Analysis and Design of Reinforced Concrete Beams and Columns using open STAAD

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Abstract: Structural designers especially in India use STAAD software to execute the structural analysis, but for the design purpose still manual calculations and excel spread sheets are being used. It leads to cumbersome and time consuming process to obtain analysis results from STAAD Pro to design calculations, hence to automate this process an MS Excel spread sheet has been developed. A vba program has been developed to access the analysis results from STAAD Pro to MS Excel such that the design process is fully automated which reduces manual interference.

Keywords: MS Excel, Open STAAD, VBA, IS 456:2000, Analysis, Design, Beam, Column.

I. INTRODUCTION

STAAD Pro comes with a library of functions allowing users access to the input and output data from STAAD files. These functions also allow users to create a STAAD input data file, launch the STAAD analysis run, and link STAAD with any program of their choice for post-analysis operations such as steel design, concrete design, connection design, etc. This library of functions goes by the name OpenSTAAD. The most convenient way to utilize these functions is through VB Macros that can be run in Excel, MathCAD, etc. For a list of these functions one can refer OpenSTAAD Reference Documentation [5] for more information. OpenSTAAD Macros can be created using any VB editor. Users may also create them using the VB editor built into Microsoft Excel. The STAAD Pro GUI (Graphical User Interface) too is equipped with a VB editor.

Visual Basic for Applications (VBA) is a programming environment designed to work with Microsoft's Office applications (Word, Excel, Access, and PowerPoint). Components in each application (for example, worksheets or documents) are exposed as objects to the programmer to use and manipulate to a desired end. Almost anything can be done through the normal use of the Office application to automate the work through programming.

A spreadsheet has been developed for the design of Selective Catalytic Reduction Pile Cap Foundation, The micro piles were modeled in STAAD Pro v8i and the forces extracted to an Excel spreadsheet through OpenSTAAD VBA macro [1].

Introduced PSA (Program for Structural Analysis) Software, and compared th e results obtained from OpenSTAAD and analysis done in PSA to MS excel [2].An Automation of structural analysis design iterations using DSM (Design Structural Matrix) and OpenSTAAD has been carried out, further the work has been extended for optimal design of sections [3]. Presented Design Optimization of Steel Members Using Openstaad and Genetic Algorithm [4].

II. PROPOSED METHODOLOGY

A. Analysis

A typical 3 Dimensional frame was considered for the analysis, and the frame was modeled in STAAD Pro V8i software, The initial beam properties were assigned based on vertical deflection limits and for the column based on slenderness ratio of IS 456:2000[9], The Dead Load and Live Load are assigned to the frame according to IS 875(Part 1 & Part 2)-1987[12], [13]. Static Analysis of the frame was carried out based on various load combinations. After analyzing the structure in Staad analysis engine, the geometry and design forces for selected beams and for particular load combination were retrieved as shown in Fig. 1 & Fig. 2.

B. Open STAAD Syntaxes

Following Syntaxes have been coded in MS Excel VB macro to retrieve geometry and design forces for selected beam and particular load combination. Beam No. have been retrieved using "Get No Of Selected Beams," Length of beam have been retrieved using "Get Beam Length,", Breadth and depth of Beam have been retrieved using "Get Beam Property,", Minimum and Maximum bending moment of Beams have been retrieved using "Get Min Max Bending Moment,", Minimum and Maximum Shear force of Beams have been retrieved using "Get Min Max Shear Force,", Node No. have been retrieved using "Get Member Incidence," for selected member, Support Reactions such as Fy, Mx, Mz have been retrieved using "Get Support Reactions,".

III. DESIGN PROCEDURE

A. RC BEAMS

A code (syntax) has been coded in MS Excel VB macro and a command button "GET REACTIONS," has been provided to retrieve the results Such as Load case, Beam No., Breadth, Depth, Length, Bending Moment, and Shear Force in their respective cells for selected beams and particular load combination as shown in Fig. 3. Provide design inputs such as Clear cover,

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Characteristic strength of reinforcement (f_y), Characteristic cube compressive strength of concrete (f_{ck}), diameter of bar, No. of stirrup legs, type of Beam (Cantilever, Simply supported, and Continuous beam) and click "DESIGN" Button to design the beams as shown in Fig. 3.

B. RC COLUMNS

A code (syntax) has been Coded in MS Excel VB macro and a command button "GET REACTIONS," has been provided to retrieve the results Such as Load case, Node No., Breadth, Depth, Bending Moment in X and Z directions and Axial Force in their respective cells for selected columns and for particular load combination as shown in Fig. 4. Design charts will be prepared based on Breadth (b), and Depth (D) located on the 1st row of the results retrieved. Now, provide design inputs such as Clear cover, Characteristic strength of reinforcement (f_y), Characteristic cube compressive strength of concrete (f_{ck}), Top, Bottom, and Middle Reinforcement diameter and No. of Bars in the respective cells and click "DESIGN" Button to design the columns as shown in Fig. 4.

IV.   DESIGN FORMULATION

A. RC BEAMS

Following equations for the design of RC Beams have been used in the form of VB syntax in MS Excel VBA macro.

1. Effective cover is calculated from table 16 and 16A of IS 456-2000, and based on Maximum Diameter of Bar to be used.

$$Eff.\cov er = clear.\cov er + \frac{Dai.of bar}{2} \qquad (1)$$

2. Effective depth (d) is difference of Overall depth (D) and Effective cover.

$$d = D - Eff.\cov er \qquad (2)$$

3. Limiting value of x_u is calculated from Clause 39.1 of IS 456-2000.

4. Limiting moment of resistance ($M_{u\lim}$) of a section without compression reinforcement is calculated by referring Annex G IS 456:2000[9].

5. Strain in compression steel (e_{sc}) is calculated from Annex G-1.1(c) of IS 456:2000[9].

$$e_{sc} = 0.0035\left(\frac{x_{u,\lim} - d}{x_{u,\lim}}\right) \qquad (3)$$

Where,

d = Effective depth of beam or slab

$x_{u,\lim}$ = Limiting value of x_u

6. Stress in compression steel (f_{sc}) corresponding to Strain in compression steel (e_{sc}) is interpolated from Table A. of SP-16 [10].

7. The minimum area of tension reinforcement ($A_{st,\min}$) is calculated from clause 26.5.1(a) of IS 456:2000[9].

$$A_{st,\min} = \frac{0.85bd}{f_y} \qquad (4)$$

Where,

b = Breadth of beam, or shorter dimension of rectangular column

f_y = Characteristic strength of reinforcement

8. The maximum area of tension reinforcement ($A_{st,\max}$) and compression reinforcement is calculated from clause 26.5.1(b) of IS 456:2000[9] [9].

$$A_{st,\max} = 0.04bD \qquad (5)$$

9. If $M_u < M_{u,\lim}$ the section is under Reinforced, and the beam is designed as singly reinforced beam (SRB). If $M_u > M_{u,\lim}$ the section is over Reinforced and the beam is designed as doubly reinforced beam (DRB).

10. Area of tension reinforcement ($A_{st.1}$) for a singly reinforced section at mid span and at support is calculated from Annex G-1.1(b) of IS 456:2000[9].

$$A_{st.1} = \frac{0.5f_{ck}}{f_y}\left(1 - \sqrt{1 - \left(\frac{4.6M_u}{f_{ck}bd^2}\right)}\right)bd \qquad (6)$$

Where,

f_{ck} = Characteristic cube compressive strength of concrete

M_u = Design moment

11. If section is over reinforced then area of compression reinforcement (A_{sc}) and additional tensile reinforcement ($A_{st.2}$) is calculated from Annex G-1.2 of IS 456:2000[9].

$$M_u - M_{u,\lim} = f_{sc}A_{sc}(d - d') \qquad (7)$$

$$A_{st2} = A_{sc}f_{sc}/0.87f_y \qquad (8)$$

Where,

d' = Depth of compression reinforcement from the highly compressed face

12. No. of bars required and No. of bars provided is calculated based on the diameter of bar selected from drop down list for tension and compression face.

13. Development length of bar is calculated from clause 26.2.1 of IS 456:2000[9].

$$L_d = \frac{\phi\sigma_s}{4\tau_{bd}} \qquad (9)$$

Where,

σ_s = Stress in bar at the section considered at design load

ϕ = Nominal diameter of the bar, and

τ_{bd} = Design bond stress

14. Section check is obtained for maximum area of reinforcement from clause 26.5.1(b) of IS 456:2000[9].

15. Nominal shear stress in beams is calculated from clause 40.1 of IS 456:2000[9].

16.

$$\tau_v = \frac{V_u}{bd} \qquad (10)$$

Where,

τ_v = Nominal shear stress

V_u = Shear force due to design loads

17. Shear stress in concrete (τ_c) is calculated from clause 4.1 of SP-16.

$$\tau_c = \frac{0.85\sqrt{0.8 f_{ck}}\left(\sqrt{1+5\beta}-1\right)}{6\beta} \tag{11}$$

$$p_t = \frac{100 A_{st}}{bd} \tag{12}$$

18. If $\tau_v \geq \tau_c$, the shear is carried by reinforcement (τ_v) hence spacing of stirrups (S_v) for design shear reinforcement in the form of vertical stirrups is calculated from clause 40.4(a) of IS 456:2000[9].

$$V_{us} = \frac{0.87 f_y A_{sv} d}{S_v} \tag{13}$$

$$V_{us} = V_u - \tau_c bd \tag{14}$$

19. If $\tau_v < \tau_c$, the shear is carried by concrete hence spacing of stirrups (s_v) for minimum shear reinforcement in the form of vertical stirrups is calculated based on diameter of bar and no. of stirrup legs from clause 26.5.1.5, and 26.5.1.6 of IS 456:2000[9].

$$\frac{A_{sv}}{bs_v} \geq \frac{0.4}{0.87 f_y} \tag{15}$$

Where,

A_{sv} = total cross-sectional area of stirrup legs effective in shear,

s_v = stirrup spacing along the length of the member,

b = breadth of the beam or breadth of web of flanged beam, and

f_y = characteristic strength of the stirrup reinforcement in N/mm^2 which shall not be taken greater than 415 N/mm^2.

20. When member is designed for torsion, transverse reinforcement for torsion in the form of rectangular stirrups provided perpendicular to axis of member from clause 26.5.1.7 (a) of IS 456:2000[9].

21.

$$S_v \leq \frac{x_1 + y_1}{4} \text{ or } 300mm \tag{16}$$

Where,

x_1, y_1 = Short and Long dimensions of stirrup.

22. Check for deflection have been calculated from clause 23.2.1, Fig. 4 and fig. 5 of IS 456:2000[9], and multiplication factor is calculated from clause 22.2 of SP-24 [11].

➢ Multiplication factor for tensile reinforcement (MF$_t$).

$$MF_t = \frac{1}{0.225 + \left(0.00322\left(f_s \dfrac{p_{t,req.}}{p_{t,prov.}}\right)\right) - \left(0.625 \log_{10} \dfrac{1}{p_{t,prov.}}\right)} \tag{17}$$

Where,

$f_s = 0.58 f_y$

$p_{t,prov.}$ = Percentage of tension reinforcement provided, and

f_s = Service stress in steel.

Multiplication factor for compression reinforcement (MF$_t$).

IF, $p_{c,prov.} < 0.75$, Then

$$MF_C = 1 + \left(0.15 \frac{p_{c,prov.}}{0.5}\right) \tag{18}$$

IF,

$$MF_c = \left(1.6 \frac{p_{c,prov.}}{\left(p_{c,prov.} + 0.275\right)}\right) \geq 1.5 \text{ Then } 1.5 \tag{19}$$

Where,

$p_{c,prov.}$ = Percentage of compression reinforcement provided.

23. The lateral stability check for beam is calculated from clause 23.3 of IS 456:2000[9].

Length for simply supported and continuous beams should be least of $60b$ or $\dfrac{250b^2}{d}$.

Length for cantilever beam should be least of $25b$ or $\dfrac{100b^2}{d}$.

B. RC COLUMNS

Following equations for the design of RC Columns have been used in the form of VB syntax in MS Excel VBA macro.

1. Effective cover is calculated from table 16 and 16A of IS 456:2000[9], and based on Maximum Diameter of Bar to be used.

$$Eff.cover = clear.cover + \frac{Dai.ofbar}{2} \tag{20}$$

2. Effective length is calculated for fixed columns from Table 28 of IS 456:2000[9].

3. Slenderness ratio is calculated from Short and Slender (long) column from clause 25.1.2 of IS 456:2000[9].

$$\frac{l_{ex}}{D}, \frac{l_{ez}}{b} \leq 12 \tag{21}$$

4. If column is slender then additional moments are calculated from clause 39.7.1 of IS 456:2000[9].

5.

$$M_{ax} = \frac{P_u D}{2000}\left\{\frac{l_{ex}}{D}\right\}^2 \tag{22}$$

$$M_{az} = \frac{P_u b}{2000}\left\{\frac{l_{ez}}{b}\right\}^2 \tag{23}$$

Where,

P_u = axial Load on the member,

l_{ex} = effective length in respect of the major axis,

l_{ez} = effective length in respect of the minor axis,

D = depth of cross-section at rightangles to the major axis, and

b = width of the member.

6. Axial load carried by the assumed section and reinforcement, is calculated from clause 39.6 of IS 456:2000[9].

$$P_{uz} = 0.45 f_{ck}.A_c + 0.75 f_y.A_{sc} \quad (24)$$

7. Modification factor for slender compression member is calculated from Table 60 of SP-16 [9].

$$P_{bx} = \left(k_1 + k_2 \frac{p}{f_{ck}} \right) f_{ck} bD \quad (25)$$

$$P_{bz} = \left(k_1 + k_2 \frac{p}{f_{ck}} \right) f_{ck} bD \quad (26)$$

$$k_x = \frac{P_{uz} - P_u}{P_{uz} - P_{bx}} \leq 1 \quad (27)$$

$$k_z = \frac{P_{uz} - P_u}{P_{uz} - P_{bz}} \leq 1 \quad (28)$$

Where,

P_{bx}, P_{bz} = axial Load about major and minor axis,

k_1, k_2 = multiplying factors,

p = percentage of reinforcement provided,

P_{uz} = axial Load resisted by adopted section and reinforcement, and

k_x, k_z = multiplying factors about major and minor axis.

8. Correction is applied to additional moment calculated in step (4) with multiplication factors k_x, k_z.

9. Minimum eccentricity about major and minor axis is calculated from clause 25.4 of IS 456:2000[9].

$$e_{min.x} = \frac{l_{ex}}{500} + \frac{D}{30} \geq 20mm \quad (29)$$

$$e_{min.z} = \frac{l_{ez}}{500} + \frac{b}{30} \geq 20mm \quad (30)$$

10. Moment due to minimum eccentricity is calculated from clause 3.4 of SP-16 [9].

$$M_{ex} = P_u e_{min.x} \quad (31)$$

$$M_{ez} = P_u e_{min.z} \quad (32)$$

11. Actual corrected moment > corrected additional moment and moment due to minimum eccentricity, is considered for total design moment for which the column is to be designed.

$$M_{ux} = M_{emin.x} + M_x \quad (33)$$

$$M_{uz} = M_{emin.z} + M_z \quad (34)$$

12. Design parameters are interpolated from interaction charts for P_u vs M_{ux} and P_u vs M_{uz} based on clause 3.2.3 of SP-16 [9].

$$\frac{P_u}{f_{ck}bd} \quad (35)$$

$$\frac{M_{uax}}{f_{ck}bd^2} \quad (36)$$

$$\frac{M_{uaz}}{f_{ck}bd^2} \quad (37)$$

13. Design check has been obtained on the basis of moments due to design loads and, moment capacity due to axial load and biaxial bending from clause 39.6 of IS 456:2000[9].refer (38)

$$\left[\frac{M_{ux}}{M_{ux1}} \right]^{\alpha_n} + \left[\frac{M_{uz}}{M_{uz1}} \right]^{\alpha_n} \leq 1.0 \quad (38)$$

Where,

M_{ux}, M_{uz} = moments about x and y axes due to design loads,

M_{ux1}, M_{uz2} = maximum uniaxial moment capacity for an axial load of P_u bending moment about x and z axes respectively, and α_n is related to P_u / P_{uz}, Where,

$$P_{uz} = 0.45 f_{ck} A_c + 0.75 f_y A_{sc} \quad (39)$$

For values of $P_u / P_{uz} = 0.2 to 0.8$, the values of α_n vary linearly from 1.0 to 2.0. For values less than 0.2, α_n is 1.0; for values greater than 0.8, α_n is 2.0.

14. Pitch and diameter for lateral ties is calculated from clause 26.5.3.2(c) of IS 456:2000[9].

15. Development length of bar is calculated from clause 26.2.1 of IS 456:2000[9].

$$L_d = \frac{\phi \sigma_s}{4 \tau_{bd}} \quad (40)$$

Following cases obtained from clause 3.2.3 of SP-16 have been used to plot interaction charts in MS Excel.

1. When the neutral axis lies outside the section.

$$\frac{P_u}{f_{ck}bD} = C_1 + \sum_{i=1}^{n} \frac{p_i}{100 f_{ck}} (f_{si} - f_{ci}) \quad (41)$$

$$\frac{M_u}{f_{ck}bD^2} = C_1 (0.5 - C_2) + \sum_{i=1}^{n} \frac{p_i}{100 f_{ck}} (f_{si} - f_{ci}) \left(\frac{y_i}{D} \right) \quad (42)$$

2. When the neutral axis lies within the section.

$$\frac{P_u}{f_{ck}bD} = 0.36k + \sum_{i=1}^{n} \frac{p_i}{100 f_{ck}} (f_{si} - f_{ci}) \quad (43)$$

$$\frac{M_u}{f_{ck}bD^2} = 0.36k(0.5 - 0.416k) + \sum_{i=1}^{n} \frac{p_i}{100 f_{ck}} (f_{si} - f_{ci}) \left(\frac{y_i}{D} \right) \quad (44)$$

$$k = \frac{x_u}{D} \quad (45)$$

Where,

C_1 = coefficient for the area of stress block to be taken from Table H (SP-16 clause 3.2.2),

$p_i = \dfrac{A_{si}}{bD}$ where A_{si} is the area of reinforcement in the ith row,

f_{si} = stress in ith row of reinforcement, compression being positive and tension being negative;

f_{ci} = stress in concrete at the level of ith row of reinforcement;

n = number of rows of reinforcement.

$C_2 D$ = distance of the centroid of the concrete stress block, measured from the highly compressed edge,

y_i = distance from the centroid of the section to the ith row of reinforcement; positive towards the highly compressed edge and negative towards the least compressed edge.

V. CONCLUSION

The objective for automation of Design of R C Beams and Columns using MS Excel and Open STAAD have been accomplished. The above Analysis and Design problem has been verified with standard Text Books. It reduces time, as compare to manual calculation for Design of Beam and column elements of a large project.

In future automation of the design processes for RC elements and optimization of RC elements can be carried out. The reactions retrieved from Open STAAD to MS Excel will be useful in advanced foundation design.

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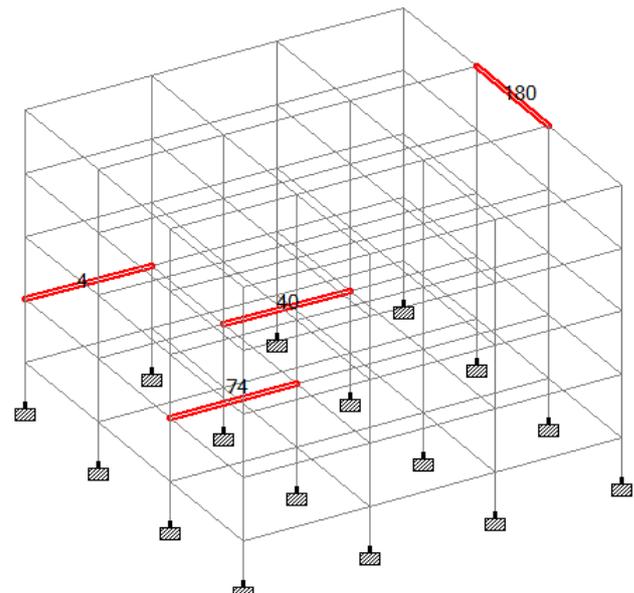
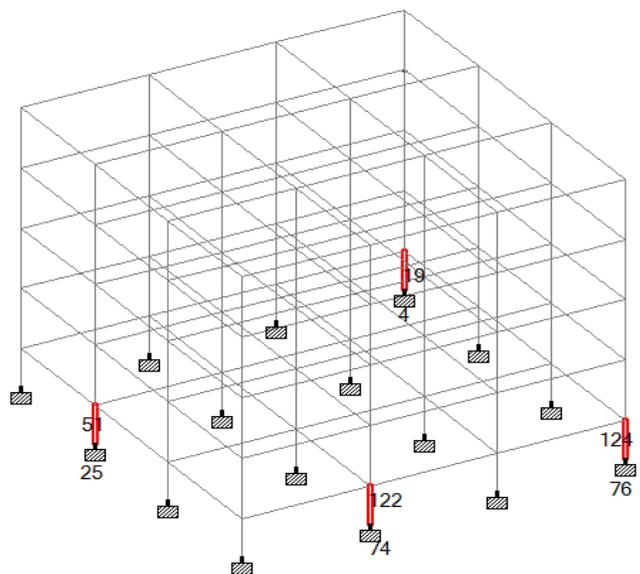**Fig. 1: Selected Beams in STAAD Pro for the design**

Fig. 2: Selected Columns in STAAD Pro for the design

DESIGN OF RC BEAMS

Clear cells   GET REACTIONS

LOAD CASES	BEAM NO.	CONTI. BEAM / BEAM TYPE	LC	Breadth(b) mm	Depth (D) mm	Length h m	Max. BM Mz(+ve) @Support	Mz(-ve) @Span	Max. shear force Fy(+ve)	Fy(-ve)	M_{ulim}
4	4	CONTI. BEAM	4	300.00	600	7.5	293.11	158.43	192.75	205.66	318.15
	180	CONTI. BEAM	4	300.00	600	7.5	197.79	70.98	116.53	116.54	318.15
	40	CONTI. BEAM	4	300.00	600	7.5	394.31	221.34	252.59	252.59	318.15
	74	CONTI. BEAM	4	300.00	600	7.5	421.31	239.97	240.61	264.56	318.15

DESIGN

BEAM NO.	Reinforcement @Support Top	Bottom	Reinforcement @Span Bottom	Top	L_d of bars (mm)	Dia of bar	Stirrups Spacing No. of legs	support	Mid	L/d prov.	L/d permi.
4	1781.52	340.72	866.69	340.72	775	8	2.00	200.00	200.00	13.53	37.18
180	1111.82	340.72	368.26	340.72	775	8	2.00	200.00	300.00	13.53	51.18
40	2404.81	425.31	1266.09	340.72	775	8	2.00	150.00	150.00	13.53	32.06
74	2551.74	576.10	1392.82	340.72	775	8	2.00	150.00	150.00	13.53	29.70

Fig. 3: Beam forces obtained from STAAD Pro to MS Excel

	fck	25	B, mm	400	Reinforcement	Nos	Dia, mm
1	fy	415	D, mm	600	Top	3	12
4	Length	4.00	Clear cover	40	Middle	0	12
			Eff cover	48	Bot	3	12

Reinforcement opposite two sides   **DESIGN OF RC COLUMNS**

Clear cells   Get Reactions

Load cases	Node	Memeber NO.	LC	Breadth(b)	Depth (D)	Leff (mm)	Axial Load Pu	Actual Moments Mx	Mz
4	74	122	4	400	600	2600	2998.579	0.358	0.039
	76	124	4	400	600	2600	1985.022	23.336	29.043
	25	51	4	400	600	2600	3051.562	4.500	10.828
	4	19	4	400	600	2600	1985.016	23.328	29.041

Design

Node	design moments Mux	Muz	%p	$(Mux/Muxa)^{\alpha n}+(Muz/Muza)^{\alpha n}$	CHECK	Lateral ties Dia	Spacing	L_d of bars (mm)
74	75.564	59.972	0.838	0.391	DESIGN IS SAFE	6	255	965
76	50.023	39.700	0.838	0.133	DESIGN IS SAFE	6	255	965
25	76.899	61.031	0.838	0.429	DESIGN IS SAFE	6	255	965
4	50.022	39.700	0.838	0.133	DESIGN IS SAFE	6	255	965

Fig. 4: Reactions for columns obtained from STAAD Pro to MS Excel