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Capacity of Composite Concrete-Steel Beams According to Euro Code 4

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Abstract: Modelling and Analysis was carried out using Finite Element to study the behaviour of composite beams according to Euro code 4 with respect to bending, shear and deflection under varying loads, and the ultimate loadings and section capacities corresponding to failure modes was evaluated. In bending the section capacity was found to increase with an increase in both concrete and steel strength however increase in flexural resistance with increase in compressive strength is very small that is 3.2% 3.1% and 3.0% when the concrete strength was increase from 25 N/mm^2 to 30, 35 and 40 N/mm^2 respectively, compare to the way it increase with increase in the steel strength by 27% and 21% when the strength was increase from 275 to 355 and 460N/mm^2 respectively, but the ultimate flexural load capacity of the beams decreases with increase in the beam span for both the three steel strength. However, shear capacity of the sections remain unchanged at constant steel strength and varying length, but increases with increase in ultimate yield strength of the steel sections by 29%, and 67% when the ultimate yield strength was increase from 275 N/mm^2 to 355 N/mm^2 and 460 N/mm^2 respectively, while allowable deflection increases with an increase in the beams span and the ultimate loadings with respect to deflection also decrease with increase in the beams span.

Keywords: Composite Beam, Eurocode, Bending, Shear, Deflection, Section Capacity

1. Introduction

In building and bridges concrete slab is usually supported by steel beams, if the two elements are connected together in a manner that they acts as a unit, then the transformed beam is referred to as composite beam [1]. In the same vein [2] explain that steel beam can be more economical than concrete beam particularly in bridges and multi-storey car parks in which susceptibility of the steel to be affected by fire is not a problem. It was a common practice in design to have the steel beams carrying the whole weight of concrete slab and its loading until 1950s when shear connectors were introduced to connect the slab to the beam to have a T-beam action which is now in used in concrete construction in order to reduce excessive shear failure between the beam and the slab. The term Composite beam often refer to this type of structure and it is a member subjected to mainly bending [3].

When a concrete slab is supported by steel beams, and there is no provision for shear transfer between the two, the result is a non-composite section [4].

Shear connectors are normally provided between the concrete slab and the steel beam to eliminate the longitudinal slip and uplifting at the elements interface and increases the structural strength and stiffness as well as achieving a full composite action [5-7].

The studs prevent slippage and also enable shear stresses to be transferred between the slab and supporting beams.

This result is increasing both the strength and stiffness of the beams, thereby allowing significant reductions in construction depths and weights of steel beams to be achieved [5, 8].

Composite beams are similar to concrete T-beams whereby the flange of the T-beam is made of a concrete slab and the web is made of a steel section [1, 9, 10]. Full composite action can be achieved by welding shear studs to the top flange of the steel beams and embedding the studs in the concrete when cast as shown in figure 1 below.

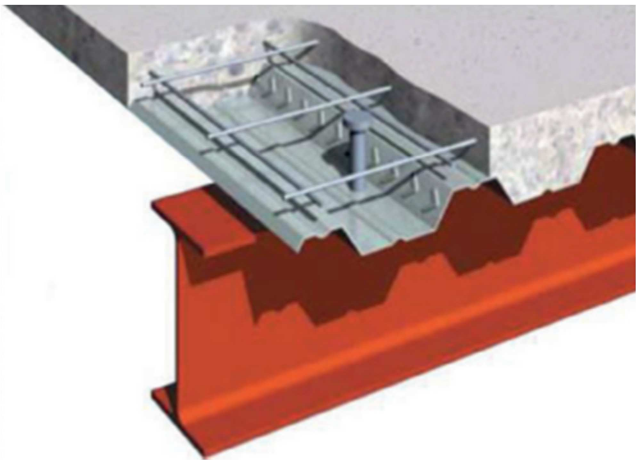

Figure 1. *Composite beam with head stud shear connectors [7].*

Composite beams have been increasingly applied in construction of buildings and bridges, in part due to development of large amounts of theoretical and experimental investigations. Also, modern design considerations include aesthetical, economical and mechanical structural requirements [11, 5]. The incorporation of steel-concrete composites in building construction provides new possibilities of balance between these requirements [11]. Concrete and steel has complimentary properties as concrete is good in compression but poor in tension, whiles steel is good in tension [12-13].

Therefore, composite beam has the advantage that concrete in the slab take all or most of the compression (for which it is best suited), while the steel beam take the overall tension in the system [1]. Concrete is one of the most applied manmade materials in engineering construction in the world [14] also a fundamental material in civil engineering construction [15-16]. The material parameters are taken from the appropriate Structural Eurocode chapters EN 1993-1-1 for steel and EN 1992-1-1 for concrete and reinforcement [17-18].

1.1. Floor Systems for Steel Framed Structures

In temporary steel framed structures such as car parks and Bailey bridges the floor deck can be formed from steel plates. In more permanent steel framed structures the floors generally comprise of precast, press-stressed concrete slabs, in-situ reinforced concrete slabs and or composite metal deck floors. [8].

1.2. Advantages of Composite Construction

Composite construction has popularly used over twenty years, and has largely accounted for the dominance of steel frames in multi-storey buildings The main advantages of composite beams applications are;

- i Steel weight saving between 30 to 50% can be achieved compare to non-composite construction.
- ii The increased stiffness of composite beams can result in them being lower than non-composite beams for the same span; this can lead to lower storey heights and a reduction to cladding costs (which is significant, as cladding can represent up to 20% of the total building cost or allowing more room for mechanical services [6].
- iii The steel sheeting as integral part of the structure acts as a safe working platform and protects the workers and the sheeting also, acts as permanent formwork for the concrete slab.
- iv Composite construction not only reduces frame loadings but also results in smaller and hence cheaper foundations [8].

1.3. Finite Element Analysis (FEA)

FEA is a numerical method for solving problems in engineering and mathematical physics. It is useful for problems with complicated geometries, loadings, and material properties where analytical solutions cannot be obtained. It is used to obtain approximate solutions of boundary value problems which often represent a physical structure. It subdivides a large problem into smaller, simpler parts called finite elements. The finite elements are then assembled into larger (global) systems of equations that model the entire problem [18].

FEA have found very appreciable applications in numerical modelling of structures or components to be built. The results conform well to those obtained in actual laboratory tests and modelling.

2. Methodology

The modelling and finite element analysis of the composite beam was carryout using ConSteel11. The first step is definition of composite beam cross-section. There are two types available: composite beam with solid concrete slab and composite beam with profiled steel sheeting. The cross-section macros can be found among the MACRO SECTIONS. [3] Gives the details guide lines governing analysis and design of composite beam. The design involves section classification which can be plastic, semi-plastic or elastic. The class of the section determine the calculation method to be used weather rigid plastic or elastic theory with moment redistribution. The second step is determination of the effective width of the concrete slab that will act compositely with the steel beam [3] gives the various method of evaluating the effective width as shown in figure 2, for simply supported beams, the effective width b_{eff} is given in equation 1.

$$b_{eff} = \frac{L}{4} \tag{1}$$

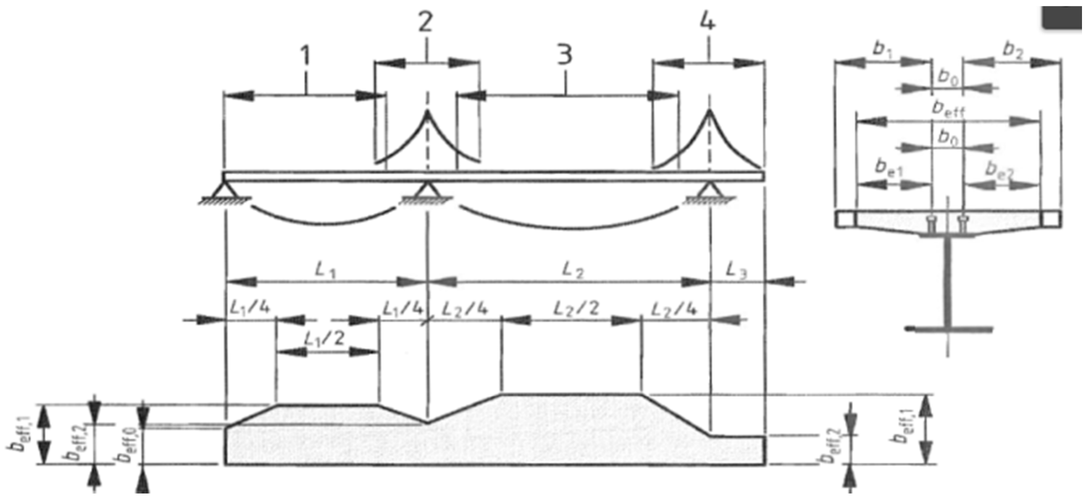

Figure 2. Equivalent spans, for effective width of concrete flange [3].

Finally is determination of critical sections and performing related checks at those points. The critical cross-section to be determined and analyse in composite beams includes; sections of maximum bending moment, supports, sections subjected to concentrated loads or reactions and Places where a sudden change of cross-section occurs, other than a change due to cracking of concrete.

Criteria to be checked in composite beams for ultimate and serviceability limit state include;

2.1. Ultimate Limit States

i Moment resistance of critical cross section
ii Resistance to vertical shear
iii Resistance in longitudinal shear (resistance of shear connectors)

2.2. Serviceability Limit States

Deflections.

2.3. Moment Resistance

The ultimate moment capacity of the composite section is independent of the method of construction i.e. propped or unpropped. The moment capacity of a composite section depends upon where the plastic neutral axis falls within the section. Three outcomes are possible [8-9]

1. Plastic neutral axis occurs within the concrete flange;
2. Plastic neutral axis occurs within the steel flange;
3. Plastic neutral axis occurs within the web

Figure 3 shows composite beam and the three cases of neutral axis position and their corresponding stress distribution respectively.

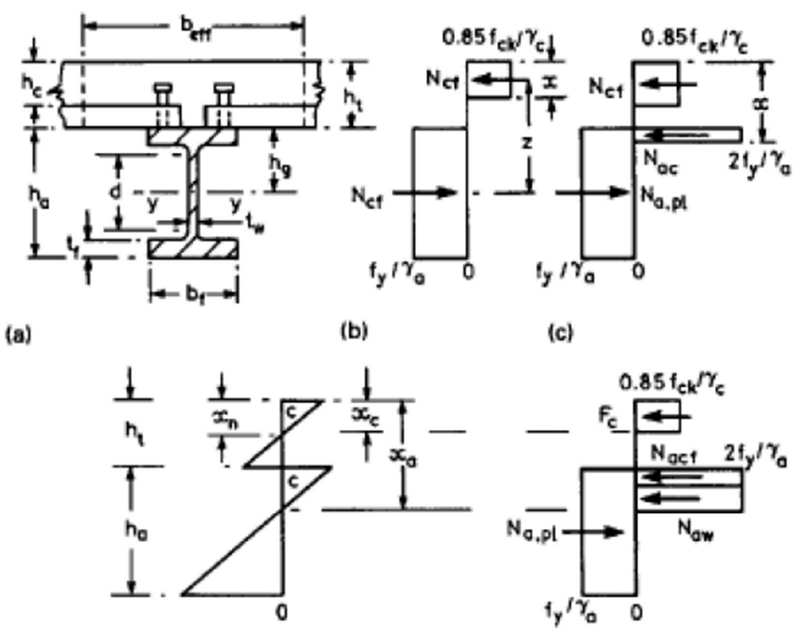

Figure 3. Figure 8 Stress distributions with respect to the three neutral axis positions [2].

x = Depth of the neutral axis.

h_t = Depth of concrete slab.

h_g = Depth of centre of steel section from top of steel flange.

For equilibrium, stress in concrete must be equal to stress in steel.

$$N_{cf} = \frac{A_a F_y}{\gamma_a} = b_{eff} \frac{0.85 F_{ck}}{\gamma_c} \quad (2)$$

If $x \leq h_c$ the neutral axis is within the concrete slab and taking moment about top flange, the plastic moment resistance will be

$$M_{PL,RD} = \frac{A_a F_y}{\gamma_a}\left(h_g + h_t - \frac{x}{2}\right) \quad (3)$$

2.4. Resistance to Vertical SHEAR

Shear resistance of composite beam is similar to that of steel pure beams. The concrete slab has no effect on the shear resistance.

$$V_{PL,Rd} = \frac{F_y A_v}{\sqrt{3}\,\gamma_a} \quad (4)$$

A_v =Is the shear area which is the area of the beam web. Figure 4 below show the shear area of I section.

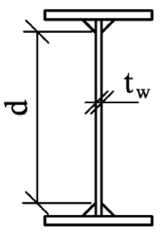

Figure 4. *Shear area of I section.*

2.5. Resistance in Longitudinal Shear (Resistance of Shear Connectors)

The longitudinal shear can be transferred from the concrete slab to the steel beam through the shear connectors and the connectors should have the capacity to resist the applied shear force.

The shear capacity of headed stud as in Euro Code 4 (EC 4) is given by Equation 3.6 below [2-3].

$$P_{Rd} = \frac{0.8 F_u \pi d^2/4}{\gamma_V} \quad (5)$$

γ_V = Partial safety factor for the shear stud =1.25

d = shank diameter of the stud

2.6. Deflection

The elastic properties relevant to deflection are section modulus and moment of inertia of the section. Applying appropriate modular ratio m the composite section is transformed into an equivalent steel section. The moment of inertia of uncracked section is used for calculating deflection. Normally unfactored loads are used for serviceability checks. No stress limitations are made in [3]. Deflection in composite beam is checked similarly to ordinary steel beam design, except gross uncracked moment of inertia of composite section is used. the allowable deflection is

$$\delta_{allow} = \frac{L}{360} \quad (6)$$

For uniformly distributed load in simply supported beam, the applied deflection is;

$$\delta = \frac{5 W_q L^4}{384 E I_g} \quad (7)$$

W_q = imposed uniformly distributed load only

E = $205 KN/mm^2$ is the elastic modulus of steel

I_g is the gross uncracked moment of inertia of composite section and is given by Equation 8 below

$$I_g = I_a + \frac{A b_{eff} h_t (h_a + h_t)^2}{4(Am + b_{eff} h_t)} \quad (8)$$

2.7. Loading

Direct static loading according to Eurocode 1 (EC 1) will be applied in this study [18]. Therefore, the load W isl given by Equation 9 below.

$$W = \gamma_G G_k + \gamma_k Q_k \quad (9)$$

γ_G And $\gamma_k$are partial safety factors for actions as in [18]. Their values depend on the limit state to be considered, and on whether the action is unfavorable or favorable for (i.e. tends to increase or decrease) the action effect considered. The values used in this study are given in Table 1 below.

G_k Is the permanent action or self-weight.

Q_k Is the variable action which depends on type and function of the structure.

Table 1. *Values of γ_G and γ_Q for persistent design situations.*

Type of action	Permanent		Variable	
	Unfavourable	Favourable	unfavourable	Favourable
Ultimate limit State	1.35*	1.35*	1.5	0
Serviceability limit state	1.0	1.0	1.0	0

*Except when coefficient of variation is large, or for checking less of equilibrium

2.8. Modeling

The main material components of the model are concrete, steel, and shear stud. Table 2 below presents the input parameters of the proposed model

Table 2. *Section properties of the model.*

S/N	Material	symbol	value
1	Steel		
	Maximum tensile strength	Fy	460 N/mm^2
	Poison ratio	Υ_{us}	0.2
2	Concrete		
	Maximum compressive strength		40 N/mm^2
	Poison ratio	Υ_{uc}	0.3
3	Studs connector		
	Maximum tensile strength	Fu	460 N/mm^2
	High		100 mm
	Diameter		19 mm

3. Results and Discussions

The modelling and Finite Element (FE) analysis were carried out to study the behaviour of the composite beams with respect to bending, shear and deflection under varying loads, and the ultimate loadings and section capacities corresponding to failure modes were evaluated using Consteel 11 (2017) [19]. A 300 X 300 X 42.2 kg IPE beam section supporting a concrete slab of 150 mm was used for the study.

3.1. Models

Using the input data as given in Table -2: runs of the ConSteel11 (2017) software gave the plastic shear resistances, plastic moment resistances and displacements in the composite beams. The Models is as shown in Figures 5 to 7.

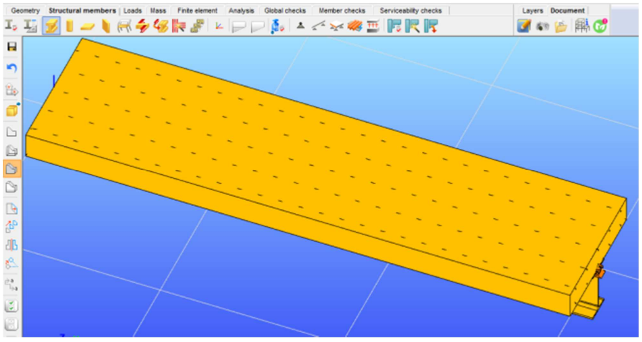

Figure 5. *The Concrete-Steel composite beam as modelled in [6].*

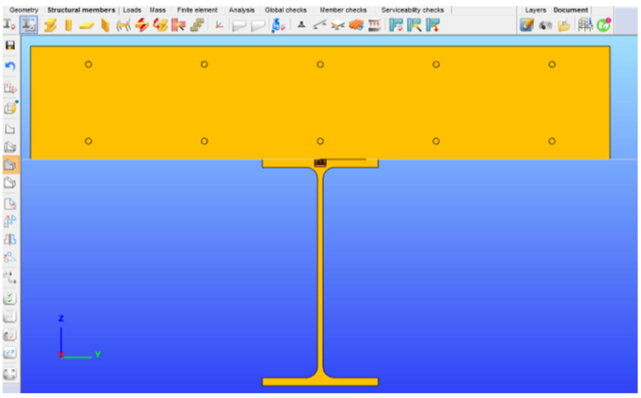

Figure 6. *The cross-section of the model.*

Figure 7 below shows the mesh cross-section of the beam for finite element analysis.

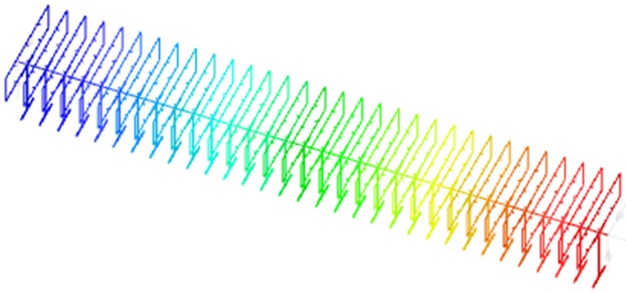

Figure 7. *The mesh cross-section of the beam.*

The moment capacity, shear capacity as well as limiting deflection of the section were evaluated according to [3]. The beams were loaded by varying the live loads until it reaches its ultimate capacity with respect to the three failure modes. The ultimate loading and the corresponding apply moment, shear and deflection were evaluated.

3.2. Shear Capacity

From the results presented in figure 8 it was observed that the shear capacity of the sections remain unchanged at constant steel strength and varying length, and it is also independent on the concrete compressive strength, but increases with increase in ultimate yield strength of the steel sections by 29% and 67% when F_{yp} was increase from 275 N/mm^2 to 355 N/mm^2 and 460 N/mm^2 respectively as shown in figure 8.

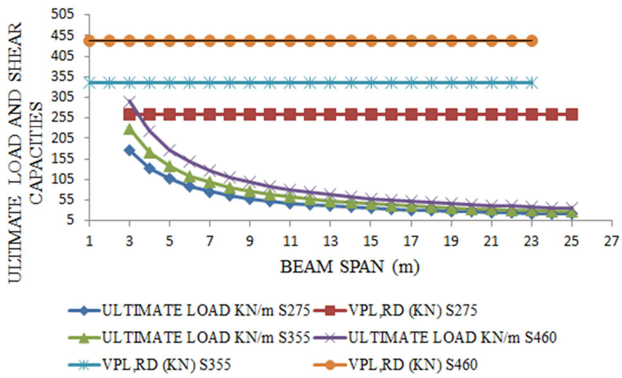

Figure 8. *Ultimate loadings and shear capacities of the sections for varying span and steel strength.*

The ultimate shear loadings of the section decreases with increase in the beams span for both the three steel grades, both the rate of reduction in ultimate shear loads with increase in span decreases significantly between 10 to 25m span with 2% differences compare to 11% differences between 3 to 10m beams span as shown in *Figure* 8 above.

The independency of the shear capacity with the concrete strength is as a result of the assumption that the vertical shear in composite beam is resisted by the steel beam shone as if is not composite [3]. This conformed to [2]. The high increase in shear capacity with an increase in steel strength was attributed to the fact that shear capacity of steel section is proportional to the steel strength [20].

3.3. Bending Capacity

It was observed from the results shown in figure 10 to12 that the flexural resistances of the sections at constant cylinder compressive strength increase with increase in beams span from 3 to 14 m both remain constant from 14 to 25 m for both the three steel strength 275, 355 and 460 N/mm^2. It was also observed an increase in flexural resistance with an increase in steel strength by 27 and 21% when the strength was increase from 275 to 355 and $460N/mm^2$ respectively, but the ultimate flexural load capacity of the beams decreases with increase in the beam span for both the three steel strength.

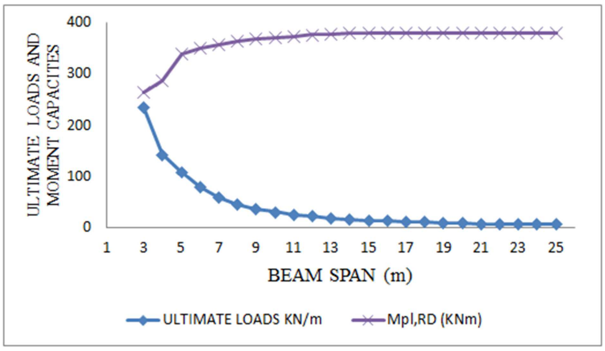

Figure 9. *Ultimate loading and shear capacities of the sections for Fy = 275N/mm².*

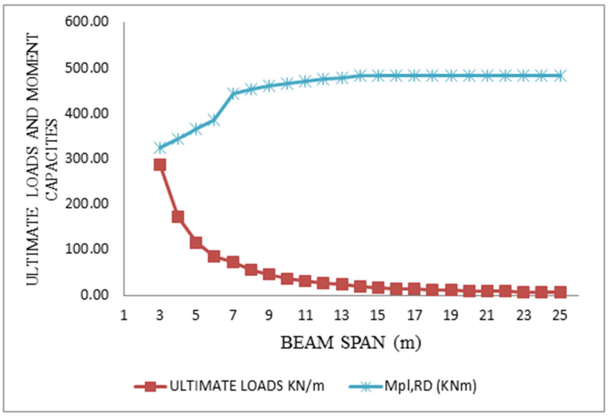

Figure 10. *Ultimate loading and shear capacities of the sections for grad Fy = 355N/mm².*

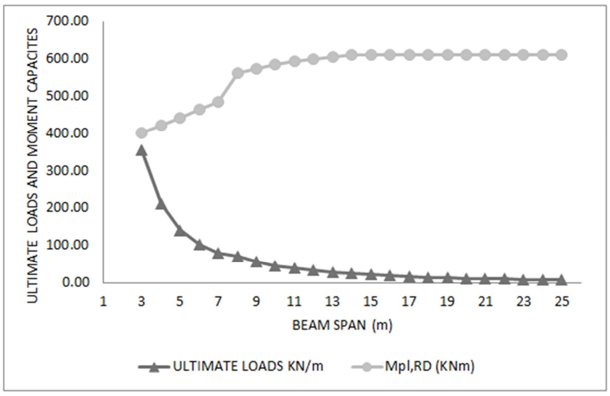

Figure 11. *Ultimate loading and shear capacities of the sections for Fy = 460N/mm².*

The increase in plastic moment resistance of the section between 3 to 14m was attributed to the increase in effective width of concrete slab at this range, in which the values was less than the spacing between the parallel beams. The plastic moment resistance of the section between 14 to 25m remain unchanged this is as a result of constant effective width at that range as is less than one-fourth of the beams span as recommended in [3].

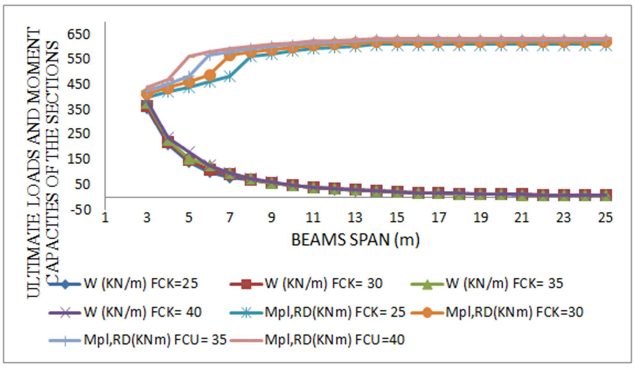

Figure 12. *Ultimate loadings and moment capacities against beam span for F_y= 460 N/mm². at varying concrete strength.*

The same behaviour was observed at constant steel strength and varying compressive strength as shown in figure 13 The only difference is increase in flexural resistance with increase in compressive strength is very small that is 3.2% 3.1% and 3.0% when the concrete strength was increase 25 *N/mm²* to 30, 35 and 40 *N/mm²* respectively. Compare to the way it increase with increase in the steel strength.

3.4. Deflections

From the results shown in figure 14, it was observed that the apply deflections does not depend on the strength of steel or concrete cylinder strength but depend on the spans, apply loads, modulus of elasticity of steel and gross moment of inertia of the beam in which the allowable deflection increases with an increase in the beams span. The ultimate loadings with respect to deflection also decrease with increase in the beams span.

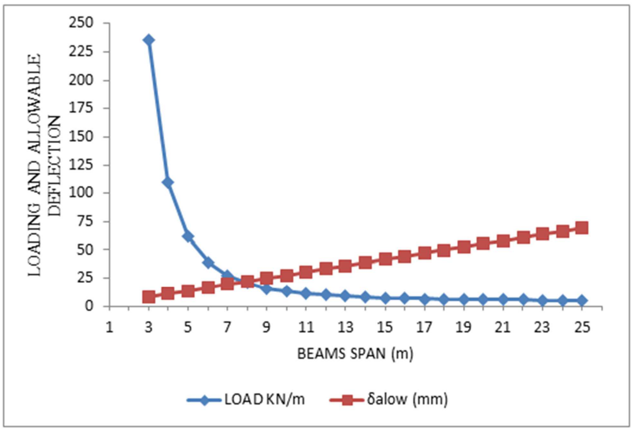

Figure 13. *Ultimate loading and deflections of the sections.*

4. Conclusions

From the FEA analysis results the following conclusions were drawn

1. A numerical model proposed, based on the finite element theory can be used to examine the mechanical characteristics of concrete-steel composite beams.
2. The ultimate loading and section capacities were found to be affected by concrete and steel strength, position of the neutral axis, effective width of concrete slab and the depth and position of neutral axis in bending; influenced by web thickness, area and strength of structural steel in shear; and depend on the beam span, gross moment of inertia live loads and modulus of elasticity of steel in deflections.
3. The results of the CONSTEEL11 analysis can be used as basis for further analysis to have a better interpretation and to be able to further understand the behaviour of the beams.

References

[1] Al-duri, S. (2015). *Structural steel design of composite beam* (Tech. Rep.) Memorial University Canada.

[2] Johnson, R. P. & Anderson, D. (2004) Designers' guide to en 1994-1-1: Eurocode 4: design of composite steel and concrete structures, Part 1-1: General Rules and Rules for Buildings, Thomas Telford.

[3] BS EN (2005). Eurocode 4: Design of composite steel and concrete structures. General rules and rules for bridges. *British Adopted Standard*.

[4] Mc Cormac J. C., & Csernak, S. F. [Ed] (2012). Structural steel designs (5th ed.) Prentice Hall Ltd New York.

[5] Shuaibu Y. K. A. & Airong (2006). Conceptual design and analysis of steel-concrete composite bridge *steel structure* vol. 6 pp 393-407.

[6] Hicks, S. J. Lawson, R. M., Rackham, J. W. & Fordham, P. (2004). Comparative structure cost of modern commercial buildings *SCI Publication The Steel Construction Institute* vol. 7 pp 137- 85.

[7] Ashraf M. M., (2016). Finite element modeling of steel-concrete beam considering double composite action. *In shams Engineering Journal vol. 2 pp73-88.*

[8] Lawson S. J. R. M., , Rackham J. W., & P. Fordham, (2004). Comparative structure cost of modern commercial buildings *SCI Publication The Steel Construction Institute* vol. 7 pp 137- 85.

[9] Arya, C. (2009). Design of structural elements. Spon Press London.

[10] Owen G. W., & Davison, B. [Ed.](2003) Steel designer's manual (6th ed.) Blackwell Science Ltd UK.

[11] Kapil G. & Sajshi G. (2016). Flexural capacity of composite beams (steel & concrete). *Journal of Mechanical and Civil Engineering (IOSR-JMCE)* vol. *40* pp 66-72.

[12] Igor, I. A. A. T. Beck, & Malite, M. (2010). Reliability based evaluation of design guidelines for cold-formed steel-concrete composite beam. *Journal of Brazilian Society of Mechanical Science & Engineering* vol. 32 pp 442-449.

[13] Mosley, B. B. & Hulser, J. R. (2007). Reinforced concrete design to Eurocode 4. Palgrave Macmillan Press. London.

[14] Qia., M. F. Gai, Zhao, J. & Sheng S. (2015). Analysis on time-dependent reliability of steel structural components under fire conditions. *International Journal of Smart Home* vol. 9 pp 29-36.

[15] Abubakar, A., Mohammed, A., & Duna S. (2017). Mechanical Properties of concrete containing Corn cob ash. *International journal of Scientific Research and Engineering* studies vol 3 pp 47-51.

[16] Omoniyi, T., Duna, S., & Mohammed A. (2014). Compressive Strength Characteristics of Cow dung Ash Blended Cement Concrete *International journal of Scientific and Engineering Research.* vol.3 pp770-776

[17] Rajesh, K. & Devi, Ch. (2017). Study on Ordinary Concrete with Waste Plastic as A Fibre *International Journal of Engineering and Technical Research (IJETR)* Vol. 7 p 2454-4698.

[18] EN 1990 -11 (2002) (English): Eurocode 2 - Basis of Structural Design [Authority: The European Union per Regulation 305/2011, Directive 98/34/EC, Directive 2004/18/EC].

[19] EN 1992-1-1 (2004) Design of concrete structures – Part 1-1: General rules and rules for buildings [Authority: The European Union Per Regulation 305/2011, Directive 98/34/EC, Directive 2004/18/EC].

[20] Abubakar I. & Nabade A. M. (2014). "Bending Strength Classification of Some Common Nigerian Timber Species". *Jordan Journal of Civil Engineering,* Volume 8 (2) 2014.

[21] Consteel11 (2017). Composite Concrete and Steel Design software according to EC4 Version 11.0 *www.consteelsoftware.com*.

[22] EN 1993-1-1 (2003) (English): Eurocode 3: Design of steel structures – Part 1-1: General rules and rules for buildings [Authority: The European Union Per Regulation 305/2011, Directive 98/34/EC, Directive 2004/18/EC].