Support Condition B

Joint	Member	Fixed End Moment (kN.m)	Stiffness	Total Stiffness	D.F
A	AB	-57.11	_	_	_
B	BA	88.69	1.21	4.75	0.25
	BC	-2.96	3.54		0.75
C	CB	2.96	_	_	_

Table no.4 Moment Distribution Table for Support Condition B Elastic reaction

D.F		0.25	0.75	_
JOINT	A	B		C
MEMBER	AB	BA	BC	CB
F.E.M	-57.11	88.69	-2.96	2.96
D.M		-21.82	-63.92	
C.O	-10.91	-31.96	-10.91	-31.96
D.M		10.91	31.96	
C.O	5.46	15.98	5.46	15.98
D.M		-5.46	-15.98	
FINAL MOMENT	-62.56	56.35	-56.35	-13.02

Elastic reaction

152.93	98.39	77.08	-45.70
	175.47		
Redistribution reaction			
152.37	98.95	58.67	-27.28
	157.62		

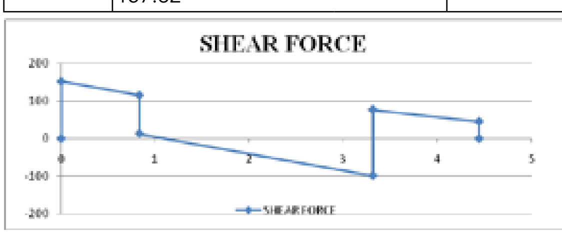


Figure no. 8 Shear Force Diagram for case-I

BEFORE REDISTRIBUTION			
DISTANCE X FROM SUPPORT		MAX B.M	
SF(AB)=0	1.13	FOR AB	81.50
SF(BC)=0	0.57	FOR BC	-17.23
AFTER REDISTRIBUTION MOMENT			
DISTANCE X FROM SUPPORT		MAX B.M	
SF(AB)=0	1.12	AT AB	98.36
SF(BC)=0	0.57	FOR BC	-10.73

Table no. 6 Curve Calculation Table For Support Condition B

CURVE -1		CURVE -2		CURVE -3	
		AFTER REDISTRIBUTION		AFTER REDISTRIBUTION	
X AXIS	Y AXIS	X AXIS	Y AXIS	X AXIS	Y AXIS
0	62.56	0	43.79	0	43.79
1.13	-81.50	1.12	-98.36	1.12	-57.05
3.31	56.35	3.31	39.44	3.31	39.44
3.88	-17.23	3.88	-10.73	3.88	-12.06
4.44	-13.02	4.44	-9.12	4.44	-9.12

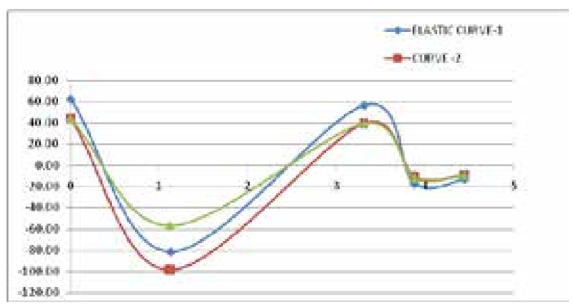
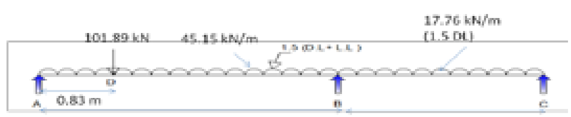


Figure no. 8 Bending Moment Diagram for support B

Case – II Span AB is loaded with 1.5(DL + LL) and span BC is loaded with 1.5 (DL)



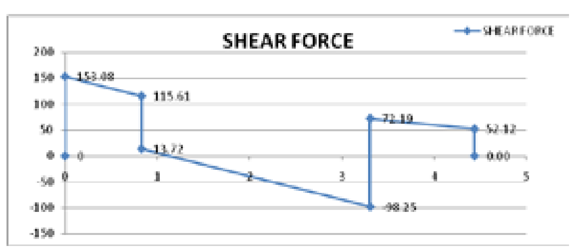


Figure no. 10 Shear Force Diagram of beam for span AB

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Table no.7 Curve Calculation Table For Span Condition AB

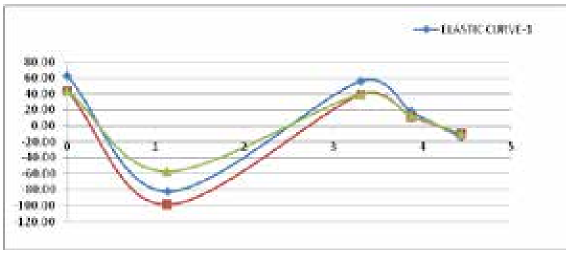

Figure no. 10bending Moment Diagram for span AB

Case – III Span BC is loaded with 1.5(DL + LL) and span BC is loaded with 1.5 (DL)

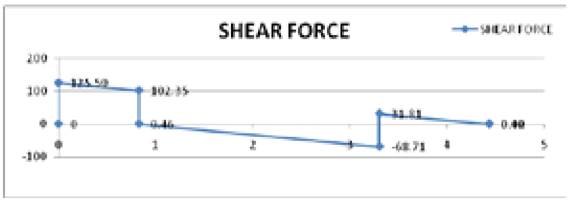

Figure no. 11 Shear Force Diagram for span BC

Table no. 8 Curve Calculation Table for Span Condition BC

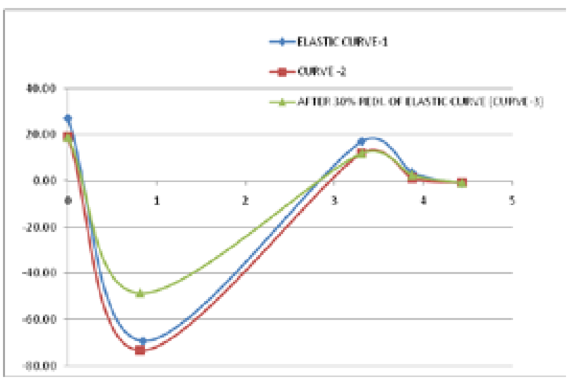

Figure no. 12 ELASTIC CURVE

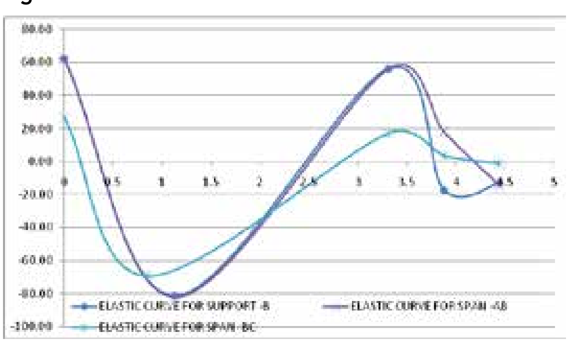

Figure no. 13 AFTER 30% REDISTRIBUTION

Figure no. 14 AFTER REDISTRIBUTION OF EACH POINT OF ELASTIC CURVE

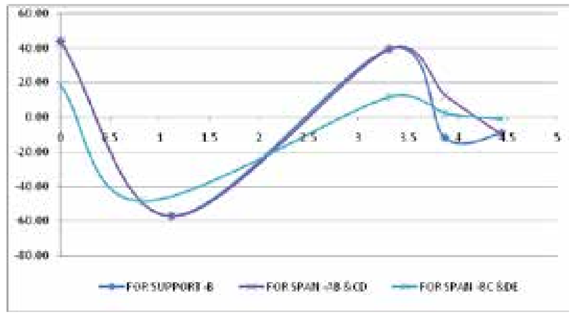

Figure no. 12

5.1.5 Conclusion

- The redistribution moment reduces the absolute maximum moment in the negative moment region and vice versa increases in the positive moment region.
- Utilizes the Complete potential of positive moment capacity of beam section at column faces.
- It equalize the critical moment demands in beams at either side of an interior column.
- It reduces the bending moment in peak region of indeterminate structures, there by the congestion of reinforcement is reduced.
- It helps in reducing the reinforcement at support due to reduction in support moment. It also utilizes higher moment resisting capacity of the flanged section in the span region.
- It ensures the under reinforced section failure.
- It gives better distribution of moments along the length of the member and makes detailing easier and gives economical design.

5.1.6 Limitations of Redistribution of moment

- No inelastic deformations of any kind are expected to occur within any of the columns while the moment redistribution takes place.
- Moment redistribution between columns should not change the maximum value of the combined end moments in any column.
- More than four storey percentage redistribution is limited up to 10%.
- No redistribution of moment is carried out for cantilever moment.
- Envelope of moment redistribution is within the capacity curve.

REFERENCE Is 456:2000 – Plain and reinforced concrete | Is 875(Part 1-5) –Code of practice for design loads (Other than earthquake load) | SP 34:1987 – hand book on concrete reinforcement and detailing. | • Design Example of a six Storey Building By Dr.H.J.Shah, and Dr. Sudhir k Jain page no – 3, 5, 16 | • Computer analysis and Reinforced concrete Design of Beam By R. S. Rostom page no – 1, 2, 15, 16 | • Reinforced concrete Design By Dr. V. L. Shah, and Dr. S.R.Karve page no –69-98, 133, 137, | • Moment Redistribution Effect in Beam By R.H. Scott, and R.T. Whittle | • Times saving Design AID with Moment redistribution By Portland Cement Association page no – 6,7,9 | • Moment Redistribution principal and practice using ACI318-02 by Kenneth B. Bondy PTI Journal page no – 1,3,21 | • Illustrated design of reinforced concrete building By Dr. V. L. Shah, and Dr. S.R.Karve page no – 38-41,145-157,190-195 |