PROKON TECHNICAL WHITEPAPER

DESIGN OF CONCRETE COLUMNS IN PROKON

Including a discussion of second-order effects

PROKON

ABSTRACT

When confronted with the design of a reinforced concrete column, there are three modules in Prokon that can be used: Rectangular, Circular and General Column Design. General column, as its name implies, can design a column of any shape, however this does not necessarily mean it is the best module to design a column in each case. This article will discuss the different design approaches used in each module as well as recommend typical cases where each module should be used.

SUMMARY OF DESIGN CODES

Prokon currently supports the following codes in the column design modules:

- United States of America (ACI 318 – 1999, 2005, 2011, 2014)
- Australia (AS3600 – 2001, 2009, 2018)
- Great Britain (BS8110 – 1985, 1997)
- Singapore (CP65 – 1999)
- Canada (CSA-A23.3-04 - 2010)
- European Union (Eurocode 2 – 2004)
- Hong Kong (HK Concrete – 2004, 2013)
- India (IS:456 – 2000)
- New Zealand (NZ 3101 – 2006)
- South Africa (SABS 0100 – 2000)

Most design codes stipulate a similar approach to column design. The design approach is a simplified one that allows one to compile a set of design charts, and read off reinforcement values for different column sizes and design loads.

A typical column section is designed for axial force and bending. Some codes allow for bi-axial bending and an increased bending moment due to eccentric loading caused by deflection in slender columns. The codes give guidelines on the classification of slender columns.

Failure of a column is defined by the moment-axial force interaction curve.

The design is simplified by the following assumptions:

- Columns are often rectangular and symmetrically reinforced.
- Designing for maximum values of axial load and bending moments is usually considered conservative, except for a column with a small axial load.
- Deflections in columns are usually small, hence the increased moment from bending due to eccentric axial loads are not excessive.
- Shear is usually not a concern.
- Serviceability issues such as deflection and cracking do not require consideration.
- For practical reasons, reinforcement quantity throughout the column remains constant. It is therefore only required to consider maximum and minimum bending moments within the column.

These assumptions make the design of concrete columns relatively simple. It does however limit the scope of columns that can be designed using this simplified method.

PROKON'S APPROACH TO COLUMN DESIGN

The column design modules design reinforced concrete columns subjected to axial force and bi-axial bending moments.

The following conditions apply to the design of rectangular and circular columns:

- The design codes give simplified procedures for designing columns of which the ratio of the larger to the smaller dimension does not exceed 4:1.
- The procedure used for the design of rectangular columns is applied to the design of circular columns.
- The reinforcement layout is assumed to be symmetrical and can only exist in one plane on each face.
- The bracing and end fixities can be set independently for bending about the X and Y-axes.
- The design axial loads are taken to be constant over the height of the column.
- The maximum side dimension is 3 m for a rectangular column, and a 3 m diameter for a circular column.
- Second order effects due to imperfections are considered according to each code's requirement.

RECTANGULAR COLUMN DESIGN (RecCol)

The design procedure given in the codes is applied. The column is evaluated at the top, middle and bottom and the critical section is identified as the section requiring the greatest amount of reinforcement.

The design procedure can be summarised as follows:

- Column design charts are constructed for bending about the X and Y-axis.
- If the column is slender, additional slenderness moments are calculated as required about a single or both axes.
- For slender columns, the applied moments and additional moments are summed for each axis.
- In the case of bi-axial bending, the moments are converted to an effective design moment about a single design axis for certain codes. For other codes the full bi-axial formulas as given in the codes are used.
- The reinforcement required to resist the design moment is obtained from the applicable column design chart.
- Using the same procedure, a design moment is derived about the axis perpendicular to the design axis. Reinforcement resisting the secondary design moment is obtained from the relevant chart.

- If slenderness is involved, an iterative process is followed because the slenderness moments often also depend on the reinforcement percentage. Convergence usually occurs after less than ten iterations.

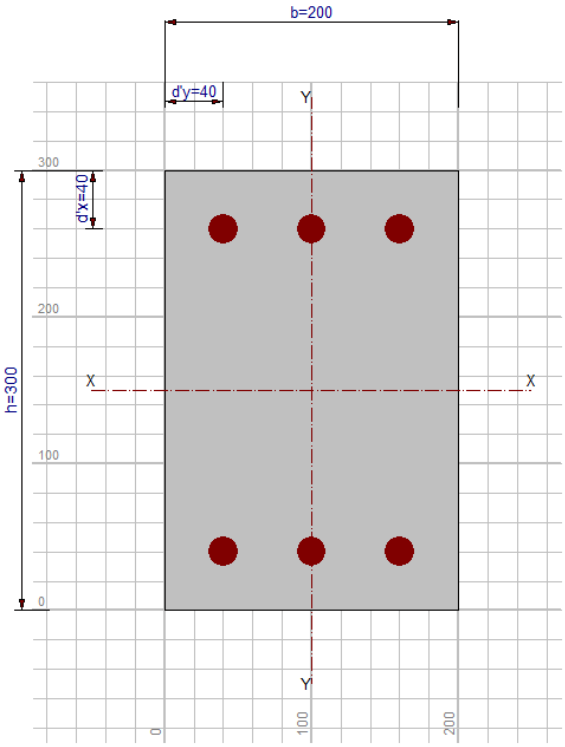

FIGURE 1: TYPICAL CROSS SECTION IN RECTANGULAR COLUMN DESIGN

CIRCULAR COLUMN DESIGN (CirCol)

The same simplified design procedure as for rectangular columns is used. The major and minor column dimensions, h and b, are both set equal to the column diameter.

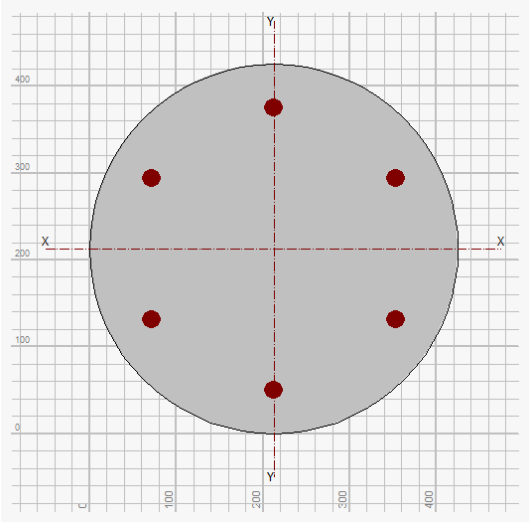

FIGURE 2: TYPICAL CROSS SECTION IN CIRCULAR COLUMN DESIGN

GENERAL COLUMN DESIGN (GenCol)

GenCol designs columns that cannot be designed by using the simplified method suggested in most codes. The program therefore reverts to basic principles to analyse columns, i.e. strain compatibility and equilibrium.

The following procedure is followed:

- The section properties are calculated and the column slenderness evaluated.
- For a slender column, the additional slenderness moment is calculated and applied about the weak axis, i.e. axis of lowest second moment of inertia. The output gives the X and Y-axis components.
- The design moment is determined by taking the vector sum of the applied and additional moments.
- The M-M axis is perpendicular to the design moment.
- The D-D axis is iteratively obtained by using strain compatibility and equilibrium as criteria.
- The simplified rectangular stress block given by the codes is used.

In GenCol, bracing and end fixities cannot be set independently for bending about the X and Y-axis.

Second order effects due to imperfections are considered according to each code's requirement.

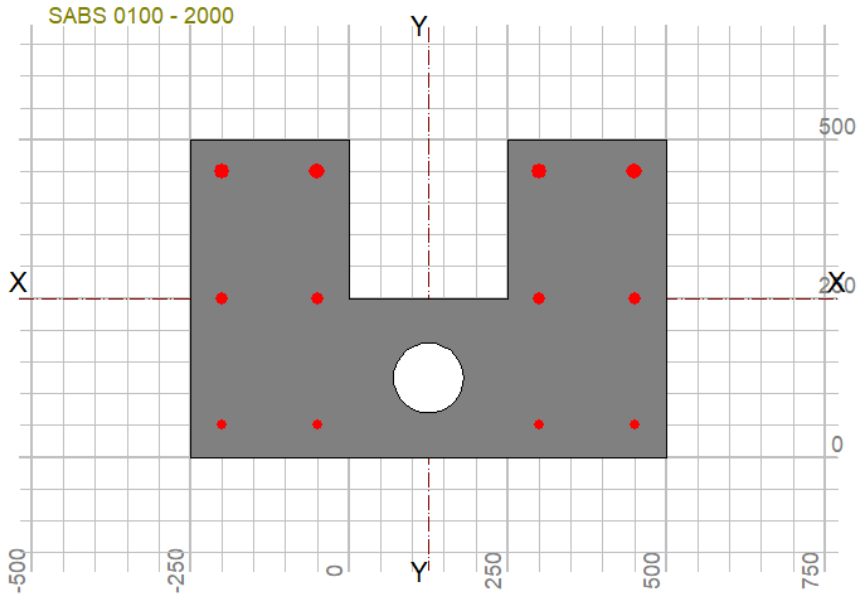

FIGURE 3: EXAMPLE INTRICATE CROSS SECTION IN THE GENERAL COLUMN DESIGN MODULE

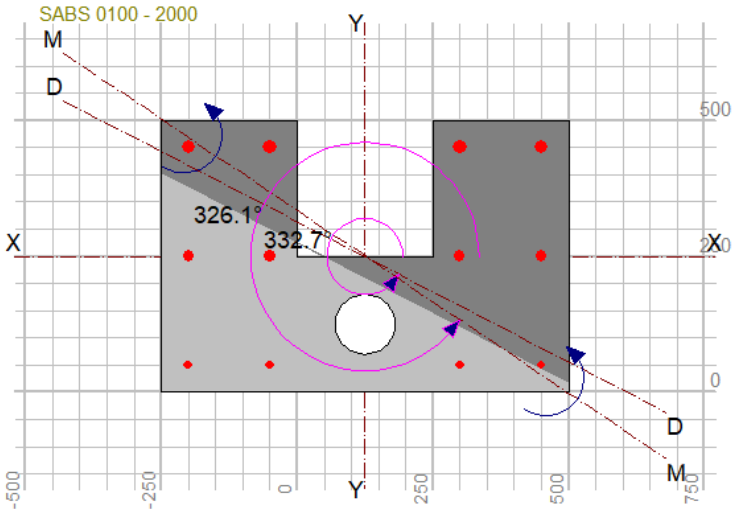

FIGURE 4: ROTATED DESIGN AXIS

INTERPRETING THE DESIGN RESULTS

RecCol and CirCol use the user input and produces an efficient reinforcement layout. Not much interpretation from the designer is needed.

However, because GenCol uses a different approach, the designer needs to interpret the results in order to refine the design. The column section and reinforcement entered by the user might be insufficient or vastly over designed. The onus rests on the user to obtain an optimal design.

GenCol calculates a safety factor for the entered design loads, and graphically presents it as a dot on the column design curve. This can be seen in Figure 5.

A safety factor of 1.0 or slightly larger suggests an optimal design. With a safety factor lower than 1.0, you should increase the size of the reinforcement bars or add more bars. Likewise, you may want to reduce the amount of reinforcement when the safety factor is much higher than 1.0.

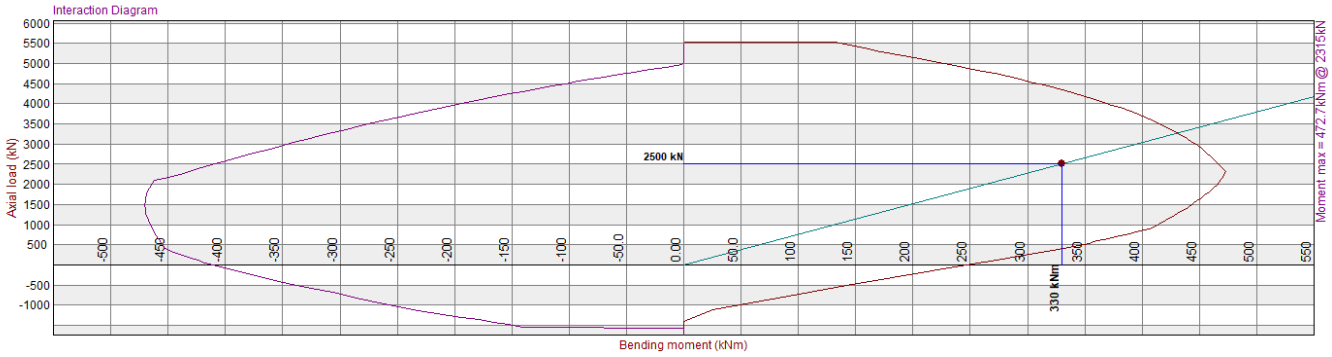

FIGURE 5: INTERACTION DIAGRAM CONSTRUCTED BY THE GENERAL COLUMN DESIGN MODULE

COMPARING DESIGN RESULTS

The different design approach of the GenCol (compared to RecCol and CirCol) may yield different design results for similar column inputs. The difference can be significant in some cases. This is true especially for slender columns, and mainly due to the following factors:

- GenCol calculates the additional moment about the weakest axis only. Using the code method, additional moments are added to one or both main axes.
- GenCol uses a rational approach to determine the concrete and reinforcement stress distribution throughout the column section. In comparison, the design procedure in some codes simplifies the situation by using an inflated effective design moment about one of the main axes.
- RecCol considers the gross area of concrete, while GenCol uses the net area. This will cause a slight difference in design moment and nominal steel required.

EXAMPLE COLUMN DESIGN

The following example will illustrate the difference between the results obtained from RecCol and GenCol. The exact same input was entered in both modules.

The input parameters that were used are as follow:

Column: 800 x 800, L_0 = 8 m, f_{cu} = 30 MPa, unbraced, partially fixed at the top, fully fixed at the bottom and an effective length factor of β = 1.3.

Reinforcing: 28Y20 bars with 50 mm concrete cover, E_s = 200 GPa, f_y = 450 MPa.

Ultimate limit state loads: Axial load P = 7000 kN, M_{xtop} = 500 kN.m, M_{ytop} = 500 kN.m

A cross section of the column is showed in Figure 6.

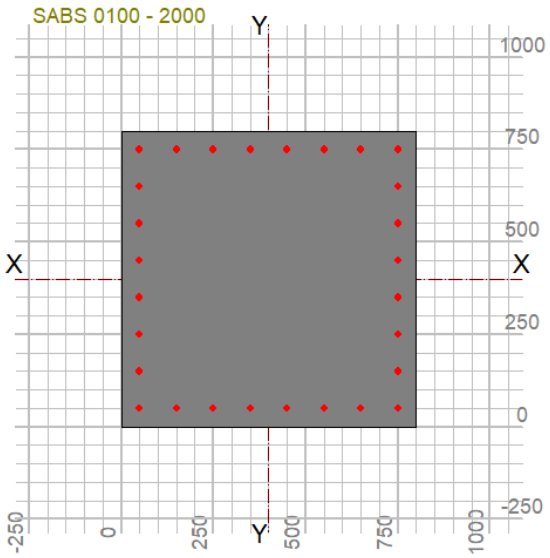

FIGURE 6: CROSS SECTION OF THE COLUMN USED FOR COMPARISON

The table below summarises the output from the two design modules:

Design module	**Design axis**	**Reinforcement (mm^2)**		
		Entered	**Required**	**Nominal** (0.4% A_c)
Rectangular column design	X-X	5027	2564	2560
	Y-Y	5027	6174	2560
General column design	New	8796	7700	2542

Take note of the remarkable difference in reinforcement entered. RecCol considers 16Y20 bars which adds up to 5027 mm^2 when evaluating about each of the axes. GenCol considers 28Y20's which adds up to 8796 mm^2 when evaluating the column about the design axis. According to the RecCol, the reinforcement content in the column is insufficient, while GenCol tells the user that the reinforcement is more than required.

This example perfectly illustrates how RecCol only considers the steel in the furthest layer parallel to the design axis. GenCol, on the other hand, calculates a new design axis and considers all the reinforcement entered by the user.

The difference in nominal steel required is because RecCol considers the gross area of concrete, while GenCol considers the net area of concrete.

DESIGN CODE LIMITATIONS

The design codes provide engineers with simplified approaches to complex problems. However, this does limit the scope of columns that can be designed. The following designs are not explicitly allowed for in the code and are subsequently not supported by Prokon's concrete design modules:

- Slanted columns
- Columns with loads applied between endpoints
- Perforated columns

CONCLUSIONS

GenCol can be used to design a column of any shape, including simple rectangular and circular columns. However, for such simple cases, it may be better to use RecCol and CirCol instead for the following reasons:

- RecCol and CirCol follow the simplified design procedure set out by the various codes. The Calcsheets set out every step of the design, making auditing of your design calculations quite easy.
- When using GenCol, you need to enter the reinforcement during the input phase. The program requires knowledge of the size and position of each bar for the section analysis. You may also need more than one attempt at designing the column before you feel satisfied with the results, potentially making it a time-intensive exercise. This is not the case for the other two modules where you enter the concrete geometry without reinforcement, and arrive at the required reinforcement immediately after analysis.
- You can use GenCol to produce bending schedules for columns with irregular shapes. However, when detailing rectangular and circular columns, several more steps are needed to place rebar in the section compared to using RecCol and CirCol. In the interest of productivity and easy auditing, it is usually best to use the RecCol and CirCol for simple columns, and reserve GenCol for the special situations.

When designing large columns with multiple layers of steel, GenCol will provide a much more economical design. RecCol will do a conservative design, as showcased in the example above.

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