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Set Up Reinforcement Calculation Table For Oblique Eccentric Compression Column By Interactive Chart Method

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Abstract: *Interactive diagrams have been widely used in countries around the world and have been included in design standards such as ACI-318, BS-8110. In Vietnam, recent studies have also mentioned the construction of interactive charts to design reinforced concrete columns. The article researches to set up an automatic calculation table to calculate reinforcement for rectangular columns subjected to oblique eccentric compression. The author team also built a calculation table to check the bearing capacity of columns by the interactive chart method. many calculation examples were also conducted to verify the proposed calculation table and compare it with the calculation theory and the existing reinforcement calculation program.*

Keywords: *Interactive chart, oblique eccentric compression, rebar calculation, bearing capacity, reinforced concrete column.*

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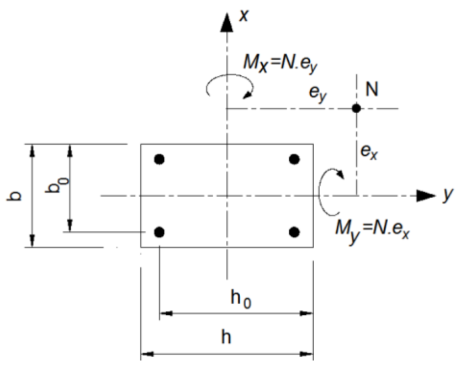
I. INTRODUCTION

Reinforced concrete column structures subject to simultaneous effects of longitudinal forces and bending moments in both directions of the section is very common in multi-story building construction. In frame structural systems, columns supporting load-bearing beams are members subjected to both bending moment and compressive force, often they are called eccentric compression members. The column members in the frame will receive the load from the floors above, they transmit this load to the floors below and the building foundation through the foundation structure. If these compression-bearing members are not capable of bearing forces at adverse locations, they can cause damage to the entire structure. Damaged columnar structure in a building can cause more damage to people and property than horizontal load-bearing structures such as beams and bars. So the design is often calculated with a higher level of safety. Failures due to the compressive or brittle failure are more abrupt than plastic failure.

A column subjected to oblique eccentric compression is a column that is simultaneously subjected to an axial compression force N and a bending moment in the two directions Mx, My taken for the major axes of the section. Currently, there are several methods of calculating oblique eccentric columns such as: The additive method introduced by Moran, the reinforcement is calculated separately from (N, Mx)và (N, My), then add the results, detailed in [1]; Method to convert oblique eccentricity to internal flat eccentric [2], Bresler's test method is based on the idea of failure side [3], the method introduced by Row and Paulay [8] is to use directly the interaction diagram for rectangular cross-section subjected to oblique eccentric compression. Each graph contains four quadrants, each of which corresponds to a load application angle. When the actual load angle does not coincide with the load angle in the chart, it must be interpolated.



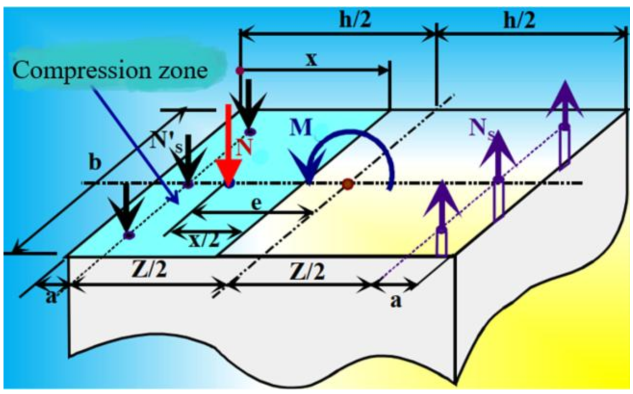


Figure 1. Cross-section of columns subjected to oblique eccentric compression

The internal force to calculate the column subjected to oblique eccentric compression is taken from the result of the load combination, in which it is necessary to pay attention to the following triples of internal forces (N, M_x, M_y):

+ N_{max} and M_x, M_y respectively
+ M_{ymax} and N, M_x respectively
+ M_x and M_y great value and N respectively.

II. METHODOLOGY

The research method is theoretical. That is to build a calculation table using Excel to calculate reinforcement for reinforced concrete columns with rectangular cross-section subjected to oblique eccentric compression according to the interactive chart method. Perform example calculations and tests with other software.

2.1 Interactive chart surface

With oblique eccentric compression, the bearing capacity is represented as interactive graph faces. It is a curved surface represented by the three Oxyz axes. The vertical axis Oz represents the compressive force value. The horizontal axes Ox and Oy represent moments M_x, M_y. Each point on the graph plane is defined by three coordinates x, y, z and represents the corresponding internal forces.

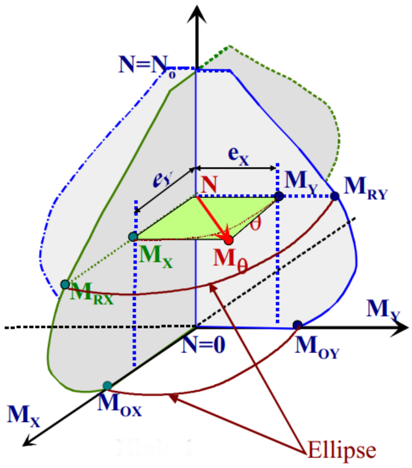


Figure 2. 3D Interactive Diagram

The oblique eccentric moment is synthesized from the moments of the two X and Y directions and has the magnitude calculated by the formula: $M_\theta = \sqrt[2]{(M_X)^2 + (M_Y)^2}$

Eccentric angle $\boldsymbol{\theta}$=arctan(M_Y/M_X)

The method of plotting the space surface infers the factor of safety similar to the planar problem.

Each cross-section is subjected to eccentric compression with the size and arrangement of reinforcement defined, we will build a corresponding interaction chart face ***(N_z,M_x,M_y).*** With the results of calculating internal forces from the structural diagrams, each eccentric compression member, at each cross-section will have the values $\boldsymbol{N_{z(tt)}}$, $\boldsymbol{M_{x(tt)}}$, $\boldsymbol{M_{y(tt)}}$.

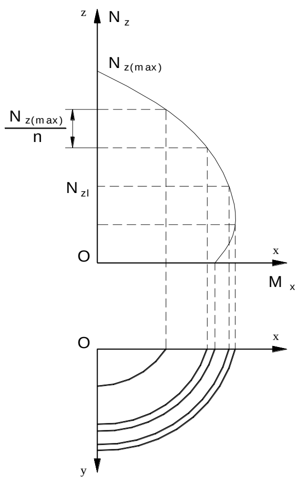


Figure 3. The family of interaction curves

To check the bearing capacity of the section, we will calculate $N_z^*=N_{z(tt)}$, $M_x^* = N_{z(tt)}\eta e_{0x}$; $M_y^* = N_{z(tt)}\eta e_{0y}$. These are the moment values including longitudinal bending and random eccentricity.

If the point (N_z^*, M_x^*, M_y^*) lies in the surface of the interaction diagram (N_z, M_x, M_y) then that section is capable of bearing $N_{z(tt)}$, $M_{x(tt)}$, $M_{y(tt)}$ and reinforcement have been completely determined.

If they are not on the surface of the interaction chart (N_z, M_x, M_y), we will change the reinforcement or the section, which will correspond to the new interaction surface $(N_z, M_x, M_y)^*$. And the calculation and testing end when we determine the interaction surface that ensures the point (N_z^*, M_x^*, M_y^*) lies in it.

2.2 ***Principles of building interactive charts according to current Vietnamese standards***

Assumptions: The compressive strength of concrete is conventionally defined as the compressive stress of concrete, equal to R_b and uniformly distributed over the compression zone of the section. Neglecting the behavior of tensile concrete, the flat section and reinforced concrete have the same strain at each position. The reinforcement is arranged evenly along the edges, the four corners of the column are all placed with steel.

$$N_u = R_b bx - \sum \sigma_{si} A_{si} \tag{1}$$

$$M_u = N_u \eta e_0 = R_b bx\left(\frac{h}{2} - \frac{x}{2}\right) + \sum \sigma_{si} A_{si} z_{si} \tag{2}$$

$$\sigma_{si} = \frac{\sigma_{sc,u}}{1 - \frac{\omega}{1,1}}\left(\frac{\omega}{\xi_i} - 1\right) \tag{3}$$

$$\xi_i = \frac{x}{h_{0i}} \tag{4}$$

In which: N_u - limiting compressive force, M_u - limiting moment in the plane containing side h, η - coefficient taking into account the effect of longitudinal bending, R_b - calculated compressive strength of concrete. σ_{scu} = 500 (MPa), $\omega = -$ 0,85 - 0,008Rb , h_{0i} is the distance from the centroid of the ith steel layer to the compression edge, if $\sigma_{si} < 0$ the i reinforcement layer is in compression, if $\sigma_{si} > 0$ the i reinforcement layer is in tension.

Calculation principles: Let parameter x change from 0 to h_o step by step 0.1.h_o.

For concrete: Calculate $N_b=R_b bh_o$ x and $M_b= R_b bh_o^2$ x***(1***-x***)/2*** with x=x/h_o,

For reinforcement in tension zone A_S: With the assumption that the tensile stress σ_s does not exceed R_S herefore, when x (small): $\xi \le \xi_R$ then $\sigma_s = R_S$: Big eccentricity

when x (large): $\xi > \xi_R$ then $\sigma_s < R_S$: Small eccentricity until $\sigma_s = 0$ then switch to compressed $\sigma_s < \mathbf{0}$ we can consider it a very small eccentric state (or little). When $x=h_o$**:** $\xi = 1$: the reinforcement reaches the maximum compressive value $\sigma_s = -R_S$.

Compression zone types: When the compression zone limit line is on the top right point, the entire concrete is in tension, then it will fall into the case of eccentric tension. Thus, to ensure that the cross-section is subjected to eccentric compression, there are only 5 types of compression zones of concrete as shown below.

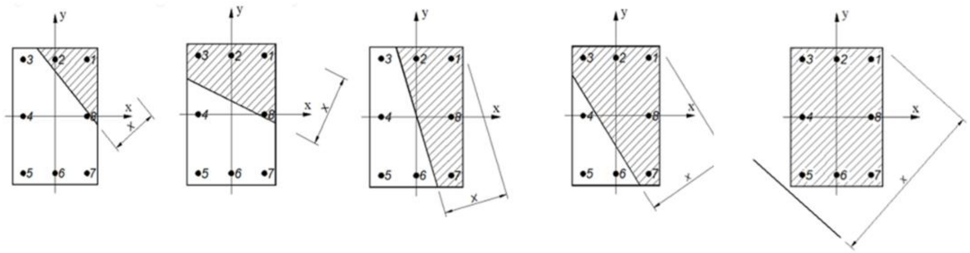


Figure 4. Types of compression zones

2.3 Calculation of column reinforcement subjected to oblique eccentric compression

The reinforcement is calculated based on the perimeter reinforcement. According to the allowed norm, we convert the reinforcement into a circumference with a total area of Ast. They are distributed according to the main bearing direction A_{S1} and according to the intermediate edge A_{S2}. When converting, the intermediate steel is increased by one and removed from the main bearing steel bar. It can be understood simply that the four corner plates of steel will work in the main bearing direction, but each bar only has ¾ section and ¼ is shared for the intermediate edge and then we have the reinforcement distributed according to the circumference (m^2/m). In this way, when calculating the eccentricity in one direction, we have considered the work of the reinforcement in the direction perpendicular to it. The oblique moment is calculated from the moment in each direction based on the ellipse.

III. RESEARCH RESULTS

3.1. Calculation by theoretical formula

For concrete columns B30 has size 400x400 mm, column height 3.9m, R_b = 17 MPa, R_{bt} = 1,2 MPa, E_b = 32,5.103 MPa; bar steel CII có: R_s = 280 MPa, R_{sc} = 280 MPa, E_s = 21.104 MPa; The most dangerous pair of internal forces of the column N = 1601,36 kN; My = 108,46 (kNm); Mx = 94,907 (kNm)

Calculation length***:***

$$l_{ox} = l_{oy} = l.\psi = 3900.0,7 = 2730\,\mathrm{mm}$$

Random eccentricity:

$$e_{ax} = \max\left(\frac{1}{600}l;\frac{1}{30}b\right) = \max\left(\frac{3900}{600};\frac{400}{30}\right) = 13,33(\mathrm{mm})$$

$$e_{ay} = \max\left(\frac{1}{600}l;\frac{1}{30}h\right) = \max\left(\frac{3900}{600};\frac{400}{30}\right) = 13,33\ (\mathrm{mm})$$

Thinness in two directions

$$\lambda_x = \frac{l_{ox}}{i_x} = \frac{2310}{0,288.b} = \frac{2730}{0,288.400} = 23,70 < 28 => \eta_x = 1$$

$$\lambda_y = \frac{l_{oy}}{i_y} = \frac{2310}{0,288.h} = \frac{2730}{0,288.600} = 23,70 < 28 => \eta_y = 1$$

⇒ Ignore the effect of longitudinal bending

Calculate the values

$$M_{x1} = \eta_x M_x = 1.94,907 = 94,907(\mathrm{kNm})$$

$$M_{y1} = \eta_y M_y = 1.108,46 = 108,46(\mathrm{kNm})$$

$$\frac{M_{x1}}{C_x} = \frac{94,907}{0,40} = 237,27(\mathrm{kN})$$

$$\frac{M_{y1}}{C_y} = \frac{108,46}{0,40} = 271,15(\mathrm{kN})$$

Because $\frac{M_{y1}}{C_y} > \frac{M_{x1}}{C_x}$ should convert the calculation in the Y direction

So $h = C_y = 400(mm); b = C_x = 400(mm)$; $M_1 = M_{y1} = 108,46(kNm); M_2 = M_{x1} = 94,907(KNm)$

Assumption
a=40(mm)

$$h_0 = h - a = 400 - 40 = 360(mm)$$

$$Z = h_0 - a = 360 - 40 = 320(mm)$$

Eccentricity

$$e_a = e_{ay} + 0,2e_{ax} = 13,33 + 0,2.13,33 \approx 16$$

$$x_1 = \frac{N}{R_b b} = \frac{1601,36 \cdot 10^3}{17.400} = 235,49(mm) < h_0 = 360(mm)$$

$$\Rightarrow m_0 = 1 - \frac{0,6 \cdot x_1}{h_0} = 1 - \frac{0,6.235,49}{360} = 0,608$$

$$M = M_1 + m_0 \cdot M_2 \cdot \frac{h}{b} = 108,46 + 0,608.94,907 \cdot \frac{0.4}{0.4} = 166,163(kNm)$$

$$e_1 = \frac{M}{N} = \frac{166,163 \cdot 10^6}{1601,36.10^3} = 103,76(mm)$$

$e_0 = max(e_1; e_a) = max(103,76;16) = 103,76$

$\xi_R \cdot h_0 = 0,573.360 = 206,28(mm) < x_1 = 235,49(mm)$

$\varepsilon_0 = \frac{e_0}{h} = \frac{103,76}{400} = 0,259$

The area of reinforcement is calculated as follows:

$$A_{st} = \frac{\frac{\gamma_e N}{\varphi_e} - \gamma_b \cdot R_b \cdot b \cdot h}{R_{sc} - \gamma_b R_b} = \frac{\frac{1,837.1601,36 \cdot 10^3}{1} - 0,85 \cdot 17.400.400}{280 - 0,85.17} = 2371,30\,mm^2$$

$$\mu = \frac{A_{st}}{bh} = \frac{2371,30}{400.400} \cdot 100\% = 1,48\% < 4\%$$

3.2 Calculation program for column reinforcement subjected to oblique eccentric compression

The program is programmed to automatically design A_S reinforcement for columns subjected to oblique eccentric compression. It allows the user to check any cross-section, or adjust the size as desired. The authors have checked most of the examples in Professor Nguyen Dinh Cong's textbook, showing that the solutions are satisfied with $k_{at} \approx 1,1$, (because the reinforcement is always chosen to be larger than the calculated reinforcement). Therefore, it is proposed to choose h x b and A_S such that (k_{at}=1÷ 1,2).

There are a total of 11 numbers that need to be entered (in red). Other parameters are automatically calculated by the program. The user will adjust the number and diameter of reinforcement so that the safety factor kat =1÷1,2 is reasonable. The output of the program includes the number of reinforcement bars arranged in the section and interactive charts.

The program interface, data input and output calculation results of reinforcement are as follows:

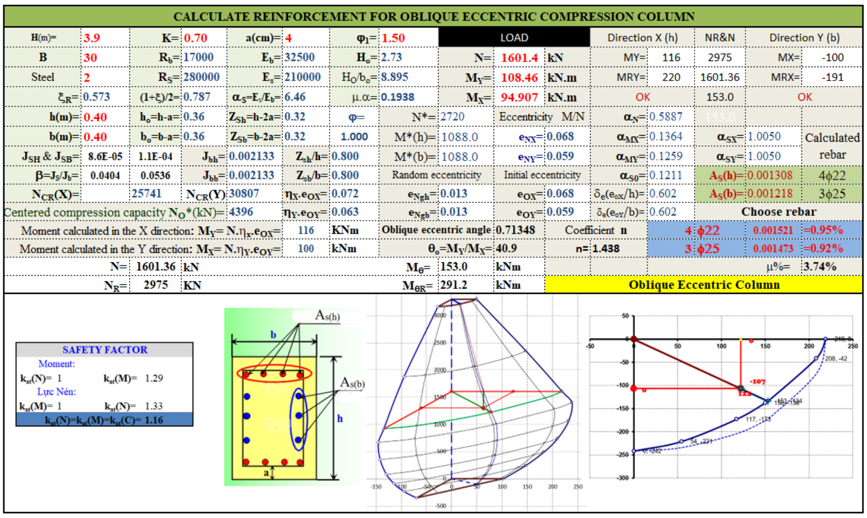


Figure 5. Program interfaces calculation results of reinforcement

3.3 Program to test the bearing capacity of columns by interactive chart method

It is very good to build a computer program to draw interactive curves used to test the bearing capacity of reinforced concrete members subjected to oblique eccentric compression. It helps the user to get the job done quickly and accurately. To be able to use the interactive chart surface, we must build a family of curves that are the cross-sections of the interactive chart surface. Here, the family of curves is constructed as cross-sections of the interactive chart plane.

The user enters the parameters of strength level, steel group, internal force of the column, and the amount of reinforcement placed in the section. The program will automatically calculate whether the position has enough bearing capacity.

This is the interface of the program to test the bearing capacity of reinforced concrete columns.

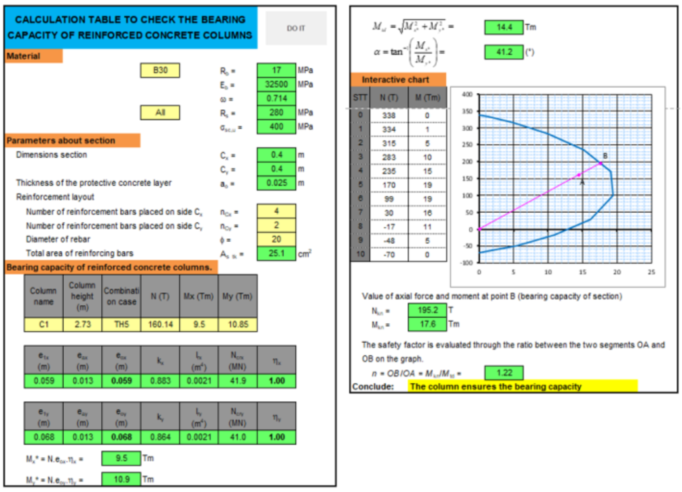


Figure 6. Program interfaces test the bearing capacity of reinforced concrete columns

3.4 Evaluate the results of the proposed calculation table

Take a look at some examples. Calculation by 3 programs with the same input data. It is the proposed calculation table, the RDW program has been licensed and calculated using the theoretical formula. From the comparison table of reinforcement calculation results, we can see that the calculation according to the new calculation table proposed for the reinforcement value is larger and close to that calculated by the theoretical formula (see the column of percentage comparison between reinforcement calculated according to the proposed program and the theoretical formula). At the same time, the calculation of reinforcement using the proposed new calculation table is smaller than that in RDW (see the percentage column in the table comparing reinforcement calculated by RDW and calculated by theory).

Table 1. Comparison of reinforcement values when calculating by three programs

Numerical order	Proposed calculation table		RDW		The theoretical formula
	Ast	%	Ast	%	Ast
1	26.1	10.08	27.5	16.0	23.71
2	35.2	6.02	36	8.4	33.2
3	50.3	5.23	51.5	7.7	47.8
4	15.4	9.22	16	13.5	14.1
5	18.5	8.82	19	11.8	17
6	20.4	7.37	21.7	14.2	19
7	7.8	8.33	7	-2.8	7.2
8	52.3	6.52	52.1	6.1	49.1
9	16.4	9.33	17	13.3	15
10	66.2	2.95	68.1	5.9	64.3
11	10.3	0.98	9.8	-3.9	10.2
12	12.7	0.79	12	-4.8	12.6
13	44.5	5.70	44.7	6.2	42.1
14	40.8	11.78	41	12.3	36.5
15	35.8	6.23	36	6.8	33.7

IV. CONCLUSION

The results of calculating reinforcement for columns subjected to oblique eccentric compression using the RDW program give results that are too safety-biased compared with those calculated by the theoretical formula in the standard. The article presented the construction of a program to test the bearing capacity of columns by the interactive chart method. At the same time, a program to calculate reinforcement for columns subjected to oblique eccentric compression was built. Calculation results have been verified through many examples, typically some of the examples above. During the implementation of the reinforcement calculation program, it is necessary to select the reinforcement options so that the safety factor reaching from 1.0 to 1.2 is the most reasonable. The program to draw the cross-sectional curve of the interactive chart according to N_z gives quick results and is very convenient for testing the oblique eccentric compression resistance of a given reinforcement layout section.

Conflict of interest

There is no conflict to disclose.

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