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Analysis of the Deflection of Over-Truss Bridge Deck Using Finite Element Approach

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Abstract: Deflection is basically the bend or curve that occurs within materials when loads are applied to them. A structure should be designed to be able to properly resist the applied loads and failure to do that makes the deflection visible and consequently lead to failure. During the course of this work the dead load, live load and environmental wind load acting on the bridge structure were calculated using the Analytical method and the calculated loads were used to analyze the bridge numerically using the STAAD pro software. The Plate stress animation from the STAAD software showed portions that were under intense loading on the concrete deck. From the animation, Steel beams 42, 45, 49, 53 and 57 were directly supporting these portions of the decks and were chosen for analysis. These beams were analyzed in terms of deflection, shear and bending. The values for shear, deflection, and bending for the five steel beams were compared under both approaches and their percentage difference was calculated. Comparing the results obtained from the analytical and numerical method gave a percentage difference of 4.39 %, 0.6 %, 0.93 %, 3.67 % and 1.19 % for shear, 6.29 %, 3.23 %, 1.07 %, 4.28 % and 1.14 % for bending, 12.5 %, 7.6 %, 4.08 %, 2.45 % and 2.6 % for deflection. 80 % of results obtained were less than 5 % in percentage difference and with this result, it is concluded that both methods are suitable for design. The Numerical method was nevertheless chosen to be a more economical and accurate method because it incorporates reliable safety factors that cater for uncertainties in its approach.

Keywords: Analytical, Bending, Deflection Numerical, Shear

I. Introduction

Every engineering structure is subjected to deflection under loading conditions. Designing a strong, structurally sound and cost-effective bridge is the major consideration in the design of a bridge [1]. In the design of any engineering structure, it is very important to keep the issue of deflection to a minimum so that the structure can maintain its appearance and functionality throughout its design life [2]. Trusses deflect when loaded and these loads are characterized by the sagging of the bottom and top chords and the consequent movement of the web and diagonal members [3]. Deflection of trusses can be analyzed using the virtual work method, direct stiffness method and the finite element analysis method. Deflection in this study was analyzed using the finite element approach with the STAAD Pro software.

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The finite element analysis approach is becoming more prominent for bridge design because of its economic viability and ability to produce a more accurate assessment and design [4]. The finite element analysis (FE) modelling allows for the adoption of a more accurate analysis approach which leads to a more economical result than some codified methods [5]. The P-Delta analysis feature of the STAAD Pro software was used to calculate the lateral deflections (bending and shear deformations) for large stress effects due to axial forces on the beam elements.

The use of steel in the construction of a bridge is an ideal choice because of its economic viability, constructability, and sustainability [2]. A bridge must be designed to be able to safely resist all the imposed loads including the static, dynamic and environmental loads. To be able to safely resist these loads material selection is a very core aspect that must not be taken for granted. The use of high-strength steels (HSS) for bridge structures offers a lot of comparative advantages in terms of increased design stress and reduced plate thickness which leads to significant weight savings and reduced design cost [6]. It has an increased advantage in terms of its strength and ductility. HSS has a higher strength-to-cost ratio in tension and a slightly lower strength-to-cost ratio in compression when compared with other commonly used materials such as concrete [8]. This fact makes the use of steel an efficient and economic material for the design of an Over-truss Bridge. In this study, grade 50 high steel strength was used to support the bridge structure.

For an over-truss bridge, the bridge deck is supported by trusses. The truss refers to a series of connected steel elements arranged in a triangular array which could be stressed from tension, compression or both when there is dynamic loading [7]. The main aim of every design is to produce a structure that can effectively function throughout its design period with minimal cost. The STAAD Pro software was used to perform the numerical analysis during the course of this study. It ranks among the best software used globally for bridge design and will be used for computer-aided design.

High-strength steels are weight-saving and provide reduced fabrication, transportation and erection costs [6]. The study also shows how the steel's property affects our design. The problem of deflection in the design of any engineering structure is an aspect that must be thoroughly considered. Deflection is basically the bend or curve that occurs within materials when loads are applied to them. A structure should be designed to be able to properly resist the applied loads and failure to do that makes the deflection visible and consequently lead to failure. This entails that the structure should be designed to withstand the maximum deflection caused by any applied load.

The issue of deflection results from design deficiencies and if this problem is not well catered for during design it will pose a great risk in the long run. Deficiencies could result from the use of inappropriate data for design, lack of robust design tools and the method used for analysis. Compared to previously used design methods such as the plate theory and grillage method, the finite element method has been proven to be one of the best because of its ability to cater for design inadequacies. The STAAD Pro software employs the finite element approach in bridge design which is why it has been selected for this project work as a more robust design tool.

This study catered for all design inadequacies and can serve as a guide in the design of a structurally sound bridge. In this study, we carefully analyzed the effects of the applied load on the structure.

It is very important to minimize deflection in any engineering structure, especially one whose failure could result in very high casualties such as a bridge. Successful completion of this project will aid in the minimization of deflection in an over-truss bridge structure thereby improving the durability of the structure, reducing its cost and preventing the sudden failure of the structure.

The analysis of the bridge was limited to both the Analytical approach and the Numerical approach using the STAAD Pro software. The bridge loadings to be considered will include the dead load, probabilistic/dynamic loads, and environmental loads with the main focus on the effect of the probabilistic load. The bridge's design in this study was limited to the analysis of the steel beams under intense loading conditions. This work focus on the loading of the bridge deck and the design of certain steel truss members to minimize the effect of the imposed and dead loading on the structure.

This study will serve as a guide for future civil engineering students and those in the field of practice to help in the manual design of an over-truss bridge and will also show the step-by-step procedure in the design of the bridge using the STAAD Pro software. Engineers who wish to use this software for analysis will be guided by this work.

II. .Materials and Methods

A. Materials

The STAAD.pro software is the major material used for this project work. It possesses state of the art user interface, powerful analysis and design engines, advanced finite element and dynamic analysis capabilities [9]. The software was designed by practicing engineers around the world and it has evolved for over 20 years to meet the requirements of the ISO 9001 certification [10]. The software supports several concrete, steel and timber design codes and is most widely used for structural analysis and design.

Figure 1 shows the 2D model for the proposed over-truss bridge. The dimensions for the model are shown in the Figure and are represented in meters. The dimensions in the model will serve as a guide while attempting the Numerical model of the bridge

Figure 2 presents the 3D model of the proposed structure to be analyzed. It shows the dimension for the width of the bridge and also the Coordinate plane of the bridge. This will also serve as a guide while attempting the Numerical model of the bridge.

B. Methodology

a) Calculating Notional Lane Width

The bridge will be designed to carry two notional lanes. The notional lane width was calculated with the formula in equation 1;

$$W_N = \frac{W_c}{n} \tag{1}$$

Where W_N = Notional lane width

W_c = width of the carriageway

n = number of notional lanes

b) Calculating the live loading on the bridge

The HA, HB and wind load were assigned as live loading on the bridge in accordance with the specifications in [11], the HA and HB loading are used to calculate the traffic live load requirement for highway bridges. The two-lane road will be designed to occupy one HA loading and 30 units of HB loading

Equations 2-6 and the Steps followed in analyzing the HA loading include;

1) The lane factor α is calculated using the formula

$$\alpha = 0.0137\ [b_L\ (40\text{-}L) + 3.65\ (L\text{-}20)] \tag{2}$$

Where; b_L = notional lane width in meters

L = span of the bridge

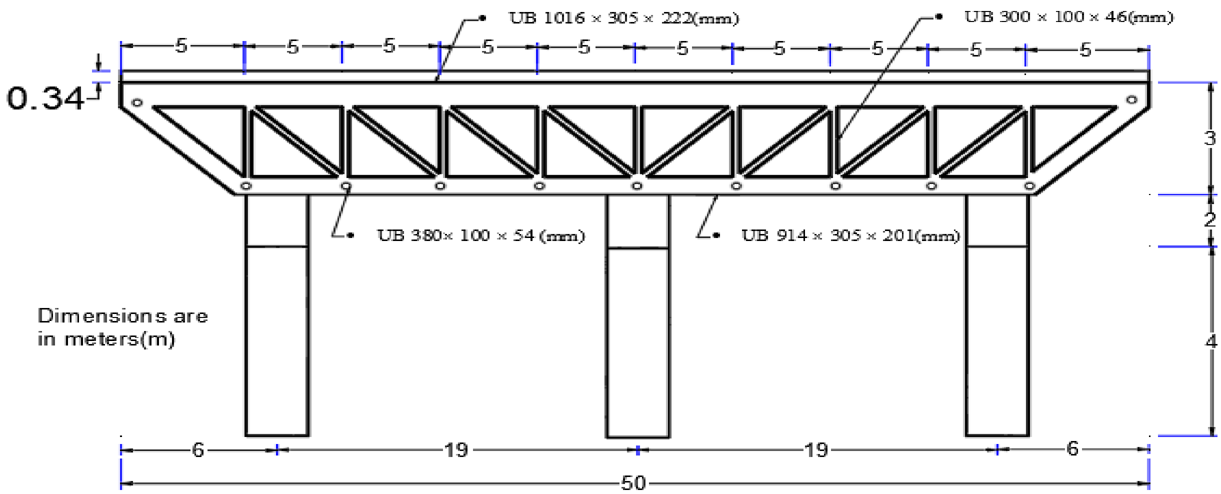

Figure 1: Proposed 2D model for the Over-Truss Bridge. (AutoCAD)

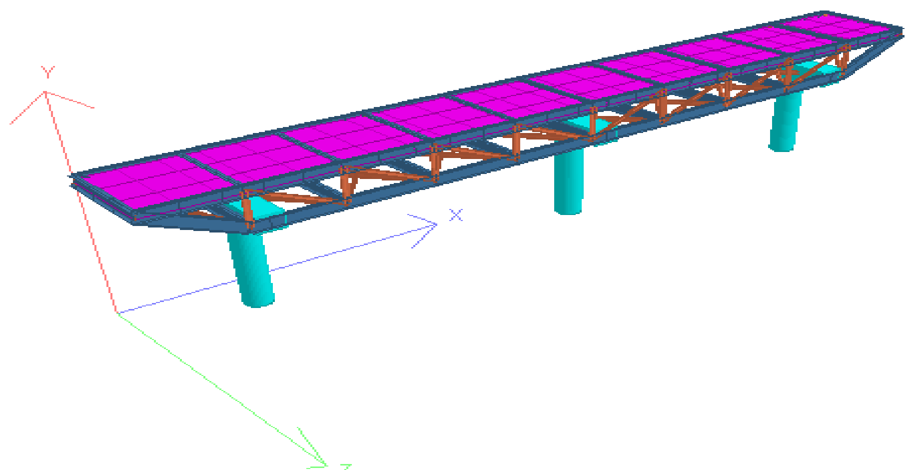

Figure 2: Proposed 3D model for the Over- Truss Bridge. (STAAD pro)

2) The total HA loading is a combination of the uniformly distributed load plus the knife edge load. The uniformly distributed load per notional lane was calculated using the formula in order of increasing number of lanes ;

$$W = 151(\frac{1}{L})^{0.475} \geq 9 \qquad (3)$$

According to BS 5400 part 2 (1978), the knife edge load is taken as 120 kN. The ultimate limit states were also calculated by multiplying the loads for each span with a factor of 1.5.

3) Considering the lane factors and notional lane width per meter width of the deck, the uniformly distributed load and knife edge load was calculated using the formulas;

For UDL, $w' = \frac{W \times \alpha}{W_N}$ (4)

For KEL $p' = \frac{P \times \alpha}{W_N}$ (5)

4) The maximum mid-span moment was calculated with the Knife edge load acting on the centre using the expression;

$$M = \frac{w' \times L^2}{8} + \frac{P' \times L}{4} \qquad (6)$$

5) In accordance with the provisions in [11], the load factors γ_{fl} were introduced for both the ultimate and serviceability limit state under this loading condition,
6) The HA design moments per meter width of the deck were calculated using the load factors for both limit states.

The Steps followed in analyzing the HB loading include;

1) According to the BS 5400 part 2 (1978), 1 unit of HB is 10 kN per axle and 30 units of HB loading are to be generated for this class of bridge (i.e. other principal roads). The nominal load per axle was calculated by multiplying the unit load by the number of units.
2) BS 5400-2: 1978 Figure 12 shows the length for the shortest HB vehicle as 6 m. The maximum bending moment per meter width of the deck was calculated with this length.
3) According to the BS 5400 part 2 (1978), the load factors γ_{fl} were introduced for both the ultimate and serviceability limit state under this loading condition.
4) The HB design moments per meter width of the deck were calculated using the load factors for both limit states.

c) Calculating the Dead loading on the bridge

The self-weight of the concrete, asphalt and any other superimposed load will constitute the dead load from the deck.

1) The first step was calculating the dead weight of the concrete slab. The expression

$$W = L_W \times \text{depth} \times \text{Pconc} \quad (7)$$

Was used, where; L_W = Notional lane width

Depth = depth of concrete

Pconc = concrete density in KN/m^3

2) The dead weight of the wearing coat was calculated using the expression;

$$W = L_W \times \text{depth} \times \text{Asphalt density} \quad (8)$$

Where; L_W = Notional lane width

Depth = asphalt thickness

Asphalt density is expressed in Kg/m^3

3) In accordance with the provisions in [11], the load factors γ_{fl} were introduced for dead load ultimate limit states.
4) The UDL was calculated for using applying the load factors for ultimate limit states.
5) A diagram was used to represent the total live and dead loading for both lanes

d) Calculating Shear, Bending Moment and Deflection for Critically Loaded Steel Elements

From the STAAD model, steel beams 42, 45, 49, 53, and 57 were located in the region with the most plate stress. These beams were analyzed as follows;

1) All the beams are of the same section 914 × 305 × 201 UB, The section properties gotten from [12] include;

$S_x = 8351\ cm^3$ $D = 903.0\ mm$ $t = 15.1\ mm$ $I_{xx} = 325300\ cm^4$

$T = 20.2\ mm$ $\frac{b}{T} = 7.51$

Where; S_x =Plastic modulus

D = Depth of section

t = Thickness of web

I_{xx} = Second moment of Area

T = Thickness of flange

$\frac{b}{T}$ = ratio for local buckling

2) The cross sections for the beams were shown with their dead and live loading. The position of the beams on the staad model was also shown.

3) The design strength of steel ρ_y was obtained from [13]
4) The design load was calculated using the expression in equation 9;

$$DL = 1.4G_k + 1.6Q_k \quad (9)$$

Where; 1.4 and 1.6 are Load factors

G_k= Dead load

Q_k= Live load

5) The bending moment was calculated using the expression in equation 10;

$$M = \frac{wl^2}{8} \quad (10)$$

Where; W = design load

l = span of beam

6) The shear force was calculated using the expression in equation 11;

$$F_v = \frac{wl}{2} \quad (11)$$

The plastic modulus was calculated using the expression in equation 12;

$$S = \frac{M}{p_y} \quad (12)$$

Where; M= bending moment

ρ_y = design strength for Grade 50 steel

7) The sections were classified using the constant in equation 13;

$$\varepsilon = \left(\frac{275}{p_y}\right)^{0.5} \quad (13)$$

8) The shear capacity ρ_v was calculated using the expression in equation 14;

$$P_v = 0.6t.D.p_y \quad (14)$$

Where; t = Web thickness

D = depth of section

9) The deflection for the sections was calculated using the expression in equation 15;

$$\delta = \frac{5Q_k.L^4}{384EI} \quad (15)$$

Where; E = second moment of area in the x-x axis

10) The limiting deflection was calculated by dividing the length of the span in mm by 360. The section is ok if the limiting deflection is greater than the value for deflection.

III. Results and Discussion

The notional lane width to carry the live loading and to be used for the bridge assessment was calculated to be 3 meters. The BS 5950 recommends a width of 3.65 m but allows for an interval between 2.3 m and 3.8 m.

A. Live Load

i. HA Load

The results of the HA loads are presented in Table 1. The span length of the bridge ranges between 5-50 m. The computed uniformly distributed loads (23.55-70.3 kN/m) and loads at the ultimate limit state (35.33-105 kN/m) on the spans are shown in Table 1.

HA design moments were computed with loads obtained from Table 1, effects of the uniformly distributed load and the Knife edge loads per meter width of the deck were also calculated as shown in Table 1. The results obtained were used in calculating the maximum bending moment with the knife edge load at the mid-span. Load factors for both serviceability and ultimate limit states were obtained from [14] and used to obtain the HA design moments under both limit states, per meter width of the deck.

The uniformly distributed load produced an ultimate load of 35.55 kN/m while the Knife edge load produced an ultimate load of 180 kN. The Knife edge load produced the maximum moment along the bridge length and produced higher values for moment in terms of the

Table 1: HA Design Loads at various span lengths

SPAN LENGTHS, L (M)	Uniformly Distributed Loads (kN/m)	Knife Edge Load (kN)	Load factors at Ultimate state	Distributed Loads at Ultimate Limit State (kN/m)	Knife Edge Load at Ultimate Limit State (kN)
5	70.3	120	1.5	105.45	180
10	50.58	120	1.5	75.87	180
15	41.72	120	1.5	62.58	180
20	36.39	120	1.5	54.59	180
25	32.73	120	1.5	49.1	180
30	30.02	120	1.5	45.03	180
35	27.89	120	1.5	41.84	180
40	26.18	120	1.5	39.27	180
45	24.76	120	1.5	37.14	180
50	23.55	120	1.5	35.33	180

Table 2: HA design moments per meter width of the deck

Parameter	Ultimate load		Load per meter width of deck		Maximum moment	HA design moment per meter width (kNm)	
	(kN/m)	(kN)	(kN/m)	(kN)	(kNm)	Serviceability limit	Ultimate limit
UDL	35.33	-	12.83	-			
KEL	-	180	-	65.35	4826.5	5791.5	7239.38

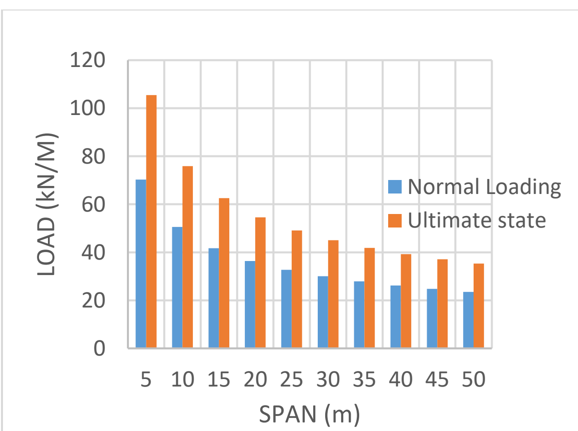

Figure 3: Decrease in HA loading with Increasing Span Length.

ultimate and serviceability limit states. Figure 3 shows a decrease in HA loading with increase in span length. The HA loading is minimum at 50 m span length and maximum at 5 m span length

ii. HB Load

In accordance with the specifications in [14] for the generation of HB loads, 30 units of HB axle loads were generated. One unit of axle load is said to exert a force of 10 kN. Tables 3 and 4 show HB design moments, the ultimate and serviceability moments for the HA and HB design moments per meter width of the deck. The right and left reactions were calculated and obtained as 564 kN and 636 kN, respectively. The result for the bending moment at the point of load action X was also calculated. The HB bending moment under both the serviceability and ultimate limit states was obtained using the calculated values for the right and left lane reactions. Figure 4 shows the distribution of HB loadings acting on the bridge deck. Figure 5 revealed the estimated HA and HB design moments. HA had the highest computed moments at both serviceability and ultimate limit state. The value is about 37.5 % and 33.8 % higher than that of the HB loading at ultimate limit state and serviceability limit state respectively.

Table 3: HB design moments per meter width of deck

Reactions (KN)		**Moment at X (kNm)**	**Bending moment per meter width of deck (kNm)**	**HB design moment per meter width (kNm)**	
RR	LR			Serviceability limit	Ultimate limit
564	636	12714	3483.29	3831.62	4528.28

Table 4: HA and HB design moments

Loading	**design moment per meter width (kNm)**	
	Serviceability limit	Ultimate limit
HA	5791.5	7239.38
HB	3831.62	4528.28

Table 5: Parameters used and results obtained for wind load

S/N	**Parameters**	**Value**	**Variable**	**Result**
1	Reference height (Z_e)	12 m	Terrain factor K_r	0.215
2	Wind velocity	38 m/s	Roughness factor $(C_r(Z))$	0.793
3	Density of air	1.25 kg/m^3	Mean wind velocity $(V_m(Z))$	30.1 m/s
4	roughness length for category III (Z_o)	0.3 m	Wind turbulence $(I_V(Z))$	0.271
5	roughness length for category II $(Z_{o,II})$	0.05 m	Peak velocity pressure $(Q_p(Z))$	1.640 kN/m^2
			Wind force F_{WK}	7.626 kN/m

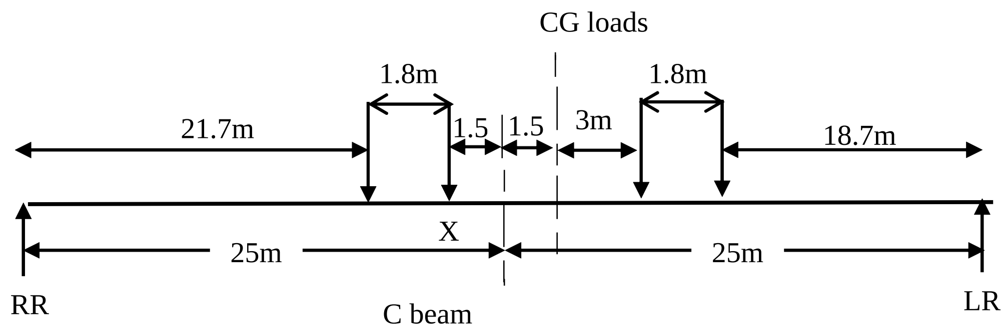

Figure 4: HB Load acting at CG of the deck

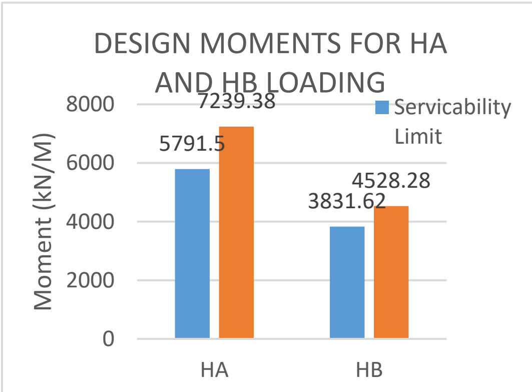

Figure 5: Design moments for HA and HB loading

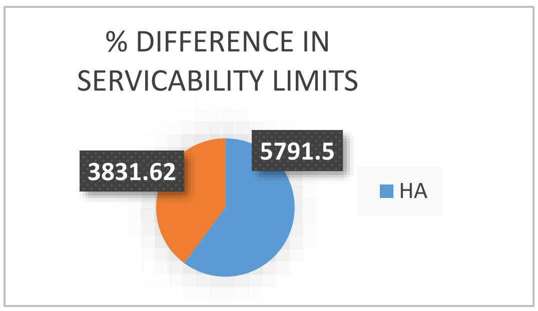

Figure 6: % Difference in serviceability limits for HA and HD Loading

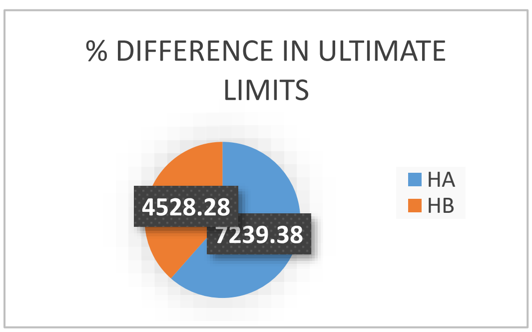

Figure 7: % Difference in Ultimate Limits for HA and HD Loading

These are presented in Figures 6 and 7

B. Dead Load

Table 6 presents the results for the calculated dead loads. The UDL was obtained by multiplying the dead weight of the concrete slab and asphalt layer with the appropriate load factors under the ultimate limit state. The Numerical analysis presented the stress diagram shown in Figure 8 above. The legend for the diagram is arranged in the order of increasing stress intensity from top to bottom as gotten from the STAAD pro model. Plates 184 and 208 showed the most stress while plates 183, 184, 190, 196, 202 and 209 also showed signs of intense loading. These plates are supported by the steel beams 42, 45, 49, 53 and 57 which are of section 914 × 305 × 201 UB. The parameters used for evaluating these beams as obtained from [12] and are presented in Table 7. The results obtained after analysis for beams 42, 45, 49, 53 and 57 are shown in Tables 8 and 9. They presents their maximum moments, shear force, plastic modulus, section type, shear capacity and deflection.

All the sections were considered plastic because **8.5ε** > **ε** in all cases. This was calculated as provided in [12]. In any case where the limiting/Allowable deflection is greater than the actual deflection the structure is considered safe with respect to deflection, Hence the remark OK. The deflection curve for the beams in Figure 9 revealed a decrease in deflection with an increase in beam sections for both analytical and numerical computations.

C. Method of Comparison

The comparison between the numerical and analytical methods of analysis of beams in shear, bending and deflection are presented in Table 10. Beam 42, 45, 53 and 54 have analytical values in shear, bending and deflection higher than numerical computations. This may be due to the degree of uncertainty in the assumption of loadings using the analytical approach. Their percentage difference is within the range of 1.18-4.3 % for shear, 1.14-6.09 % for bending and 2.4-12.5 % for deflection. The numerical method seemed more accurate since it analyses the beam elements by splitting them into finite numbers and then integrating such solutions. Figures 10, 11 and 12 shows the comparative analysis of shear forces, bending moments, deflection and percentage differences using both analytical and numerical approaches.

Table 6: Dead load results for the bridge deck

S/N	Variable	Result
1	Dead weight of concrete slab	22.81 kN/m
2	Dead weight of wearing coat	7.61 kN/m
3	UDL	39.55 kN/m

Table 7: Design Parameters for the steel beams (BS4: part 1: 1993 and EN10056: 1999)

S/N	Parameters	Values
1	Steel grade	BS Grade 50 steel
2	Plastic modulus (S_x)	8351 cm^3
3	Depth of section (D)	903.0 mm
4	Thickness of web (t)	15.1 mm
5	Second moment of Area (I_{xx})	325300 cm^4
6	Thickness of flange (T)	20.2 mm
7	ratio for local buckling ($\frac{b}{T}$)	7.51
8	Design strength of steel ρ_y	340 N/mm^2

Table 8: Analysis of Sections Capacity

Beam	Design load (kN/m)	Bending moment (kNm)	Shear force (kN)	Plastic Modulus (cm^3)	ε	8.5ε	Section type	Shear capacity (kN)
42	236.3	1063.34	708.9	3127.47	0.9	7.65	Plastic	2781.6
45	167.71	754.68	503.13	2219.65	0.9	7.65	Plastic	2781.6
49	146.14	657.62	438.42	1934.18	0.9	7.65	Plastic	2781.6
53	134.52	605.35	403.56	1780.44	0.9	7.65	Plastic	2781.6
57	127	571.51	381	1680.91	0.9	7.65	Plastic	2781.6

Table 9: Analysis of deflection of sections

S/N	Beam	Deflection (mm)	Limiting Deflection (mm)	REMARK
1	42	2.86	16.67	OK
2	45	1.78	16.67	OK
3	49	1.44	16.67	OK
4	53	1.25	16.67	OK
5	57	1.13	16.67	OK

Table 10: Shear, bending moment and deflection results for both analytical and Numerical Approach

		Shear (kN)		Bending Moment (kNm)		Deflection (mm)	
S/N	Beam	Analytical	Numerical	Analytical	Numerical	Analytical	Numerical
1	42	708.9	678.42	1063.34	998.5	2.86	2.52
2	45	503.13	500.12	754.68	730.68	1.78	1.65
3	49	438.42	442.52	657.62	650.62	1.44	1.5
4	53	403.56	389	605.35	580.01	1.25	1.22
5	57	381	376.5	571.51	565	1.13	1.1

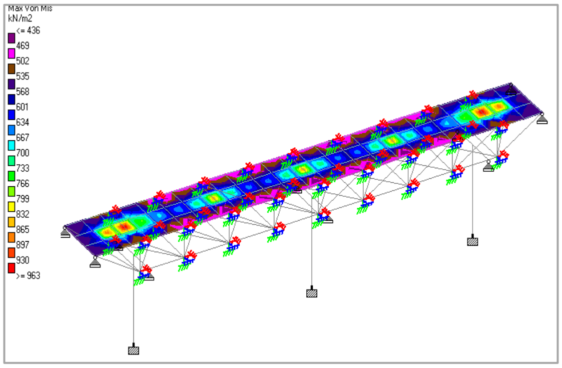

Figure 8: Plate Stress Obtained from Numerical Analysis

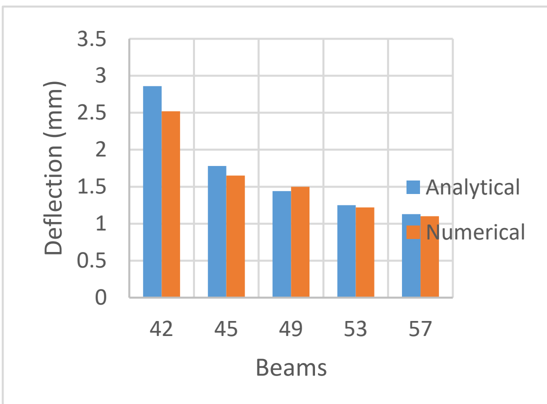

Figure 9: Comparing values for deflection

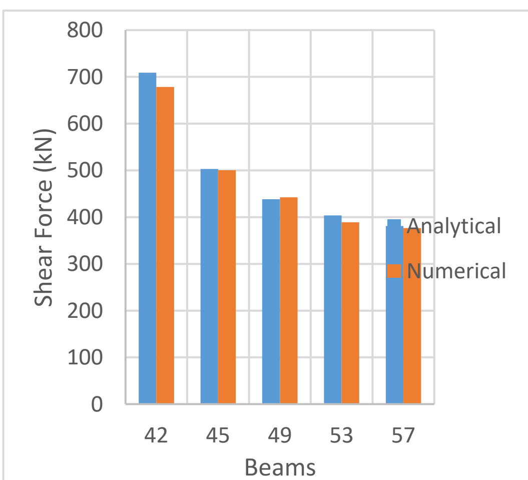

Figure 10: Comparing values of shear force Obtained from both analytical and numerical

The differences for deflection, bending and shear are 12.5 %, 6.3 % and 4.5 % for beam 42; 7.5 %, 3 % and 0.5 % for beam 45; 4 %, 1.2 % and 1 %

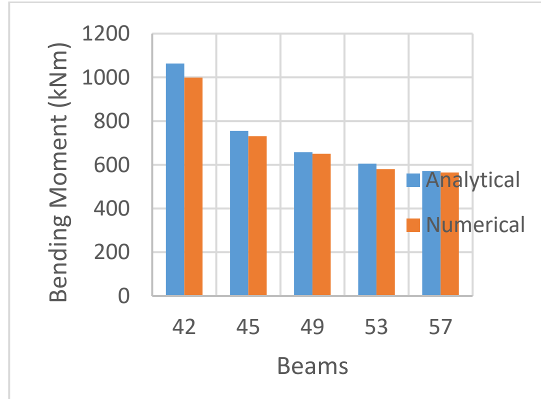

Figure 11: Comparing Bending moments for both analytical and numerical approach

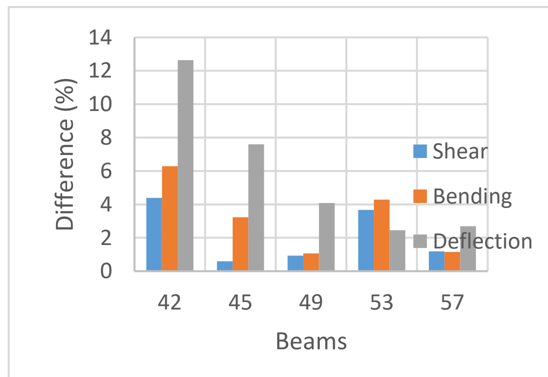

Figure 12: Percentage differences in shear, Bending and deflection

for beam 49; 3 %, 4.2 % and 3.8 % for beam 53; 2.5 %, 1.2 % and 1.2 % for beam 57, respectively.

IV. Conclusion

i. The maximum percentage difference calculated for the beams in terms of deflection, bending or shear was 12.5 % while the minimum was 0.64 % with most having a value less than 5 %. These low results of percentage difference show the accuracy of these methods for structural design.

ii. The charts plotted to show the results of both the analytical and numerical modelling produced a near symmetry across all the diagrams. With these results, we can conclude that both the Analytical and the Numerical analysis using STAAD Pro is suitable for bridge design.
iii. From Table 10 we can observe that the Analytical approach provided higher values for shear, deflection and bending. These higher values will influence design greatly and possibly lead to overdesign. We can therefore conclude that the Numerical approach using the STAAD pro software will be a much more economical option for the design of an over-truss bridge than the analytical method.

References

[1] Johnson, D. V. "*Essentials of bridge engineering"*, Oxford and IBH Publishing, 2017.

[2] Larsen, A., and Ostenfeld, K. H. "*Bridge engineering and aerodynamics"*, In Aerodynamics of large bridges, 2017, pp. 3-22. Routledge.

[3] Ola, Q. "*Analysis and Design of Steel Truss Bridges",* 2017, 10.13140/RG.2.2.21477.29923.

[4] Cakebread, T. "The role of finite element analysis in bridge assessment and design", *6th New York City Bridge Conference*, 2010.

[5] S., Icke, P., and Lyons, P., Rhodes. "Application of Finite Element Methods to Masonry Bridges", *5th International Conference on Road and Rail Infrastructure*, 2019.

[6] Gogou, E. "*Use of high strength steel grades for economical bridge design"*, Delft University of Technology, 2012.

[7] Gaylord, C. N., Gaylord, E. H., and Stallmeyer, J. E. "*Design of steel structures"*, 2008.

[8] Csernak, S. F. "*Structural steel design"*, Pearson, 2012.

[9] Kulkarni, A., Kumbhar, P., and Khot, P. M. M. S. "Materials for Foot-over Bridges", *International Research Journal of Engineering and Technology*, vol. 3, no.4, 2016, pp. 2701-2703.

[10] Nouban, F., and Onur, A. Z. "Software in the architectural presentation and design of Buildings", State-of-the-art, *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, vol. 8, no.10, 2019.

[11] Standard, J.B. 5400: Part 2. "*Specification for loads*" IS J, 1978.

[12] Joannides, F., and Weller, A. "*Structural Steel Design to BS 5950: Part 1",* Thomas Telford, 2002.

[13] British Standard, B.S. 5950-Part 1: '*Structural Steelwork Design*', British Standards Institute, 1990.

[14] Pope, R. "*Specification for Materials, Fabrication and Erection: Rolled and Welded Sections"*, Structural use of Steel work in building, New Steel Construction, vol. 9, no.2, 2001, 9(2).