

User Notes for the
Analysis of Reinforced Concrete Rectangular Sections in
Bi-Axial Bending & Shear Under Compression or Tension
for Designing to BS8110

RC Beam-Column-Tie

by

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1- Introduction

RC Beam-Column-Tie is an Excel spreadsheet for calculating the shear and bending moment capacities in two directions and a bi-axial moment capacity of rectangular reinforced concrete sections under axial compression or tension. The calculated shear capacities in the two directions are non-concurrent. The calculated bending moment capacities in two directions are non-concurrent and the bi-axial moment capacity is concurrent.

Sections can be singly, doubly or randomly reinforced to resist axial load and bending. They can also have links to enhance their shear resistance. The capacities are calculated using BS8110-1. The applied axial load can be any value in the range of pure compression capacity as the maximum positive upper value and pure tension capacity as the maximum negative lower value.

A single file of RC Beam-Column-Tie on your disk can hold design information for as many sections as required e.g. over 30,000 sections if necessary. Using the command buttons at the top of its screen display, the design information for any section can be retrieved, amended and re-saved for later use.

2- Loading the Template on to your Computer

RC Beam-Column-Tie is an Excel Template file. You can use this file by opening it directly or copying it into the Microsoft Office folder for its Templates.

When opening the RC Beam-Column-Tie file, Excel routinely issues its **WARNING** about running Macros and prompts whether or not to load and use these macros.

Answer **YES** to Load and Enable Macros. RCBeam-Column-Tie incorporates VB Macros. Allowing your computer to use them is vital for its operation.

3- Using RC Beam-Column-Tie

Cells shaded **Light Green** indicate locations for the input of analysis data. Whenever this data is input or changed, a message in red [**Click "Analysis & Update Button" for Analysis Results Using Current Data**] appears diagonally across the screen. Clicking of this command button at top right of the screen updates the results and removes this message.

In addition to the Job reference information in the top heading part, the analysis data is entered in 4 parts of the screen.

The first part in top left of the screen is for the section size, the strengths of concrete and steel and the magnitude of axial applied axial load for analysis. The values to be input in this part are f_{cu} , γ_{ms} , f_y , γ_{ms} , b , h , N , b' and h' .

The second part towards the bottom left of the screen is for the input of reinforcing bars in the section. Up to 50 bars in the section can be specified by giving area, coordinate-x and coordinate-y for each bar.

The third part in the top middle of the screen is for the shear resistance about the X-axis. The input values required are A_{st} , A_{sv} , S_v , V_y , M_x and Yes/No option to avoid shear cracking under the influence of axial load.

The fourth part at top right of the screen is for shear resistance about the Y-axis. The input values required are A_{st} , A_{sv} , V_x , M_y and a Yes/No option as above.

RC Beam-Column-Tie employs an interactive procedure to calculate the shear and bending strength of sections in two directions subjected to a given axial load. When the data input for a section is complete, the user needs to click the "Analyse and Update" button at top left of the screen. Beam-Column calculates the section shear and bending capacities and updates the screen display to show the results. As required, the RC Beam-Column-Tie results can be printed and or saved by clicking "Store Displayed Data" command button.

Just below its input value, outcome of the axial capacity check is shown only when the strength is inadequate in pure compression or tension.

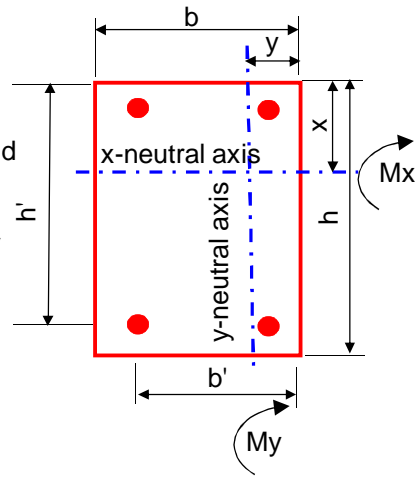
The outcome of 4 shear and bending strength checks are included in the 3rd and 4th input

4- Section Dimensions and Neutral Axes

Dimensions h , b , h' and b' are shown in the adjacent sketch together with the calculated positions of x - x and y - y neutral axes in two directions.

The positive directions of applied moment M_x and M_y are also shown in the adjacent sketch. Both M_x and M_y cause compression at top right corner of the rectangular section.

The axial load can be positive as compression and negative as tension.



5- Axes for the Position of Reinforcing Bars

In order to specify the position of each reinforcing bar, the origin is located at bottom left corner of the section.

When the section is not reinforced symmetrically, caution is necessary in the use and selection of this corner as origin. Under applied moments M_x and M_y , this corner at bottom left is stressed most in tension; the diagonally opposite corner at top right is stressed most in compression.

6- Origin for Applied Loads and Calculated Section Capacities

In the calculation of shear and moment capacities, the applied axial load is assumed to act at centroid of the concrete section i.e. the rectangular unreinforced section. Any eccentricity the axial load may have relative to this point is not input directly. The user needs to include the influence of involved eccentricities in values of the applied moments M_x & M_y .

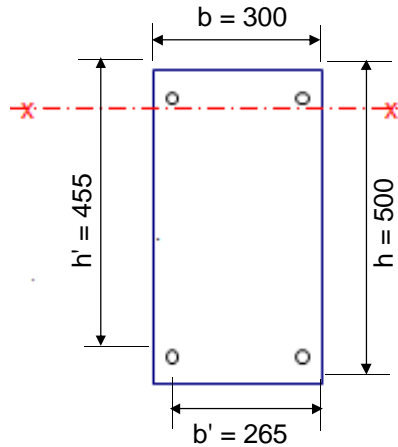
7- Units

RC Beam-Column-Tie employs mixed units for ease of use and in line with the code provisions. The used units are shown next to the displayed values and results.

In general, the section size and stresses are in N and mm units. The applied loads and calculated capacities are in kN and m units.

8- Default Sectional Data

Default sectional data is needed to avoid division by zero errors when some values for analysis are blank and or undefined. These default values are shown here. They are located towards right of the RC Beam-Column-Tie worksheet and can be changed to suit required usage.



Rebar Areas & Position			
	Ast, mm ²	X-dist mm	Y-dist mm
1	491	35	45
2	491	265	45
3	491	265	455
4	491	35	455

Default Values (when Zero or Not defined)	
Concrete fcu N/mm ²	35
γ_{mc}	1.5
Steel fy N/mm ²	500
γ_{ms}	1.15
Width b of Column mm	200
Depth h of Column mm	500
Area of Steel Bars mm ²	491
Cover to Steel cg h - h' mm	45
Cover to Steel cg b - b' mm	35

9- Creating a Section for Analysis Using Default Data

A section for analysis can be created based on the default data by clicking the command button located at top right of the screen. The created section values can then be edited to satisfy immediate design needs.

The above created member section details are not written to the worksheet "Store" but assigned an invalid analysis number of 1000. When required, this data can be written to the "Store" worksheet in a normal manner by giving it a valid store number of 1001 upwards.

10- Storing & Managing Design Information

RC Beam-Column-Tie stores data for as many sections as required in its "Store" Worksheet. For each column, over 190 data fields (in Excel columns) are used to store this data. The field names can be viewed as being the column headings in the "Store" worksheet.

A casual Excel user generally does not need to tweak or amend the "Store" worksheet. An experienced Excel user, however, can benefit by generating and using this information by Copy, Paste-Special and Fill-Down commands of Excel. It is strongly advised that Cut Command of Excel is not used in such manipulations of data; the use of this cut command affects the worksheet layout and can disrupt the working of Beam-Column.

Clicking the "Store Displayed Data" button writes the information to the "Store" Worksheet (without saving to your hard disk). For saving data to your hard disk, it is necessary for the user to employ the standard File and Save commands of Excel for saving Files.

To keep design data of each section, RC Beam-Column-Tie uses a Store Number. This number is in the range starting from 1001 upwards. This number is used to recall and or Store data for a given member.

11- Heading & Job Details

The first four items of the job heading details are included in the "Beam-Column-Tie" worksheet only. They are not kept in the "Store" worksheet and are therefore fixed for all analyses stored in a single Beam-Column File. These items are as follows:

- Company
- Address
- Project and
- Client Name

The other seven items of the job heading are kept in the "Store" worksheet. They can be varied and made specific to each Beam-column analysis and are as follows:

- Column Reference
- Made by
- Page No
- Checked by
- Job No
- Revision

12- Axial Resistance Capacities in Pure-Compression and Pure-Tension

The calculated pure axial load capacities in compression and tension are shown in the RC Beam-Column-Tie output. It is to be noted that these loads do not act at centroid of the unreinforced concrete section.

The ultimate pure compression load acts at centroid of the transformed reinforced section. It is calculated by the following equation:

$$N_{uz} = 0.67 f_{cu} b d / \gamma_{m\chi} + f_y A_s / \gamma_{m\sigma}$$

The ultimate pure tension load acts at centroid of the reinforcing bars in the section. It is calculated by the following equation:

$$N_{uz} = - f_y A_s / \gamma_{ms}$$

13- Balanced Axial Load Capacities

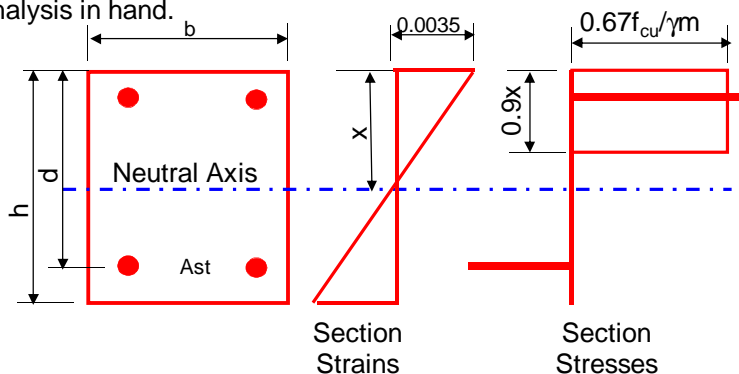
The moment capacity of reinforced concrete sections is maximum at their balanced axial loads. The magnitude of this load and its corresponding moment capacity usually differ in bending about the X and Y axes. Using iterative procedures, RC Beam-Column-Tie calculates N_{bal} and M_{bal} values for each of the two bending directions. These values and their corresponding depths of neutral axes $x-N_{bal}$ and $y-N_{bal}$ are shown in the screen display and included in the printed output.

14- Non-concurrent Bending Resistance Capacities in Two Directions

The two ultimate moment capacities of a section subjected to a given axial load are found by the use of equilibrium equations. As outlined in clause 3.4.4.1 of BS 8110-1, the following assumptions are made for the section behaviour:

- The strain distribution in the concrete in compression and the strain in each reinforcing, whether in tension or compression, is derived from the assumption that plane sections remain plane.
- The stresses in the concrete in compression is derived from the simplified stress block illustrated in Figure 3.3 of the code. It is based on an extreme concrete compression edge strain of 0.0035 and a uniform stress block depth of 0.9 times the neutral axis depth.
- The strength of concrete in tension is ignored.
- The stresses in the reinforcement are derived from the bi-linear stress-strain curve in Figure 2.2 of the code.
- The material factors of strength for both the concrete and the steel reinforcement are editable. As any other data, the user can change them on the screen.

As the equilibrium equations to be solved are at times quadratic or cubic, an iterative technique is adopted to solve them. They are set up and solved for moment capacities corresponding to the balanced axial failure load and the axial load input by the user for the analysis in hand.



Simplified Stress Block Used for Concrete at Ultimate Limit State
(Fig 3.3 of BS8110)

15- Biaxial Bending Resistance Capacity

Clause 3.8.4.5 of BS 8110-1 is used for checking the moment capacity of sections in biaxial bending. By considering that the sections is symmetrically-reinforced, the applied larger moment about one of the two perpendicular axes is increased by the code. The section is then designed to withstand this increased moment.

The axis and the increase in applied moment about this axis is determined by using equations 40 & 41 of BS8110-1 as follows:

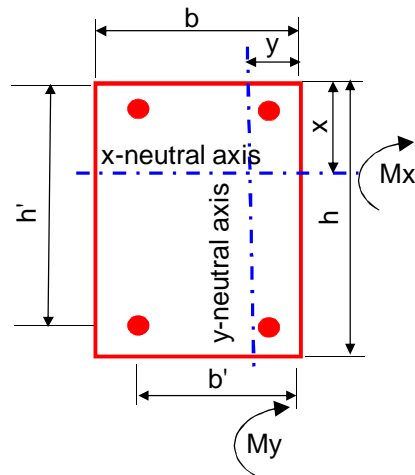
a) for $M_x/h' \geq M_y/b'$, $M_x' = M_x + B h'/b' M_y$ and $M_y' = M_y$

b) for $M_x/h' < M_y/b'$, $M_y' = M_y + B b'/h' M_x$ and $M_x' = M_x$

where

h' and b' are shown in Figure 3.22;

B is the biaxial moment capacity coefficient obtained from Table 3.22.



16- Shear Resistance of Concrete Sections

The induced shear stress v for design at any cross-section is calculated as $v = V/b d$. In no case this stress v is to exceed $0.8\sqrt{f_{cu}}$ or 5 N/mm^2 , whichever is the lesser and whatever shear reinforcement has been provided. The two limits include an allowance of $\gamma_m = 1.25$ as a partial safety factor for the strength of concrete.

The corresponding permissible design shear stress v_c is calculated by using the equation given in Table 3.8 of BS 8110. This equation is:

$$v_c = 0.79 \{100 A_{st}/(bd)\}^{(1/3)} (400/d)^{(1/4)} / \gamma_m$$

In the above equation, $100A_{st}/bd$ is not to exceed 3 and it is taken as a minimum of 0.15 in view of its used lower limit in Table 3.8 of BS8110-1; $(400/d)^{(1/4)}$ is not to be taken as less than 0.67 for members without shear reinforcement; $(400/d)^{(1/4)}$ is not to be taken as less than 1 for members with shear reinforcement to provide a design shear resistance equal to or greater than 0.4 N/mm^2 . The above equation is meant for a characteristic concrete strength of $f_{cu} = 25 \text{ N/mm}^2$ and using a value of $\gamma_m = 1.25$. Where f_{cu} is greater than 25 N/mm^2 , the value of this equation may be multiplied by factor of $(f_{cu}/25)^{1/2}$. However, the value of f_{cu} should not be taken as greater than 40 as upper value. Where f_{cu} is less than 25 N/mm^2 , BS8110 is non-committal and Beam-Column uses the specified actual value of f_{cu} in this factor.

The value of A_{st} used in v_c calculation is that area of longitudinal tension steel which continues for a distance at least equal to d beyond the section being designed. At support, the full area of tension reinforcement at the section may be used provided curtailment and anchorage requirements of the code are complied.

At monolithic beam & column/tie junctions, where the beam has been designed as having a simple support and where some nominal top steel has been provided to control cracking, v_c may be calculated by using the bottom steel area provided it complies the code anchorage requirements. Where the beam has been designed as continuous over supports, v_c is calculated by using the top steel which extends into the span for a distance of at least three times the effective depth from the face of the support.

17- Shear Resistance of Provided Links

The shear resistance of links is calculated by using the following equation based on Table 3.7 of BS8110-1.

$$V_s = f_{yv} A_{sv} d / (s_v \gamma_m)$$

As mentioned in the notations of Clause 3.4.5.1, f_{yv} should not be taken as more than 500 N/mm^2 .

BS 8110-1 suggests that links should be provided in all beams of structural importance. However, in members of minor structural importance such as lintels or when the maximum design shear stress is less than $0.5 v_c$ e.g. slabs, links may be omitted.

When the maximum shear stress v is in the range $0.5v_c$ to $(v_c+0.4)$, minimum links are to be provided to resist a shear force of:

$$V_s = 0.4 b d.$$

When the maximum shear stress v is in the range $(v_c+0.4)$ to $0.8\sqrt{f_{cu}}$ or 5 N/mm^2 , links or links combined with bent-up bars are to be provided to resist a shear force of:

$$V_s = (v - v_c) b d.$$

The spacing of links in the direction of the span should not exceed $0.75 d$. At right angles to the span, the horizontal spacing should be such that no longitudinal tension bar is more than 150mm from a vertical leg. This transverse spacing should not exceed the effective depth d in any case.

18- Influence of Axial Load on Shear Resistance

The permissible design shear stress v_c' for a section subjected to shear and axial load is calculated by the following equation 6a of BS8110-1:

$$v_c' = v_c + 0.6 (N/A_c) (V_h/M)$$

The value of N/A_c in this equation is intended to be the average uniform compressive or tensile stress in the concrete section. The factor V_h/M is not to exceed 1.

Where it is necessary to avoid shear cracking prior to the ultimate limit state, shear stress v_c' should be limited to that given by equation 6b of BS8110-1 as follows:

$$v_c' = v_c \sqrt{1 + N/(A_c v_c)}$$

Where the induced shear stress v exceeds v_c' , additional shear resistance is to be provided in the form of links and or bent-up bars.

The axial load in the above two equations is taken as a negative value for tension and positive for compression. This implies that the design shear stress v_c corresponding to zero or no axial load reduces under axial tension and increases under axial compression. When the magnitude of axial tension is excessive, the value of v_c' may even become negative or less than zero. In the Beam-Column analysis, the negative values of v_c' are taken as zero implying that the concrete section has no shear resistance capacity and all shear is to be resisted by links or links combined with bent-up bars.

In the use of RC Beam-Column-Tie, the selection of equation 6a or 6b is made via **Yes/No** response to "Avoid Shear Cracking".

19- Auto Analysis of All Section

RC Beam-Column-Tie includes a facility so that all sections in the worksheet "Store" can be checked by a single click of "Auto Analyse/Print" Button. To use this facility, two columns coloured in yellow at the right of the "Store" worksheet are provided. One column is headed "Analyse Y?" and the other as "Print, Y?". The "Auto Analyse/Print" Button is located at the top of these two columns in the "Store" Worksheet.

Entering "Y" in the "Analyse Y?" column, signifies that the section in this row need to be analysed. Leaving the cells blank signifies No-analysis for the section. On a machine with Pentium 200 MHz CPU, one Beam-Column analysis takes less than 1 second.

Entering "Y" in the "Print" column, signifies that the analysis results in its row need to be analysed. Leaving the cells blank signifies that no printing of results is required.

Start AUTO Analysis & Print	
Analyse Y?	Print
y	
y	y
y	

In the above display cut-out of the "Store" worksheet, the input of letter "y" in the two columns indicates the following:

- 1st Row: Analyse Only
- 2nd Row: Do not Analyse or Print
- 3rd Row: Analyse & Print
- 4th Row: Analyse Only

20- Analysis Checks for Section Capacities and Some Code Requirements

RC Beam-Column-Tie reports 5 capacity checks. The outcome of these checks is included in the "Store" worksheet while storing the section data and results of analysis checks. These checks are

- N against the axial capacity in compression or tension
- Vx against the shear resistance $V_c + V_{sv}$ in X-direction
- Vy against the shear resistance $V_c + V_{sv}$ in Y-direction
- Mx against the bending resistance M_{ux} in X-direction
- My against the bending resistance M_{uy} in Y-direction

In addition to the above five capacity checks, five checks for some code requirements are also carried out. These checks are shown on the screen but not included in the printed output or reported in the "Store" worksheet. These checks are:

- 1- steel amount is within the minimum and maximum allowable limits;
- 2- minimum number of bars in the section are not less than four;
- 3- bar diameter is not less than 12 mm.
- 4- Links provide minimum shear resistance of 0.4 N/mm² about x-axis

21- Limitations of Use and Scope

RC Beam-Column-Tie handles uni-directional shears only. The calculated shear capacities are non-concurrent capacities for the two directions.

BS 81110-1 is non-committal for the value of design shear stress v_c for concrete strengths less than 25 N/mm². Beam-column opts to use the same BS 8110 equation as for the concrete strength exceeding 25 N/mm².

BS8110 method to design for biaxial bending assumes a symmetrical of arrangement. When the reinforcement is unsymmetrical, this assumption may not be valid.

The influence of member slenderness and or span deflections is not included. Hence the calculated capacities are for sections and not whole members.

The pure axial load capacities are the maximum possible loads acting in the axial direction. These loads do not necessarily act at centroid of the concrete section. The pure compression load acts at centroid of the transformed steel and concrete section. The pure tension load acts at centroid of the reinforcing bars. If these two maximum capacity loads in tension or compression do not act at their stated positions, section instability will occur.

Clause 3.4.4.4 of BS 8110 limits the neutral axis depth for beams to 0.95d. This provision is ignored for sections in pure bending and having no compression steel.

The area of concrete replaced by the reinforcing bars in the compression zone is ignored. Hence the area of reinforcing bars occurring in the compression zone depth of 0.9 times the neutral axis is assumed to be carrying compression at a stress of $0.67f_{cu}/\gamma_{mc}$.

Beam-column does not include torsional moments in its analysis. Eccentric shears are assumed to cause no torsion.

22- References

BS 8110-1:1997, Structural use of concrete - Part 1: Code of practice for design and construction, 31 August 2007