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Vertical Shear Strength Contribution of Concrete to the Steel Concrete Composite Beam

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***Abstract:*— In the current structural codes, the vertical shear strength of the composite beam is considered solely due to the steel beam. The contribution of the concrete slab to the vertical shear strength of the composite beam is neglected. This paper presents the comparisons of provisions of the different codes of practice of the design of the steel-concrete composite beams and also presents the comparisons of the formulae (available from the past studies) of the vertical shear strength contribution of the concrete slab to the steel-concrete composite beams.**

***Index Terms* :-- Composite beams, Concrete slab, Vertical Shear Strength, Eurocode 4, AISC 360-10.**

I. INTRODUCTION

In composite construction, steel beams support concrete slabs which are rested over them. When the load is applied the concrete slab and the steel beam act independently. If there is no connection between them, a relative slip occurs. The slip can be eliminated by providing the deliberate and appropriate connection between the concrete slab and the steel beam. Their action is similar to that of a monolithic T-beam and act as a “composite beam”. For the composite beam construction material such as timber and pre-stressed concrete can also be used other than steel and concrete. Concrete is weak in tension but strong in compression, steel buckles in compression. We can utilize their respective advantages to the maximum extent by adopting the composite action between the two.

The vertical shear strength of the steel-concrete composite beam is considered solely due to the steel beam but from the previous experimental studies it can be noted that the concrete slab also contributes to the vertical shear strength of the composite beam. In the current structural codes of practice such as AISC 360-10 (American Institute of Steel Construction) and Eurocode 4, the contribution of the concrete slab to the vertical shear strength of the composite beam is neglected.

George Vasdravellis et al. (2014) studied the effects of the shear reinforcement in the slab and the partial shear connection and also carried the numerical and experimental studies of the moment-shear interaction and the shear strength of the steel-concrete simply supported composite beams. He stated that the concrete slab contribution to the shear strength of the composite beam varies from 16-60% and also given a formulae for the contribution of the concrete slab to the vertical shear strength of the composite beam. Johnson et al. (1972) concluded that the contribution of the concrete slab to the shear strength is 20-40% and Nie et al. concluded that the contribution of the concrete slab to the shear strength of the composite beam is 33-56%.

Qing Quan Liang et al. (2005) investigated the vertical shear strength of the steel-concrete composite beam and the shear strength contribution of the concrete slab to the composite beam. He also studied the moment-shear interaction and the effect of the shear connection on the vertical shear strength of the composite beam. He also stated a formulae for the shear strength contribution of the concrete slab to the composite beam.

Jianguo et al. (2004) carried out both the experimental and analytical studies of the composite beam to know the contribution of the concrete slab to the vertical shear strength. The shear span aspect ratio, the width and the thickness of the concrete slab were the main parameters considered in the study.

As the vertical shear strength of the composite beam from the concrete slab is neglected in the present design codes and as there are different conclusions of the contribution of the concrete slab to the composite beam, it is an area which requires an extensive research. In this paper the comparisons of the various provisions of the different international codes and comparing the formulae given by the Jianguo et al., Vasdravellis et al. and Qing Quan Liang et al. have studied.

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II. PROVISIONS OF THE CODE

1. AMERICAN CODE: AISC 360 (Specification for structural steel buildings).

$\phi_b M_n$ is the positive flexural strength of the composite section . In LRFD $\phi_b = 0.9$. M_n is calculated by the two methods one is plastic stress distribution method and the other is elastic stresses considering shoring.

(a) M_n is determined from the plastic stress distribution method if $\frac{h}{t_w} \leq 3.76\sqrt{E/F_y}$

(b) M_n is determined from the superposition of elastic stresses considering shoring if $\frac{h}{t_w} > 3.76\sqrt{E/F_y}$

A. Specifications of the Composite Beams with Formed Steel Deck.

1. Concrete strength should be in between 3 ksi and 10 ksi.
2. Rib height: $h_r \leq 3$ inches.
3. Average rib width: $w_r \geq 2$ inches.
4. Use steel headed stud anchors ¾ in. or less in diameter
5. Steel headed stud anchor diameter: $d_{sa} \leq 2.5t_f$
6. Steel headed stud anchors, after installation, shall extend not less than 12 in. above the top of the steel deck.
7. Minimum length of stud anchors = 4 d_{sa} .
8. There shall be at least 1/2 in. of specified concrete cover above the top of the headed stud anchors.
9. Slab thickness above steel deck ≥ 2 in.

B. Design Steps of the Composite Beam:

1. Fix the material properties from the table 2-4 of the AISC manual.
2. Load calculations
(a) Pre-composite
(b) Composite
3. Fixing dimensions of the composite deck and the anchors.
4. Design for the pre-composite condition from table 3-2 of the AISC manual.
5. Find Zx min and find the appropriate section.
6. Checking for the pre-composite deflection.
(a) If the deflection exceeds the L/360 then select an higher section or provide camber in the deck.
7. Design for the composite condition.
(a) Find the effective width.
(b) Find the flexural strength from the table 3-19 in the AISC manual.
8. Check for the live load deflection.
(a) Find lower bound moment of inertia from the table 3-20.
9. Calculate number of flutes and number of shear studs required.
10. Check for the shear strength.

2. Eurocode 4: Design of Composite Steel and Composite Structures.

Composite beams shall be checked for:
1. Resistance of critical cross-sections.
2. Resistance to lateral-torsional buckling.
3. Resistance to shear buckling and transverse forces on webs.
4. Resistance to longitudinal shear.

A. Bending Resistance of Cross-Section of Beams:

1. Rigid plastic theory is used for calculating bending resistance of only class 1 and class 2 cross-sections.
2. The bending resistance can also be calculated from the elastic analysis and non-linear theory.
3. The tensile strength of the concrete is neglected.

B. Plastic Resistance Moment of Composite Cross Sections:

1. Full interaction of steel and the concrete is assumed.
2. Both in the tension and compression the stress in the steel is taken as fyd.
3. 0.85fcd is taken as the stress in the concrete.
4. Non-linear resistance to bending is employed when the distance between the extreme fiber of the concrete and the plastic neutral axis exceeds 40% of total h. A reduction factor β is employed when the distance exceeds 15% of total h.

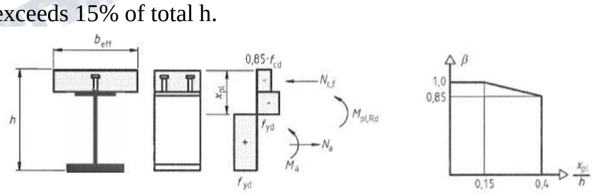

Fig.1 Reduction Factor β. (Eurocode 4)

C. Plastic Resistance to Vertical Shear:

The plastic resistance to the vertical shear is considered only by the steel section and the contribution of the concrete flange to the vertical shear strength is neglected in the Eurocode 4.

D. Bending and Vertical Shear:

The moment capacity of the composite cross section should be reduced by a factor (1-ρ), when the vertical shear force Ed
V exceeds half of the shear resistance pl , Rd
V . P is given by

$$\rho = \left(\frac{2V_{Ed}}{V_{Rd}-1}\right)^2 \quad \text{----------- (1)}$$

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E. Design Steps of Eurocode 4:

1. Calculating the actions on the composite beam.
(a) Permanent Actions.
(b) Variable Actions.
(a) Properties of Materials.
(b) Design values of combined actions and design values of effects of actions.
(a) Calculate moment acting on the composite beam both in the construction stage and composite stage.
(b) Calculate the shear acting on the composite beam both in the construction stage and composite stage.
4. Check for the construction stage.
(a) Selection of steel cross-section.
(b) Classification of the steel cross-section.
5. Vertical Shear Resistance.
6. Plastic Resistance moment of the steel cross-section.
7. Interaction of M-V. (Bending and Shear force)
8. Lateral Torsional buckling of the steel beam.
9. Check for the composite stage.
(a) Effective width of the concrete flange.
(b) Check for Shear connector.
(c) Plastic Resistance moment of the composite cross section.
(d) Lateral torsional buckling of the composite beam.
(e) Check of longitudinal shear resistance of the concrete flange.

From the above study of the provisions of the different codes, it is well recommended to use the Eurocode 4 for the analysis and the design of the composite beams. Eurocode has a separate code for the composite beams compared to other country codes and Indian code has taken most of it part from the Euro code. AISC code does not taken the interaction of M-V into consideration as it has a considerable effect on the flexural capacity of the composite beam it cannot be neglected. As in all the codes the contribution of concrete slab to the shear strength is not considered, from the literature review, the concrete slab has 25% shear carrying capacity on an average. To quantify the number and to compare it with different journals my interest lies in calculating the contribution of the concrete slab to its shear strength.

III. COMPARISON OF EQUATIONS OF SHEAR STRENGTH CONTRIBUTION OF THE CONCRETE FLANGE TO THE COMPOSITE BEAM.

From the literature review, Jianguo et al, Vasdravellis et al and Qing Quan Liang et al. had given their respective equations on the shear strength contribution of the concrete slab to the vertical shear strength of the composite beam.

The equations given by Jianguo et al. are:

$$V_{uc} = 0.8\sqrt{f'_c} B_f h_f / \lambda \qquad \text{----------------- (2)}$$

And $V_{uc} = 2.6\sqrt{f'_c} B_f h_f / \lambda_f$ ----------------- (3)

Table 1: Comparisons of the Provisions of the Different Codes.

Parameters	AISC 360-10	Eurocode-4	IS: 11384
Limitations on grade Of materials. (Mpa) (a)Concrete (b)Steel	$21 \le f'_c \le 70$ $f_y \le 525$	$20 \le f'_c \le 60$	Not specified for concrete $250 < f_y < 350$
Partial safety factors (a)Materials (i) Concrete (ii) Steel (b)Loads (i) Permanent (ii) Temporary	 1.0 1.0 1.2 1.6	 1.5 1.10 1.35 1.50	 1.5 1.15 1.35 1.50
Effective Width	Not mentioned at different locations	Specially mentioned at different locations.	Not mentioned about it. Uses Eurocode4
Design Method	LRFD and ASD	Only Limit State	Only limit state
Flexural Strength	Tables are given	Detailed Procedure	Detailed procedure
Shear Strength	Tables are given	Detailed Procedure	Not mentioned
Strength of Shear Stud	$Q_n = 0.5 A_{sa}\sqrt{f'_c E_c}$ For 19mm 77KN	$P_{Rd} = \frac{0.8 f_u \pi d^2 / 4}{\gamma v}$ For 19mm 73KN	Tables are given
Deflection	L/360 and no long term deflections	L/360 and long term deflections	L/325 for steel section only
Camber	Camber of 80% restriction to deflection	Pre-camber is provided for the deflection of dead load and creep and shrinkage.	Not mentioned
Interaction of M-V	No provision is there	Took into account	Not mentioned
Partial Shear connection	No provision is there	Took into account	Not mentioned

The equations given by Vasdravellis et al. is:

$$V_{slab} = \varphi_s f(\lambda_{sd})(b_f D_{slab})^{0.7}\sqrt{f'_c} \qquad \text{------------ (4)}$$

Where $f(\lambda_{sd}) = 110 \times \lambda_{sd} + 13$ ------------ (5)

The equations given by Qing Quan Liang et al. is:

$$V_{slab} = 1.16(f'_c)^{1/3} A_{ec} \qquad \text{------------ (6)}$$

Where B_f is the width of the concrete flange and $\lambda_{sd} = \frac{D_{slab}}{D_{beam}}$

b_f is the width of the top flange of the steel beam and h_f is the height of the concrete flange. F'c is the compressive strength of the concrete and $\phi_s = safetyfactor = 0.8$

By taking the experimental sizes of the specimens conducted by Jianguo et al., the formulae given by the Jianguo et al., Qing Quan Liang et al. and Vasdravellis et al. for the contribution of the concrete flange to the composite beam were compared. By varying the shear span aspect ratio, width and depth of the concrete flange the three equations were compared.

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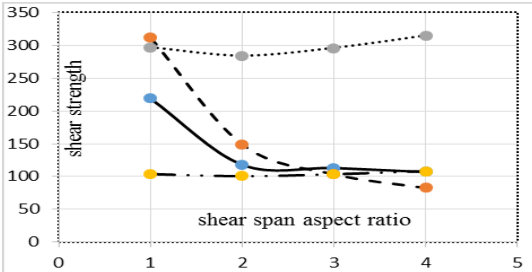
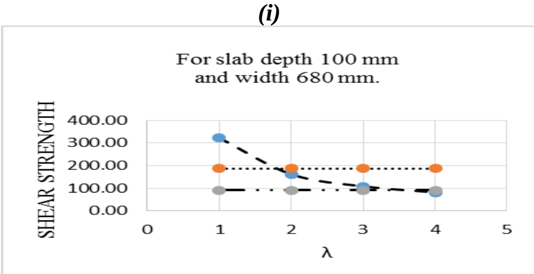


(i)



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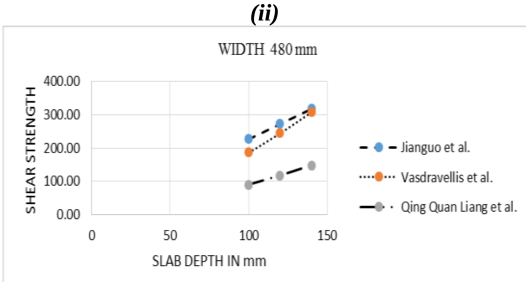

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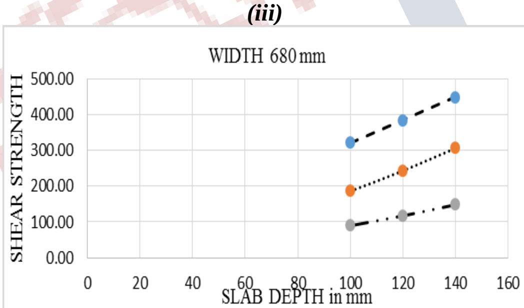

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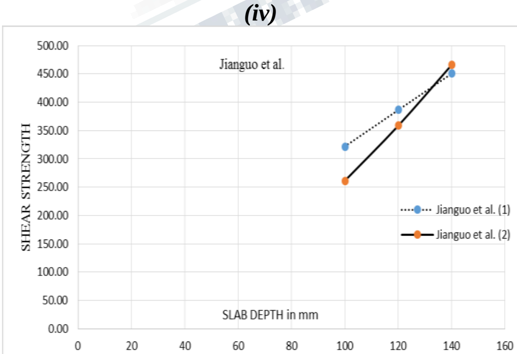

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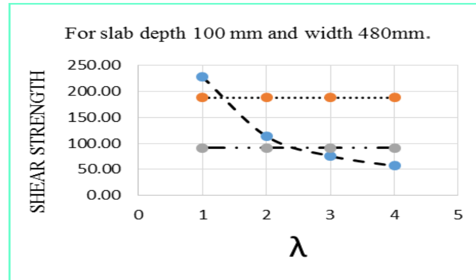

(vi)

Fig 2. Graph Showing Shear Strength vs different Parameters.

From the graph (i), it is clear that with the increase of the shear span aspect ratio the shear strength of the concrete slab decreases. It is to be noted that the results from the

1. Jianguo et al. and George Vasdravellis et al. are giving higher values for the shear span aspect ratio of 1 and 2.

2. Qing Quan Liang et al. are giving conservative results.

3. The equations given by Vasdravellis et al. and Qing Quan et al. have not considered the effect of the shear span aspect ratio.

4. In the experiments conducted by Jianguo et al. he had changed the compressive strength of the concrete for every specimen. If the compressive strength of the concrete is not changed then the results given by the equations of vasdravellis et al. and Qing Quan Liang et al. would be constant for different shear span aspect ratio.

5. By taking an ISMB 300 beam, the parameters width and depth of concrete slab and also the shear span aspect ratio are varied. From the graph (ii), by taking the slab depth as 100 mm and slab width as 680 mm and for varying shear span aspect ratio, graph showing the shear strength of the concrete given by the formulae of Vasdravellis et al., Jianguo et al. and Qing Quan Liang et al.

6. From the graph (vi), it is clear that the shear strength given by Jianguo et al. is decreases with the increase in the shear span aspect ratio whereas Vasdravellis et al. and Qing Quan Liang et al. have not taken the shear span aspect ratio into consideration.

7. From the graph (iv), for a constant width of 680 mm and for constant shear span aspect ratio, by
increasing the slab depth the shear strength of the beam increases.

8. From the graph (iii), for a constant width of 480 mm and for constant shear span aspect ratio, by increasing the slab depth the shear strength of the beam increases. For a constant depth of 100 mm and shear span aspect ratio of 1, the shear strength of the beam decreases with the decrease in the width of the beam according to the formula given by the Jianguo et

al. but the slab width has no any effect according to Qing Quan Liang et al. and Vasdravellis et al.

9. Jianguo et al. had given two formulae for calculating the shear strength of the concrete slab from equation From the graph (v), of these two, the first one is giving closer results to the experimental.

$$(a)\ V_{uc} = 0.8\sqrt{f'_c}B_f h_f / \lambda$$

$$(b)\ V_{uc} = 2.6\sqrt{f'_c}B_f h_f / \lambda_f$$

From the graph (v), of these two, the first one is giving closer results to the experimental.

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