The 2015 World Congress on
Advances in Structural Engineering and Mechanics (ASEM15)
Incheon, Korea, August 25-29, 2015

An Experimental Study On The Positioning Of Shear Connectors In Steel-Concrete Composite Beams

* T. Valsa Ipe[1] and H. Sharada Bai[2]

[1] *Department of Civil Engineering. SVCE, Bangalore, 562157 India*
[2] *Faculty of Engineering, Civil UVCE Bangalore, 560056 India*
[1] valsaipe@yahoo.co.in [2] sharadaj29@yahoo.com

ABSTRACT

The flexural and shear behaviour of thin walled steel-concrete composite beams are improved in the presence of shear connectors. This study is concerned with finding the effect of positioning of shear connectors on the behaviour of composite beams. Cold-formed steel Channel section with lips on compression side with concrete infill is considered as the cross section of the composite beam for the experimental study. Rectangular bars obtained from leftover pieces of the same steel used for the fabrication of channel section are used as bar type shear connectors and their locations are varied. Simply supported composite beam specimens are tested under progressive two point loading till failure of beams. Test results are utilized to evaluate the effect of shear connector positioning for two different shear span to depth ratios.

Study shows that load carrying capacity, stiffness and energy absorption capacity are considerably dependent on the positioning of shear connectors in the composite beam.

Keywords: shear connector, composite beam, flexure, shear span.

1. INTRODUCTION

Cold-formed steel-concrete composite beams are obtained by filling concrete into cold-formed steel beam sections such that the concrete and steel act together in resisting the load. Shear connectors are key elements in bringing about composite action between the two materials and thus to support and transfer the load as single unit. They are provided to transmit the horizontal shear between the two component materials steel and concrete. They also resist uplift force acting at the steel-concrete interface.

George (1982) and Richard (1991) reported a testing programme using composite beams made of concrete with cold-formed steel channels as soffits and embossment as connectors. Oduyemi, et al. (1989) in their research on sandwich beams showed that bottom shear connections were much more critical than top connections. Deric, et al. (1993, 1994) conducted experimental study on composite eams, consisting of RCC beams with cold-formed steel sheets binding in the soffit and sides of the beams wherein the trapezoidal profiles in the steel sheet acted as connectors. Dubey, et al. (1999) presented experimental study on cold-formed steel square box filled with concrete with Spiral type shear connectors to show the crucial role played by shear connectors. Anwar (2003, 2005) conducted tests on cold-formed channel sections with various interface connections at the open end only. Authors Valsa, et al (2013) in their earlier studies conducted tests on flexural behaviour of cold formed steel concrete composite channel section beam with simple type rectangular shear connectors and without connectors.

These studies indicate the importance of shear connectors in enhancing the flexural and shear behaviour of composite beams but no specific conclusions regarding the optimum type and placing or positioning of shear connectors are available. It is necessary to find out suitable arrangement of shear connectors so that the composite action between steel and concrete can be made more effective. Hence, this study is concerned with finding the effect of positioning of shear connectors on the flexure and shear behaviour of composite beams.

2. EXPERIMENTAL PROGRAMME

Specimen of channel section with lips on compression side were fabricated and formed the cross section of simply supported beams (Fig.1). Rectangular bars (10mm* 30mm) obtained from left over pieces of the same steel used for the fabrication of channel section were used as shear connectors. Tests were conducted to evaluate the effect of positioning of shear connectors on the flexural and shear behaviour of composite beams in two setups in each case. The shear span to depth ratios (a/d) considered were 5.5 for flexure and 2 for shear behaviour. In the first test setup, the study was conducted to know whether it was beneficial to provide shear connectors throughout the span (Fig. 2a) or only in the shear span (Fig. 2b). In the second test setup (Fig. 3) three cases of arrangements of shear connectors in the composite beams considered were 1) at bottom sides and top (BST), 2) at bottom and sides (BS) 3) at bottom and top (BT), only in the shear span to evaluate their relative performance.

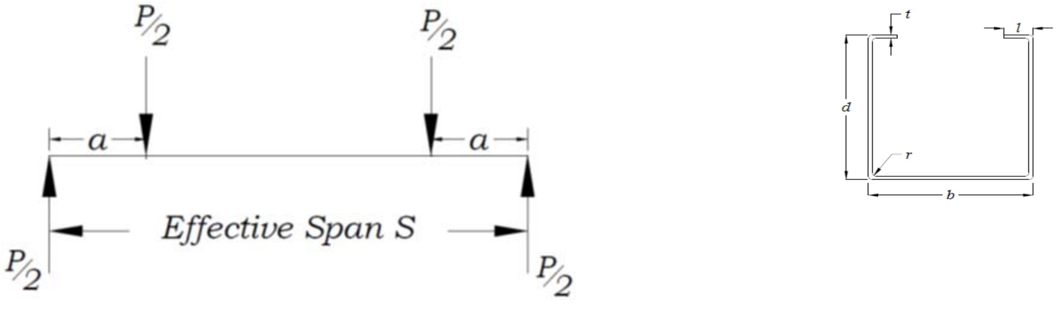
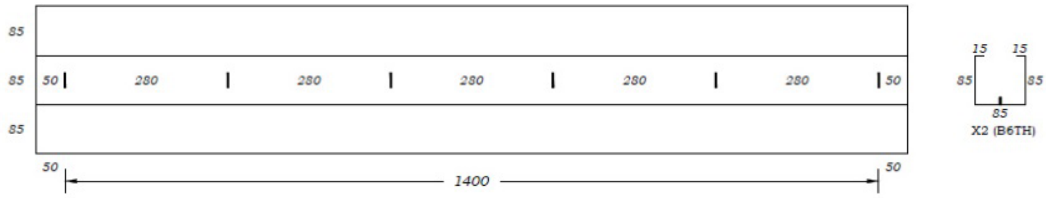
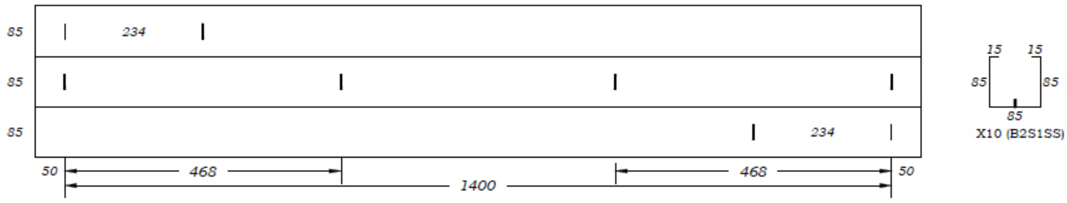


Fig. 1 Schematic of the beam with loading and cross section of channel

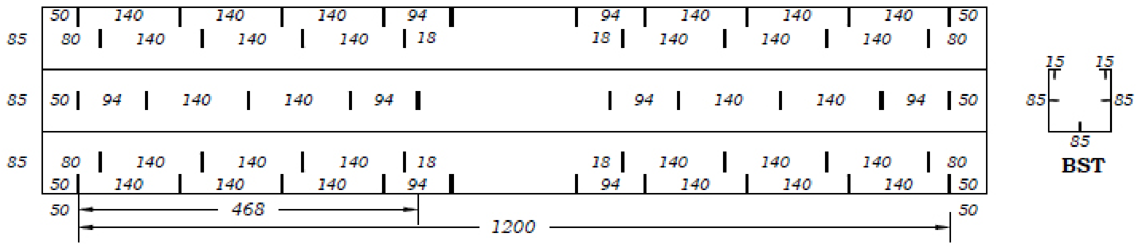


a) Connectors throughout the span

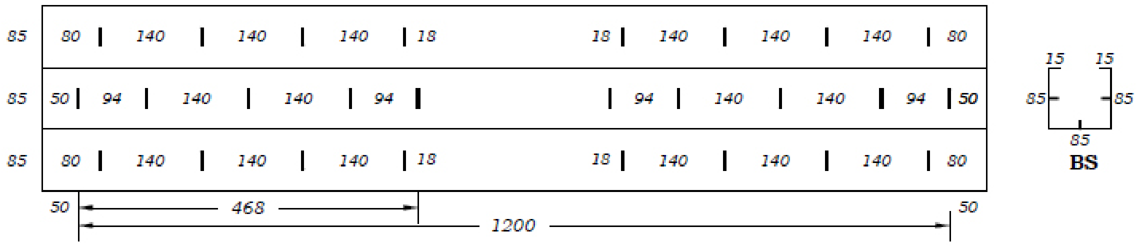


b) Connectors in the shear span

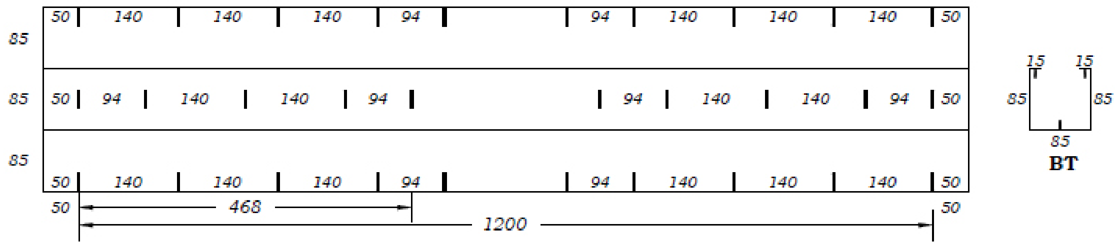
Fig. 2 Typical arrangement of connectors-Test setup 1



a) Connectors at bottom, sides and top (BST)



b) Connectors at bottom and sides (BS)



c) Connectors at bottom and top (BT)

Fig. 3 Different arrangements of connectors-Test Setup 2

2.1 SPECIMEN DETAILS AND MATERIAL PROPERTIES

The test specimens were of A series with depth to thickness (d/t) ratio 42.5 and shear span to depth ratio (a/d) 5.5 for flexure behaviour in the test setup 1. The beams had depth d=breadth b=85mm, thickness t=2mm and lip length l=15mm. The simply supported span of beam=1400mm. The designation of beams (X1 to X10) and descriptions of arrangements of connectors are given in Table 1. In the case of B6TH (X2) and S6TH (X7) the connectors were provided throughout the span and in other cases the connectors were provided only in the shear span. Yield stress of steel was 214.7MPa and average cube strength of concrete was 45MPa.

In the test Setup 1, for shear behaviour (a/d =2) seventeen composite beam specimens of effective span 1400 mm were tested. The test specimens were classified into three series based on depth to thickness ratio (d/t) as A (d/t=42.5), had depth d=breadth b=85mm, thickness t=2mm, lip length l=15mm, B (d/t=70), had depth d=breadth b=140mm, thickness t=2mm and lip length l=25mm and C (d/t=90), had depth d=breadth b=180mm, thickness t=2mm and lip length l=35mm, series of beams.

Designation and descriptions of test specimens are given in Table 2. Yield stress of steel and average cube strength of concrete are 230.8MPa and 46MPa.

In the test setup 2, for flexural behaviour (a/d = 5.5) and shear behaviour (a/d = 2) eight composite beams were tested. The test specimens were classified into two series as A (d/t=42.5) had depth d=breadth b=85mm, thickness t=2mm and lip length l=15mm and B (d/t=70) had depth d=breadth b=140mm, thickness t=2mm and lip length l=20mm of effective span 1200mm and 1800mm respectively for flexure behaviour and 1000mm for shear behaviour. The beam designation and description of positioning of connectors are given in Table 3. In Table 3, numericals 5.5 and 2 represent the shear span to depth ratio (a/d), N represents natural bond and BS, BT and BST represent the location of shear connectors as explained in the table. Yield stress of steel is 281MPa and average cube strength of concrete is 44MPa.

Table 1 Designation and Description of Test specimens - Test Setup 1 a/d=5.5

Beam Designation	Description
AN (X1)	Composite beam with no shear connectors (only natural bond)
B6TH (X2)	Composite beam with six numbers of connectors at bottom throughout
B1SS (X3)	Composite beam with one connector at bottom in shear span
B2SS (X4)	Composite beam with two connectors at bottom in shear span
B3SS (X5)	Composite beam with three connectors at bottom in shear span
S1SS (X6)	Composite beam with one connector on side in shear span
S6TH (X7)	Composite beam with 6 connectors on side throughout
S2SS (X8)	Composite beam with two connectors on side in shear span
B4S2SS (X9)	Composite beams with four connectors at bottom and two on side in the shear span
B2S1SS (X10)	Composite beams with two connectors at bottom and one on side in the shear span

Table 2 Designation and Description of Test specimens - Test Setup 1 a/d=2

Specimen Designation	Description
AN	Series A B & C filled with concrete and no shear connectors are provided (only natural bond)
BN	
CN	
AD (B2S4SS)	Series A filled with concrete connectors 2 bottom, 4sides in shear span
AE (B3S2SS)	Series A filled with concrete connectors 3 bottom, 2sides in shear span
AF (B1S2SS)	Series A filled with concrete connectors 1 bottom, 2 sides in shear span
AG (B11S14TH)	Series A filled with concrete connectors 11 bottom, 14 sides throughout the span
AH (B7S14TH)	Series A filled with concrete connectors 7 bottom, 14 sides throughout the span
BD (B8S8SS)	Series B filled with concrete connectors 8 bottom, 8sides in shear span
BE (B6S4SS)	Series B filled with concrete connectors 6 bottom, 4 sides in shear span
BF (B4S2SS)	Series B filled with concrete connectors 4 bottom, 2 sides in shear span
BG (B2S2SS)	Series B filled with concrete connectors 2 bottom, 2 sides in shear span
BH (B14S13TH)	Series B filled with concrete connectors 14 bottom, 13 sides throughout the span
CD (B8S8SS)	Series C filled with concrete connectors 8 bottom, 8sides in shear span
CE (B6S4SS)	Series C filled with concrete connectors 6 bottom, 4 sides in shear span
CF (B4S2SS)	Series C filled with concrete connectors 4 bottom, 2 sides in shear span
CH (B14S11TH)	Series C filled with concrete connectors 14 bottom, 11 sides throughout the span

Table 3 Designation and Description of Test specimens - Test Setup 2 a/d=5.5,2

Specimen Designation	Series	Description
A5.5N,A2N	A	Composite beam without connectors (Natural bond)
B5.5N,B2N	B	
A5.5BS,A2BS	A	Composite beam with connectors provided at bottom and sides in shear span
B5.5BS,B2BS	B	
A5.5BST,A2BST	A	Composite beam with connectors at bottom sides and top in shear span
B5.5BST,B2BST	B	
A5.5BT,A2BT	A	Composite beam with connectors at bottom and top
B5.5BT,B2BT	B	

2.2 TEST PROCEDURE

A loading frame of 500kN capacity was used for testing the beams. The beams were simply supported at ends and subjected to two point loading such that the shear span to depth ratios were 5.5 and 2 for flexure and shear behaviour respectively. The load was applied gradually from zero to failure (ultimate load) of the specimen. At each increment of load, the maximum transverse deflection at mid-span was measured using digital dial gauge. In the test setup 2, surface strains were also measured in the specimen at mid-span using digital strain indicator both on the compressive and tensile zone at each increment of load. The electrical strain gauges were fixed at top and bottom allowing a gap of 5mm from top and bottom respectively for measuring strain.

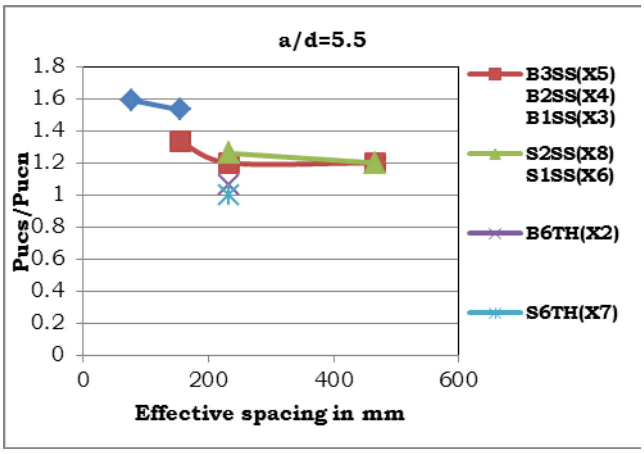


Fig. 4 Load capacity ratio vs Effective Spacing - Test setup 1

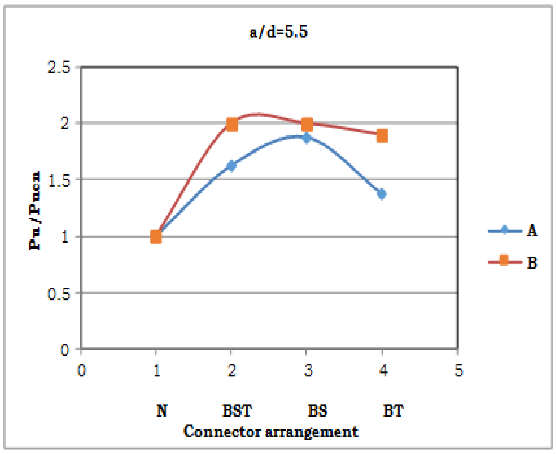


Fig. 5 Load capacity ratio vs Connector arrangement -Test Setup 2

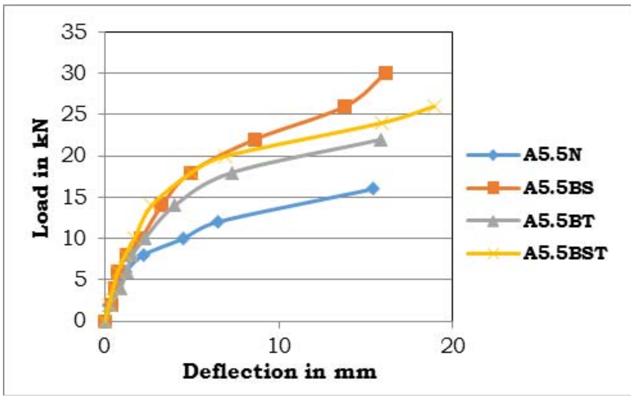


Fig. 6 A typical load-deflection behaviour

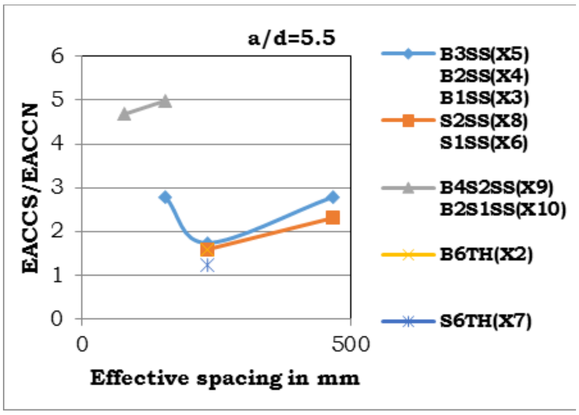


Fig. 7 Energy Absorption Capacity ratio vs Effective Spacing - Test Setup 1

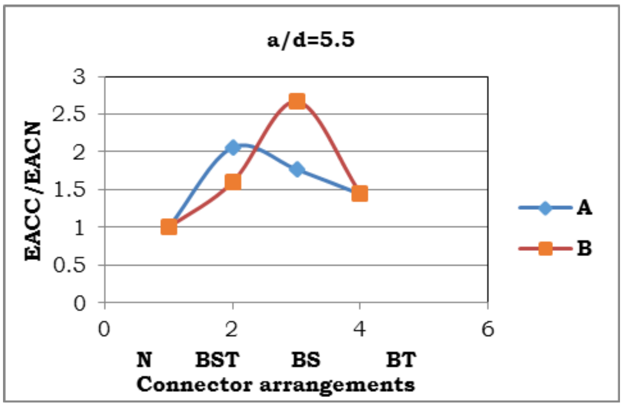


Fig. 8 Energy Absorption Capacity ratio vs Connector arrangements - Test Setup 2

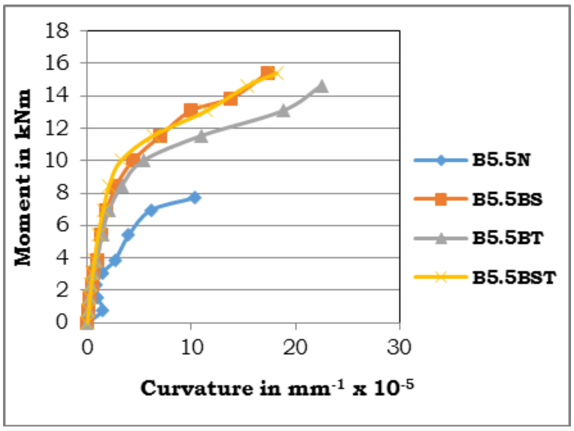


Fig. 9 Moment-curvature plot - B series Test Setup 2

3. TEST RESULTS AND DISCUSSION

3.1 FLEXURAL BEHAVIOUR

Fig. 4 shows the relation between load carrying capacity of the composite beams with shear connectors in terms of load carrying capacity of the composite beam without shear connectors (Pucs/Pucn) and effective spacing of shear connectors for the test setup 1. Effective spacing is the ratio of length over which connectors are provided and total number of connectors in that length. Generally, it is seen that load carrying capacity reduces as the effective spacing is increased. Comparing specimens with connectors provided at bottom only and sides only in shear span with connectors provided at bottom only and sides only throughout the span, for the same effective spacing, the first case has the maximum load carrying capacity, possibly due to the presence of connectors closer to the support. When the failure patterns were observed, it was found that in specimens without connectors, the separation between steel and concrete was maximum and was more towards support. Hence, it is better to concentrate the connectors in the shear span, wherever the central zone between the two shear spans is small compared to the sum of shear spans (for a/d=5.5).

In test setup 2, three different positioning of shear connectors in the shear span was experimented with same spacing and ultimate load in terms of that of composite beam without connectors (Pu/Pucn) is given in Fig. 5. In both series Pu/Pucn is maximum for the bottom and side arrangement of connectors.

In both setups of tested specimens, all the load-deflection curves (Fig. 6) show a linear region initially, which slowly modify to nonlinear region. In beams where connectors are provided at bottom and sides show maximum load carrying capacity and ductility.

The energy absorption capacities of composite beams (EACC) in terms of composite beam without connectors (EACCN) are given in Figs. 7 and 8 for setup 1 and 2 respectively. This is a measure of ductility which is given by the area under the load-deflection curve. The maximum energy absorption capacity ratios are found where connectors are provided at bottom and sides.

Load versus tensile strain and compressive strain were measured at mid-span of specimens with different arrangement of shear connectors for B series, test setup 2. Using the load strain data, moment-curvature curves are plotted as shown in Fig. 9. All the curves have an initial elastic portion followed by inelastic behaviour and then gradually the stiffness reduces. Composite beams with shear connectors provided at bottom and sides and bottom side and top have maximum flexural stiffness.

Fig. 9 clearly demonstrates the better behaviour of composite beams with shear connectors, in terms of substantial increase in moment carrying capacity and curvature in comparison to composite beam with natural bond.

3.2 SHEAR BEHAVIOUR

The load-deflection behaviour clearly shows that strength and stiffness of the beams increase with increase in number of shear connectors. Maximum strength and

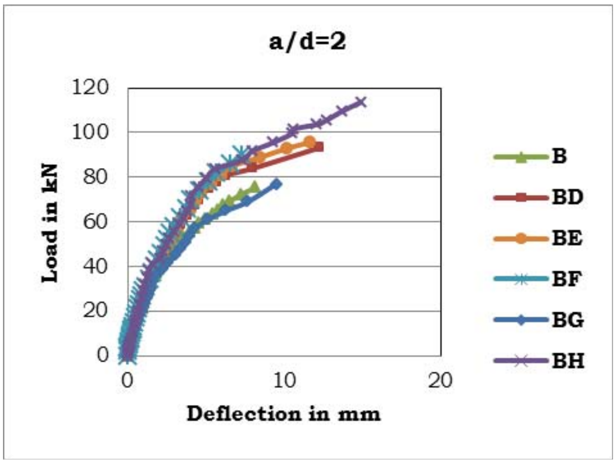


Fig. 10 Load-deflection behaviour for Setup1 - B series

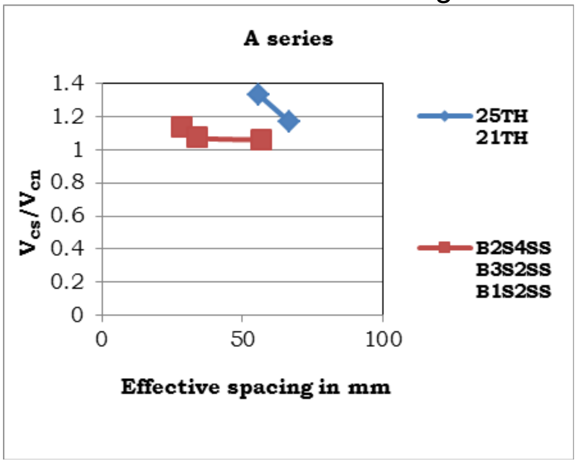


Fig. 11 Shear capacity ratio vs Effective Spacing – A series Test Setup1

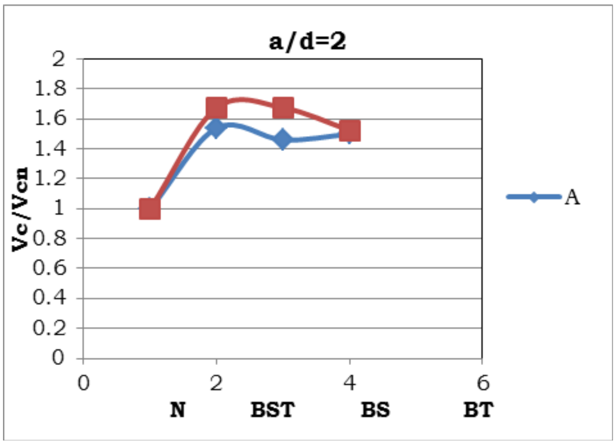


Fig. 12 Shear capacity ratio vs positioning of connectors – Test Setup 2

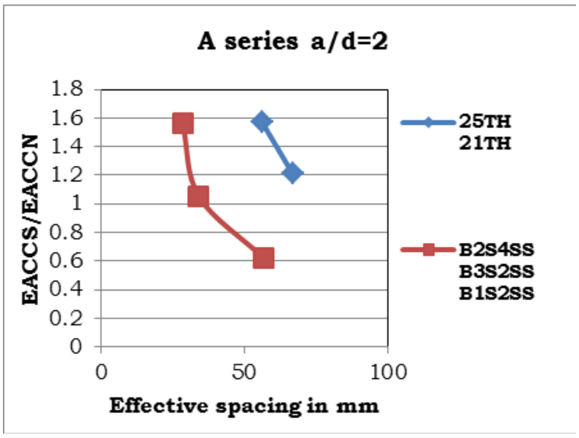


Fig. 13 Energy absorption capacity ratio vs effective spacing-A series Test Setup1

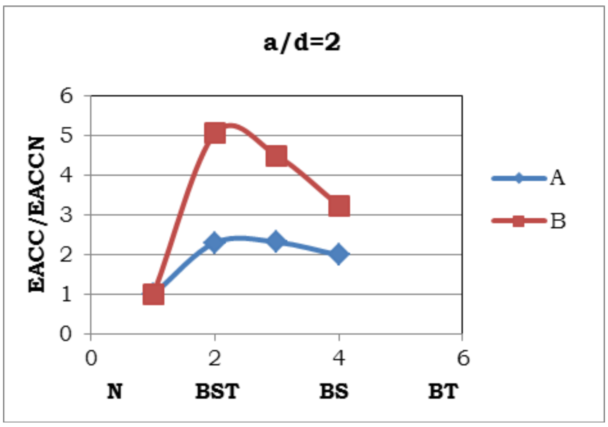


Fig. 14 Energy absorption capacity ratio vs

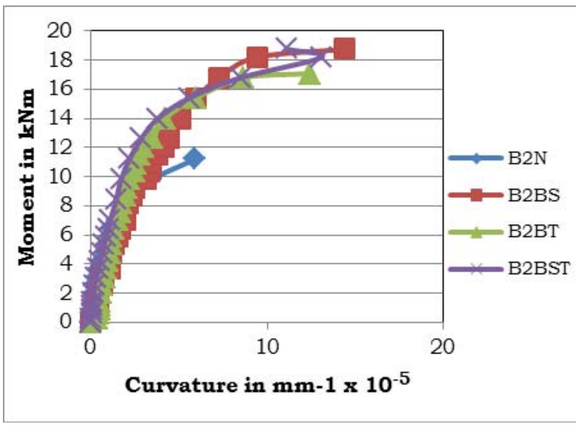


Fig. 15 Moment-curvature behaviour–

positioning of connectors - Test setup 2 B series

stiffness is shown by composite beam with shear connectors provided throughout the span. A typical load vs mid-span deflection behaviour is shown in Fig. 10. In setup 2, bottom side and top arrangement of shear connectors (BST) shows maximum strength and stiffness.

The study on shear capacity of Composite beam with connectors to without connectors with respect to effective spacing clearly indicates that provision of shear connectors, throughout the span is considerably more effective than that only within the shear span. A typical plot is shown in Fig. 11.

In the test setup 2, three different positioning of shear connectors in the shear span was experimented (BST, BS, BT) to determine shear capacity. It is seen from Fig. 12, that shear connectors provided bottom sides and top (BST) arrangement can attain higher strength.

The effect of effective spacing of connectors on the energy absorption capacities of composite beams with shear connectors in terms of energy absorption capacity of composite beam with natural bond (EACC/EACCN) for test setup 1 is studied. A typical plot is shown in Fig. 13. When connectors are provided throughout the span, maximum energy absorption capacity is observed.

In test setup 2, energy absorption capacities in terms of energy absorption capacity of composite beams with natural bond are shown in Fig. 14 for different arrangement of connectors. Considering both A and B series, bottom sides and top (BST) arrangement of connectors has obtained the maximum energy absorption capacity.

Using the load strain data, moment curvature curves are plotted (Fig. 15). All the curves are initially closer, linear and then show non-linear behaviour with gradual decrease in stiffness until maximum moment is reached. Among all arrangements the beam with bottom sides and top arrangement of connectors shows maximum stiffness.

4. CONCLUSIONS

For flexure behaviour (a/d = 5.5), it can be concluded that pattern of shear connectors provided on bottom and sides (BS) in shear span attain maximum load carrying capacity, stiffness and ductility. For shear behaviour (a/d=2), providing shear connectors at bottom, sides and top (BST) throughout the span achieved maximum shear capacity, stiffness and energy absorption capacity compared to shear connectors provided only in the shear span. The ductility increases and stiffness reduces by reduction in number of connectors.

REFERENCES

Anwar Hossain K.M. (2003) “Experimental & Theoretical Behaviour of Thin Walled Composite Filled Beams”, Electronic Journal of Structural Engineering, Vol. 3, 117-138.

Anwar Hossain K. M. (2005) “Designing Thin-Walled Composite-Filled Beams” Proceedings of the Institution of Civil Engineers, Structures and Building 158, Issue SB4, 267-278.

Deric J. Oehlers, Howard D. Wright, and Matthew J. Burnet. (1994) “Flexural Strength of Profiled Beams”, Journal of Structural Engineering, ASCE, 120(2), 378-393.

Deric John Oehlers. (1993) “Composite Profiled Beams”, Journal of Structural Engineering, ASCE, 119, 4, 1085-1100.

Dubey A. K., Nayak A. N. and Bhattacharyya S.K. (1999) “Strength of Thin Walled Steel Concrete Composite Beams: Experimental Study” Journal of the Institution of Engineers, Vol. 80, 37-41.

George Abdel-Sayed. (1982) “Composite Cold-Formed Steel-Concrete Beams”, Journal of the Structural Division, ASCE, Vol. 108, No. ST11, 2609-2622.

Oduyemi T.O.S. and Wright. (1989) “An experimental investigation into the behaviour of double-skin Sandwich beams” Journal of Constructional Steel Research, 14, 197-220.

Richard P. Nguyen. (1991) “Thin-Walled Cold-Formed Steel Composite Beams”, Journal of Structural Engineering, ASCE, 117(10), 2936-2952.

Valsa Ipe T., Sharada Bai H., Manjulavani K. and Merchant Mohd Zafar Iqbal. (2013) “Flexural behaviour of cold-formed steel-concrete composite beams” Steel and composite structures, 14(2), 105-120.