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Structural Design : Comparison between STAAD Pro and Manual Calculation

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Abstract : Structural design is an art and science of constructing a systems that are economical, practical and resilient. In general, this project is an application of theorectical design knowledge combined with practical skill of utilizing modern engineering tools. A structural frame is selected as design model. Engineering data partaining to design process such as type of materials, geometrical arrangement adnd sizing were feeded into STAAD Pro. Analysis was run according to prevalent code of practice. The output generated is feed into AUTOCAD to produce working engineering drawing. To comply with standard engineering practice, output from any automated design software such as STAAD Pro is counter check with manual calculation. Outcome of this project prove that both output were within reasonable engineering expectation. Using software for design process did expedite time and reduce error, but familiarity with using commands and procedures is necessary.

Keywords: Structural Design, Code of Practice, STAAD Pro.

1. Introduction

This project is a building structural design through modelling, analysis and production of technical drawings using a specific software suitable for use by Diploma's level students.

There are many software available for structural engineering design such as Linpro, Skyciv, SAP200, Esteem, Tekla and STAAD Pro. For this project, STAAD Pro will be used because this software is readily available as part of UTHM online facility.

1.1 Project Aim:

The general aim of this project is to analyze a multi-storied building design of a residential building using STAAD Pro and compare the output with manual calculations. The specific expected outcome of this project are as follow:

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1. Skillfully navigate the required commands and parameters during data input process in StaadPro to produce a design that would comply with acceptable engineers standards, specification and professional practice.
2. Applying knowledge learned during the course of Diploma study to produce manual calculation as mean of comparison against StaadPro output.

1.2 General

Historically, preparing a design and documentation for an engineering project would comprise process of calculation for structural analysis, calculation in design step and drawing production based on project and the tender they received. The only way they carried out their task was by manual methods by using a formula and hand calculator. This is on inefficient and time consuming especially for big scale project or when fast information on modification is needed.

2. Materials and Methods

Most of design concrete in Malaysia was based on British Standard (BS 8110) Code of Practice. Within the improvement of technology and change of time, Eurocode 2 (EC2) has been introduced to Malaysia as a new guideline in design concrete structure. There have few differences between BS 8110 and EC2 in design specification where EC2 are less prescriptive than the British Standards, with more aspects left open to the designer. [1]

2.1 Building material

Dead load and imposed loads: Dead loads and imposed loads may be calculated according to British Standard Code of Practice (BSCP 3 Chap V Part 1). [2] It should be applied to new buildings and new structure, structural alterations and addition to existing buildings and existing structures. Dead loads can be calculated from unit weight given in BS 648 or from the original weights of materials used.

2.2 Type of Materials Used

Reinforced Concrete

Reinforced concrete is concrete in which steel is embedded in such way that the two materials act together in resisting forces. In the reinforced concrete, the tensile strength of the steel and compressive stress of the concrete will work together to ensure the member can withstand these stresses over the considerable spans. For this project, the adopted code of practice is BS 8110. [3]

Steel Section

The Eurocode is a set of structural design standards, was developed by CEN (European Committee for Standardisation) over last 30 years, to combine all types of structures in steel, concrete, timber, masonry and also aluminium. In the UK, it was developed by BSI under designations BS EN 1990 to BS EN 1999. [4] Figure 1 shows sample of nominal values of basic yield strength f_{yb} and ultimate tensile strength f_u.

Type of steel	Standard	Grade	f_{yb} N/mm²	f_u N/mm²
Hot rolled products of non-alloy structural steels. Part 2: Technical delivery conditions for non alloy structural steels	EN 10025: Part 2	S 235	235	360
		S 275	275	430
		S 355	355	510
Hot-rolled products of structural steels. Part 3: Technical delivery conditions for normalized/normalized rolled weldable fine grain structural steels	EN 10025: Part 3	S 275 N	275	370
		S 355 N	355	470
		S 420 N	420	520
		S 460 N	460	550
		S 275 NL	275	370
		S 355 NL	355	470
		S 420 NL	420	520
		S 460 NL	460	550
Hot-rolled products of structural steels. Part 4: Technical delivery conditions for thermomechanical rolled weldable fine grain structural steels	EN 10025: Part 4	S 275 M	275	360
		S 355 M	355	450
		S 420 M	420	500
		S 460 M	460	530
		S 275 ML	275	360
		S 355 ML	355	450
		S 420 ML	420	500
		S 460 ML	460	530

Figure 1: Nominal values of basic yield strength f_{yb} and ultimate tensile strength f_u

2.3 STAAD Pro Software

STAAD Pro is a structural design oriented software with interactive user interface. It can be used for modelling, designing and analyzing various type structures and structural configurations. Designs can include building structures incorporating culverts, petrochemical plants, bridges, tunnels, piles and construction materials such as timber, steel, concrete, aluminium and cold-formed steel. [5]

2.4 Methods

Following are detail steps planned and undertook for the execution of this project:

Step 1: In order to be able to run the program smoothly, the application and functions of the selected software, including STAAD Pro and Esteem software were learn consecutively.

Step 2: Using the respective tools, a few working examples which were available in the software manuals were tried out.

Step 3: By evaluating and comparing the result output obtained from the various work examples using the two selected software and manual measurement, the efficacy of the software was checked.

Step 4: The columns were constructed using the manual calculation. It calculated the amount of the reinforcement needed in the columns of the various structural models. The manual calculation was used to calculate these fixed column sizes because it employed the most traditional approaches to design.

Step 5: In order to validate the efficiency of the selected program in generating the most economical and feasible column design with regard to manual calculation, the resulting outputs were compared. [6]

2.5 Equations

Following are sample of equations referred for this project:

Wind Load

$$\text{Design wind pressure, p} = C_e \times C_q \times Q_s \quad \textbf{Eqn. 1}$$

The wind stagnation pressure, Qs is calculated using the following equation.

$$Q_s = 0.00256 \times V^2 \quad \textbf{Eqn. 2}$$

Load Combination

$$\text{Dead Load} + \text{Imposed Load} + \text{Wind Load} \quad \textbf{Eqn. 3}$$

3. Results and Discussion

Some of the sample analysis and design results have been shown below.

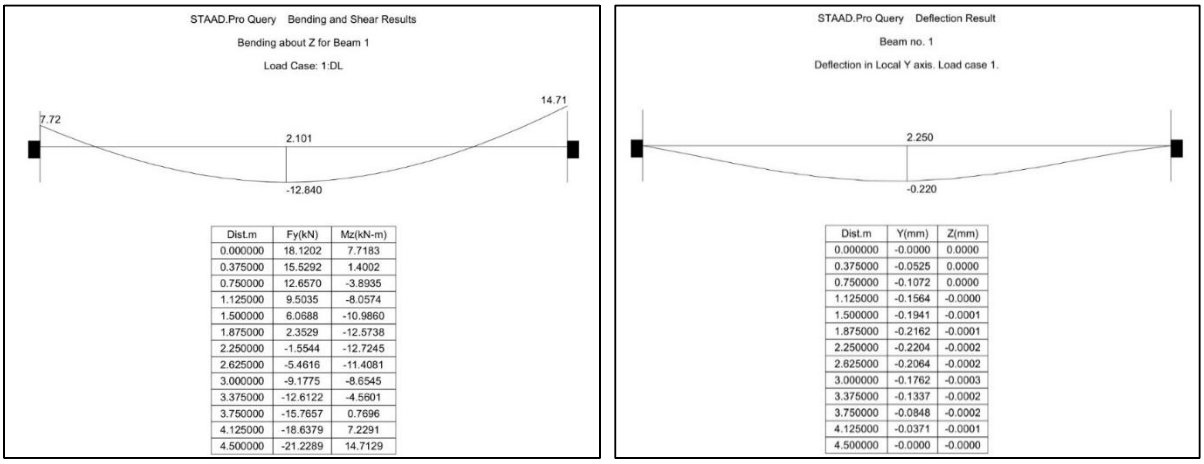
3.1 Results from STAAD Pro

Figure 2 shows the reaction summary output result for all the building's support.

	Node	L/C	Horizontal FX (kN)	Vertical FY (kN)	Horizontal FZ (kN)	Moment MX (kN¯m)	MY (kN¯m)	MZ (kN¯m)
Max FX	11	3:ULC, 1.4 DE	13.532	205.032	-4.177	-1.348	0.010	-4.924
Min FX	35	3:ULC, 1.4 DE	-17.806	218.592	-22.303	-8.016	0.002	6.661
Max FY	34	3:ULC, 1.4 DE	10.434	298.096	-24.213	-8.483	0.019	-3.901
Min FY	15	2:LL	-0.692	20.630	5.523	1.854	0.010	0.297
Max FZ	15	3:ULC, 1.4 DE	-2.525	135.321	20.554	6.905	0.037	1.091
Min FZ	34	3:ULC, 1.4 DE	10.434	298.096	-24.213	-8.483	0.019	-3.901
Max MX	47	3:ULC, 1.4 DE	1.561	184.351	20.487	7.154	0.002	-0.485
Min MX	34	3:ULC, 1.4 DE	10.434	298.096	-24.213	-8.483	0.019	-3.901
Max MY	15	3:ULC, 1.4 DE	-2.525	135.321	20.554	6.905	0.037	1.091
Min MY	35	2:LL	-4.737	41.733	-6.002	-2.153	-0.000	1.771
Max MZ	35	3:ULC, 1.4 DE	-17.806	218.592	-22.303	-8.016	0.002	6.661
Min MZ	11	3:ULC, 1.4 DE	13.532	205.032	-4.177	-1.348	0.010	-4.924

Figure 2 : Reaction summary

Figure 3 shows the comparison of shear, bending moment and deflection of beam no. 1.



Dist.m	Fy(kN)	Mz(kN-m)
0.000000	18.1202	7.7183
0.375000	15.5292	1.4002
0.750000	12.6570	-3.8935
1.125000	9.5035	-8.0574
1.500000	6.0688	-10.9860
1.875000	2.3529	-12.5738
2.250000	-1.5544	-12.7245
2.625000	-5.4616	-11.4081
3.000000	-9.1775	-8.6545
3.375000	-12.6122	-4.5601
3.750000	-15.7657	0.7696
4.125000	-18.6379	7.2291
4.500000	-21.2289	14.7129

Dist.m	Y(mm)	Z(mm)
0.000000	-0.0000	0.0000
0.375000	-0.0525	0.0000
0.750000	-0.1072	0.0000
1.125000	-0.1564	-0.0000
1.500000	-0.1941	-0.0001
1.875000	-0.2162	-0.0001
2.250000	-0.2204	-0.0002
2.625000	-0.2064	-0.0002
3.000000	-0.1762	-0.0003
3.375000	-0.1337	-0.0002
3.750000	-0.0848	-0.0002
4.125000	-0.0371	-0.0001
4.500000	-0.0000	-0.0000

Figure 3 : Shear, bending moment and deflection of beam no. 1

Figure 4 shows summary of stress for plate center.

			Shear		Membrane			Bending		
	Plate	L/C	Qx (N/mm²)	Qy (N/mm²)	Sx (N/mm²)	Sy (N/mm²)	Sxy (N/mm²)	Mx (kN·m/m)	My (kN·m/m)	Mxy (kN·m/m)
Max Qx	125	3:ULC, 1.4 DE	0.013	0.005	-0.002	-0.022	-0.002	-0.916	0.341	-0.225
Min Qx	123	3:ULC, 1.4 DE	-0.009	0.015	-0.018	-0.004	-0.001	0.754	-0.885	0.202
Max Qy	123	3:ULC, 1.4 DE	-0.009	0.015	-0.018	-0.004	-0.001	0.754	-0.885	0.202
Min Qy	120	3:ULC, 1.4 DE	0.007	-0.004	-0.004	-0.015	0.003	-0.739	0.316	0.056
Max Sx	121	2:LL	-0.000	-0.001	-0.001	-0.003	0.000	-0.091	0.106	-0.005
Min Sx	124	3:ULC, 1.4 DE	-0.001	0.001	-0.018	-0.016	-0.001	0.952	0.624	-0.029
Max Sy	123	2:LL	-0.002	0.004	-0.005	-0.001	-0.000	0.202	-0.238	0.055
Min Sy	125	3:ULC, 1.4 DE	0.013	0.005	-0.002	-0.022	-0.002	-0.916	0.341	-0.225
Max Sxy	120	3:ULC, 1.4 DE	0.007	-0.004	-0.004	-0.015	0.003	-0.739	0.316	0.056
Min Sxy	125	3:ULC, 1.4 DE	0.013	0.005	-0.002	-0.022	-0.002	-0.916	0.341	-0.225
Max Mx	124	3:ULC, 1.4 DE	-0.001	0.001	-0.018	-0.016	-0.001	0.952	0.624	-0.029
Min Mx	125	3:ULC, 1.4 DE	0.013	0.005	-0.002	-0.022	-0.002	-0.916	0.341	-0.225
Max My	129	3:ULC, 1.4 DE	0.000	-0.001	-0.010	-0.011	0.000	0.807	0.932	-0.039
Min My	123	3:ULC, 1.4 DE	-0.009	0.015	-0.018	-0.004	-0.001	0.754	-0.885	0.202
Max Mxy	123	3:ULC, 1.4 DE	-0.009	0.015	-0.018	-0.004	-0.001	0.754	-0.885	0.202
Min Mxy	125	3:ULC, 1.4 DE	0.013	0.005	-0.002	-0.022	-0.002	-0.916	0.341	-0.225

Figure 4 : Plate center stress summary

Figure 5 shows the interface for properties selection in STAAD Pro.

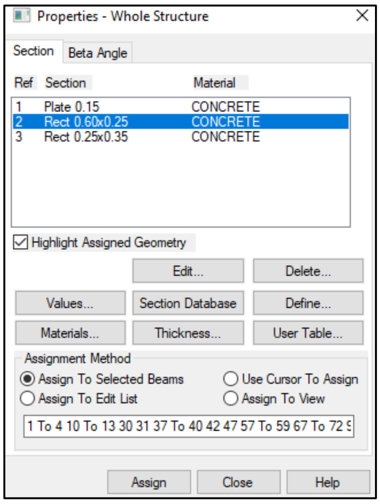


Figure 5 : Interface for Properties in STAAD Pro

Figure 6 shows full 3D view of project using STAAD Pro software.

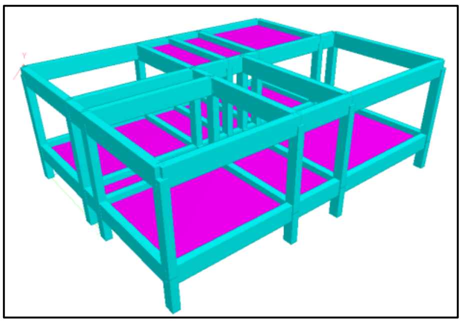


Figure 6 : 3 Dimensional view

3.2 Results from manual calculation design

This section shows brief output data from manual calculation for selected element for comparison. Detail calculation steps are presented in APPENDIX.

Slab design

Figure 7 shows a slab for panel 1 of the structure.

Slab thickness : 200 mm
Concrete grade : 25 N/mm^2
Steel grade : 460 N/mm^2
Weight of concrete : 25 kN/m^3

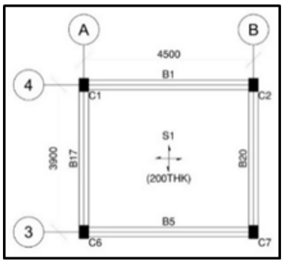


Figure 7 : Slab panel 1

Beam design

Figure 8 shows result of beam no 1 of the structure.

Beam size : 250 mm × 600 mm
Beam length : 4500 mm
Concrete grade : 25 N/mm^2
Steel grade : 460 N/mm^2
Weight of concrete : 25 kN/m^3

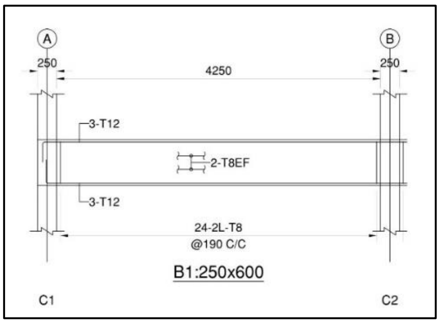


Figure 8 : Beam no. 1 section

Column design

Figure 9 shows the detail of column no 1 of the structure.

Column size : 250 mm × 350 mm
Weight of concrete : 25 kN/m^3
Concrete grade : 25 N/mm^2
Steel grade : 460 N/mm^2

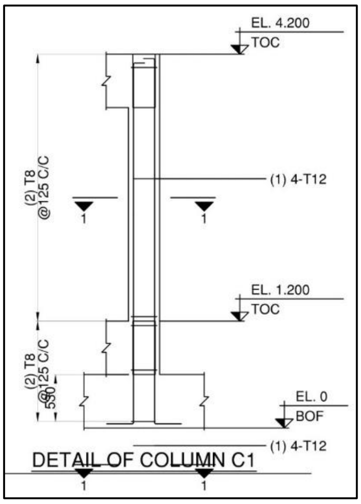


Figure 9 : Column no. 1 section

3.3 Comparison

Table 1 : Results comparison between STAAD Pro and manual design calculation

Parameter	STAAD Pro	Manual design calculation
Slab thickness	150 mm	200 mm
Beam size	250 mm × 600 mm	250 mm × 600 mm
Column size	250 mm × 350 mm	250 mm × 350 mm
Concrete grade	25 N/mm^2	25 N/mm^2
Steel grade	460 N/mm^2	460 N/mm^2
Weight of concrete	25 kN/m^3	25 kN/m^3

Table 1 summarize various value of design output between STAAD Pro and manual design calculation while others parameters remain constant.

3.4 Discussion

Figure 10 shows the analysis and design results. It can be concluded that this project had no failures for the analysis and design. This is because there are 0 Error (s), 0 warning (s) and 0 note (s). So that means, the residential building is safe to occupy.

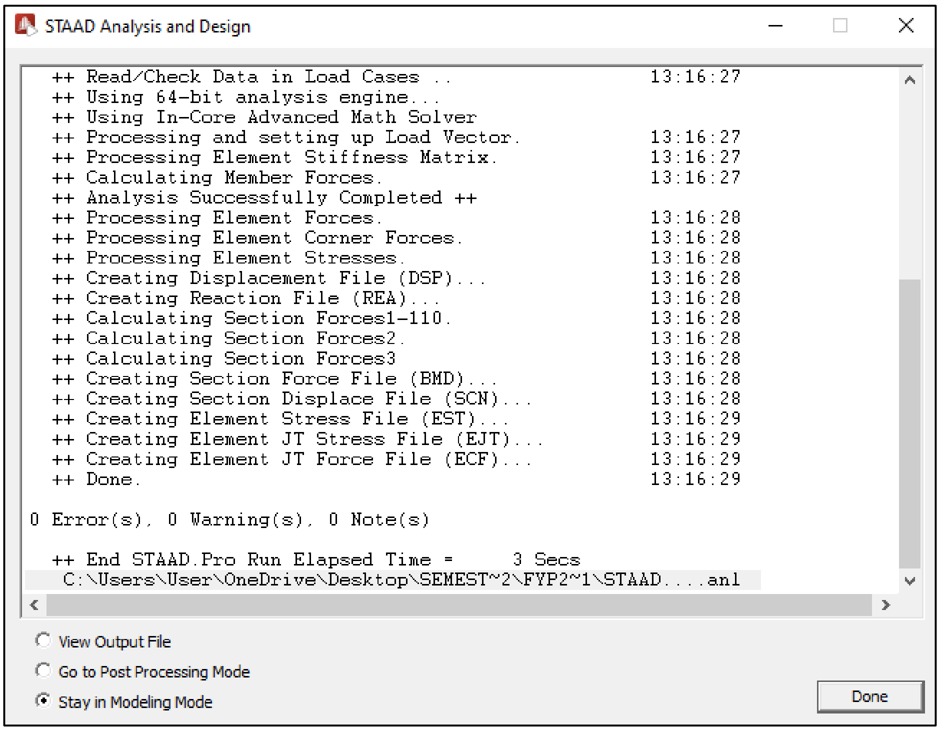


Figure 10 : Analysis and design results

4. Conclusion

Overall, it can be said this project has achieved its objectives that is produce a satisfactory design of a single-storey building using STAAD Pro software. Comparison with manual calculation also yield satisfactory deviation. The employment of AutoCAD software to produce final engineering drawing also enhance the suitability of STAAD Pro.

Acknowledgement

The authors would also like to thank the Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia for its support.

Appendix

1. Slab Design

Bending (short span) :

$M_{sx} = \alpha_{sx}\, n\, l_x^2 = (0.084)(15.3)(3.9)^2 = 19.55$ kNm

Exposure XC2, minimum cover = 35 mm

Assume bar size = 10 mm

d = 200 – 35 – 10/2 = 160 mm

$K = M_{sx} / bd^2 f_{ck} = 19.55 \times 10^6 / 1000(160)^2(25) = 0.031$

$z/d = 0.5\left[1+\sqrt{1-3.53K}\right] = 0.5\left[1+\sqrt{1-3.53(0.031)}\right] = 0.97$ (Use z = 0.95d)

z = 0.95(160) = 152 mm

$A_{sx} = M_{sx} / 0.87\ f_{yk}\ z = 19.55 \times 10^6 / 0.87(460)(152) = 321\ mm^2/m$

Provide H10 at 200 mm centre, $A_s = 393\ mm^2/m$

Bending (long span) :

$M_{sy} = \alpha_{sy}\ n\ l_y^2 = (0.059)(15.3)(3.9)^2 = 13.73\ kNm$

d = 200 - 35 - 10 - 5 = 150 mm

$K = M_{sy} / bd^2 f_{ck} = 13.73 \times 10^6 / 1000(150)^2(25) = 0.024$

$z/d = 0.5\left[1+\sqrt{1-3.53K}\right] = 0.5\left[1+\sqrt{1-3.53(0.024)}\right] = 0.98$ (Use z = 0.95d)

z = 0.95(150) = 143 mm

$A_{sy} = M_{sy} / 0.87\ f_{yk}\ z = 13.73 \times 10^6 / 0.87(460)(143) = 240\ mm^2/m$

Provide H10 at 300 mm centre, $A_s = 262\ mm^2/m$

2. Beam design

Maximum design moment at mid span = $wL^2/8 = 39.80(4.5)^2/8$

= 100.74 kNm

Assume; Link = 10 mm, Bar = 20mm

d = h - cover - link - diameter – bar size/2

= 600 - 25 - 10 - 20/2 = 555 mm

$$K = \frac{M}{bd^2 f_{ck}} = \frac{100.74 \times 10^6}{(250)(555)^2(25)}$$

= 0.052 < 0.167 OK

$$z = \frac{d}{2}\left[1+\sqrt{1-3.53K}\right] \leq 0.95d = \frac{555}{2}\left[1+\sqrt{1-3.53(0.052)}\right] \leq 0.95(555)$$

= 528 mm > 527 mm (Use = 527 mm)

Tension steel require, A_s =

$$\frac{Md}{0.87 f_{yk} z} = \frac{100.74 \times 10^6}{0.87(460)(527)}$$

= 478 mm^2 628 mm^2, 2 Nr, 20 mm diameter

Minimum reinforcement:

C25 minimum of reinforcement :

$0.14\% \times bh = (0.14)(250)(600) / 100 = 210\ mm^2$

$628\ mm^2 > 210\ mm^2$ OK

Maximum reinforcement provide :

$$\frac{628}{(250)(600)} \times 100\ \% = 0.42\ \% < 4\ \%$$

Minimum spacing between bar :

- Max bar size = 20 mm
- 20 mm, aggregate size
- Maximum aggregate size + 5 = 20 (assume) + 5 = 25 mm

Check bar spacing :

250 - 25(cover) - 25(cover) - 10(link) - 10(link) - 20(diameter) - 20(diameter) = 140 mm > 25 mm OK

Maximum spacing between bars :

$435(g_k + 0.87q_k) / 1.35g_k + 1.5q_k$

$g_k = 19.48 \times 4.5 = 87.66$ kN

$q_k = 9 \times 4.5 = 40.5$ kN

Steel stress = 435 [87.66 + 0.8(40.5)] / 1.35(87.66) + 1.5(40.5)

= 292 N/mm^2

Maximum spacing = 150 mm > 140 mm Accept; OK

3. Column design

The clear height is 3000 – 600 = 2400 mm

l_o = 0.75 X clear height = 0.75 × 2400 = 1800 mm

l_o / b = 1800 / 600 = 14.25

Limiting l_o /b = $6.19\sqrt{(bhf_{ck}/N_{Ed})}$

= $6.19\sqrt{((250 \times 350 \times 25)/(1100 \times 10^3)}$

= 8.73

14.25 > 8.73, the column is slender

$N/bhf_{ck} = 1100 \times 10^3 / (250 \times 350 \times 25) = 0.5$

$A_s = 0.17 \text{ X}10^{-3} \times 250 \times 350 \times 25 = 372$ mm^2

$0.12N/f_{yk} = 0.12 \times 1100 \times 10^3 / 460 = 287$ mm^2

or 0.002 bh = 0.002 × 250 × 350 = 175 mm^2

Provide Nr 4, H12 bars,

$A_{s,prov}$= 452 mm^2

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