Republic of Iraq
Ministry of Higher Education & Scientific Research
University of Technology
Department of Building & Construction
Structural Division

Study of Unsymmetrical Reinforcement of the RC Rectangular Short Columns under Eccentric Loading

A study presented to the University of Technology
Department of Building and Construction
As a requirement for
BSc degree in civil engineering

May 20 2010 Dr. Bassman R. Muhammad

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بسم الله الرحمن الرحيم

﴿قالوا سبحانك لا علم لنا الا ما

علمتنا

انك انت العليم الحكيم﴾

صدق الله العظيم

Dedication

I dedicate this work to my dear parents who supported me in my life ...

To my dear sister Dr. Zeena & to my brothers who stood beside me

To my friends Hassan & Ahmed who helped me by all means

Acknowledgement

I would like to express my sincere thanks and gratitude to my supervisor Dr. Bassman R. Muhammad, Department of Building and Construction, University of Technology for his encouragement, facilitation, instructions, and supervision throughout the period of preparation of this study.

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Ali Al_Asadi

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Chapter I – Introduction and general discussion

1- Introduction

Members carrying direct axial load which causes compressive stresses of such magnitude that these stresses largely control the design of the members are classified as "COLUMNS".

Columns are almost subjected to bending moments as well as to axial loads. Because of the nature of the material, concrete column are relatively short. Longitudinal bars are added to assist in supporting the axial load, also main hoops (ties) and spirals serve the same purpose or at least enable the concrete and main bars to work more effectively. Sometime structural steel sections are considered as a sort of reinforcement.

Columns need not to be vertical, but to avoid confusion it will be advisable to consider them to be so.

Columns may have different shapes of their cross sections; they may be square, rectangular, octagonal or other shapes depending on the architectural requirement. Some of these cross sections are shown in fig (1).

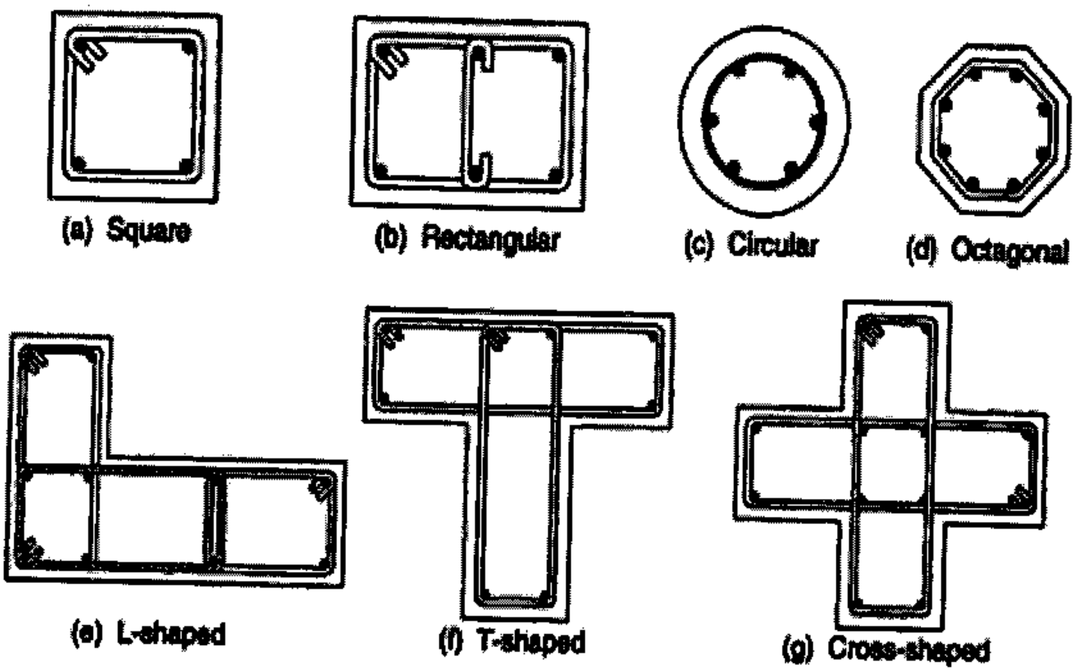


Fig (1): shapes of column cross section

2- Types of column

Concrete compression member whose unsupported length is more than three times the least dimension of the cross section are classified as columns, such member should not built without reinforcement of some types.

There are four types of reinforced concrete columns used in construction, namely:

1- Columns reinforced with longitudinal steel and lateral ties.
2- Columns reinforced with longitudinal steel and closely spaced spirals.
3- Composite columns in which structural steel is thoroughly encased in concrete that is reinforced with longitudinal bars and spirals.
4- Combination columns in which a structural steel column is wrapped with wire and encased in at least $2\frac{1}{2}$ inches of concrete over all metal.

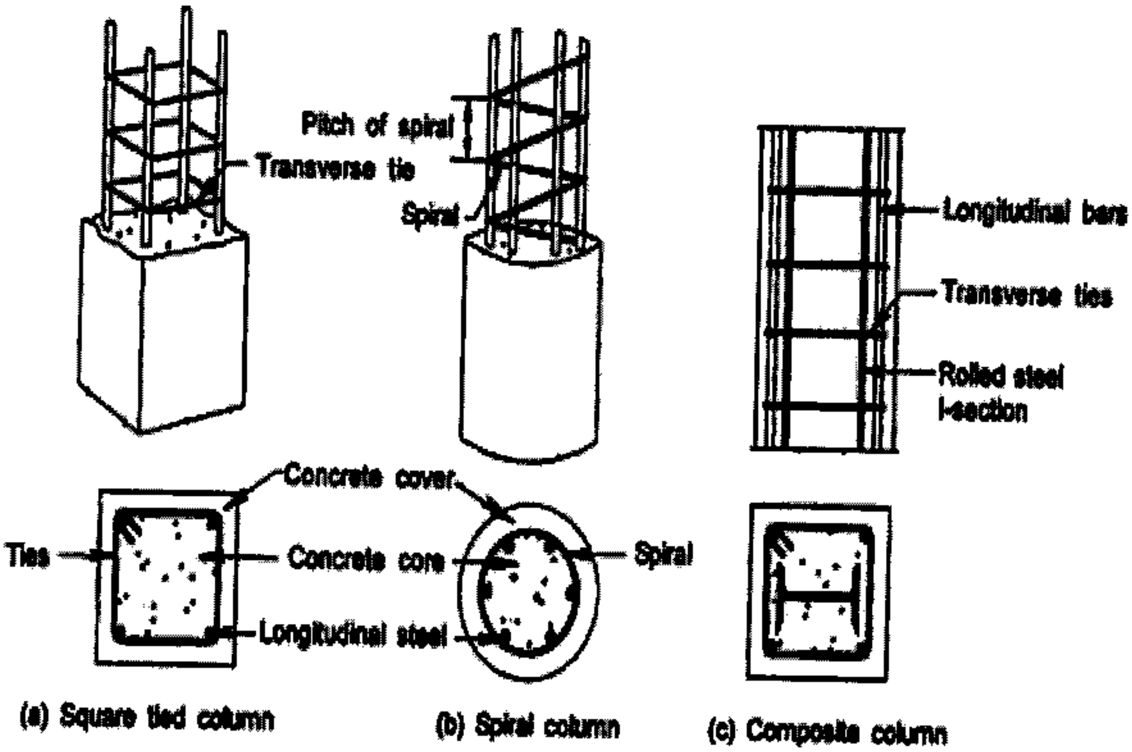


Fig (2): Types of column

3- Classification according to the type of loading

The column, which carries a purely axial load, is termed as concentrically loaded columns. Such an ideal column is rarely encountered in practice. The columns in industrial buildings are not only subjected to high compression but also to bending and shear forces.

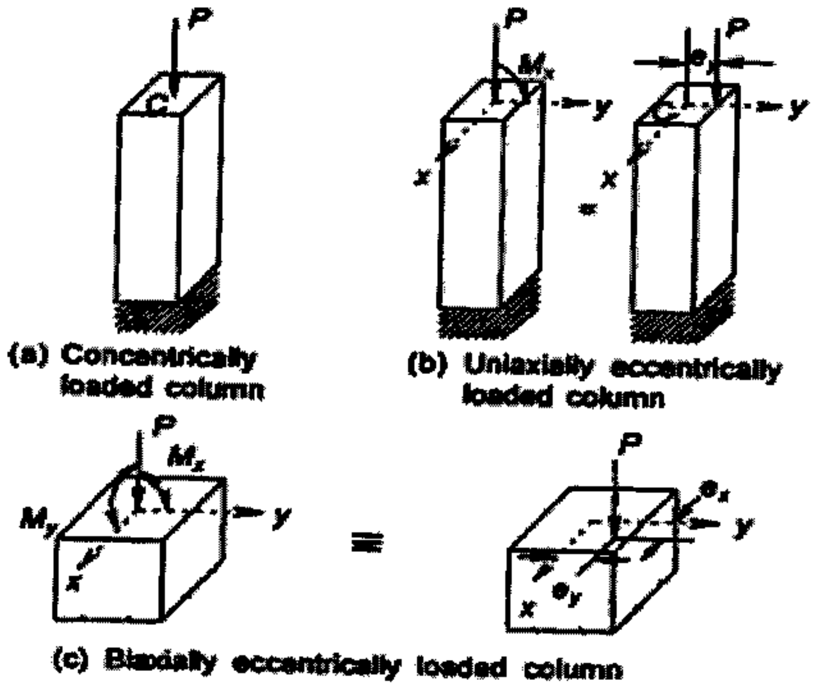


Fig (3): Types of loading

If a column carries an axial load and bending moment about either the x- or y- axis only, it is classified as a uniaxially loaded column. The peripheral columns located on the sides of a building are of this category.

A column subjected to an axial load along with moments about both axes is termed as a biaxial eccentrically loaded column e.g. corner columns of building carry axial loads along with moments about the x-and y-axes.

4- Unsupported length of column

The strength of compression members of any material depended not only on the ultimate compressive strength of the members. Members which are very slender that is long in relation to their least cross-sectional dimension fail by buckling rather than by direct crushing of material, their strength therefore decreases with increasing slenderness ratio (kl / r) or (l / b), where: l = unsupported length, b = least dimension of the column cross section. It's customary in specifications to establish a limiting ratio for (l /b) above which this lost of strength must be considered.

Columns whose (l /b) relative is smaller than the limit are known as "short columns ".

On the base of extensive test, the "ACI 318 Code "limits a short column to one whose unsupported length is not greater than (10) times its lateral dimension. Columns with (l / b) larger than (10) are known as "long columns".

5- ACI 318 Code requirements

Concerning column design here below some of the American Concrete Institute Code (ACI 318) requirements:

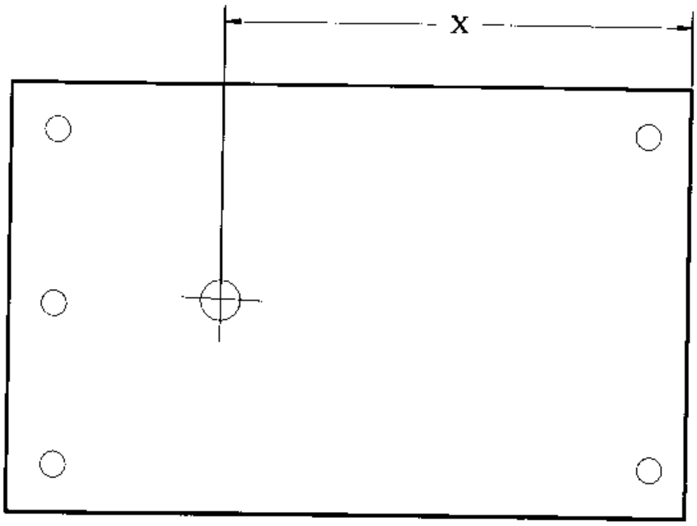
1- The longitudinal reinforcement cross-sectional area should be not less than 1% and not more than 8% of the gross area (Ag) of column section.
2- The longitudinal reinforcement should consist of at least 4 bars in the column with lateral ties, and should consist at least 6 bars in the column with circular ties or spiral.
3- The longitudinal reinforcement bars should not be less than 16 mm in diameter.
4- The clear spacing between spirals should not exceed 80 mm and not less than 25 mm. Where the spiral bars are spliced, the length of lap should be not less than 48 times the spliced bar diameter nor 300 mm
5- Spacing between ties should be the smaller value of:
    - A- 16 times the longitudinal bars diameter.
    - B- 48 times the diameter of the ties bar.
    - C- The least dimension of the column cross section.

6- Combined bending and compression

In ordinary construction there are many cases in which members are subjected to a combination of bending moment and direct axial loads, generally in reinforced concrete work the direct load in such combination is a compressive force. Lateral earth pressures which act upon foundation walls; column to which beams are connected eccentrically; frame action between beams and columns where by the deflections of the beams compel the columns to be bend also because of the rigidity of the connections; wind loads which force the columns of a building to bend sidesways, all these are ordinary causes of the combined compressive and flexural stresses in the members that are affected by them.

Problem involving compression and bending are generally come into one of two classes: The first includes those members which have compression upon their entire cross section. The second covers these which have compression upon part of the section and tension upon the reminder, the analysis of the later situation generally involves considerable calculations.

7- Unsymmetrical Reinforcement



Most reinforced concrete columns are symmetrically reinforced about the axis of bending. However, for some cases, such as the columns of rigid portal frames in which the moments are uniaxial and the eccentricity is large, it is more economical to use an unsymmetrical pattern of bars, with most of the bars on tension side; such columns can be analyzed by the same strain compatibility approach. However, for an unsymmetrically reinforced column to be loaded concentrically the load must pass through a point known as the plastic centroid, the plastic centroid is defined as the point of application of the resultant force for the column cross section (including concrete and steel force) if compressed uniformly to the failure strain $\varepsilon_{cu} = 0.003$ over its entire cross section according to the ACI 318 Code. Eccentricity of the applied load must be measured with respect to the plastic centroid, because only when e = 0 will correspond to axial thrust with no moment. The location of the plastic centroid for the column is the resultant of the three internal forces to be accounted for. Its distance:

$$\overline{X} = \frac{0.85\, f_C^{'} b\, h^2/2 + \sum A_S f_y d}{0.85\, f_C^{'} b h + \sum A_S f_y}$$

Clearly, in a symmetrically reinforced cross section, the plastic centroid and the geometric center coincide.

Chapter II – Calculation and results

1- Introduction

Previous chapter (I) includes material which covers some requirements and specifications concerning reinforced concrete columns.

This chapter (II) includes typical calculations in addition to the tables and charts results from calculations concerning the study in this research.

The procedure that have been carried-out regarding the above-mentioned coculations was as follows :

A tied concrete column at $f_C' = 30\ N/mm^2$ of a rectangular cross sectional area of 800x500 mm, reimforced by longitudinal bars of $f_y = 420\ N/mm^2$ with $\rho = 1\%$ has been considerd in the beginning of the calculations.

Reinforcing bars which have been assumed in the faces of the column parallel to the bending moment axis have been considered in 5 different situations, starting with symmetrical distribution i.e 50% on each face and then as an unsymmetrical distribiton starting with (40% and 60%) then (30% and 70%), (10% and 90%) and at last (0% and 100%) i.e all steel bars are in one side (tension side only) of the column .

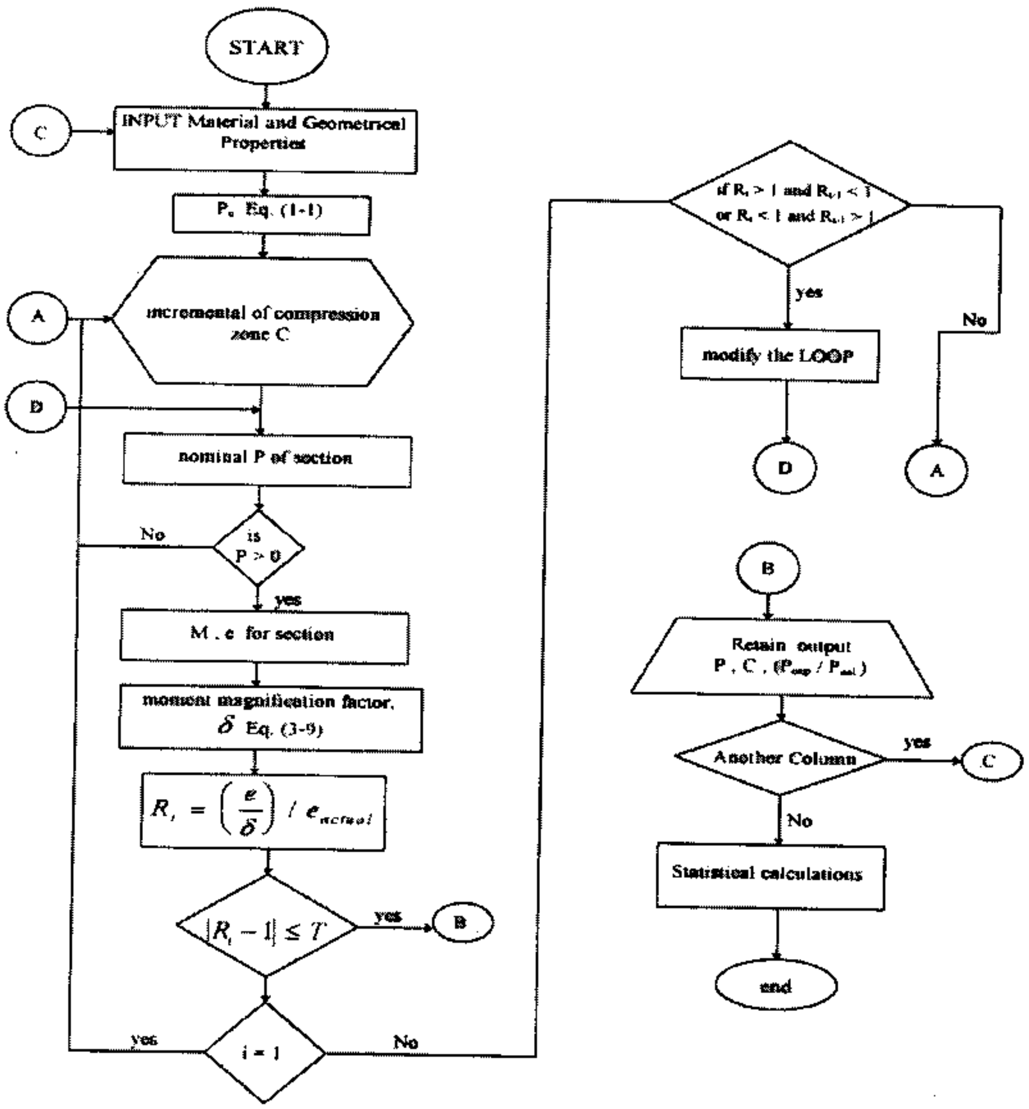
Then the same calculations are repeated 4 more times with different values of ρ which has been taken as 2% , 4% ,6% and 8%.

Calculations have been carried out as shown in the typical calculations sheet included in the study. The results of the said calculations have been included in the herewith attached tables and charts sheets.

Finally at the end of this study there is a conclution that summarize the results of the study.

2- Computer Programmed

A computer programmed is developed to obtain the capacities of each column using the ACI 318 M-08 that are considered in this work. This programmed is developed in Microsoft Office Excel 2007 – Microsoft Visual Basic 6.5 Version 1040. The programmed has been developed for moment magnifier approach for column stability with rectangular stress block used for sectional analysis.



Algorithm for moment magnification approach analytical procedure

3- Notation

Ag = gross area of concrete section, mm^2. For a hollow section, ***Ag*** is the area of the concrete only and does not include the area of the void(s).

As = area of nonprestressed longitudinal tension reinforcement, mm^2

h = overall thickness or height of member, mm

b = width of compression face of member, mm

fc = specified compressive strength of concrete, MPa

fy = specified yield strength of reinforcement, MPa

fs = calculated tensile stress in reinforcement at service loads, MPa

Mn = nominal flexural strength at section, N·mm

Pn = nominal axial strength of cross section, N

βt = ratio of torsional stiffness of edge beam section to flexural stiffness of a width of slab equal to span length of beam, center-tocenter of supports

ρ = ratio of ***As*** to ***bd***

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

c = distance from extreme compression fiber to neutral axis, mm

4- Calculations sheet

Ex:

A rectangular shape short reinforced concrete column with the following dimensions and specifications has been taken as an example,:

$h = 800\ mm$, $b = 500\ mm$

$f_C' = 30\ N/mm^2$, $f_y = 420\ N/mm^2$

solution:

$$\rho = \frac{A_s}{A_g} = \frac{8000}{500*800} = 0.02$$

$$f_C' > 28 \text{ then } \beta_1 = 0.85 - \frac{f_C' - 28}{140}$$

$$\beta_1 = 0.85 - \frac{30 - 28}{140} = 0.8357$$

$$f_C'' = 0.85 * f_C'$$

$$f_C'' = 0.85*30 = 25.5\ N/mm^2$$

$$d_1 = 40 + 12 + \frac{25}{2} = 64.5\ mm$$

$$d_2 = h - d_1 = 800 - 64.5 = 735.5\ mm$$

$$\overline{X} = \frac{A_{S1} f_y d_1 + A_{S2} f_y d_2 + (A_g - A_{St}) f_C'' \, h/2}{A_{S1} f_y + A_{S2} f_y + (A_g - A_{St}) f_C''}$$

$$\overline{X} = \frac{4000*420*64.5 + 4000*420*735.5 + (800*500 - 8000)*25.5*800/2}{4000*420 + 4000*420 + (800*500 - 8000)*25.5}$$

$$\overline{X} = 400\ mm$$

$$Assume\ c = 80$$

$$Cc = \beta_1 * c * b * f_C^{"}/1000$$

$$Cc = 0.8357 * 80 * 500 * 25.5/1000 = 852.428\ kN$$

$$f_S = \frac{c-d}{c} * 600$$

$$f_{S1} = \frac{80-64.5}{80} * 600 = 116.25\ N/mm^2 < f_y = 420 \quad o.k$$

$$f_1 = \frac{A_{S1}}{1000} * (f_{S1} - f_C^{"})$$

$$f_1 = \frac{4000}{1000} * (116.25 - 25.5) = 363\ kN$$

$$f_{S2} = \frac{80-735.5}{80} * 600 = -4916.25\ N/mm^2 < f_y = -420$$

$$\therefore f_{S2} = -420$$

$$f_1 = \frac{4000}{1000} * (-420) = -1680\ kN$$

$$P_n = Cc + \sum f_S$$

$$P_n = 116.25 - 1680 + 852.428 = -464.572\ kN$$

$$M_n = Cc * (\overline{X} - \frac{\beta_1 c}{2}) + \sum f * (\overline{X} - d)$$

$$M_n = 852.428 * (400 - \frac{0.8357 * 80}{2}) + 363 * (400 - 64.5) - 1680 * (400 - 735.5)$$

$$M_n = 997.9024\ kN.m$$

$$P_{n\ Stress} = \frac{P_n * 10^3}{h * b * f_C^{'}} = \frac{-464.572 * 10^3}{800 * 500 * 30} = -0.0387$$

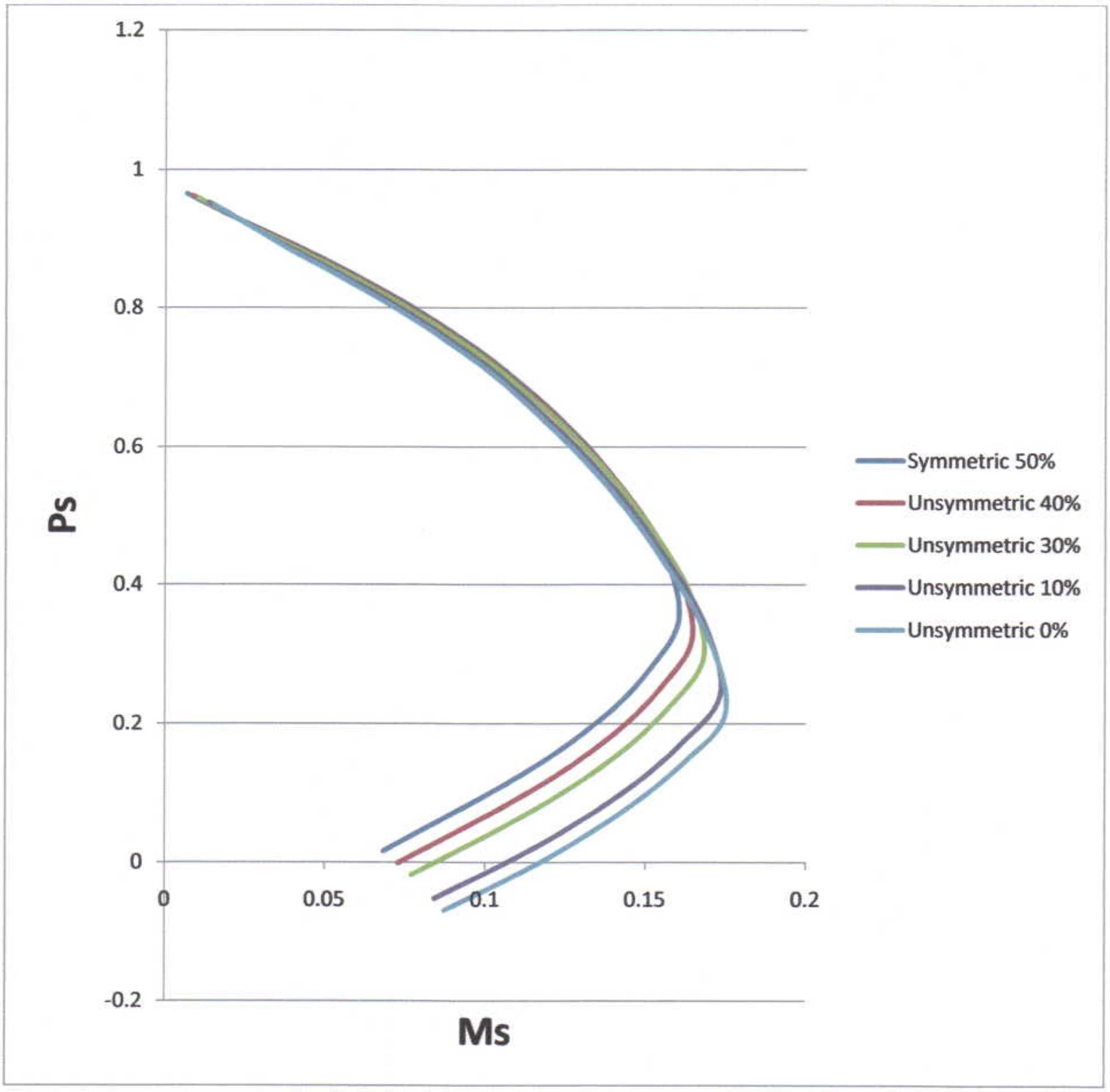
$$M_{n\ Stress} = \frac{M_n * 10^6}{b * h^2 * f_C^{'}} = \frac{997.9024 * 10^6}{800^2 * 500 * 30} = 0.103948$$

Now choose another (c) and repeat the same calculation procedure to determin another magnitude for P_n and M_n , and so on.

5- Tables and Charts

Case 1									
h = 800		b = 500		Rho = 0.01		fc = 30		fy = 420	
Area steel 50%		Area steel 40%		Area steel 30%		Area steel 10%		Area steel 0%	
Symmetric		Unsymmetric		Unsymmetric		Unsymmetric		Unsymmetric	
Ms	Ps	Ms	Ps	Ms	Ps	Ms	Ps	Ms	Ps
0.068249	0.016161	0.072841	-0.00086	0.077026	-0.01789	0.084174	-0.05194	0.087137	-0.06896
0.111768	0.127509	0.114215	0.102421	0.116061	0.077334	0.117953	0.027159	0.117999	0.002071
0.136769	0.208857	0.1393	0.181707	0.14118	0.154557	0.142993	0.100257	0.142925	0.073107
0.151509	0.279893	0.154889	0.252743	0.15762	0.225593	0.161132	0.171293	0.161914	0.144143
0.160312	0.350929	0.164543	0.323779	0.168123	0.296629	0.173335	0.242329	0.174967	0.215179
0.156146	0.438735	0.16006	0.414939	0.163405	0.391143	0.168386	0.343552	0.170023	0.319756
0.143896	0.531661	0.147138	0.512243	0.149916	0.492825	0.154077	0.453989	0.155461	0.434571
0.128005	0.619114	0.130956	0.602979	0.13352	0.586845	0.137491	0.554576	0.138898	0.538442
0.107707	0.702919	0.11062	0.689338	0.113208	0.675758	0.117409	0.648596	0.119022	0.635016
0.084326	0.77992	0.087674	0.767532	0.090726	0.755145	0.09594	0.73037	0.098102	0.717982
0.054005	0.859313	0.057622	0.848597	0.060982	0.837881	0.066934	0.81645	0.069525	0.805734
0.019549	0.934885	0.023502	0.925563	0.027233	0.91624	0.034025	0.897594	0.037086	0.888271
0.017077	0.940779	0.020621	0.932635	0.02397	0.92449	0.030083	0.908202	0.032848	0.900058
0.014959	0.94583	0.018152	0.938696	0.021174	0.931563	0.026705	0.917295	0.029215	0.910161
0.013123	0.950208	0.016011	0.94395	0.01875	0.937692	0.023778	0.925175	0.026067	0.918917
0.011516	0.954039	0.014138	0.948547	0.016629	0.943055	0.021216	0.93207	0.023312	0.926578
0.010099	0.957419	0.012486	0.952603	0.014758	0.947787	0.018955	0.938154	0.020882	0.933338
0.008839	0.960424	0.011017	0.956208	0.013094	0.951993	0.016946	0.943563	0.018721	0.939347
0.007712	0.963112	0.009703	0.959434	0.011606	0.955757	0.015149	0.948401	0.016788	0.944724
0.006697	0.965531	0.00852	0.962338	0.010267	0.959144	0.013531	0.952756	0.015048	0.949563

Case1



1.2
1
0.8
0.6
0.4
0.2
0
-0.2
Ps
0
0.05
0.1
0.15
0.2
Ms
Symmetric 50%
Unsymmetric 40%
Unsymmetric 30%
Unsymmetric 10%
Unsymmetric 0%

				Case 2					
h = 800		b = 500		Rho = 0.02		fc = 30		fy = 420	
Area steel 50%		Area steel 40%		Area steel 30%		Area steel 10%		Area steel 0%	
Symmetric		Unsymmetric		Unsymmetric		Unsymmetric		Unsymmetric	
Ms	Ps	Ms	Ps	Ms	Ps	Ms	Ps	Ms	Ps
0.10394	-0.0387	0.11161	-0.0727	0.11785	-0.1068	0.12601	-0.1749	0.12793	-0.209
0.16437	0.11294	0.16814	0.06277	0.16979	0.01259	0.16674	-0.0877	0.16204	-0.1379
0.19369	0.20460	0.19758	0.15030	0.19917	0.09601	0.19549	-0.0126	0.19021	-0.0669
0.20843	0.27564	0.21382	0.22134	0.21691	0.16704	0.21622	0.05844	0.21244	0.00414
0.21724	0.34667	0.22412	0.29237	0.22871	0.23808	0.23102	0.12948	0.22874	0.07518
0.20604	0.45125	0.21246	0.40366	0.21686	0.35607	0.21966	0.26089	0.21804	0.2133
0.18461	0.56607	0.18996	0.52723	0.19367	0.4884	0.19619	0.41073	0.19499	0.37189
0.16183	0.66994	0.16676	0.63767	0.17033	0.60540	0.17338	0.54087	0.17286	0.5086
0.13618	0.76651	0.14111	0.73935	0.14490	0.71219	0.14904	0.65787	0.14938	0.6307
0.11030	0.84948	0.11603	0.82470	0.12072	0.79993	0.12696	0.75038	0.12851	0.72561
0.07647	0.93723	0.08272	0.91580	0.08807	0.8944	0.09606	0.85151	0.09869	0.83007
0.03909	1.01977	0.04598	1.00112	0.05208	0.98248	0.06192	0.94519	0.06565	0.92654
0.03415	1.03155	0.04035	1.01526	0.04585	0.99898	0.05481	0.96641	0.05825	0.95011
0.02991	1.04166	0.03552	1.02739	0.04052	1.01313	0.04872	0.98459	0.05191	0.97032
0.02624	1.05041	0.03133	1.0379	0.03589	1.02538	0.04344	1.0003	0.04642	0.98783
0.02303	1.05807	0.02767	1.04709	0.03185	1.03611	0.03882	1.01414	0.04161	1.00315
0.02019	1.06483	0.02444	1.05520	0.02828	1.04557	0.03474	1.02631	0.03736	1.01668
0.01767	1.07084	0.02157	1.06241	0.02511	1.05399	0.0311	1.03712	0.03359	1.02869
0.01542	1.07622	0.01900	1.06886	0.02227	1.06151	0.02788	1.04680	0.03021	1.03944
0.01339	1.08106	0.01669	1.07467	0.01972	1.06828	0.02496	1.05551	0.02718	1.04912