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Development of P-M Interaction Curve for Chimney with Opening at Any Arbitrary Location

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ABSTRACT : *Chimneys are tall structures and an effective means of air pollution control. Current Indian code follows the Working Stress Design (WSD) approach, assuming elastic behavior of materials and use of permissible stresses on cracked section. For solid circular sections, necessary charts are available to compute flexural strength in presence of axial loads as per Limit State Design (LSD) .Currently there are no charts available for designing hollow circular sections by limit state design method. The 'interaction curve' is a complete graphical representation of the design strength of a chimney of given proportions. Each point on the curve corresponds to the design strength values of P and M. Percentage of reinforcement can be obtained directly from chart when openings are present. Longitudinal steel design is very tedious and involves lengthy calculations. Formulas give only strength for openings at particular location. We have to assume openings symmetrically and this gives conservative results. Furthermore if there are many openings of varying sizes at one particular section an accurate design becomes very difficult. This paper presents a method of designing by dividing the section in to a number of trapezoidal strips of equivalent area and developing the interaction curve. Using design interaction curve - for a given chimney section, quick judgment as to whether or not the section is safe can be made.*

Keyword - *Equivalent area, Interaction curve, LSD ,Trapezoidal strips, Ultimate bending moment, Ultimate force.*

1 .INTRODUCTION

As per current Indian practice chimney sections are designed using working stress approach. It is necessary that these structures are checked for the ultimate load conditions in view of large tensile stresses caused by horizontal loads due to earthquake and strong wind conditions, which is also stipulated in IS 456 2000. The analysis for ultimate flexural strength involves selecting a position of neutral axis and calculating the ultimate axial force and ultimate bending moment resisted by the resulting stress envelope of steel and concrete. All international concrete codes have addressed this issue and a detailed comparative study is reported by them. These codes use slightly different stress-strain curve in developing the strength estimates.

Using design interaction curve for a given chimney section, quick judgment as to whether or not the section is safe can be made. If the point given by the coordinates *(Pu,Mu*) falls within the design interaction curve, the chimney is safe; otherwise, it is not for a particular reinforcement.

Bhairav K Thakkar (2001) [6], developed an interaction diagram which is a graphical summary of the ultimate bending capacity of a range of RC columns with different dimensions and areas of longitudinal reinforcement. ***K.S.Babu Narayan***(2006) [4], developed interaction diagram for chimneys of heights over 400 meters..***Durgesh C. Rai*** (2010) [2],conducted the analysis for ultimate flexural strength by selecting a position of neutral axis and calculating the ultimate axial force and ultimate bending moment resisted and plotted the resulting stress envelope of steel and concrete. IS 456 2000 recommended material models for limit state design method is used. For some commonly occurring parameters, these interaction curves are also plotted in non-dimensional form, which can be easily used for analysis and design of thin RC hollow circular sections. None of these authors have considered the effect of openings.

The paper published related to the topic interaction curve for chimney is very less. "Ultimate flexural strength of reinforced concrete circular hollow sections" by ***Durgesh C.Rai*** (2010) [2] ,is the only available paper that explains about interaction curve for circular hollow section. In no papers is there any method for development of interaction curve for sections with openings. Current work's aim was to development of interaction curve which take openings into an account.

A computer program in C SHARP language was developed to generate the interaction curves. The program calculates moment capacity of hollow circular section of a particular diameter and thickness for various values of axial loads and given percentage of longitudinal steel in shell. Interaction curves are drawn by plotting several such points for different percentage of longitudinal steel in the section.

2. LOCATIONS OF CHIMNEY OPENINGS

Following are the locations for which formulas are readily available

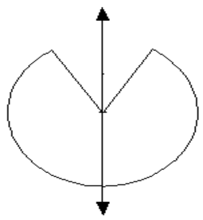

Fig 1 One Opening

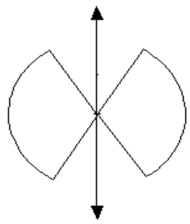

Fig 2 Two Diametrically Opposite Openings

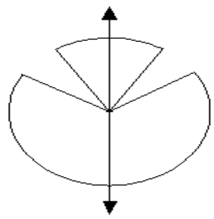

Fig 3 Two Equal Openings

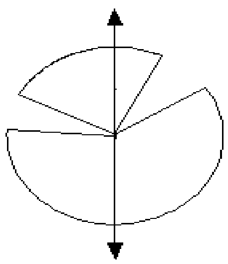

Fig 4 Two Equal Openings

(Not Located Diametrically Opposite)

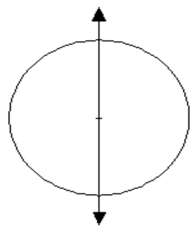

Fig 5 No Opening

Fig 6 Chimney with three equidistant equal opening

3. EQUIVALENT AREA METHOD

Circular section is divided into small trapezoidal strips. So that the properties does not change.

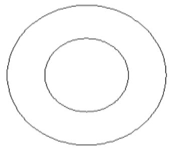

Fig 7 Chimney cross section

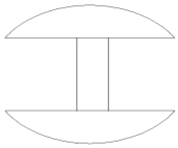

Fig 8 Equivalent area of cross section

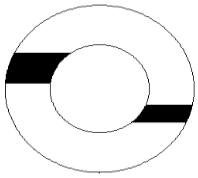

Fig 9 Chimney cross section with two openings

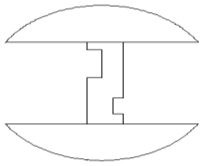

Fig 10 Equivalent area of chimney with two openings

- The whole structure is divided into small strips. One strip=0.001m.
- Calculate the total strip area of chimney.
- Calculate the area of reinforcement in each strip.
- Reinforcement is assumed to be uniformly distributed. Steel area=Percentage of concrete area.

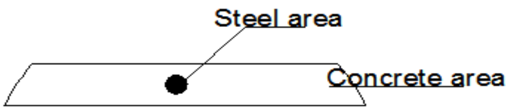

Figure11 Graphical representation

- Centre of gravity of equivalent section is found out.
- Calculate the total force and total moment with varying neutral axis location.
- Plot the interaction diagram by using force and moment.

For any given section the depth of neutral axis should be such that *Cu=Tu*, satisfying equilibrium of forces. When the steel has not yielded the true location of neutral axis is obtained by trial and error method. Similar to elastic analysis, three zones of neutral-axis position are considered, one where it falls inside the section, coincide with the diameter and it is outside the section.

2.1 Case 1: Neutral Axis outside the Section

Under this condition the entire section is in compression and further to produce a uniform concrete stress block. At this stage, the stress in the concrete is 0.446 f_{ck}. Compressive stress in concrete is uniform at 0.446 f_{ck} for a depth of $\frac{3}{7}D$ and below this it varies parabolic over a depth of $\frac{4}{7}D$ to zero at the neutral axis. In this case relationship between *M* and *P* can be assumed to be linear and thus the point given by a uniform compressive stress block is joined by a straight line.

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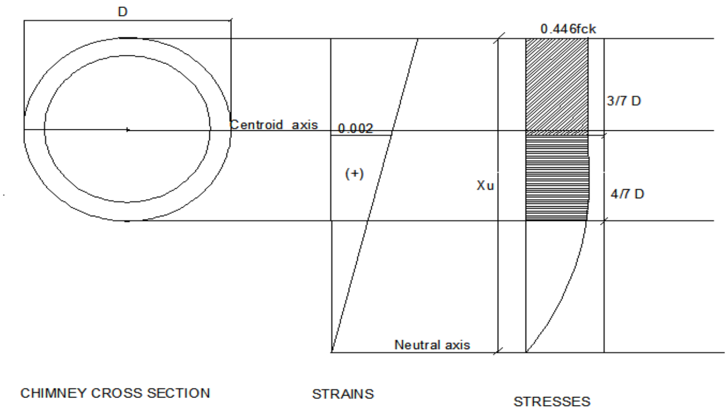

Fig 12 Concrete stress block parameters in compression *(Xu>D)*

2.2 Case 2: Neutral Axis Coincide With the Diameter

Compressive stress in concrete is uniform at 0.446 *fck* for a depth of $\frac{3}{7}$D and below this it varies parabolic over a depth of $\frac{4}{7}$D to zero at the neutral axis.

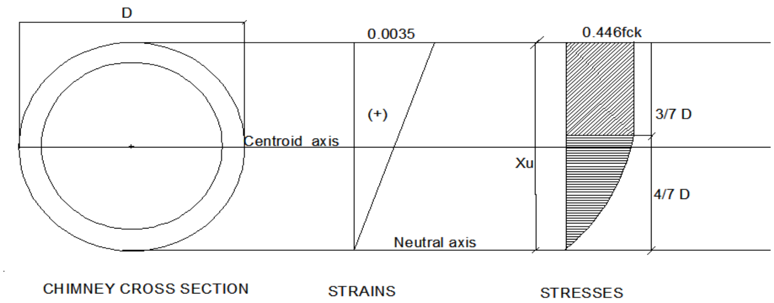

Fig13 Concrete stress block parameters in compression *(Xu=D)*

2.3 Case 3: Neutral Axis Falls inside the Section

Compressive stress in concrete is uniform at 0.446 *fck* for a depth of $\frac{3}{7}$Xu and below this it varies parabolic over a depth of $\frac{4}{7}$Xu to zero at the neutral axis.

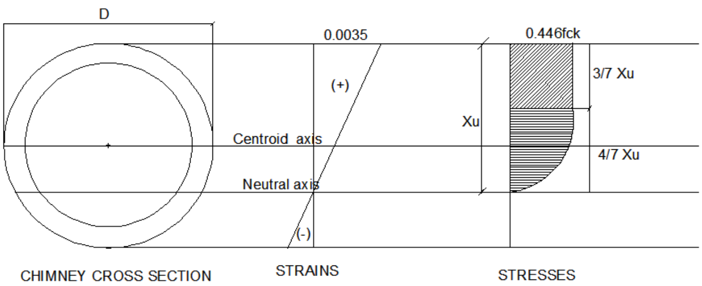

Fig 14 Concrete stress block parameters in compression *(Xu<D)*

Neutral Axis is varied as given in three cases, from NA> D to NA reaches the compression edge. For each NA depth, total compression force in concrete (P_c) and total compression force in steel (P_s) are added together

$P_u = P_c + P_s$

Force in steel due to tension is found out.Bending moment of each strip force about center of gravity is found out.

$M_u = M_c + M_s$

The values of *Pu* and *Mu* which defines the interaction curve for a given R C chimney section with an opening for a given percentage of steel. Interaction curves are drawn by plotting several such points for different percentage of longitudinal steel in the section

3. INTERACTION CURVE

The 'interaction curve' is a complete graphical representation of the design strength of a chimney of given proportions. Each point on the curve corresponds to the design strength values of *P* and *M* .The interaction curve defines the different (*P*,*M*) combinations. For design purposes, the calculations of *P* and *M* are based on the design stress-strain curves (including the partial safety factors). Using the design interaction curve for a given chimney section, it is possible to make a quick judgment as to whether or not the section is 'safe'. If the point given by the coordinates (*Pu,Mu*) falls within the design interaction curve, the chimney is 'safe'; otherwise, it is not.

3.1 Use of Interaction Diagram as an Analysis Aid

The chimney strength analysis problem reduces to determining whether a given chimney section, subjected to given factored load effects *P, M,* is 'safe' or not. One way of checking this is by determining the design strength *P, M,* and if *P<Pu* and *M<Mu*, the chimney section can be considered safe according to the Code. An alternative method of checking safety is by assuming that the ultimate limit state has been reached under the factored load *Pu*, i.e., *P = Pu*, and then comparing the corresponding ultimate moment of resistance *Mu* with the applied factored moment *Mu* if *M<Mu*, the chimney section is 'safe'.

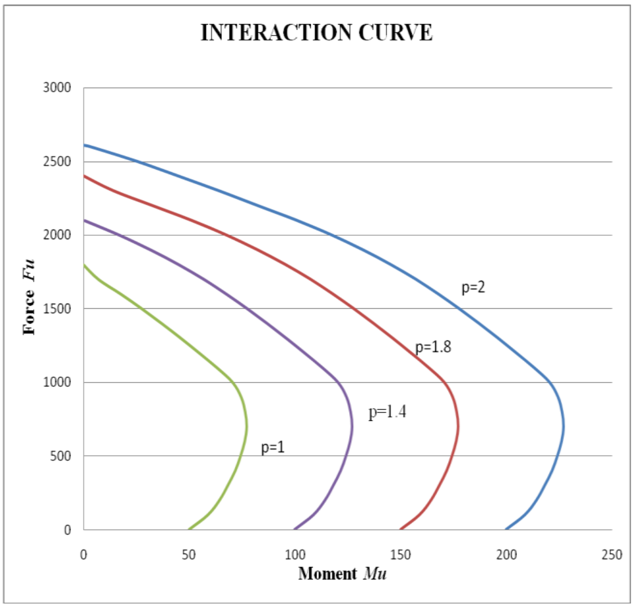

Fig 15 Interaction curve for a particular thickness and diameter

p=percentage of steel

3.2 Advantages of the developed Interaction Curve

- The percentage of reinforcement can be obtained from the chart, instead of going for lengthy calculations. Formulas give only strength for openings at particular location and only if these are symmetric where as with this program, we can design with opening at any arbitrary location and also with any opening sizes. (It need not be symmetric).
- The use of interaction curve is very helpful while deciding the sizes of chimney at the preliminary design stage with several possible alternatives.

- The curve gives the amount of compression reinforcement obtained from the chart are always within the minimum and maximum percentages i.e., from 0.8 to 4 per cent. Hence, it is not needed to examine if the computed area of steel reinforcement is within the allowable range.

4. CONCLUSIONS

A computer program in *C SHARP* language was developed to generate the interaction curves. The program calculates moment capacity of hollow circular section for various values of axial loads and given percentage of longitudinal steel in shell. Interaction curves are drawn by plotting several such points for different percentage of longitudinal steel in the section.

The following conclusions are drawn from the work

1. Thin hollow circular sections of chimneys should be designed by ultimate strength (limit state design) method instead of currently used working stress method to ensure higher reliability against collapse and possible reduction of overall cost.
2. Moreover, the IS 456 2000 requires members subjected to combined bending moment and axial force to be designed by limit state method using appropriate load factors.
3. This becomes even more necessary when the bending moment is due to horizontal loads, such as earthquakes which can result in significantly large bending moment demands.
4. In order to minimize the iterative calculations, the flexural strength of typical sections has been presented in form of non dimensional *P-M* interaction curves, which will be useful for the design engineers.
5. The interaction diagrams can be used quite simply and with sufficient accuracy to design of circular cross sections of reinforced concrete.
6. Circular cross sections are often encountered in practice as many chimneys presently used in thermal power plant of circular cross section.
7. Although many commercial computer program packages can calculate and automatically design of reinforced-concrete structures, they do not take in accommodate location of openings.
8. Interaction diagrams can be used as a highly welcome tool for checking accuracy of dimensioning made using computer software packages where programming procedures are often impaired by certain initial simplifications and interpretations of standards and reinforced-concrete structure theories that are unknown to users.
9. Can be use for hollow circular stem of water tank and similar structures.

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