

# Novel Flowchart for Design of Concrete Rectangular Beams

Abdul Kareem M.B. Al-Shamma

**Abstract**— For flexural design of R/C rectangular section beams, there is a number of steps procedure and equations provided by ultimate strength design method according to ACI-code. The large number of equations and fork of solution steps causes a lot of confusion and boredom for student or designer. Checked the most common and authoritative textbooks that dealt with design of concrete structures according to (ACI-08). From long experience in teaching reinforced concrete material, show that the novel flowchart has more effect to give beginner engineering students speed to achieve design steps by less time and effort. This study focuses on flexural of straight beams due to the loads applied vertically, with single and double reinforcement, using SI units. Finally, I reached a simplified flowchart to track flexural design steps easily and conveniently.

**Index Terms**— Flexural design, Concrete flowchart, beams reinforcement, Stress distribution

## 1 INTRODUCTION

In concrete structures, there are many textbooks and re-searches which dealt with how to get flexural and its reinforcement. But, I have not found anybody to tell us a simple and easy way of how to calculate[1]. I've been personal suffering in conveying information of this subject to the beginner engineering students.

Concrete beams are widely used as a main member to construct buildings in Iraq. STAAD/pro is widely used as a structural analysis and design program. Sometimes, to give design more confidently, we need to compare the results of program with the results of manual calculations.

Most common beams, which are rectangular section and T-section, apply vertical loads (dead and live loads). Beams, like that, will be subjected to the bending moment, shear force and torsional moment. This study focuses on beams of rectangular section considering bending moment only. Flexural created by bending moment, makes the beam in case of tension or compression failure[2].

In case of tension failure, provided reinforcement ratio ( $\rho$ ) at tension zone is less than balanced reinforcement ratio ( $\rho_b$ ). So that, steel will reach to the yield stress ( $f_y$ ) and strain ( $\epsilon_y$ ). While, concrete at compression zone has not yet reached to the ultimate strain ( $\epsilon_{cu}=0.003$ )[3][4].

In case of compression failure, provided ( $\rho$ ) at tension zone is greater than ( $\rho_b$ ). Concrete at compression zone will reach ultimate stress ( $f_c$ ) and strain ( $\epsilon_{cu}$ ). While steel has not yet reached ( $f_y, \epsilon_y$ ). For each case, there is a number of design equations derived. To identify those equations, textbooks can be reviewed for the principles of the design of reinforced concrete[3][4].

Usually, longitudinal reinforcement is used for flexural strength in addition to flexural resist by concrete in compression zone.

## 2 NOTATION

The terms in this list are used in the study [5][6].

$w_u$  = factored load per unit length of beam.

D = dead loads.

L = live loads.

$\beta_1$  = factor relating depth of equivalent rectangular compressive stress block to neutral axis depth.

$M_u$  = applied factored moment at section, N.mm.

$f_y$  = specified yield strength of steel, MPa.

$f_c$  = specified compressive strength of concrete, MPa.

b = width of beam, mm.

d = distance from extreme compression fiber to centroid of tension reinforcement, mm.

$d'$  = distance from extreme compression fiber to centroid of compression reinforcement, mm.

C = distance from extreme compression fiber to neutral axis, mm.

$A_s$  = area of longitudinal tension reinforcement,  $mm^2$ .

$A_b$  = area of an individual bar,  $mm^2$ .

$A'_s$  = area of longitudinal compression reinforcement,  $mm^2$ .

$f'_s$  = calculated stress in compression reinforcement, MPa.

$\rho$  = reinforcement ratio in tension zone =  $A_s/bd$ .

$\rho'$  = reinforcement ratio in compression zone =  $A'_s/bd$ .

$\rho_b$  = reinforcement ratio producing balanced strain conditions in case of single reinforcement.

$\rho_{lim}$  = reinforcement ratio producing balanced strain conditions in case of double reinforcement.

$\rho_{max}$  = maximum reinforcement ratio.

$\rho_{min}$  = minimum reinforcement ratio.

$M_{max}$  = maximum factored moment carried by  $\rho_{max}$ .

$M_{u1}$  = factored moment carried by compression reinforcement.

## 3 PROPOSED METHOD AND THE APPLICATION

The study related to prepare flowchart (Fig.1) for design beams has the following properties:

- Concrete rectangular section, straight profile.
- Subjected vertical load (dead and live loads) concentrated or distributed uniformly.
- Using ultimate strength design method with (ACI318-08).

- Using equations with SI unit, consider beam in case of tension failure.
- Design of flexural with single or double reinforcement.
- Designer either is free to choose the appropriate depth or restricted by required depth.

### Application Example

For rectangular concrete beam, given:  $b=300\text{mm}$ ,  $d=350\text{mm}$ ,  $d'=62.5\text{mm}$ ,  $M_u=342\text{ kN.m}$ ,  $f'_c=34.5\text{MPa}$ ,  $f_y=414\text{ MPa}$ . Find  $A_s$ ?

### Solution

$$\beta_1 = 0.85 - 0.05 \left( \frac{f'_c - 28}{7} \right) = 0.85 - 0.05 \left( \frac{34.5 - 28}{7} \right) = 0.80 < 0.85 \dots \dots (o.k)$$

$$\rho_b = 0.85 \beta_1 \frac{600}{600 + f_y} \frac{f'_c}{f_y} = 0.85(0.8) \frac{600}{600 + 414} \frac{34.5}{414} = 0.0341$$

$$\rho_{max} = 0.75 \rho_b = 0.75(0.0341) = 0.02558$$

$$\rho = \frac{f'_c}{1.18 f_y} \left( 1 - \sqrt{1 - \frac{2.36 M_u}{0.9 b d^2 f'_c}} \right) = \frac{34.5}{1.18(414)} \left( 1 - \sqrt{1 - \frac{2.36(342) \cdot 10^6}{0.9(300)(350)^2(34.5)}} \right) = 0.0324$$

$\rho > \rho_{max}$  Design beam as double reinforcement

$$M_{max} = \phi \rho_{max} b d^2 f_y \left( 1 - 0.59 \rho_{max} \frac{f_y}{f'_c} \right) = 0.9(0.02558)(300)(350)^2(414) \left\{ 1 - 0.59(0.02558) \frac{414}{34.5} \right\} \cdot 10^{-6}$$

$$M_{u1} = M_u - M_{max} = 342 - 286.83 = 55.17 \text{ kN.m}$$

$$A'_s = \frac{M_{u1}}{\phi f_y (d - d')} = \frac{55.17 \cdot 10^6}{0.9(414)(350 - 62.5)} = 515 \text{ mm}^2 = A_{s1}$$

$$A_s = \rho_{max} b d + A'_s = 0.02558(300)(350) + 515 = 3201 \text{ mm}^2$$

$$\rho = \frac{A_s}{b d} = \frac{3201}{300(350)} = 0.03048, \quad \rho^- = \frac{A'_s}{b d} = \frac{515}{300(350)} = 0.0049$$

$$\begin{aligned} \rho_{lim} &= 0.85 \beta_1 \frac{f'_c}{f_y} \frac{600}{600 - f_y} \frac{d'}{d} + \rho^- \\ &= 0.85(0.80) \frac{34.5}{414} \frac{600}{600 - 414} \frac{62.5}{350} + 0.0049 = 0.0381 \end{aligned}$$

$\rho < \rho_{lim}$  Compression steel does not yield,  $A'_s$  must be correct it

$$c = \frac{\rho_{max} d f_y}{0.85 f'_c \beta_1} = \frac{0.02558(350)(414)}{0.85(34.5)(0.80)} = 155 \text{ mm}$$

$$f'_s = 600 \frac{c - d'}{c} = 600 \frac{155 - 62.5}{155} = 358 \text{ MPa} <$$

$$f_y \dots \dots (o.k)$$

$$A'_s = A_{s1} \frac{f_y}{f'_s} = 515 \frac{414}{358} = 595 \text{ mm}^2$$

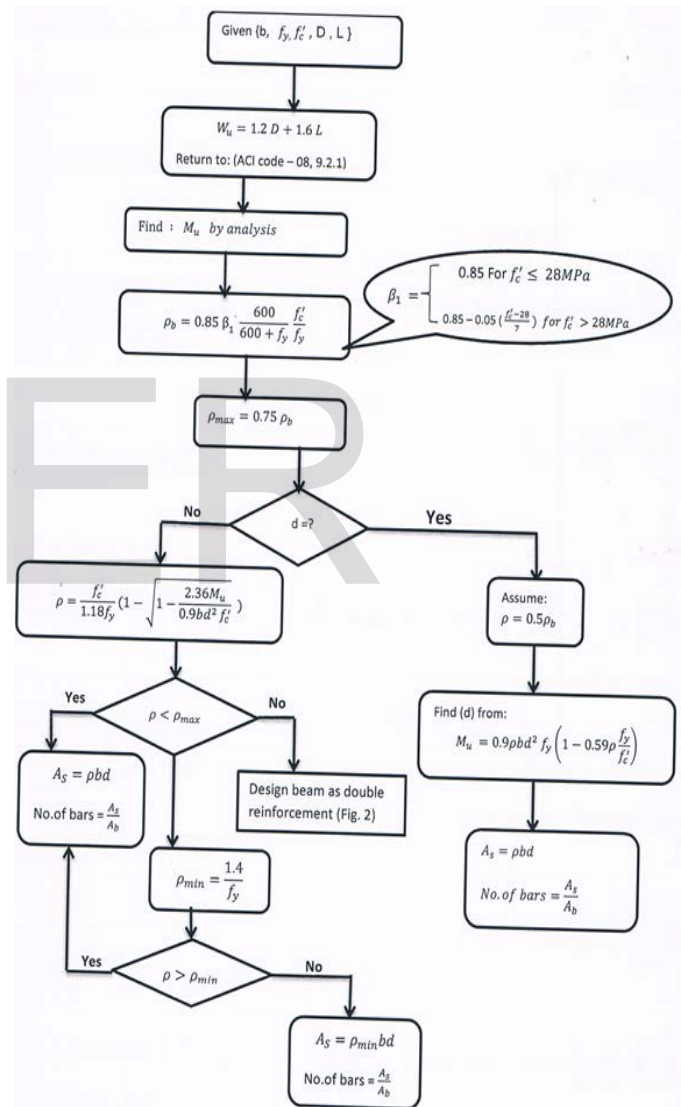


Fig.1. Proposed Flowchart for single reinforcement

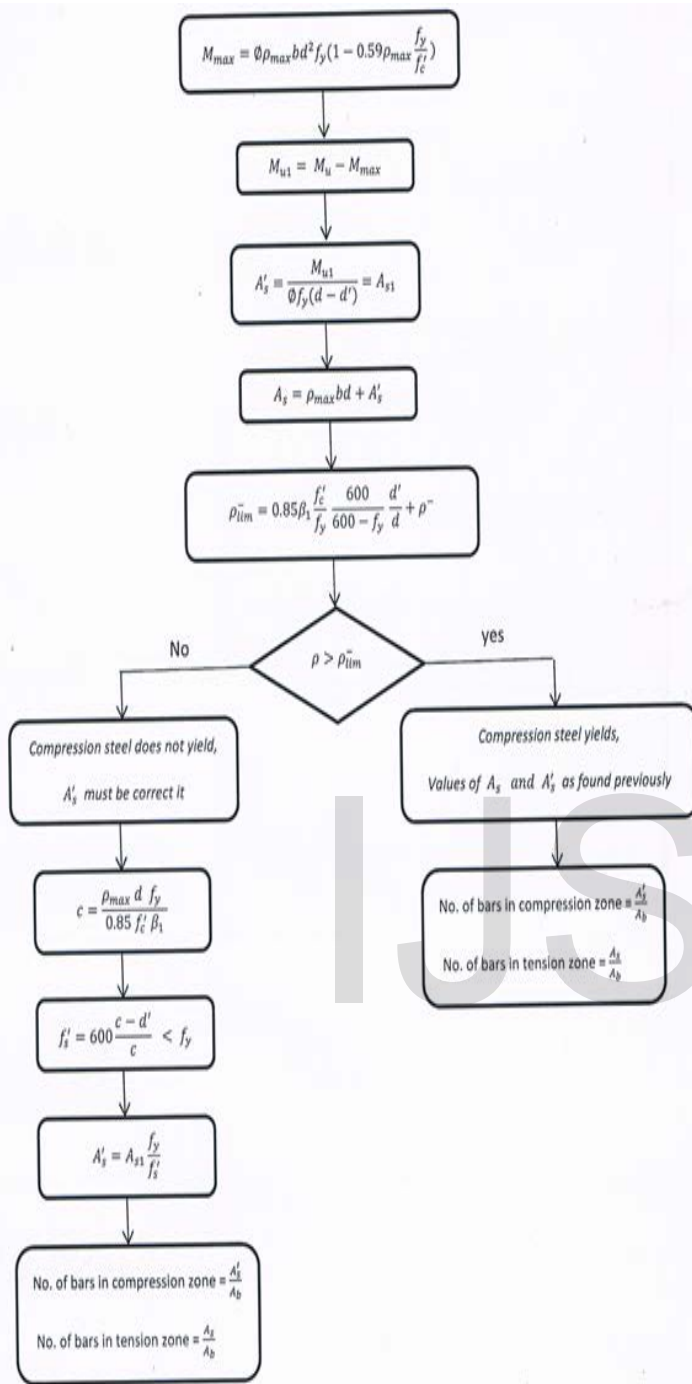


Fig.2. Proposed Flowchart for double reinforcement

## 4 CONCLUSION

From my academic and practical experience, has concluded the following points:

- By using STAAD/pro program, the researcher can recognize the value of moment at any section of the beam. Proposed flowchart is a simple and easy way to see how much steel area required for any moment. Obviously, the program has the facility to do so, but

sometimes to promote confidence can be calculated manually.

- Manually, proposed flowchart is a quick way to design beams and one way slabs. Especially, when they are in accordance with the properties as mentioned in (ACI-08, 8.3.3).
- I noticed that the flowchart is considered clear and easy path. Students or designers accept it without confusion or boredom.

## REFERENCES

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