

## Introduction

Rect-Column is an Excel Spreadsheet template for the design of rectangular columns to BS8110. The bending due to axial loads can be Uni-axial or Bi-axial. As real columns are rarely if ever subjected to pure Uni-axial bending, all columns are considered to have bi-axial bending irrespective of the type of applied loading.

When a column is in Uni-axial bending, a zero moment is specified in the two perpendicular direction. Corresponding to an applied axial load, Rect-Column automatically incorporates nominal eccentricity moments in both the X and the Y direction.

Rect-Column can hold design information for as many columns as required e.g. over 30,000 columns. Using command buttons at the top of its screen, the design information for any column can be retrieved, amended and re-saved for design use as and when necessary.

Each design of a column can have up to 6 Loading Cases. Although the design results are displayed for one load case at a time, Rect-Column checks the design for all 6 loading cases in one step. When a column fails any of its load case checks, a Fail-Code is shown indicating the failure. Detailed results for any load case can be displayed by the click of its radio button and also printed as and when required.

## Provision of BS 8110 Used for Column Design

### Column Section Size

Larger section dimension is limited to four times its smaller dimension

### Short and Slender columns

A column is SHORT when its two ratios  $L_{ex}/h$  and  $L_{ey}/b$  are less than 15 when braced and 10 when unbraced. It is otherwise a SLENDER column.

### Braced and unbraced columns

A column is BRACED in a given plane if lateral stability to the structure as a whole is provided by walls or bracing or buttressing designed to resist all lateral forces in that plane. It is otherwise be an UNBRACED column.

### Effective height of a column

Using Eq(30) of BS8110 Cl 3.81.61, the effective height of a column in a given plane is obtained from the following equation:

$$L_e = B L_0$$

The values of B are given in Table 3.19 for Braced and Table 3.20 for unbraced columns. These values are a function of the end conditions of the column and may be different in the two planes of biaxial bending.

## End Support Conditions

BS8110 defines these values in terms of a fixity scale of 1 to 4. An increase in this scale corresponds to a decrease in the end fixity. The four scales of fixity are described in Cl 3.8.1.6.2 as follows:

- a) **Condition 1.** The end of the column is connected monolithically to beams on either side which are at least as deep as the overall dimension of the column in the plane considered. Where the column is connected to a foundation structure, this should be of a form specifically designed to carry moment.
- b) **Condition 2.** The end of the column is connected monolithically to beams or slabs on either side which are shallower than the overall dimension of the column in the plane considered.
- c) **Condition 3.** The end of the column is connected to members which, while not specifically designed to provide restraint to rotation of the column will, nevertheless, provide some nominal restraint.
- d) **Condition 4.** The end of the column is unrestrained against both lateral movement and rotation (e.g. the free end of a cantilever column in an unbraced structure).

## Describing End Support Conditions in Rect-Column

When using Rect-Column, the fixity at top and bottom ends in two direction is described via radio button. Corresponding to BS 8110 conditions of fixity 1 to 4, these button are: Rigid, Semi-rigid, Pinned and Free. It is to be noted that Free end condition can be described at top column end only and not at its bottom end. In the worksheet "Tables", the values for Braced columns are noted in Table-2 and for Unbraced in Table-3.

## Slenderness Limits for columns

When a column is braced, its clear distance  $L_0$  between end restraints should not exceed 60 times the relevant section thickness i.e.

$$L_{ox}/h \text{ \& } L_{oy}/b \leq 60.$$

When is column is unbraced, it should satisfy the following:

$$L_{ox}/h \leq 60 \text{ \& } \leq 100 \text{ h/b \& }$$

$$L_{ox}/b \leq 60 \text{ \& } \leq 100 \text{ b/h}$$

## Design Moments and Forces

In columns of monolithic construction designed to resist lateral forces. the moments, shear forces and axial forces are determined by usual analysis methods.

In slender columns additional moments induced by deflection at ULS should also be included. These deflection moments are calculated using Cl 3.8.3.

The foundations or beams members restraining and supporting the ends of these columns should also be designed to resist these additional moments at ULS.

When a column is subject only to an axial load with no significant applied moment, the design ultimate axial force need be considered acting together with a design moment representing the influence of a nominal recommended eccentricity  $e_{min}$ .

## Minimum Eccentricity

All design moment are to be not less than the design ultimate axial load times the minimum eccentricity,  $e_{min}$ , equal to 0.05 times the overall dimension of the column in the plane of bending. This eccentricity however should not be more than 20 mm. Where there is biaxial bending, it is only necessary to consider the nominal eccentricity moment about one axis at a time.

*(When the applied axial load is tension, "Rect-Column" ignores this eccentricity and displays a "Not Applicable" message in its moment cell.)*

## Deflection induced moments in slender columns

The cross sections of the slender columns are designed as short column but an account is taken of the additional deflection moments.

The deflection induced additional moment  $M_{add}$  is given by Eq 35:

$$M_{add} = N \Delta u$$

*(when axial load  $N$  is tension, Rect-Column assumes  $\Delta u=0$  and displays a "Not Applicable" message in its moment cell)*

The deflection  $\Delta u$  for a rectangular column under ultimate conditions is calculated by the following (Eq 32):

$$\Delta u = B_a K h$$

Here  $B_a$  is calculated by using the following Eq 34:

$$B_a = (L_e/b')^2 / 2000,$$

In the above,  $b$  is generally the smaller dimension of the column except when considering biaxial bending and designing in two directions it can be the  $h$  dimension.

$K$  is a reduction factor that corrects the deflection to allow for the influence of axial load and is calculated by using Eq 33 as follows:

$$K = (N_{uz} - N) / (N_{uz} - N_{bal}) \leq 1$$

### Design Moments in Braced Columns Bent About a Single axis

Figure 3.20 of BS8110 shows the distribution of moments assumed over the height of a typical braced column. The initial moment at the point of maximum additional moment (i.e. near mid-height of the column) is given by Eq 36:

$$M_i = 0.4M_1 + 0.6M_2 \geq 0.4M_2$$

where

$M_1$  is the smaller initial end moment due to design ultimate loads;

$M_2$  is the larger initial end moment due to design ultimate loads.

Assuming the column is bent in double curvature,  $M_1$  should be taken as negative and  $M_2$  positive. As can be seen from Fig 3.20 of BS 8110, the maximum design moment for the column will be the greatest of these 4 values:

- 1)  $M_2$ ;
- 2)  $M_i + M_{add}$ ;
- 3)  $M_1 + M_{add}/2$ ;
- 4)  $N \epsilon_{min}$ .

### Design Moments in Slender columns Bent About a Single Axis (major or minor)

Where ratio of the length of the longer side to the shorter side is less than three and that, for columns bent about their major axis,  $L_e/h$  does not exceed 20, the additional moment may be calculated using equations 32 to 35 and added to the appropriate initial moments to obtain the total design moment. The initial moment  $M_i$  is the maximum moment at the critical section calculated for the ultimate limit state.

### Slender Columns with $L_e/h$ Exceeding 20 & Bent About their Major Axis

The cross sections of these columns should be designed as bi-axially bent, with zero initial moment about the minor axis.

### Columns Bent About their Major Axis

Where the ratio of the longer to the shorter side equals three or more, the section should be designed as bi-axially bent with zero initial moment about the minor axis.

### Slender Columns Bent About Both Axes

Where the bending is significant about both axes, the additional moments are calculated from equations 32 to 35 for both directions of bending. For each direction,  $b$  in Table 3.21 should be taken as  $h$ , the dimension of the column in the plane of bending considered. These additional moments are then combined with the appropriate initial moments  $M_2$  &  $M_1$  to obtain total design moments in the two directions. The critical section is then designed to withstand the design ultimate axial load,  $N$ , plus the total design moments in the two directions.

### Unbraced Structures

The distribution of moments assumed over the height of an unbraced column is indicated in Figure 3.21 of BS 8110. The additional moment may be assumed to occur at whichever end of the column has the stiffer joint; the additional moment at the other end may be reduced in proportion to the ratio of the joint stiffnesses at either end. The moment will act in a direction such that it increases the absolute magnitude at the critical section.

### Deflection of Unbraced Columns

All unbraced columns subject to lateral load are usually constrained to deflect sideways by the same amount. Hence, an average ultimate deflection may be applied to all the columns. This deflection can be assessed from the following equation:

$$a_{uav} = \sum a_u / n$$

After the calculation of  $a_{uav}$  any values of  $a_u$  more than twice  $a_{uav}$  should be ignored and the average recalculated; in this case  $n$  in equation 37 should be reduced appropriately.

### Design of Column Sections for ULS

In the analysis of a column cross-section for its design ultimate moment capacity under axial force, the assumptions are the same as when analysing beam sections.

Short columns usually need only to be designed for their maximum design moment about one critical axis.

### Biaxial bending

When designing columns in biaxial bending, symmetrically-reinforced rectangular sections may be designed to withstand an increased moment about one axis given by the following two equations Eq 40 & Eq 41:

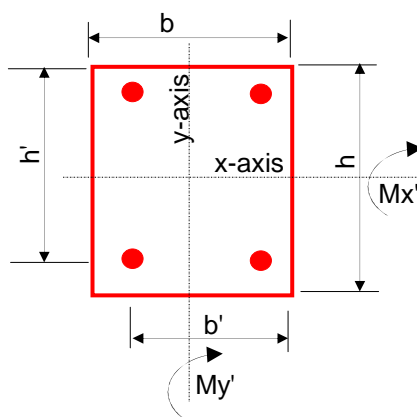
a) for  $M_x/h' \geq M_y/b'$   $M_{x'} = M_x + B' h'/b' M_y$

b) for  $M_x/h' < M_y/b'$   $M_{y'} = M_y + B' b'/h' M_x$

where

$h'$  and  $b'$  are shown in Figure 3.22;

$B'$  is the coefficient obtained from Table 3.22 and its values are shown in Table-4 of worksheet "Tables".



### Loading the Template on to your computer

Rect-Column is supplied as an Excel 2003 Template.

To load and open its file use standard Excel procedure.

If you receive an Excel Warning about running Macros and are prompted for whether to load them, answer YES to Load and Enable Macros. Rect-Column incorporates VB Macros and allowing your computer to use them is vital for its operation.

## Using Rec-Column

Cells shaded in **Light Green** indicate positions for the user input. Cells shaded in **Light Blue** also indicate user input but via cells for Loading Case Data; the Light Blue cells cannot be edited directly.

In addition to describing Job Information in the heading part, column data is entered in 4 parts of the screen. The first part in top left of the screen is for the column size and the strengths of concrete and steel. The second part in the middle top of the screen is for bending about the X-axis. The third part at top right of the screen is for bending about the Y-axis. The fourth part at the bottom full width of the template is for describing details of six loading cases.

Rect-Column employs an interactive procedure to check the design of columns. When the data input for a column is complete, the user needs to click the "Analyse and Update" button at top left of the screen. Rect-Column checks the column design for all six loading cases and updates the screen display to show its results. This is indicated by the disappearance of a red diagonal warning across the screen "Results Invalid – Click Analyse and Update Button". At this stage, Rect-Column results can be printed and also saved by clicking "Log Data (Using Store No 1001 to (No Suggestions)):" command button.

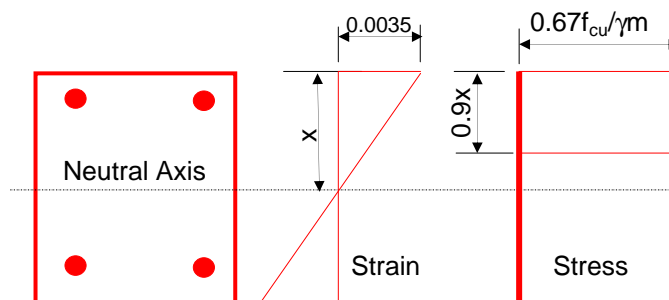
## Method of Design

The ultimate moment capacity of a column section subjected to a given axial load is found by setting up equilibrium equations. As these equations are at times quadric or cubic, an iterative technique is used to solve them. These equations are set up and solved for finding moment capacities at the balance failure load and at each axial load for the six loading cases.

As far as possible, the method of design is in accordance with the recommendation of the code. The deflection moment equations are summarised in Table-1 of worksheet "Tables".

The strain distribution in concrete in compression and the strain in the reinforcement whether tension or compression are derived from the assumption that plane sections remain plain. The assumptions used are those stated in Clause 3.4.4.1 of BS8110: Part 1.

To derive stresses in the compression zone of the concrete, the simplified stress block illustrated in figure 3.3 of the Code is used. It is based on an extreme concrete compression edge strain of 0.0035 and a stress block depth of 0.9 times the neutral axis depth.



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

To derive stresses for steel reinforcement in both the compression and tension zone of the column section, the Short term design stress strain curve shown in Fig 2.2 of the Code is used.

The material factors of strength for both the concrete and the steel reinforcement are variable. As any other data, the user can change them on the screen.

### Origin for the Location of Rebar

To specify the position of rebar, the origin is located at bottom left corner of the section.

When the column is not reinforced symmetrically, care is necessary in selecting this corner. The origin needs to be located at a section corner which is stressed most in tension i.e. a point diagonally opposite to the corner stressed most in compression.

### Origin for Applied Loads and Calculated Section Capacities

When calculating moment capacities of the column section, the location of the applied axial load is taken at centroid of the rectangular unreinforced section.

Any eccentricity the axial load may have relative to this point cannot be specified directly. The user needs to include the induced eccentricity moments in the values of M2x, M1x, M2y & M1y.

### Units

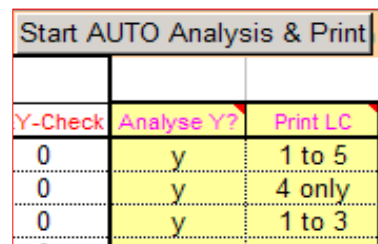
Rect-Column employs mixed units for ease of use and compliance with the code provisions. The used units are stated beside the displayed information and results.

### Auto Analysis of All Columns

A facility is provided in Rect-Column for designing all columns in the worksheet "Store" by a single click of "Auto Analyse/Print" Button. To use this facility, two columns coloured in yellow to the right of the "Store" worksheet are provided. One column is headed "Analyse Y?" and the other as "Print LC". 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 RC column in its row need to be analysed. Leaving the cells blank signifies that the respective Column is not be analysed. On a machine with Pentium 200 MHz CPU, one Rect-Column analysis takes about 3 seconds.

Entering a Positive number 1 to 6 in the "Print LC" column indicates that all Loading Cases for the column up to this number need to be printed. Entering a Negative number indicates that only one specific Loading Case need to be printed. Rect-Column converts the display to 1 to n when a positive number n is entered and to n only when a negative number n is entered. Leaving the cells blank signifies that no printing of results is required.



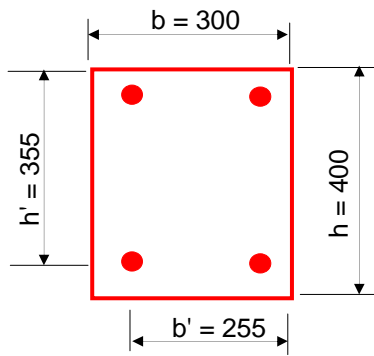
Y-Check	Analyse Y?	Print LC
0	y	1 to 5
0	y	4 only
0	y	1 to 3

In the above part display of the "Store" worksheet, the following numbers have been entered in the column headed "Print LC":

- 1st Row:  
5 to imply that loading cases 1 to 5 are to be printed;
- 2nd Row:  
4 to imply that only loading case 4 is to be printed.
- 3rd Row:  
3 to imply that loading cases 1 to 3 are be printed.

### Default Column Size

In order to avoid division by zero errors for columns with blank and or undefined data, default details need to be specified. These details can be change if required. A typical set of these details are shown below.



Steel Areas & Position			
	Ast, mm <sup>2</sup>	X-dist mm	Y-dist mm
1	201	45	45
2	201	255	45
3	201	45	255
4	201	255	255

Default Values (when Zero or Not Specified)	
fcu N/mm <sup>2</sup>	35
γ <sub>mc</sub>	1.5
f <sub>y</sub> N/mm <sup>2</sup>	500
γ <sub>ms</sub>	1.15
Width b of Column mm	300
Depth h of Column mm	300
Cover to Steel c <sub>g</sub> h - h' mm	45
Height L <sub>ox</sub> (m)	6
Cover to Steel c <sub>g</sub> b - b' mm	45
Height L <sub>oy</sub> (m)	6
Area of Steel Bars mm <sup>2</sup>	201

### Storing & Managing Column Design Information

Rect-Column stores information for as many columns as required in its "Store" Worksheet. For each column, over 190 data fields (in Excel columns) are used to store the design data. The field names can be viewed as being the column headings by activating 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 noted that Cut Command of Excel is not used on this worksheet; use of this command affects the worksheet layout and can disrupt the working of Rect-Column.

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

To keep design information for each column, Rect-Column uses a Store Number. This number is in the range from 1001 to Store-Size-Number. This number is used to recall and or Store data for a given column.

### Heading & Job Details

The first four items of the job heading are included in the "Rect-Column" worksheet only. They and are not kept in the "Store" worksheet and are therefore common to all columns designed by using one Rect-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 are specific to each column design and are as follows:

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

## Check-Codes

Rect-Column shows Check-Codes corresponding to the design of each column and each of its 6 loading cases.

The check code summarises 8 design checks. The components of this code includes the following checks:

- 1- axial capacity;
- 2- moment Capacity;
- 3- steel amount being within the minimum and maximum allowable limits;
- 4- slenderness limit;
- 5- minimum number of bars in the section being not less than four;
- 6- bar diameter being not less than 12 mm;
- 7- connections in X-direction being OK to Table 3.19 and 3.20;
- 8- connections in Y-direction being OK to Table 3.19 & 3.20.

The above components are combined to make them an 8-digit number to form a concise code. For example, a Check-Code is 00 00 03 01 it means that the column is failing in axial compression and not satisfying the maximum/minimum steel amount requirements of the code. A null 00 00 00 00 or no code display means that the column is passing all checks.

## Limitations

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

Rect-Column allows axial load both in Compression (+ve) and Tension (-ve). When the specified axial load is high and unrealistic, Excel crash can occur.