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Design Of A Composite Truss System In A Multistorey Building

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***Abstract*— The design specifications of composite trusses are only partially included in Euro code standards. However, this construction system can be considered as one of the most economical for building and bridge structures. The composite trusses can be used for greater spans up to 30 m, which allows better use of internal space without restricting the columns. They are appropriate also to meet the requirements for building height limitation, the need to run complex installation systems. To create the interaction between steel and concrete, it is necessary to prevent the relative slip at the steel and concrete interface using the shear connectors. Whereas the local effects of a concentrated longitudinal force and the distribution of the shear force between the steel section and the concrete slab, as special task, should be appropriately examined. In this research, composite truss of 10m span is considered. The finite element analysis using ROBOT and STAADPRO software packages was used to investigate and compare numerically to determine the structural system behaviour. The total deflection results obtained in the manual and software design satisfy permissible deflection which must be < l/365. This shows that composite truss system provides the best solution in the range of 10m span with a least steel weight.**

Keywords—Composite truss, shear connection, numerical study, ROBOT and STADPRO.

INTRODUCTION

Composite steel-concrete trusses can be considered as one of the most economical systems for building, especially for greater spans, commonly to the 20 m. The continuous structural elements of this composite type can be used for even greater spans up to the 30 m, which allows better use of internal space without restricting columns [1].

The trusses are appropriate also to meet the requirements for building height limitation as well as the need to run complex electrical, heating, ventilating, and communication systems. Also composite steel bridges, whose carriageway deck is supported on a filigree steel truss structure and slim piers, are particularly preferable especially to ordinary concrete bridges. Primarily considering the technical and architectural aspects as well as compromise between protections of the landscape on the one hand and hard transports necessities on the other. Thus a composite truss bridge, with its speedy assembly engineering can be a structural type which is both economically and aesthetically attractive. To create the interaction between steel parts and concrete, it is necessary to prevent the relative slip at the steel-concrete interface using the shear connectors. But the local effects of a concentrated longitudinal force and the distribution of the shear force between steel section and concrete slab, as special task, should be appropriately examined. The finite element analyses can be used to investigate numerically this structural system behavior, exploiting several computer procedures [2]. In multi-story buildings, the composite truss systems also reduce the total height of the building, by accommodating the services (heating, ventilation, lighting and telecommunication ducts) within the depth of the truss, thus integrating structural, mechanical and electrical systems within the floor space. This minimizes the inter-floor height. Considering functional and structural efficiency and economy, it is only natural that composite steel-concrete trusses are a popular choice for long span and high-rise construction.

1.2 Structural Framing of Composite truss

Experiences abroad have shown that trusses are economically viable for spans greater than 20m. Composite truss system are most often used with composite slabs comprising steel decking which act as a main reinforcement and permanent shuttering. Other system such as pre-cast planks or cast in situ slab can be used but are usually less cost effective.

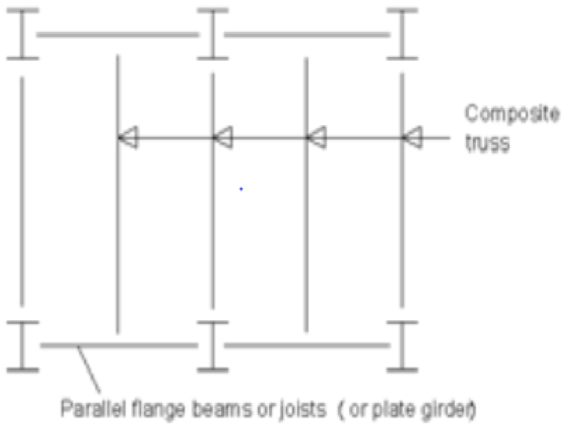

Fig. 1: Composite truss used as secondary beam

1.3 Truss shear connections

In Euro code, there is no particular recommendation for the design of composite truss, except the formulas in EC 4 [1], clause 6.6.2.3 for the local effect of a concentrated longitudinal force and the distribution of the longitudinal shear force into local shear flow between steel section and concrete slab. In the case of a composite truss, the longitudinal forces are introduced into the concrete slab similarly only locally in the nodes, where the web members are connected to the compressed chord.

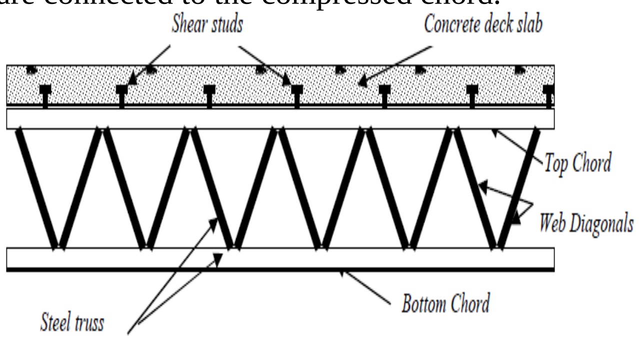

Fig. 2: Geometrical composite truss system

1.4 Shear connection Properties

First of all the influence of the connectors size considering numerous theoretical values of shank diameter varying on truss beam stiffness. These values represent the progression of the degree of shear stud connection in the truss from no connection to full interaction. It was recognized that the usual diameter of 19 mm is quite sufficient to obtain a full connection. Moreover, the composite effect obtained by the shear connector diameter variation can increase even twice the stiffness of the truss with no connection in comparison to the composite truss beam with full connection.

In case of very long span length pitched roof, trusses having trapezoidal configuration, with depth at the ends are used. This configuration reduces the axial forces in the chord members adjacent to the supports. The secondary bending effects in these members are also reduced. The trapezoidal configurations having the sloping bottom chord can be economical in very long span trusses (spans > 30 m), since they tend to reduce the web member length and the chord members tend to have nearly constant forces over the span length. It has been found that bottom chord slope equal to nearly half as much as the rafter slope tends to give close to optimum design.

2.0 METHODOLOGY

To determine the basic component like displacement and base shear, this design has been carried out using manual design of composite truss system as well as finite elements software packages such as ROBOT and STAADPRO V8I and comparing both results for the design purpose.

2.1 Building Modeling

In this building model composite truss of multistory structures is considered. The building models, properties of the considered composite trusses models are detailed below here.

2.2 Material Properties

The materials used for design of composite truss models construction is reinforced concrete with M-25 grade of concrete and fc-415 grade of steel and the stress-strain relationship is used as per Euro code 4.

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Table 1: Materials

Material	Name	E (kN/mm²)	V	Density (kg/m³)	□ (/°C)
2	STEEL	205.000	0.300	7.83E 3	12E -6
3	STAINLESSSTEEL	197.930	0.300	7.83E 3	18E -6
4	ALUMINUM	68.948	0.330	2.71E 3	23E -6
5	CONCRETE	21.718	0.170	2.4E 3	10E -6

2.3 Section Properties

Table 2: Section properties

Prop	Section	Area (cm2)	I_{yy} (cm4)	I_{zz} (cm4)	J (cm4)	Material
2	UA150X150X10	29.300	1.01E 3	262.165	9.833	STEEL
3	UA70X70X6	8.130	59.931	15.689	0.986	STEEL

2.4 MODEL

Three dimensional models considered for the design purpose of composite truss system.

3.0 RESULTS

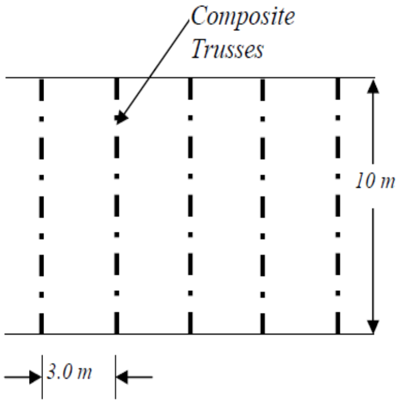
3.1 Manual results

PROBLEM:

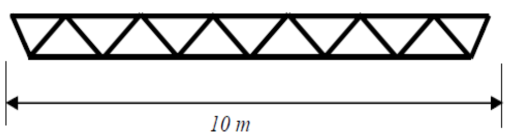
Design a composite truss of span 10.0 m with following data:

DATA:

Span = l = 10.0 m
Truss spacing = 3.0 m
Slab thickness = D_s = 175 mm
Profile depth = D_p = 75.0 mm
Self weight of deck slab = 3.0 kN/m2
Maximum laterally un-restrained length in top chord is 1.5 m.
Grade of concrete, M25 =$(f_{ck})_{cu}$=25 MPa



FLOOR PLAN



TRUSS ELEVATION

Loading:

Loading	kN/m2	Factored Load (kN/m2)
Deck slab weight	*3.0*	*3.0*1.5 = 4.50*
Truss weight (assumed)	*0.4*	*0.4*1.5 = 0.60*
Ceiling, floor finish and Services	*1.0*	*1.0*1.5 = 1.5*
Construction Load	*1.0*	*1.0*1.5 = 1.5*
Superimposed live load	*5.0*	*5.0*1.5 = 7.5*

PRE-COMPOSITE STAGE:

Loading	*kN/m2*	*Factored Load (kN/m2)*
Deck slab weight	*3.0*	*3.0*1.5 = 4.50*
Truss weight	*0.4*	*0.4*1.5 = 0.60*
Construction load	*1.0*	*1.0*1.5 = 1.5*

Total factored load = 6.60 kN/m2

Choose depth of truss = Span/20 = 10000/20

= 500 mm

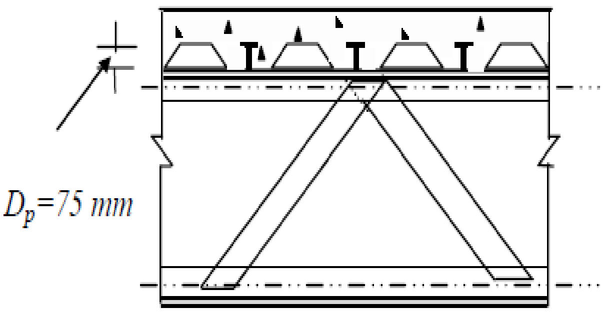
*Total factored load = 6.60 * 3 = 19.8 kN/m*

Maximum bending moment $= wl^2/8 = 19.8 * 10^2/8 = 247.5$ *kN-m*

Maximum shear $= wl/2 = 19.8*10/2$ *= 99.0 kN*

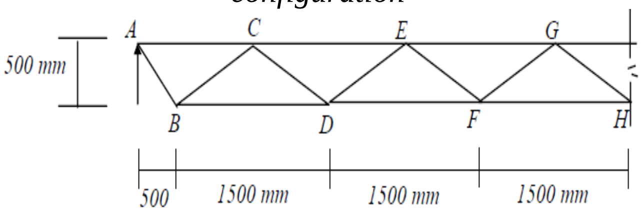
Depth of truss (centre to centre distance of chords) = 0.5 m

Maximum axial compressive force in top chord = 247.5/0.5 =495.0 kN



$D_t = 500 + x_t + x_b$

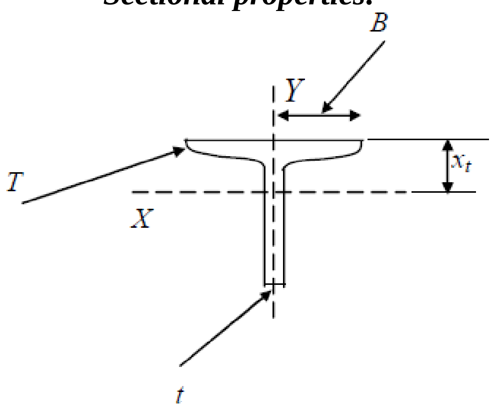
Truss configuration: *Choose the following truss configuration*



Top chord design:

Try ISNT 150 X 150 X 10 mm @ 0.228 kN/m

Sectional properties:



Area of cross-section = A_t = 2908 mm^2

Depth of section = 150 mm

Width of section, b = $2b_1$ = 150 mm

Thickness of flange = T = 10.0 mm

Thickness of web = t = 10.0 mm

Centre of gravity = x_t = 39.5 mm

r_{xx} = 45.6 mm

r_{yy} = 30.3 mm

Section classification:

$\varepsilon = (250/f_y)^{0.5} = (250/250)^{1/2} = 1.0$

Flange:

$b^1/T = 75/10 = 7.5 < 8.9\varepsilon$ Flange is plastic

Web:

$d/t = 140/10 = 14$ ($>9.98^{\varepsilon}$ and $< 19.95^{\varepsilon}$) Web is semi-compact

As no member in the section is slender, there is no need of adopting reduction factor (Yielding govern).

Given, maximum un-restrained length of top chord is 1.5 m during construction stage.

Maximum unrestrained length = l_y = 1500 mm

*l_x = 0.85*1500 = 1275 mm*

r_{xx} = 45.6 mm

r_{yy} = 30.3 mm

lamda $_x$ = 1275/45.6 = 28

lamda $_y$ = 1500/30.3 = 49.5

Then, δ_c = 202.8 N/mm2 [From Table - 3 of Chapter on axially compressed Columns]

*Axial capacity = (202.8/1.15)*2908/1000 = 512.8 kN > 437.4 kN*

*Axial capacity = (202.8/1.1)*2908/1000 =536.13 kN > 481.96 kN*

Hence, section is safe against axial compression at construction stage.

[Other member design is governed by composite loading]

COMPOSITE STATE:

Factored Load (kN/m2)	kN/m2
Deck slab weight 3.0*1.5 = 4.50	3.0
Truss weight (assumed) 0.4*1.5 = 0.60	0.4
Ceiling, floor finish and Services 1.0*1.5 = 1.5	1.0
Superimposed live load 5.0*1.5 = 7.5	5.0
Total factored load (4.5+0.6+1.5+7.5)* 3	= 14.1*3

= 42.30 kN/m

Maximum bending moment (M_c) = $wl^2/8 = 42.3*10^2/8$ = 528.75 kN-m

*Maximum shear = wl/2 = 42.3*10/2 = 211.5 kN*

Bottom chord design:

Force in bottom chord, $R_{b,req}$ is given by: [See Fig. of the text]

$R_{b,req}\{D + x_t + D_s-(D_s-D_p)/2\} = M_c$

[Assume NA is in the concrete slab]

$R_{b,req}$ (500+39.5+(175-50))/1000 = 528.75

$R_{b,req}$ (664.5/1000) = 527.85 kN-m

$R_{b,req}$ = 528.75/0.6645 = 795719 kN

*Area required = 795.71*1000/(f_y/1.1)*

*=795.71*1000/(250/1.1) = 3501.124 mm^2*

Trial-1 *Trying ISHT 150 @ 0.294kN/m*

Sectional properties:

A = 3742 mm^2 ; x_b = Centre of gravity = 26.6 mm

Width of the section, b = 2b_1 = 250 mm

Axial tension capacity of the selected section (R_b):

R_b = (250/1.1) 3742/1000 = 850.46kN > 795.71 kN*

Hence, O.K.

Capacity of Composite Section in Compression:

Capacity of concrete slab, R_c, is given by

*R_c = 0.45 $(f_{ck})_{cu}$*b_{eff}*(D_s – D_p)*

***Effective width of the slab, b_{eff}:** [See the chapter Composite beams – II]*

b_{eff} □ □/4 = 10000/4 = 2500 mm

Therefore, b_{eff} = 2500 mm

*R_c = 0.45*20*2500*75/1000 {f_{ck} = 20 N/mm^2}*

= 1687.5 kN > R_b (tension governs)

Neutral axis depth :

*x_c = (D_s – D_p)*850.46/2812.5 = 100*850.46/2812.5 = 30.24 mm*

D_t = 0.5+0.0266+0.0395 = 0.566 mm

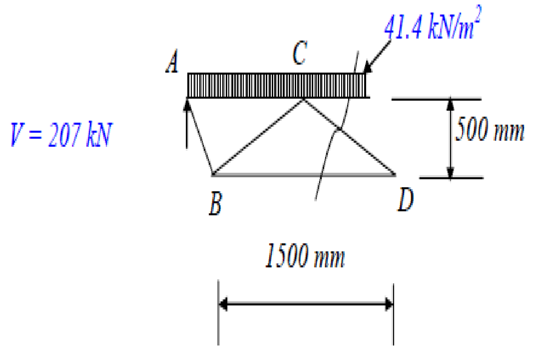
Then, maximum moment it can carry

*$M_{u,\ design}$ = 850.46(0.566+0.15-0.5*0.0302-0.0266)*

= 573.47 kN-m > 527.85 kN-m

Hence, the slab and chord members are designed.

Web members:



F_{AB} = V(1.414) =211.5(1.414) = 299.06kN (tension)

F_{BC} = (V-0.5 39.5) $(500^2+750^2)^{0.5}$/500 =345.68kN (compression)*

*F_{CD} =(V – 2.0*39.5) $(500^2+750^2)^{0.5}$/500 = 238.87kN (tension)*

Hence, maximum tensile force in bracing members =299.06kN

Maximum compressive force in bracing members =345.68 kN

Design of tension members:

*Trial gross area required =299.06*10^3/(250/1.1) =1315.86 mm^2*

Trying 2 – ISA 70 X70 X6 .0 @ 0.126 kN/m

*A_{gross} provided =2*806 =1612 mm^2*

Effective area:

(Assume, angle is welded to T- section)

$A_{net\ effective}$ = 1612 mm^2

Axial tension capacity = A_e(f_y/γ_m)*

*= 1612*250/1.1*

= 366.36 kN > 299.06 kN

Hence, 2 – ISA 70 X 70 X 6.0 are adequate

Design of compression member:

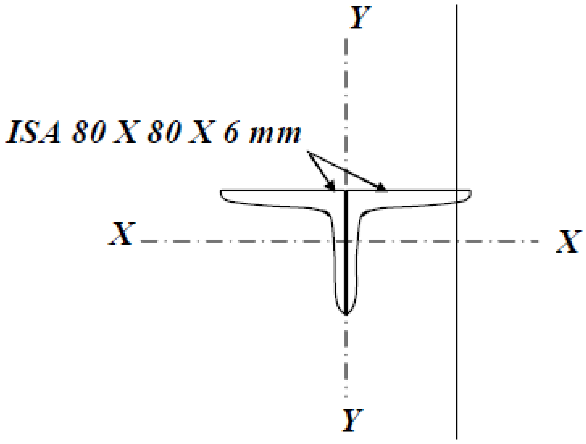
Maximum compressive load = 320 kN

Trying 2 – ISA 80 X 80 X 6.0 @ 0.146 kN/m

A = 1858 mm^2

r_{xx} = 24.6 mm

r_{uu} = 34.9 mm



Section classification:

b/t = 80/6 = 13.3 <15.75□

Hence, the section is not slender and no need to apply any reduction factor.

Slenderness ratio is taken as the greater of

Length of member = $(750^2 + 500^2)^{0.5}$ = 901 mm

*$□_{xx}$ = 0.85 * 901/24.6 = 31.1*

*$□_{xx}$ =1.0 * 901/ 34.9 =25.8*

Design buckling strength = $□_c$ = 231.2 Mpa

[Table – 3 of chapter on axially compressed columns]

Design compressive strength = 1858 (231.2/1.1)/10^3=390.52 kN > 335.86 kN*

Hence the 2 – ISA 80 X 80 X 6.0 are adequate for the web members

(The web members away from the support would have lesser axial force and can be redesigned, if so desired. Preferably use the same section for all web members)

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Weight Schedule:

Description	Section mm X mm X mm	Weight kN/m	Number	Length (m)	Total Length (m)	Weight kN
Top Chord	ISNT 150x150x10	0.228	1	10.0	10.0	2.28
Bottom Chord	ISHT 150	0.294	1	10.0	10.0	2.94
Bracing Members	2-ISA 70X70X6	0.126	2	0.71	1.42	0.18
Tension Members	2-ISA 70X70X6	0.126	6	0.9	5.4	0.68
Compression Members	2-ISA 80X80X6	0.146	6	0.9	5.4	0.79
						6.87
Allow 2.5% Extras						0.17
						7.04

Average weight per unit area of floor

$= \frac{7.04}{10*3} = 0.23\ kN/m^2 < 0.4\ kN/m^2$ *(Assumed)*

Hence, O.K.

Deflection:

Pre-composite stage:

The second moment of area of the steel truss, I_t *can be calculated from the following equation.*

Where,

A_b *- Cross-sectional area of bottom chord.*

A_t *- Cross-sectional area of top chord.*

In this problem,

$A_b = 3742\ mm^2$

$x_b = 26.6\ mm$

$A_t = 2908\ mm^2$

$x_t = 39.5\ mm$

$D_t = 566\ mm$

$$I_t = \frac{3742 \times 2908}{(3742 + 2908)}[566 - 26.6 - 39.5]^2$$

$= 409 \times 10^6 mm^4$

Loading:

	kN/m²
Deck slab weight	*3.0*
Truss weight	*0.23*
Construction load	*1.00*

	4.23

Total Load =

*4.23*3*10=126.9 kN*

Deflection at pre composite state is given by

$\delta_0 = (5*126.9*10000^3)/(384*200*409*10^6) = 20.19\ mm$

Deflection at composite state due to dead load =

$\delta_1 = (3.03/4.23)*20.19$

= 14.46 mm

[For composite stage construction load has to be removed for calculating deflections]

Deflection - Composite stage:

The second moment of area, I_c*, of a composite truss can be calculated from the following equation*

$$I_c = \frac{A_b A_c / m}{(A_b + A_c / m)}[D_t + (D_s + D_p)/2 - x_b]^2$$

Where,

A_c *= Cross-sectional area of the concrete in the effective breadth of slab*

$= (D_s - D_p)b_{eff}$

m = modular ratio

In this problem,

$A_b = 3742\ mm^2$*;* $b_{eff} = 2500\ mm$

$A_c = (175 - 75)* 2500 = 2500*10^2\ mm^2$

m = 15(light weight concrete)

$D_t = 566\ mm$

$x_b = 26.6\ mm$

$$I_c = \frac{3742 \times 1875 \times 10^2 / 15}{(3742 + 1875 \times 10^2 / 15)}\left[566 + \frac{225}{2} - 26.6\right]^2$$

$= 1298.67 \times 10^6 mm^4$

Loading:

Super Imposed load = 5.0 kN/m²

*Total Load = 5.0*3*10=150 kN*

Deflection at composite state due to superimposed load is given by

$\square_2 = (5*150*10000^3)/(384* 200* 1298.67*10^6) = 7.52\ mm$

10% allowance is given

Then, $\delta_2 = 8.27\ mm < l/360 = 10000/360 = 28\ mm$

Total deflection = $\delta_1 + \delta_2$ *=14.46 + 8.27 = 22.73 mm (l/429) < (l/325)*

Hence, design is O.K

3.2 Staad Pro Results

The figure 3 and 4 shows structural displacement and maximum bending diagram. The results of the support reaction, Principal and Von mis stress as well as shear membrane and bending are shown in table 2, 3 and 4 respectively. Figure 5 and 6 shows graphs for moment and shear force.

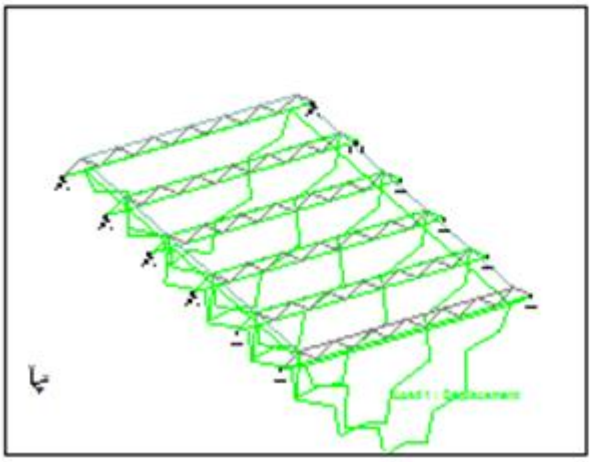

Fig 3: Structural displacement diagram

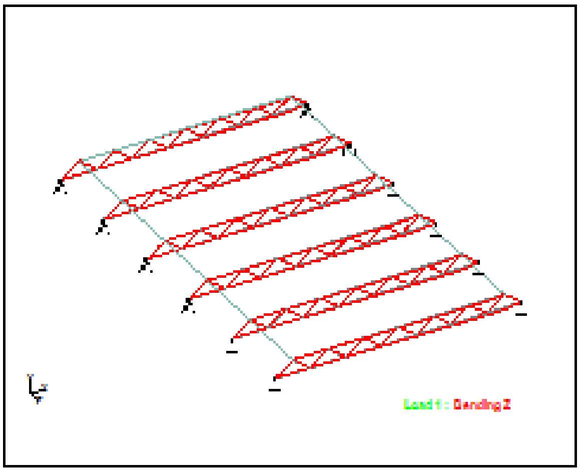

Fig 4: Maximum bending along z-direction

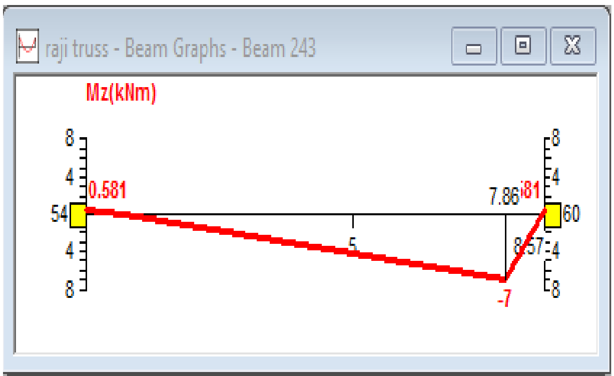

Fig 5: Beam Graph (Moment) of Beam 243

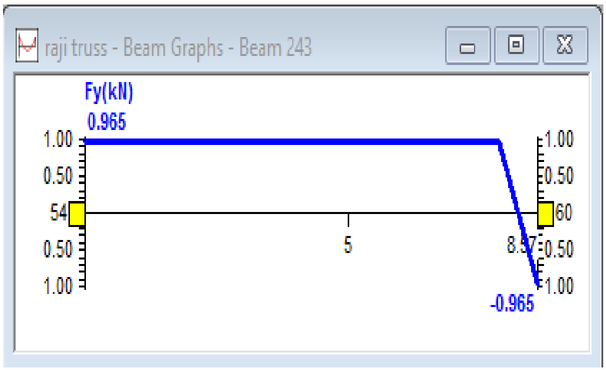

Fig 6: Shear Force Diagram of Beam 243

Table 3: Support Reaction

			Horizontal	Vertical	Horizon	Moment		
	NODE	L/C	Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
Max Fx	1	3 COMBI	468.477	268.366	6.517	1.311	-1.878	-18.726
Min Fx	5	3 COMBI	-262.733	257.085	0.649	0.383	0.539	-27.730
Max Fy	1	3 COMBI	468.477	268.366	6.517	1.311	-1.878	-18.726
Min Fy	5	2LL	64.286	-8.525	-1.834	-0.290	-0.419	-14.517
Max Fz	1	3 COMBI	468.477	268.366	6.517	1.311	-1.878	-18.726
Min Fz	76	3 COMBI	468.477	268.366	-6.517	-1.311	1.878	-18.726
Max Mx	1	3 COMBI	468.477	268.366	6.517	1.311	-1.878	-18.726
Min Mx	76	3 COMBI	468.477	268.366	-6.517	-1.311	1.878	-18.726
Max My	76	3 COMBI	468.477	268.366	6.517	-1.311	1.878	-18.726
Min My	1	3 COMBI	468.477	268.366	-6.517	1.311	-1.878	-18.726
Max Mz	5	3 COMBI	261.36	187.661	2.559	0.605	-0.863	3.215
Min Mz	5	3 COMBI	-262.733	257.085	0.649	0.383	0.539	-27.730

Table 4: Principal and Von mis Stress for Plate

		SMAX		SMIN		Von Mis		Tresca	
Plate	L/C	TOP N/mm2	Bottom N/mm2	TOP N/mm2	Bottom N/mm2	TOP N/mm2	Bottom N/mm2	TOP N/mm2	Bottom N/mm2
283	1DL	0.160	0.457	-0.464	-0.176	0.561	0.565	0.624	0.632
	2LL	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
	3 COMBI	0.224	0.639	-0.649	-0.246	0.785	0.792	0.873	0.885

Table 5: Shear Membrane and Bending

		Top Combined Stress			Bottom Combined Stress		
Plate	L/C	Comb. SX N/mm²	Comb. SY N/mm²	Comb. SXY N/mm²	Comb. SX N/mm²	Comb. SY N/mm²	Comb. SX N/mm²
283	1DL	0.160	0.464	0.000	-0.176	0.457	-0.000
	2LL	0.000	0.000	-0.000	-0.000	-0.000	0.000
	3 COM	0.224	-0.649	-0.000	-0.246	0.639	0.000

The maximum deflection obtained is 21.25mm.

3.3 Robot Software

The stress and bending along the three directions (x, y, and z) are shown in figure 6 using robot software. The maximum normal stress obtained is 131.43 N/mm^2 while the minimum is 21.99 N/mm^2. Maximum axial forces are 21.99 N/mm^2 while the minimum is 20.07 N/mm^2. The maximum deflection obtained is 30.40mm.

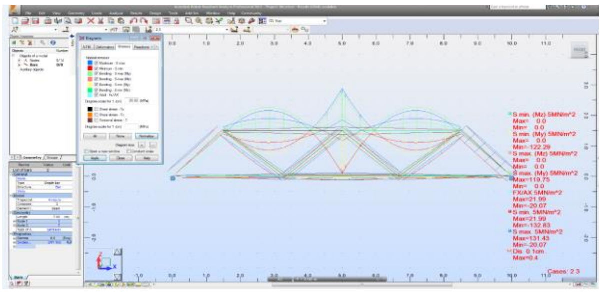

Fig 6: Stress and Bending Diagram

The support reaction is shown in figure 7 and the value obtained is shown in the diagram for the two end support.

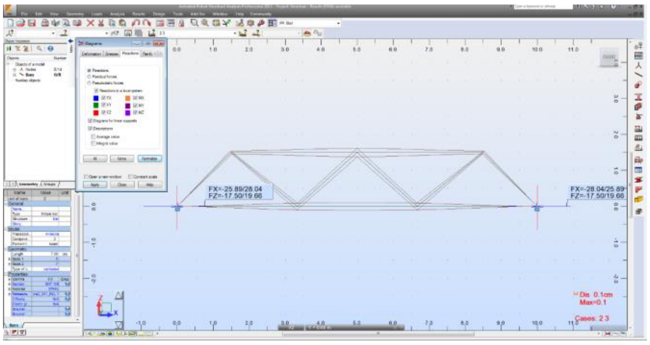

Figure 7: Support Reaction

4.0 Validation of Results

In order to validate the results obtained, the maximum deflection result obtained from ROBOT software is compared with the results obtained using STAADPRO. It can be seen that maximum deflection obtained for the two results is close (20.40mm and 21.40mm) which satisfy the permissible deflection (l/325 i.e. 30.76mm). Hence, the two results are adjudged to be satisfactory.

5.0 Conclusion

It can be seen from the manual and software design using ROBOT and STAADPRO that composite truss system provide the best solution in the range of 10m span and it has a least steel weight. The total deflection obtained for both manual and software design satisfy permissible deflection for truss system which must be < L/365. However, the analysis and design of the composite truss is depends upon the class of the compression flange and web. The truss system can facilitate the concentration of material at the structurally most efficient locations for transfer of force. Hence theoretically, composite truss can provide the least steel weight of any steel framing system.

REFERENCES

1. J. Bujňák, Z. Perkowski (2016). Performance study on composite truss. International Conference Proceedings on Contemporary achievements in Civil Engineering 22, April 2016, Subotica, SERBIA
2. Lam, D., El-Lobody, E. Behavior of Headed Stud Shear Connectors in Composite Beam. Journal of Structural Engineering, ASCE, January. p. 96-107. Assessment of temporary river crossing collapse. Forensic report. University of Žilina, 2005.
3. M. Dagliya, V. K. Goud. Composite Truss-A new Approach to composite Framing structures. Indian Journal of research. Volume 2, Issue 3, 2013.
4. The Steel Construction Institute, UK. Steel designer manual-5th Edition.
5. Institute of Steel Development and Growth (INSDAG). Design of composite Truss for building.
6. The steel construction institute, UK. Design of composite truss, 1992
7. British Standard Institute, BS 5950: 1990.
8. Bureau of Indian Standard, IS 11384:1985. Code of practice for composite construction in structural steel and concrete.
9. The steel construction institute, UK. Steel work design guide to BS 5950: Volume 4, essential data for designer, 1997.
10. Composite structures for steel and concrete by RP Johnson, Blackwell scientific publication, third Edition.