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Interaction Diagrams For Reinforced Concrete Octagonal Columns

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Abstract

Eight design charts are presented for reinforced concrete octagonal columns subjected to axial compressive load plus uniaxial bending. For design these charts can be used for determining the required column dimensions and reinforcement arrangement, while for analysis these charts can be used for estimating the loaded column capacity.

Four examples are given to explain the use of design charts for both design and analysis, two of which are design examples while the other two are analysis. It has been shown by these examples that the new proposed charts are very simple to use in structural applications.

منحنيات التصميم للأعمدة الخرسانية المسلحة مثمنة الشكل

الخلاصة

يقدم البحث الحالي ثمانية منحنيات لتصميم الأعمدة الخرسانية المسلحة مثمنة الشكل المعرضة لحمل ألضغاط محوري و عزم انحناء أحادي المحور في التصميم يمكن استخدام المنحنيات لإيجاد متطلبات العمود من حيث الأبعاد و حديد التسليح بينما في التحليل يمكن استخدام المنحنيات لإيجاد قابلية تحمل العمود للأحمال.

ولغرض توضيح و شرح عملية استخدام منحنيات التصميم المقترحة في التصميم و التحليل تم وضع أربعة أمثلة ، اثنان منها تصميمية و الاثنان الباقية تحليلية لوحظ من هذه الأمثلة أن منحنيات التصميم المقترحة تمتاز ببساطتها في التطبيق الإنشائي.

Keywords: Computer program; interaction diagram; octagonal columns; reinforced concrete; uniaxial bending.

Notation

- b width of compression face of the cross section,
- c depth of compression zone,
- C_c calculated force for compression region,
- d_{si} distance from the extreme compression fibre to the centroid of any arbitrary reinforcing bar,
- f_c' specified cylinder compressive strength of concrete,
- f_y specified yield strength of reinforcement,,
- g ratio of center-to-center distance between exterior layers of longitudinal reinforcement to overall depth of section,
- h overall thickness of the cross-section in plane of bending, equal to 2.4142*b
- $m = \dfrac{f_y}{0.85\, f_c'}$
- M_n nominal flexural strength about the axis of bending, neutral axis.

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$N.A$

P_n nominal allowable load in uniaxial bending with eccentricity e,

Rc reinforced concrete,

α_1 Ratio of the stress in the equivalent stress block to the specified compressive strength of concrete =0.85,

β_1 ratio of the depth of the equivalent stress block to neutral axis depth,

ε_{cu} specified ultimate compressive strain of concrete =0.003 , and

ρ_t gross ratio of reinforcement.

Introduction

Arbitrarily shaped reinforced concrete (RC) members subjected to uniaxial or biaxial bending and axial compression are frequently used in multistory tall buildings and bridge piers.

In recent years some methods have been presented for the ultimate strength analysis of various concrete sections, such as L-, and channel-shaped, under symmetrical bending or combined biaxial bending and axial compression [1-4]. These methods compute the ultimate flexural capacity of section. For design purposes they require trial and error procedures.

The present research also aims at obtaining direct relationships between the compression load and the uniaxial bending capacities which can be used as ready design charts for octagonal columns.

Research significance

The principal aims of this work is to furnish a method for analysing tied columns under the combined action of axial compressive load and uniaxial bending that is simple in concept and can be beneficially used in providing easy method to deal with charts for the design of such columns.

Description of the procedure

For columns subjected to uniaxial bending, the neutral axis (N.A) always remains parallel to the axis about which the moment is being applied. Since the position of the neutral axis depends on the value of the eccentricity (e), therefore the variation of the neutral axis position may in general leads to the three possible cases of compression zone shown in Fig.(1).

Estimating concrete compression force

Depending on an equivalent rectangular compression block for concrete[5],

the compressive force of the concrete is

$$C_c = \text{area of compression zone} * (\alpha_1 f_c') \quad ...(1)$$

Where

α_1= ratio of the stress in the equivalent stress block to the specified compressive strength of concrete =0.85, and

f_c' = specified cylinder compre- ssive strength of concrete .

Therefore an estimation of (C_c) according to the three different cases of Fig.(1) requires dividing the compression zone into simple geometrical areas represented by a trapezoidal area (Fig. 1-a), a trapezoidal area and rectangular (Fig. 1-b and Fig. 1-c).

Estimating strain in steel reinforcement

Based on the chosen value of ultimate usable strain at extreme concrete compression fibre (ε_{cu}) which is equal to 0.003[5] and the linear strain distribution across the depth of the cross section (see Fig.2), a correlation between the strain (ε_{si}) in any arbitrary reinforcing bar and the depth of the compression zone (c) can be obtained. Let (d_{si}) denotes the distance from the extreme compression fibre to the centroid of any arbitrary reinforcing bar.

Referring to Fig. (2), the strain in any steel bar can therefore be obtained

$$\varepsilon_{si} = \frac{\varepsilon_{cu}}{c} \left| c - d_{si} \right| \qquad ...(2)$$

since steel can be idealized as elastic-perfectly plastic material with maximum value of stress (f_y), therefore the stress in any steel bar is simply

$$f_{si} = \varepsilon_{si} E_s \quad f_y \qquad ...(3)$$

where

f_{si} = stress in reinforcement,

E_s = modulus of elasticity of reinforcement, and

f_y = specified yield strength of reinforcement.

Equilibrium criteria

For a given eccentricity (e), the value of the compressive load (P) can be estimated from the following simple equilibrium equation

$$P = C_c + \sum C_{si} - \sum T_{si} \qquad ...(4)$$

The associated uniaxial bending moment (*M*) can also be estimated by summing up the moment of the resulting forces on the cross section around the centroid of the section,

$M = C_c$ * its lever arm to the centroid of the section + $\sum$ C_{si} * its lever arm to the centroid of the section + $\sum$ T_{si} * its lever arm to the centroid of the section **...(5)**

where C_{si} and T_{si} represent the compressive and tensile force in the i^{th} reinforcing bar respectively, see Fig. (2). The subscript (*i*) refers to the reinforcing steel layer position.

Program description

The computer program is developed in Microsoft Quick-Basic Version 4.5. It is capable of producing points that describe the axial load versus moment interaction diagram for any short octagonal column under uniaxial bending. The program can only analyze section where the reinforcing steel is placed symmetrically around the perimeter of the column section, so that the plastic centroid and the centroid of the concrete section coincide.

Input data for program include: the material and section properties, and the area and coordinates of each longitudinal bar. The output of the program consists of a series of data points (P and M vales) that could be used in drawing the interaction diagram for the column.

The program assumed a linear variation of strain over the depth of the section. Strain hardening of steel, tensile strength of concrete, and slenderness effects are ignored. In addition, the output does not include the capacity reduction factor (ϕ).

Design charts

Charts 1 through 8 have been prepared for the case of uniaxial bending of octagon columns with symmetrically arranged reinforcing around the perimeter of the column section. Charts are included for 8 and 16 bar arrangements, concrete strengths (f_c') less than or equal to 30 MPa, yield strength of reinforcement (f_y) equal to 414 MPa, and ratio of center-to-center distance between exterior layers of longitudinal reinforcement to overall depth of section (g) equal to 0.6, 0.7, 0.8, and 0.9.

Examples

Example (1) – Design problem

A short RC octagonal column subjected to nominal compressive load of 5408 *kN* acting at a position with eccentricity e = 49 *mm*. Use f_c'= 28 MPa, f_y = 414 MPa, No. of bars = 8, b = 200 *mm* and cover = 58 *mm*. It is required to determine the steel ratio by using the proposed charts.

Solution :-

$$m=\frac{f_y}{0.85\,f_c'}=\frac{414}{0.85*28}=17.39$$

; h = 2.4142*b = 2.4142*200 = 482.84 *mm*

$$g=\frac{482.84-2*58}{482.84}=0.76\,;$$

$$\frac{e}{h}=\frac{49}{482.84}=0.1;$$

$$\frac{Pn}{f_c'bh}=\frac{5408*10^3}{28*200*482.84}=2$$

Enter chart 2 (g = 0.7 and No. of bars =8) with $\frac{e}{h}=0.1$ and $\frac{Pn}{f_c'bh}=2$,

read $\rho_t m = 0.64$

Enter chart 3 (g=0.8 and No. of bars=8) with $\frac{e}{h}=0.1$ and $\frac{Pn}{f_c'bh}=2$,

read $\rho_t m = 0.6$

Interpolating (g=0.76 and No. of bars =8): $\rho_t m = 0.616$.

$$\therefore \rho_t=\frac{0.616}{17.39}=0.0354$$

Example (2) – Design problem

A short RC octagonal column subjected to nominal compressive load of 4300 *kN* acting at a position with eccentricity e = 163 *mm*. Use f_c'= 25 MPa, f_y = 414 MPa, No. of bars = 16, cover = 0.1*h and steel ratio ($\rho_t = 0.0426$).It is required to determine value of dimension (b) by using the proposed charts.

Solution :-

$$m=\frac{414}{0.85*25}=19.48\,;$$

$$\rho_t m = 0.0426*19.48=0.83\,;$$

$$g=\frac{h-2*0.1*h}{h}=0.8$$

Try b = 225 *mm* ; h = 2.4142*225 = 543.2 *mm*; $\frac{e}{h}=\frac{163}{543.2}=0.3$

Enter chart 7 (g=0.8 and No. of bars = 16) with $\frac{e}{h}=0.3$ and $\rho_t m = 0.83$,

read $\frac{Pn}{f_c'bh}=1.42$,

therefore

$$Pn = 1.42 * 25 * 225 * 543.2 * 10^{-3} = 4338.8 \quad kN$$

Since this value agrees closely with the actual nominal load, therefore b = 225 *mm* is O.K

Example (3) – Analysis problem

A short RC octagonal column subjected to nominal compressive load (P_n) acting at a position with eccentricity e = 181 *mm*. Use f_c'= 30 MPa, f_y = 414 MPa, No. of bars = 8, cover = 60 *mm*, b = 250 *mm* and steel ratio($\rho_t = 0.0246$).It is required to determine the allowable nominal compressive load (P_n) by using the proposed charts.

Solution :-

$m=\frac{414}{0.85*30}=16.235$;

$\rho_t m = 0.0246*16.235=0.4$;

h=2.4142*250=603.55*mm*;

$g=\frac{603.55-2*60}{603.55}=0.8$;

$\frac{e}{h}=\frac{181}{603.55}=0.3$

Enter chart 3 (g=0.8 and No.of bars=8) with $\frac{e}{h}=0.3$ and $\rho_t m=0.4$

read $\frac{Pn}{f_c^{'}bh}=1.04$,

therefore

$Pn\ allowable = 1.04*30*250*603.55*10^{-3}=4707.7\ kN$

Example (4) – Analysis problem

A short RC octagonal column subjected to nominal compressive load of 6670 *kN* acting at a position with eccentricity e . Use $f_c^{'}$ = 26 MPa, f_y = 414 MPa, No. of bars = 16, cover = 60 *mm*, b= 250 and steel ratio ($\rho_t = 0.048$).It is required to determine the allowable nominal moment by using the proposed charts.

Solution :-

$m=\frac{414}{0.85*26}=18.733$;

$\rho_t m = 0.048*18.733=0.9$;

h=2.4142*250=603.6*mm*;

$g=\frac{603.6-2*60}{603.6}=0.8$;

$\frac{Pn}{f_c^{'}bh}=\frac{6670*10^3}{26*250*603.6}=1.7$

Enter chart 7 (g = 0.8 and No.of bars =16) with $\frac{Pn}{f_c^{'}bh}=1.7$ and, $\rho_t m=0.9$, read $\frac{e}{h}=0.235$,

therefore

$e = 0.235*603.6=141.8\ mm$,

$M\ allowable = 6670*141.8*10^{-3}$
$= 945.8\ \ kN.m$

Conclusions

The analysis and design of reinforced concrete octagonal sections subjected to axial compression and uniaxial bending are very tedious and time consuming because

1. In the analysis, a trial and error procedure is required to find the depth of the neutral axis satisfying the equilibrium conditions.
2. In the design process, a trial and error procedure is required to find the steel ratio (ρ_t) satisfying the strength requirements.

While the simplicity of the present approach enabled the construction of new design charts that can be used directly in design and analysis.

Acknowledgment

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Future research

The following iterms are recommended for future studies

1. Applying the new approach to analyse high strength RC octagonal columns and to study the effect of some important parameters on their capacity such as the amount of reinforcement ratio and ultimate compressive strain value of concrete.
2. Extending the new approach to analyse irregular shapes such as

L-, and channel shaped and providing design charts.

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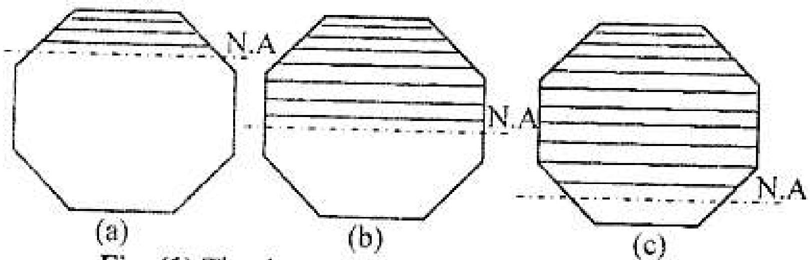

Fig. (1) The three possible cases of compression zone.

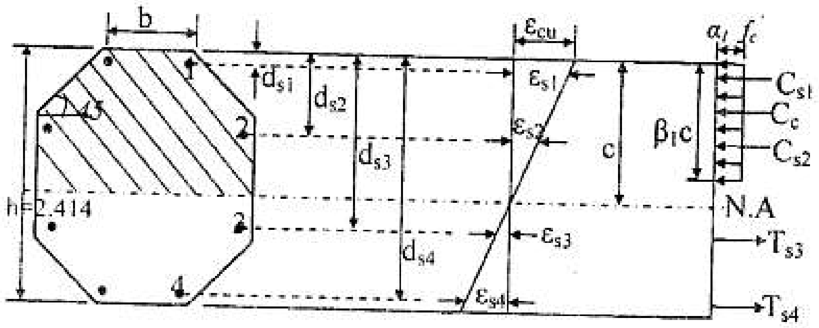

Fig. (2) Eccentrically loaded octagonal column.

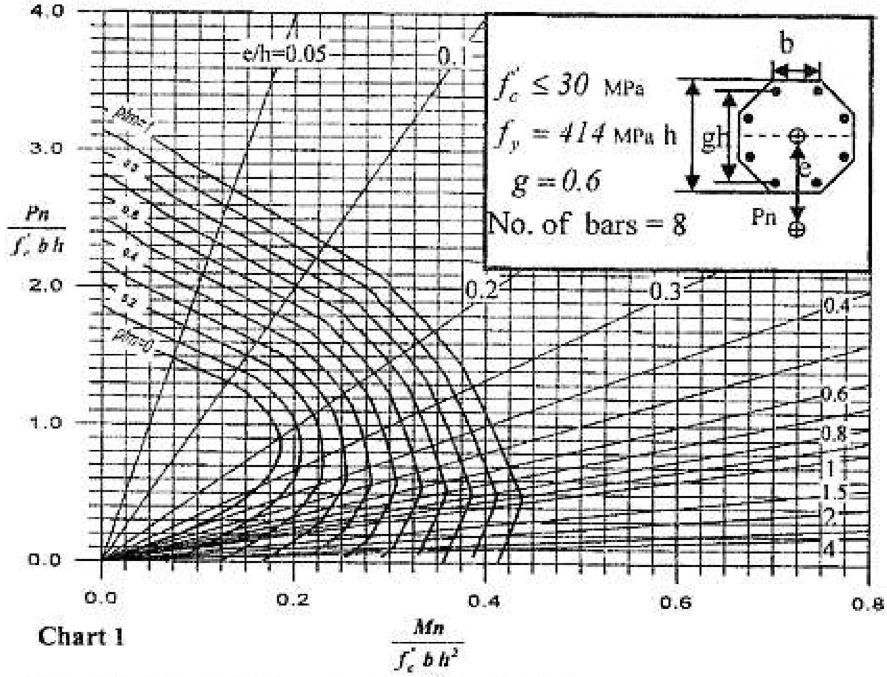

Chart 1

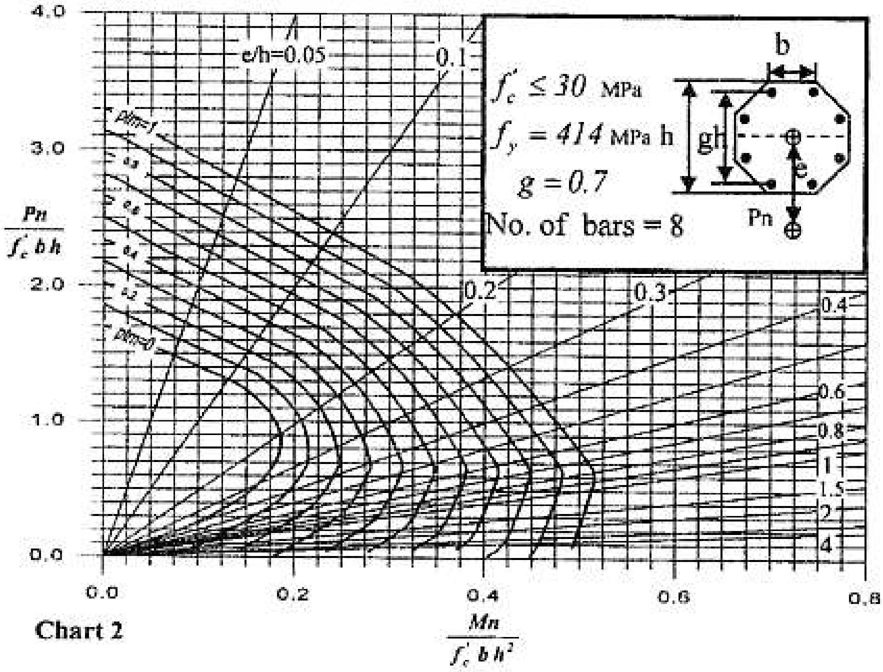

Chart 2

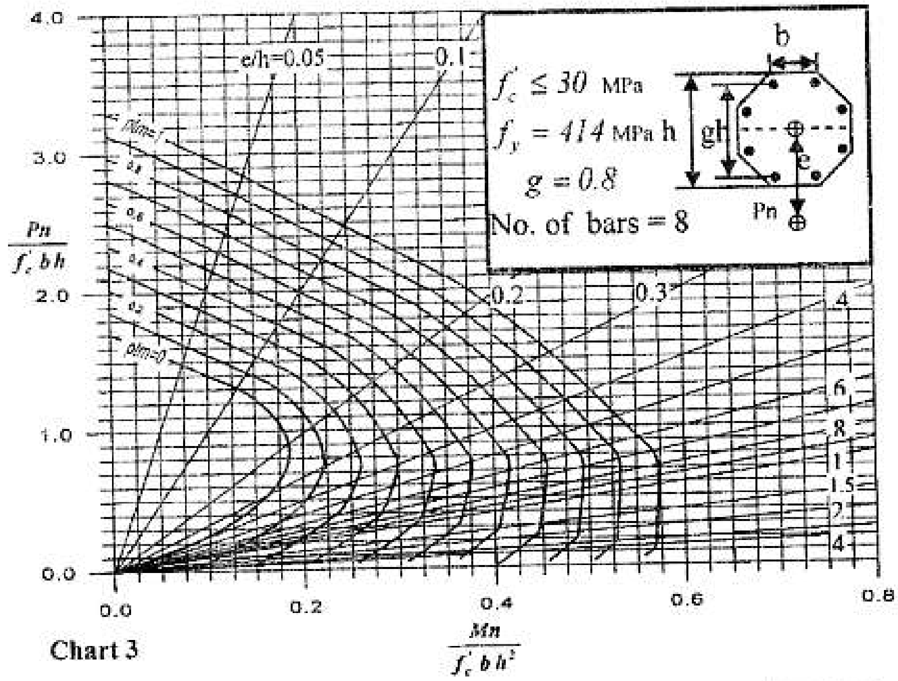

Chart 3

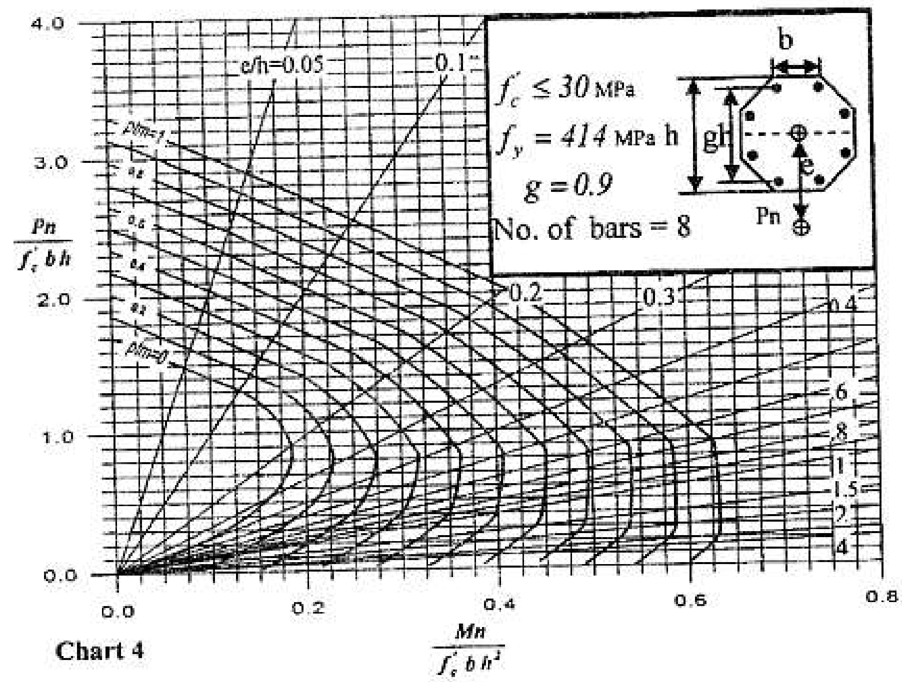

Chart 4

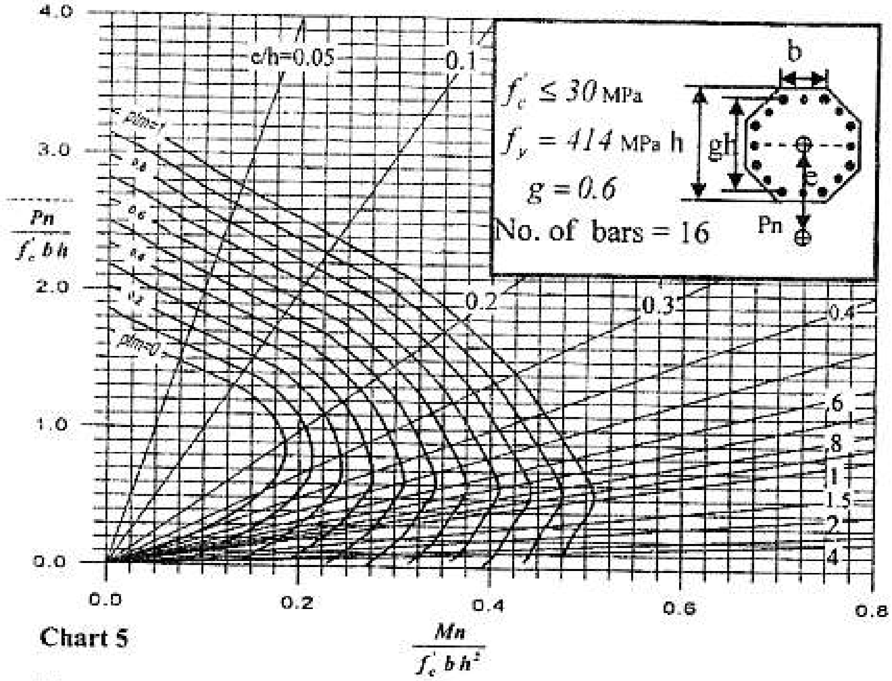

Chart 5

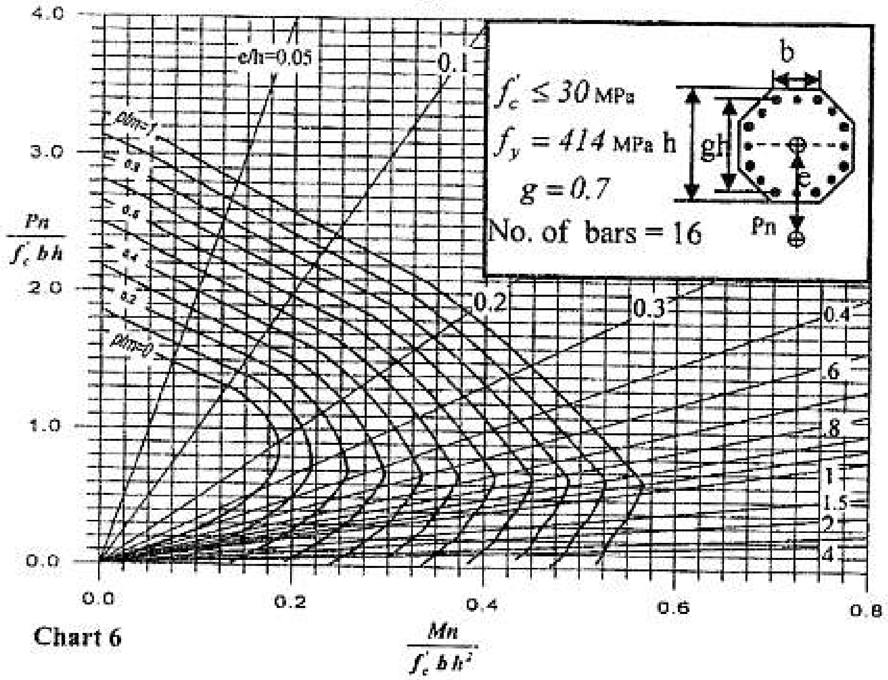

Chart 6

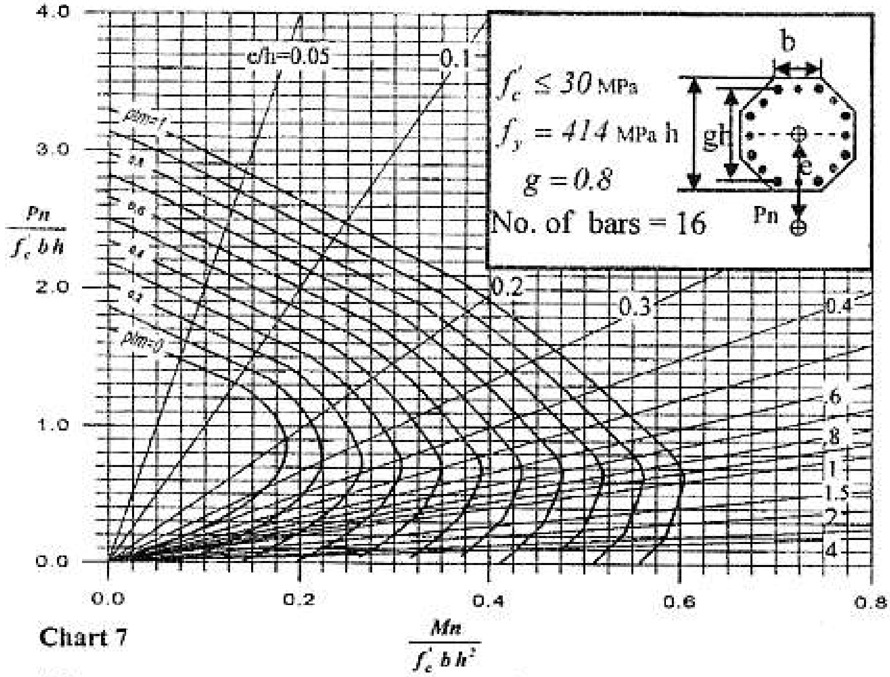

Chart 7

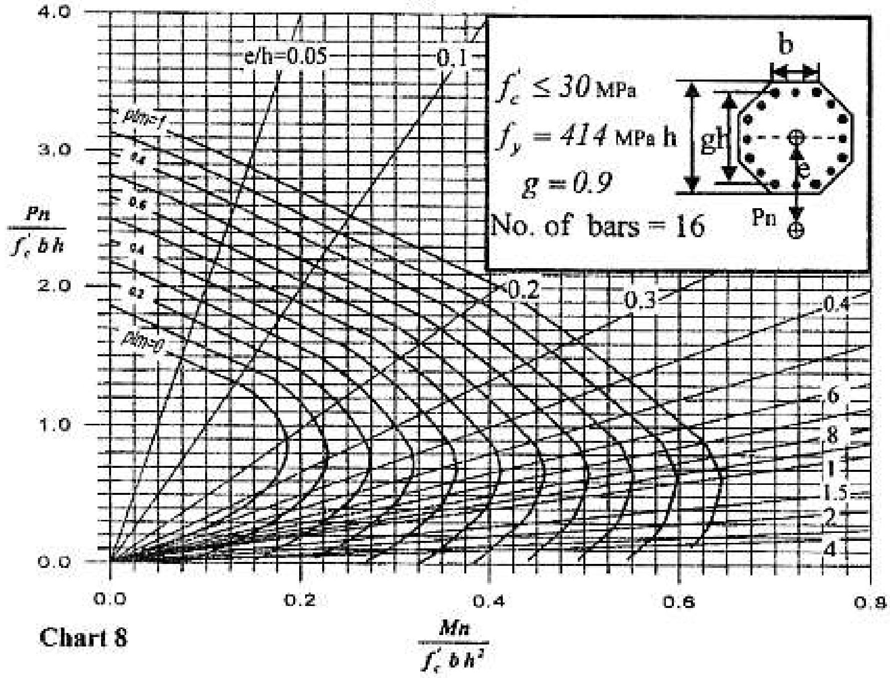

Chart 8