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Composite Action Between Light Steel And Concrete for Beams, Walls and Floor

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Abstract: *In this paper — The composite behaviour of steel beams and columns with concrete is well understood for hot rolled steel members and hollow steel sections, but is not properly researched for cold formed steel sections. In this case, the behaviour is affected by the relatively flexible shear connection between the steel and concrete and by local buckling of the thin steel sections. Shear connection may be in the form of mechanical connectors such as bolts or screws, or embossments or perforations rolled into the thin steel. In both cases, the shear connection may be assisted by local confinement of the concrete within the steel profiles. In this project addresses the behaviour of light steel composite beams using C-sections acting in tension and in shear with different forms of shear connection, and also the behaviour of composite columns using perforated C-sections in a form of box sections. The aim is to show to what extent composite action increases the stiffness and bending resistance of the thin C profiles in bending and compression. For composite beams, tests were performed on 0.8m, 1.1m and 1.7m span beams of approximately 150 mm depth using 100x 50x 1.2 mm C-sections as tensile reinforcement. The shorter span beams failed by shear-bond and possibly by pure shear, and some of the longer span beams failed in pure bending without end slip. The shear connectors were in the form of 4.8 mm diameter screws and 6 mm diameter bolts with double nuts, and also perforated webs with 5 lines of 5 mm wide slots. It was shown that the shear-bond strength of the perforated C-sections was over 1.2 N/mm^2 when expressed as a stress over the web area times the shear span. Tests were also performed on beams with side C-sections which greatly improved the shear resistance of these beams. The stiffness of the beams was analyzed by elastic theory and it was shown that the elastic stiffness of the shear connection to the perforated section is 10 N/mm/mm^2 area of web. This reduces to 4 N/mm/mm^2 for the mechanical shear connectors, partly because of the rotation of the screws and bolts at their connection to the thin web .A study will made of the application of this method of construction using perforated base and side C-sections for a beam span of 7.2m with various end conditions and it was shown to be sufficiently stiff and strong for residential loading added to the self-weight.*

Keywords: Composite Action; C-Section; CFS-Cold Formed Steel ; Shear Connection; ABAQUS; FEA; Ansyis Software

I. INTRODUCTION

The composite behaviour of steel beams and columns with concrete is well understood for hot rolled steel members and hollow steel sections, but is not properly researched for cold formed steel sections. In this case, the behaviour is affected by the relatively flexible shear connection between the steel and concrete and by local buckling of the thin steel sections. Shear connection may be in the form of mechanical connectors such as bolts or screws, or embossments or perforations rolled into the thin steel. In both cases, the shear connection may be assisted by local confinement of the concrete within the steel profiles.

In this project addresses the behaviour of light steel composite beams using C-sections acting in tension and in shear with different forms of shear connection, and also the behaviour of composite columns using perforated C- sections in a form of box sections. The aim is to show to what extent composite action increases the stiffness and bending resistance of the thin C profiles in bending and compression.

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A study will made of the application of this method of construction using perforated base and side C-sections for a beam span of 7.2m with various end conditions and it was shown to be sufficiently stiff and strong for residential loading added to the self-weight.

OBJECTIVES OF STUDY:

The main Objectives of this Project are:

The first research task was to identify the forms of light steel composite beams that should be investigated by tests, FE modelling and practical evaluations. Two forms of construction were identified in order to understand the basic structural behaviour. These were: Perform bending tests on beams with different forms of lightweight shear connection systems to evaluate the degree of composite action that can be achieved. Finite element modeling of composite cold formed steel and concrete. Adapt the shear connection system to be able to optimize the performance for the minimum degree of composite action. Develop a calculation procedure consistent with the composite design principles of Eurocode but applying to light steel framing. This will consider both the cross-sectional resistance and stiffness for partial shear connection

II. LITERATURE REVIEW

Farid Abed (2019) The main aim of this study was to evaluate the bond dependent coefficient of concrete beams reinforced with GFRP bars exposed to harsh environmental conditions of direct sunlight and seawater. After an exposure period of six months, tensile tests were conducted on the GFRP bars to determine the tensile properties of the exposed bars. A total of six beams were cast including three beams reinforced with the GFRP bars under direct sunlight only, and three beams reinforced with the GFRP bars subject to direct sunlight and seawater. The beams were then tested in flexure under two-point loading up to failure. LVDTs were used to measure crack widths of the beams, and strain gauges mounted on the GFRP bars were used to measure the strain in the bars.

Mohammad Adil Dar (2018) in this paper we study was able to successfully test and validate the feasibility of using expanded polystyrene and timber in various CFS composite beams through experimental testing. The prominent results obtained in this study are highlighted as under: Initially a low cost innovative stiffening arrangement against premature buckling was attempted using high density expanded polystyrene as packing to fill the hollow space within the proposed innovative box compression flange. However, the local buckling failure on top face of box compression flange was observed at much lower load thus failed to produce expected results. Replacement of softer expanded polystyrene by wooden pads, at vulnerable spots (i.e., under concentrated applied load points), results in to much improved load carrying capacity from 27.3 kN (Model B) to 42.5 kN (Model C) (i.e., increase in strength by 55%). This confirms the importance of proper application of stiffening arrangements in CFS composite beam sections

B. Alfarah (2017) in this paper we are studied behavior of reinforced concrete (RC) structures under severe demands, as strong ground motions, is highly complex; this is mainly due to joint operation of concrete and steel, with several coupled failure modes. Furthermore, given the increasing awareness and concern for the important seismic worldwide risk, new developments have arisen in earthquake engineering. Nonetheless, simplified numerical models are widely used (given their moderate computational cost), and many developments rely mainly on them. The authors have started a long-term research whose final objective is to provide, by using advanced numerical models, solid basis for these developments. Those models are based on continuum mechanics, and consider Plastic Damage Model to simulate concrete behavior. Within this context, this paper presents a new methodology to calculate damage variables evolution; the proposed approach is based in the Lubliner/Lee/Fenves formulation and provides closed-form expressions of the compressive and tensile damage variables in terms of the corresponding strains.

Liu (2017) investigated the effect of variation of aspect ratio on the behaviour of concrete filled cold formed steel elliptical sections. A total of 21 stub columns including 3 axially loaded elliptical hollow sections was tested with an aspect ratio from 1 to 2.5 and the steel tube area to concrete area ratio varied from 5% to 12%.

The height of all columns was taken as four times the major axis outer radius of the ellipse to ensure short column behaviour. The elliptical steel tubes were made from cold formed steel of 2.75 mm nominal thickness and were completed by seam welding. The elliptical hollow section specimens subject to concentric loading failed by local buckling. The concrete-filled columns failed by shear of the infill concrete

Pallares and Hajjar (2010), Prakash et al. (2012) modified push tests to investigate the resistance and deformation capacity of shear connectors and studied the shear characteristics between concrete and steel sections. Hanaor (2002) presented several forms of shear connectors between light weight steel and concrete, and investigated these systems by push-out test and full scale composite element tests. Large scale composite slab specimens and push out tests were investigated by Lakkavalli and Liu (2006). Loading was applied at one third span points through a distribution beam loaded at mid point. This generated a constant moment region at the center part of the span.

RESEARCH GAP

The approach to the design of cold formed sections in compression and bending that take account of local buckling of the thin steel sections and other member buckling modes, which may not occur in hot rolled steel sections. The design approach is based on BS EN 1993-1-3: Design of Steel Structures: Part 1.3: General Rules – Supplementary Rules for Cold Formed Members and Sheeting, 2006. Existing research information on composite beams using light steel sections and various forms of shear connector systems and composite columns using light steel sections.

RESEARCH MOTIVATIONS

The primary motivation for this project was to examine the potential for a new form of composite construction using cold formed steel sections and on-site concrete. It is important that the system must be easy to construct and should require the minimum deviation from current light steel framing construction. The benefits of composite construction would lead to improved load capacity particularly of columns and walls and should extend the span range of C sections in bending. In this project, new forms of shear connections were investigated. Perforated C-sections are used to provide a roofs and façade walls as a function of discontinuity of the web.

The perforations consist of 5 parallel lines of 5 mm depth and 40 mm length of 2 mm deep partially punched slots extending over a width in a zone of 65 mm of the web of the C-section. This perforated pattern is used in both 100 mm deep and 150 mm deep C-sections. Same pattern of perforations can also be added to the web of Z sections. Figure 1-5 shows a perforated C-section and the perforation pattern. This type of perforation is considered to be an excellent form of shear connector because the concrete fills into and around the perforations.

III. METHODOLOGY

Establishing the current state of the art, particularly on shear connection systems applied to light steel framing and on composite columns.

Defining and setting up tests aimed at investigating modes of failure and at determining the shear resistance and stiffness of new shear connector systems applied to light steel beams and columns.

Correlating the tests with finite element models using ABAQUS in order to understand the failure modes and to extend the test information into a wider range of cases with suitable limitations

Developing design models based on evidence from the tests and presenting the models in accordance with the general principles of composite design.

Discussing and preparing a tentative construction process for the developed systems that may be taken forward into practical application.

TEST PROGRAMME

Description

All the tests carried out by using INSTRON universal testing machines at the laboratory of the University. For the beam tests, the test machine with 600 kN capacity was used and 1000 kN for the long columns tests. Short columns and slips tests were tested using an AVERY 1000 kN compression test machine.

All the beams were cast using cleaned galvanised steel C-sections and were tested as simply supported members subject to a single central point load. The load was transferred from a 70x100 mm steel plate placed to avoid concrete crushing under the point load. The top of the beams was levelled under the load plate to ensure uniform distribution of the load to the sections and the load was applied at the mid-span of beam span to create constant shear zone in order to determine the shear transfer between the steel and concrete.

Linear variable displacement transducers (LVDTs) were placed to record the mid-span deflection and of both beam-ends to record the slip between concrete and C-section. These are shown in Figure 1 Figure 2 shows a typical composite beam test with the load application at mid-span.

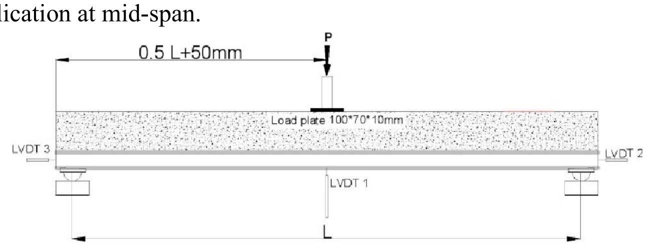

Figure **1:** Typical test of composite beam using C-section as reinforcement

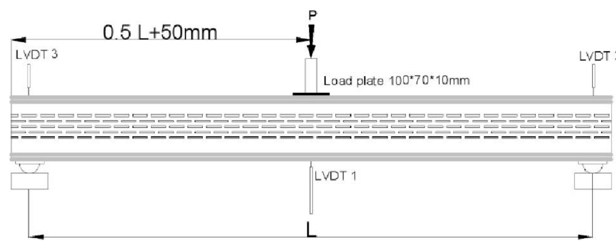

Figure 2: Test of steel C-section beam

IV. RESULTS

Results of different column analysis cases

After validating the finite element models for 1.8m heights with the theory and test results, a parametric study was carried out to extend the range of columns height and ends boundary conditions. The modelled columns were 2.4, 3 and 3.6 m height. The end boundary conditions were the same as for the test columns. From the ABAQUS results, the effect of height of the columns on the failure load of the columns is shown in the Figure. The boundary conditions of all models were fixed-ended and so the effective length was theoretically half of the actual height

The effect of the boundary conditions for the 1.8m high columns is shown in Figure . The effect of the boundary condition on the stiffness is minimal up to about 70% of the failure load.

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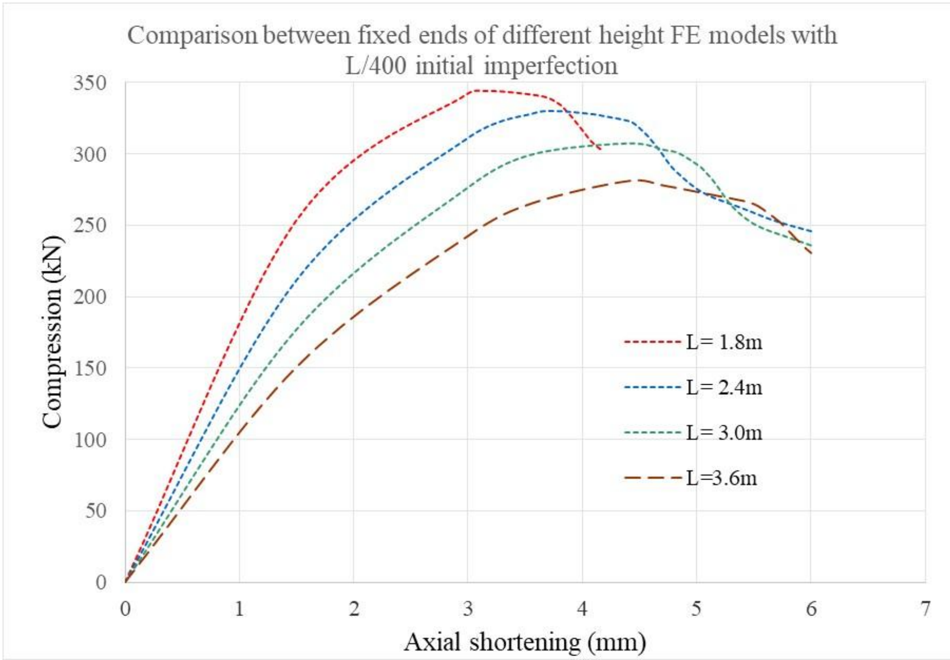

Figure 3: Effect of column height on buckling resistance of columns with fixed ends from ABAQUS model

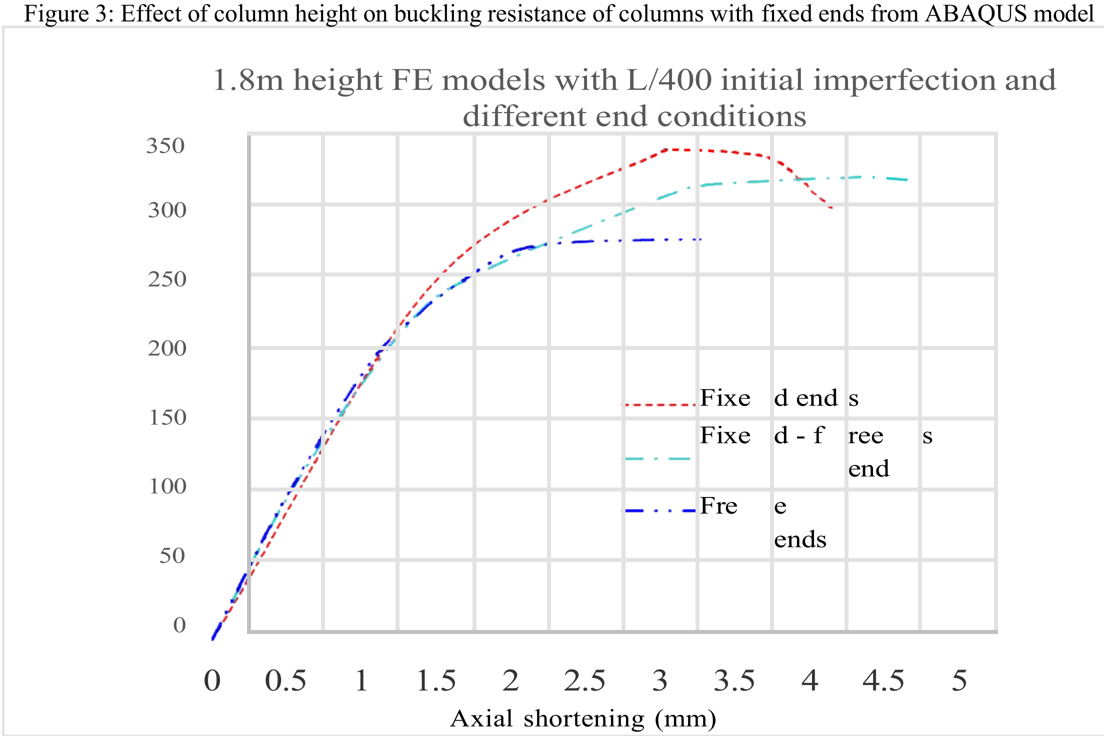

Figure 4: Effect of end conditions on the failure load of 1.8m height columns

The buckling resistances for all 24 modelled columns in ABAQUS with different heights and boundary conditions are presented in Table VII-1.

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Table VII-1: Column failure load in (kN) for several height and different boundary conditions

End conditions Column length, L (m)	Fixed –Fixed conditions		Fixed –Pinned conditions		Pinned-Pinned conditions	
	Initial imperfection					
	L/200	L/400	L/200	L/400	L/200	L/400
1.8	339	343	310	327	249	282
2.4	310	330	272	303	197	227
3.0	284	307	232	262	147	176
3.6	241	278	208	229	105	134

Comparison between ABAQUS models and calculated results based on EC3/4

A total of 24 models were analysed in ABAQUS with three different boundary conditions and two initial imperfections for 1.8, 2.4, 3 and 3.6 m height columns. The load carrying capacities of modelled columns were in good agreement with the calculated values according the BS EN 1993-1-1 and 1994-1-1 approaches (identified here as EC3/4). The ABAQUS results, theoretical (EC3/4) and test results are presented in Table 2and also in figure 4. For 1.8 m height columns, the ABAQUS results for columns with L/400 imperfection are close to the EC 3/4 results using buckling curve (b). Models with L/200 imperfection are similar to the EC 3/4 results based on buckling curve (c). The same agreements with buckling curve (b) and (c) were observed for all column heights that were modelled with both ends fixed.

The ABAQUS results for columns with height of 3m and 3.6m with free-fixed and free-free end conditions columns with L/400 initial imperfection are higher than the EC 3/4 predictions. For those heights and boundary conditions, modelling with L/200 imperfection provides better agreement with buckling curve (c). The results of the L/200 imperfection models of 3 and 3.6m height are shown on the graph.

Table VII-2: ABAQUS model results in terms of failure loads (kN) compared to EC3/4 predictions

EC3 Buckling curve	*X factor*			*Column Length (mm)*	*Initial imperfection (mm)*	*Fixed-Fixed*		*Fixed-Pinned*		*Pinned-Pinned*	
	Fix-Fix	*Fixed-Pinned*	*Pinned-Pinned*			*ABAQUS*	*EC3/4*	*ABAQUS*	*EC3/4*	*ABAQUS*	*EC3/4*
(c)	0.9	0.81	0.65	1800	L/200 = 9	339	352	310	317	249	254
(b)	0.92	0.85	0.72		L/400 = 4.5	343	360	327	332	282	282
(a)	0.95	0.9	0.8				371		352		312
(c)	0.82	0.7	0.5	2400	L/200 =12	309	321	272	274	202	196
(b)	0.87	0.76	0.56		L/400 = 6	330	340	303	297	234	219
(a)	0.91	0.82	0.62				356		321		242
(c)	0.75	0.58	0.38	3000	L/200 = 15	284	293	232	227	153	149
(b)	0.8	0.64	0.41		L/400 =7.5	307	313	262	250	185	160
(a)	0.86	0.71	0.45				336		278		176

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(c)	0.66	0.47	0.28	3600	L/200 =18	241	258	208	184	111	109
(b)	0.77	0.52	0.31		L/400 = 9	278	301	229	203	140	121
(a)	0.79	0.58	0.33				309		227		129

V. CONCLUSION

Light steel framing is widely used in low and medium-rise buildings but is limited in applications where longer spans and heavier loadings are required. Although composite action between steel and concrete is used in structural steel frames, the application of composite construction in light steel framing is relatively new, because suitable shear connection systems have not been developed.

In this research, a new form of light steel construction has been developed that uses C-sections as the effective tension and shear reinforcement and also as the encasement to concrete beam and columns. The shear connection system may be in the form of screws or bolts or perforations rolled into the C-sections. In this new form of construction, the C-sections support the concrete during the construction phase and also act compositely with the concrete to resist subsequent imposed loads. The light steel composite beams have a wide range of application by varying the depth of the side C-sections and can achieve spans up to 8m and loadings up to 5 kN/m2.

The composite cross-section may be assumed to be cracked at the serviceability limit state and the plastic bending resistance may be used at the ultimate limit state. The longitudinal shear resistance is considered to be developed on the horizontal plane between the steel and concrete, which is analogous to the shear-bond behaviour in composite floor slabs.

An experimental investigation was conducted on 33 beams of 0.8 to 1.7m span that were devised to determine the degree of composite action that can be developed between cold formed steel C-sections and concrete using different type of shear connectors. The tests and theory are described in Chapters 4, 5, and 6. Shear connectors were in the form of; self-drilling screws fixed on the side of the C-sections, bolts and nuts through the base, and perforations rolled into the web of the C-sections.

Two types of beam were tested: Type 1 beams were 146 or 150mm deep x 100mm or 150mm wide and had base C-sections as tensile reinforcement using several types of shear connectors. Type 2 beams had base and side C-sections as tensile and shear reinforcement.

The tests on Type 1 light steel composite beams with C-sections as tensile reinforcement showed that the effect of the screw and bolted shear connectors and perforations in the web of the C-section on the bending resistance and stiffness of the composite section. The mechanical shear connectors contributed relatively little to composite section. The highest degree of shear connection was obtained using the perforated C-sections.

For the tests on 1.1 m span beams with perforated C-sections, the fully composite bending resistance of the composite section was developed and the shear bond strength when expressed over the web of the C- section was calculated as 1.45 N/mm2 on average for a 100 x50x1.2 mm perforated C-section and 1.05 N/mm2 for a 150 x50 x1.2 mm perforated C-section. These values were 11% higher for the tests on 0.8 m span beams suggesting that the shear-bond strength is not fully mobilised as the span increases. The 1.7 m span beams with perforated C-sections failed in pure bending.

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