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Development of Excel Sheets for the Design of Columns Under Tension or Compression, Biaxial Bending, Shear in Both Directions and Torsion

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ABSTRACT
Many analytical softwares do not support design of columns subjected to tension or compression, biaxial bending, shear in both directions and torsion. Tension in columns occurs especially in columns of buildings subjected to horizontal loads due to wind or earthquake forces. Hence, a simple method is developed using MS excel sheet, from the existing Indian codal procedures. Results are compared with existing literature and comparison graphs show that results are matching with the existing literature. Hence, these excel sheets can be used in conjunction with the analytical softwares like STAAD and ETABS for the design of columns. Importance of this procedure lies in the fact that modification or alteratation can be made at any step and can be used for a vast number of columns in a short time during the design of mult-istoried buildings.
Keywords-Analytical softwares, Biaxial bending, columns,shear in both directions and torsion.

I. INTRODUCTION

Columns contain very low volume of materials compared to the roof it supports. However, extreme care is required to construct columns since failure of columns lead to sudden collapse of the structure, when compared to the failure of the roofing elements it supports. Hence, columns need to design in such a way that failure of beams occurs prior to failure of columns. In order to achieve this objective, the moment strength of beams or tributary slab shall be less than that of colums at a joint in a principal plane [1]. This fact shall be checked before the completion of analysis and if found not satisfying, column dimensions shall be increased to satisfy the above condition.

Design of columns are carried over a group of columns having a low variation of design values. In this group, design is carried for the highest values of axial force, moments about Y and Z directions, shear about Y and Z directions as well as torsion. However, it is a common practice among designers to ignore shear and torsion in columns. This practice will reduce safety factor in columns which are critical structural members responsible for the safety of the structure. Hence, a method is proposed from existing literature [2,3,4] for the design of reinforced concrete (RC) columns considering axial force, moment in Y and Z direction, shear in Y and Z direction and torsion. This method is presented in the excel sheet so that the calculations in each step can be verified. The results are compared with the literature and verified.

II. RESEARCH SIGNIFICANCE

Column is a critical element in a structure which need to have a high moment strength than beams or tributary slab in the principal plane considered. Ignoring shear and torsion in the design of columns reduces the safety factor for columns. Hence, a procedure is formulated using spreadsheets for the design of columns. Spreadsheet facilitates design of number of colums immediately upon entering design data values. These are significant since many analytical softwares do not support design of columns with axial force, moments, shear and torsion. Moreover, BS- 8110 [4] imposes the limitation of design of columns using charts, that the longer side of columns shall not be more than 4 times the shorter side. This imposes limitation of using these charts. Moreover SP 16 [3] also puts limitation of minimum of 8 bars (for bars places on all faces) for the charts. However, the spreadsheet developed has no such limitations, since it is developed from first principles, for application to rectangular columns.

All the individual concepts for design of this problem are available in IS 456 : 2000 and SP : 16 1980 [2,3], however, all these individual concepts are systematically combined in this programme, which takes care of all the relevant clauses concerning this problem and all the design result values received from analysis software STAADPRO V8 i series software [6]. Moreover, this programme can be used for the design of hundreds of columns (considering grouping number of columns also), in one or two days when designing a multi-storey building.

III. METHODOLOGY

Side parallel to local Y axis in Staadpro V8 i series [6], is b, and that corresponding to local Z axis is D. Note that local Y axis corresponds to global X axis and local Z axis corresponds to global Z axis. Local X axis corresponds to the longitudinal axis of column.

Step by step procedure for the design are as follows.

1. Enter Py (axial force), My (moment about local Y) for top and bottom of column, Mz (moment about local Z) for top and bottom of column, Sy (shear along local Y), Sz (shear along local Z) and Mx (torsion). Enter also the breadth of the column along Y (b) and the length of the side parallel to local Z (D). Enter the grade of steel and concrete. Enter also the column as braced or unbraced. Column is braced, it it is laterally supported.
2. As per table in IS: 456 – 2000 [2], effective length is calculated. Slenderness ratio is calculated about Y and Z axis and if it is more than 12, column is designated as long column, else, short columns.
3. If it is a long column, additional moment is calculated as per IS 456-2000 [2].
4. The above additional moment shall be reduced by multiplying with a factor k in accordance with IS 456-2000 [2]. This factor is a function of Pb, which is the axial load corresponding to a strain of 0.0035 in compression and 0.002 in tension. This Pb is found from first principles. It is assumed that bars are equally distributed on all faces. Since the strains are given, neutral axis can be located as 0.6 times effective depth. Further, Pb is found based on the method given in SP; 16- 1978 [3]. This is based on the strains at each row of steel and the corresponding stresses in steel and the compressive force in concrete. Stress in steel is found from the stress stress relations given in SP: 16- 1978 [3]. These are given for a bar configuration of four bars per face which is applicable to 3 bars per face and 2 bars per face. This can be extended to any number of bars per face, provided, the excel sheet is modified by simply copying the existing one and changing the bar number from the present to the required one. Having found Pb and Puz as per cl. 39.6 of IS 456 : 2000 [2], reduction factor k can be determined as per cl. 39.7.1.1. of IS : 456 2000 [2].
5. Having found the reduction factor about Y and Z axis, additional moments May and Maz can be calculated. These moments shall be added to the initial moments which is required to be determined as in the further steps.
6. Column has top and bottom moments initially about Y and Z direction respectively. From this, a single moment (Muy) and Muz) is required to be arrived which need to be added to the additional moments due to slenderness so as to arrive at the final moments. This is based on notes given in cl. 39.7.1 of IS 456: 2000 [2]. As per this clause, for braced columns, the single moment is the sum of 0.4 Me1 and 0.6 Me2 and not less than 0.4 Me2, where Me1 is the smaller moment and Me2 is the larger moment. This needs to be found about Y and Z axis respectively. One of Me1 or Me2 is negative if column is bent in double curvature. For unbraced columns, end moments shall be directly added to the initial moments. Ie., Higher of the top or bottom moments is required to be considered for design about Y and Z axis. Thus, the single moment which is required to be added to the moments due to slenderness as given as above.Slenderness ratio of unbraced columns for a given storey shall be taken as the average of all columns in a single storey.
7. The above obtained initial moments shall be compared with the moment due to minimum eccentricity as per cl. 39.2 of IS 456 : 2000 [2] and maximum shall be considered.. Minimum eccentricity corresponds to cl. 25.4 of IS 456 : 2000 [2], which is equal to unsupported length of column/500 plus lateral dimensions/30, subject to minimum of 20 mm. This needs to be checked about each axis at a time.
8. Thus, the initial moment obtained from above shall be added to the moment due to slenderness as given in step 5.
9. This moment shall be added to the fictitious bending moment due to torsion given in cl. 41.4.2 of IS 456 : 2000 [2]and this shall be added to above to get the final moments for design. Since rebars are provided in compression and tension faces equally, for columns, the condition of providing compression rebars as per cl. 41.4.2.1 of IS 456 : 2000 [2], on condition that Mt > Mu, is not applicable.
10. Design shear shall be found by adding input shear with the fictitious shear due to torsion as per cl. 41.3.1. of IS 456 : 2000 [2].
11. Design for uniaxial moment capacity about Y or Z, and axial force shall be found by varying the neutral axis depth, so that axial force and moment shall be greater than initial ones. If neutral axis lies outside the section, section a of cl. 3.2.3.2 of SP 16 may be resorted to, and cl. b shall be referred to in case, if neutral axis lies within the section. For this end, the coefficients for area of stress block (C1) and the distance of centroid of the concrete stress block, measured from the highly compressed edge, shall be found from equations given in cl. 3.2.2 of SP 16 : 1980 [3]. Refer to the section for validation, for further details.
12. After determining the uniaxial moment capacities about the individual axis, the check for combined axial load and biaxial moments shall be checked as per cl. 39.6 of IS 456 : 2000 [2]. If O.K., proceed for design for shear (which included shear due to input shear and torsion).
13. Use cl. 40 if the shear do not include torsion and use cl. 41 of IS 456 : 2000 [2] if the shear include the

effect of torsion.

14. Further, the design is checked for the limiting values of design as per IS 456 : 2000 [2].

15. Check for crack width is also performed considering the serviceability loads, as per Annexure F of IS 456 : 2000 [2].

IV. DETAIL OF SOME OF THE INDIVIDUAL CONSTRUCTIONS

Details of come of important constructs are given below.

Table A of SP 16 : 1980 [3], for finding stress from strain of cold-worked bars, are implemented in MS excel using the following construct.

```
IF(AND((ABS(G78)>0.0038),($G$23=415)),360.9,IF(AND((ABS(G78)>0.00276),($G$23=415)),351.8+(360.9-351.8)/(0.0038-0.00276)*(ABS(G78)-0.00276),IF(AND((ABS(G78)>0.00241),($G$23=415)),342.8+(351.8-342.8)/(0.00276-0.00241)*(ABS(G78)-0.00241),IF(AND((ABS(G78)>0.00192),($G$23=415)),324.8+(342.8-324.8)/(0.00241-0.00192)*(ABS(G78)-0.00192),IF(AND((ABS(G78)>0.00163),($G$23=415)),306.7+(324.8-306.7)/(0.00192-0.00163)*(ABS(G78)-0.00163),IF(AND((ABS(G78)>0.00143),($G$23=415)),288.7+(306.7-288.7)/(0.00163-0.00144)*(ABS(G78)-0.00144),IF(AND((ABS(G78)<0.00144),($G$23=415)),200000*ABS(G78))))))))
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Where G78 cell denote the strain in the bar. G23 denotes characteristic strength of steel.

Total axial force in any row of reinforcement is found as follows.

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IF(AND(G57<0,$G$23=415),$G$53*$G$55*-G58,IF(AND(G57>0,$G$23=415),$G$53*$G$55*G58,(IF(AND(G57<0,$G$23=500),$G$53*$G$55*-G59,(IF(AND(G57>0,$G$23=500),$G$53*$G$55*G59))))))
```

Where, G57 denotes strain in the bar, G53 and G55 denotes number of bars in each face and cross sectional area of one bar. G59 denotes absolute stress in the bar.

The above was used for finding out Pb. Here, absolute stress in the bar was considered and for negative value of strains (tensile), the construct gets switched over through if condition.

However, for evaluation of Puy,Puz,Muy1 and Muz1, absolute and relative value of stress in the bar was considered respectively for calculation of moment and axial force respectively. This is to avoid two negative signs of stress and moment arm to become positive sign in case of moment caused due to tensile axial force in any row of steel.

V. CONSIDERATION OF TORSION FOR THE DESIGN

Effect of torsion was converted in to equivalent bending moment in Y and Z directions respectively through equations given in IS : 456-2000 (Bending in Y and Z directions were considered based upon b and D values compatible to the moment direction). Further this moment was added to the other bending moments due to initial staad results (or moments due to minimum eccentricity as per IS: 456-2000 [2]) and slenderness. Further, this moment was carried over to the input for design for biaxial moments.

Note that additional rebars in the opposite face of the tension longitudinal steel phase on condition that the bending moment equivalent of torsion is more than the actual bending moment, is not considered. This is because, rebars are provided equally on all faces.

Effect of torsion was converted in to equivalent shear also in Y and Z directions as per the equations of IS 456-2000. Separate design was provided in the event of actual shear only, and shear combined with equivalent shear due to torsion.

VI. VERIFICATION OF SPREADSHEET

It is required to make sure that the results of long constructs give the same values as in code. Hence, the comparison of results obtained from excel sheet was made with the results from literature to make sure that each constructs are correct. Results of major constructs are given in Table 1.

There is another reason also that, since it is observed that available literature do not have the results for the design of columns under compression/tension, biaxial bending, shear and torsion, each of the constructs are verified with the standard codes or literature.

Table 1a Comparison of steel stresses from strains, for various stress levels (fyd = fy/1.15), for Fe415

Strain	fs as per excel(fs as per SP 16 : 1980)
0.00380	fyd (fyd)
0.00276	0.974fyd(0.975fyd)
0.00241	0.949fyd (0.95fyd)
0.00192	0.9fyd (0.0.90fyd)
0.00163	0.849fyd (0.0.85fyd)
0.00144	0.8fyd (0.8fyd)

Table 1b Comparison of steel stresses from strains, for various stress levels (fyd = fy/1.15), for Fe500

Strain	fs as per excel(fs as per SP 16 : 1980)
0.00417	fyd (fyd)
0.00312	0.974fyd(0.975fyd)
0.00277	0.949fyd (0.95fyd)
0.00226	0.9fyd (0.0.90fyd)
0.00195	0.85fyd (0.0.85fyd)
0.00174	0.8fyd (0.8fyd)

Table 2 gives comparison of Pu/(fckbD) of given excel sheet and as per SP 16 : 1980, corresponding to p/fck and Mu/(fckbD^2) for various dimensions of columns as shown below.

Table 2 Comparison of Pu/(fckbD) of excel sheet and SP 16 : 1980, corresponding to p/fck and Mu/(fckbD^2)

Column size in mm (square col.)	Neutral axis factor, 'k'	Mu /(fckbD^2)	Pu/(fckbD)(Pu/ fckbD) as per SP 16 : 1980)
600	1.4	0.015	0.481 (0.48)
	1.2	0.024	0.456(0.45)
	1.0	0.041	0.406(0.4)
	0.8	0.065	0.315 (0.3)
	0.6	0.077	0.219(0.2)
	0.4	0.071	0.129(0.14)
	0.2	0.05	0.04(0.04)
	0.05	0.009	-0.064(-0.06)
500	1.4	0.017	0.509 (0.48)
	1.2	0.027	0.48(0.48)
	1.0	0.046	0.425(0.44)
	0.8	0.071	0.323 (0.3)
	0.6	0.086	0.22(0.2)
	0.4	0.08	0.12(0.12)
	0.2	0.058	0.024(0.02)
	0.05	0.009	-0.1(-0.1)
400	1.4	0.02	0.56 (0.58)
	1.2	0.032	0.456(0.48)
	1.0	0.053	0.46(0.46)
	0.8	0.083	0.345(0.36)
	0.6	0.099	0.219(0.22)
	0.4	0.094	0.102(0.10)
	0.2	0.065	-0.019(-0.02)
	0.05	0.009	-0.168(-0.16)
300	1.4	0.026	0.67 (0.65)
	1.2	0.04	0.621(0.64)
	1.0	0.066	0.53(0.50)
	0.8	0.102	0.383(0.38)
	0.6	0.125	0.208(0.20)
	0.4	0.118	0.052(0.06)
	0.2	0.066	-0.15(-0.14)
	0.05	0.009	-0.312(-0.3)

Table 2 indicate that comparison is satisfactory.

VII. CONCLUSIONS

From the above sections, it is clear that, the spreadsheet developed for the design of columns subjected to compression/tension, biaxial bending, shear in both directions and torsion, can be used effectively.

VIII. LIMITATIONS

At present, column with four bars per face is considered, which can be increased to any number of bars per face by a little modification in the spreadsheet. This is applicable for rectangular columns only. For circular columns and odd shaped columns, this spreadsheet can be modified and could be adopted. All notations corresponds to ref [2] and [3]. The above analysis is also in line with ref [7], regarding column parameters.

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