## 3D Interaction Curve

**Design of Column Section using 3D P-M Surface**

**A. Design Steps:**

Principle used in RCDC for column design is to check the capacity of a section of given size with given reinforcement arrangement against the design-demand. Thus, for a given size of column with specific arrangement of reinforcement (in terms of location and diameter), for given grades of concrete and reinforcement, the P-M curves are generated as 'section capacity' curves. Then for all design load combinations, values of Pu, Mux and Muy (from analysis) are used and after due process for checking of minimum eccentricity, slenderness and other relevant checks, final design values are worked out as Pu-d, Mux-d and Muy-d. Now each value of this Pu-d, Mux-d and Muy-d is checked against capacity available as per the P-M curve envelope.

**B. Iterations for Reinforcement Arrangement:**

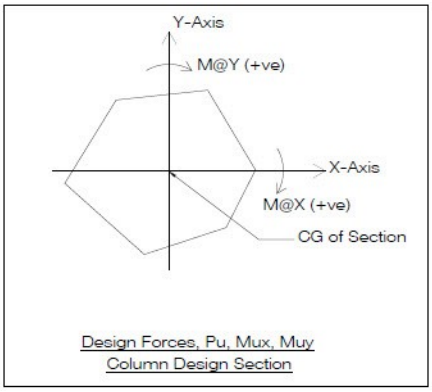
The final arrangement of the reinforcement is worked out on the basis of iterative procedure. In the first step, the reinforcement arrangement is finalized for a given size of column based on the 'preferred spacing' setting.

The iteration is done between minimum and maximum percentage steel. Starting with minimum Bar diameter and optimum number of bars based on preferred spacing, RCDC progressively increases the reinforcement. RCDC optimizes the reinforcement such that at for a given value of Ast (provided reinforcement) all the design checks are satisfied.

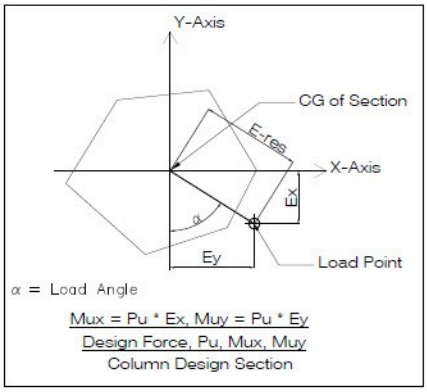
**Conversion of Bi-axial moment to Resultant moment**

As per earlier concept bi-axial design was performed using uniaxial moment capacities in major and minor directions and the biaxial ratio was checked as per provisions in the code. As per fundamental design principle and as mentioned in the codes, this method of superimposed bi-axial check is an approximation. Hence to provide more precise and in turn economical design, RCDC will now perform the design check for P-M using inclined Neutral Axis.

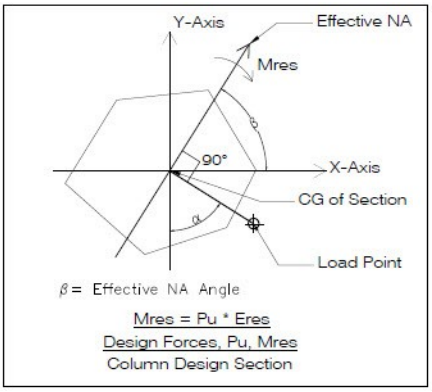
In this method, first step is to convert the final design moments into a 'Resultant Moment' acting along an angle to one of the principle local axis of section. This angle can be called as 'Load angle'. This resultant moment is calculated from first principles of eccentricity about CG of the section. Please find representation in sketches below for detailed reference.




Design Forces, Pu, Mux, Muy
Column Design Section




Mux = Pu * Ex, Muy = Pu * Ey
Design Force, Pu, Mux, Muy
Column Design Section




Mres = Pu * Eres
Design Forces, Pu, Mres
Column Design Section

Please note that,

Mux-d = M-res * Cos (Load Angle)
Muy-d = M-res * Sin (Load Angle)

**D.2 Preparation of 3D surface curve: (Mx-My curve)**

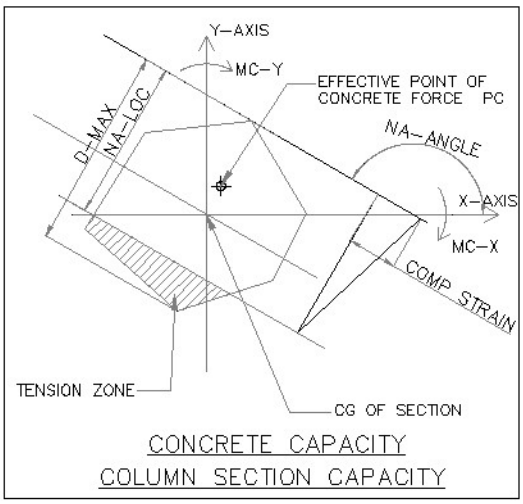
For preparing 3D P-M curve for a given section of column, Neutral Axis angle is varied between 0 to 90 degrees for a rectangular column. For columns of irregular shape, the NA angle is varied between 0 to 360 degrees owing to asymmetry. Please refer the drawing below for understanding. Angles A1 to A4 are between 0 to 90 degrees and 90 to 180 degrees and so on. This step is similar to earlier method.

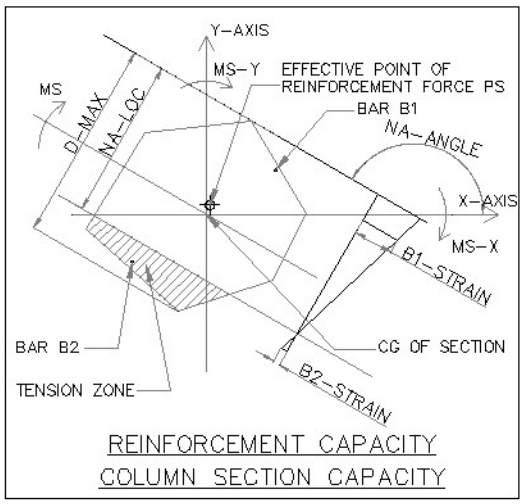
For a given NA angle, the P-M curve is prepared by varying the NA location (with reasonable steps) and finding the P-Mx-My capacity for a given location of NA. The stress-strain curve and material safety factors are considered as per relevant code. Please refer procedure in the following image as per ACI code. For other codes, similar procedure is followed. The stress-strain curve is considered for inclined NA similar to earlier method.

While calculating the Axial capacity (Pu) for a given NA angle and location, summation of Force in concrete (Pc) and Force in reinforcement (Ps) is done. Similarly, for Moment capacity of section (Mux and Muy) about X and Y axis respectively, summation of Moment capacity of concrete (Mc) and Moment capacity of reinforcement (Ms) is done. Please refer below figures.

There is internal algorithm based integration formulation to work out Axial Force Capacity (Pc) of concrete and its corresponding Moment Capacity (Mc) about local X and Y axes. Similarly, for the reinforcement bars, the stress levels in the bars are worked out based on strains and Axial Force Capacity (Ps) of

reinforcement (steel) and its corresponding Moment Capacity (Ms) about local X and Y axes. Please refer below figures.



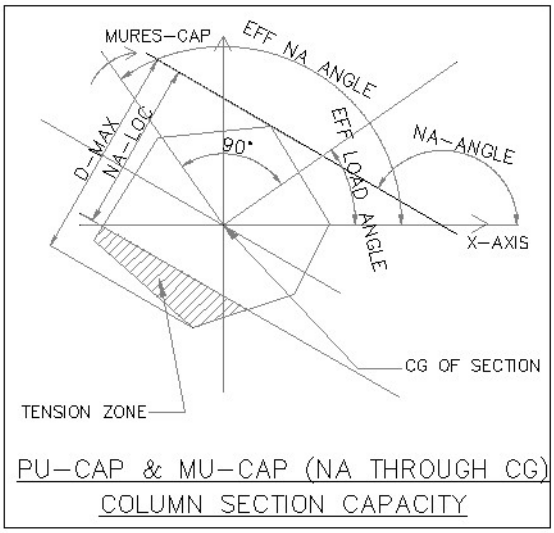




Hence, Section capacity for a given NA angle and location –

Pu-cap = Pc + Ps
Mux-cap = Mc-x + Ms-x
Muy-cap = Mc-y + Ms-y

The moment capacity can also be represented like

Mures-cap = Sqrt (Mux^2 + Muy^2)
With Effective Load Angle = Tan^-1(Muy/Mux)




Thus, for current NA-angle,

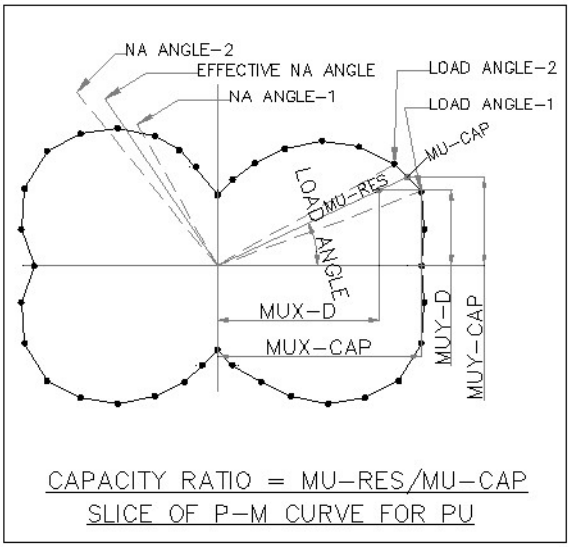
Pu = Axial capacity,
Mures-cap = Resultant moment capacity as defined above
Effective LA = Effective Load Angle as defined above
Where,
Mures-cap * Cos (LA) = Mux-cap
Mures-cap * Sin (LA) = Muy-cap

**D.3 Checking the section capacity for a set of forces:**

For checking the section capacity for a set of forces, following steps are adopted –

a) For a given value of P, horizontal slice is of the 3D interaction curve is plotted. This is done by calculating the moment capacity for that P value from various P-M curves plotted as explained above.

b) These values for a given value of P for all NA angles are plotted as horizontal slice of 3D P-M curve. Each value of M is for a given Load Angle
c) The current value of M-resultant is plotted at current Load angle.
d) The line connecting the origin and M-resultant is extended to meet the horizontal slice of M-curve. This angle would be between two angles on M-curve.
e) The value of M-cap is interpolated between these angles.
f) The capacity ratio is calculated as explained in the figure below –




a) Thus, in the design report, following is presented –
Load Angle
Capacity Ratio = Mu-res/ Mu-cap
Effective NA Angle = The NA angle for which the 'Load Angle' is achieved