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Experimental investigations on ultra-lightweight-concrete encased cold-formed steel structures

Part II: Stability behaviour of elements subjected to compression

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A B S T R A C T

In the field of structural engineering the design of cost efficient structures is highly important. This led to the development of cold-formed steel structures (CFS). An advanced CFS structure is introduced in this paper, which uses a special type of polystyrene aggregate concrete (PAC) as bracing material. This material has beneficial insulating and fire protection properties, which makes it a reasonable choice for residential buildings. An experimental programme was performed, to gain information on the flexural and axial behaviour of PAC-encased CFS elements and panels. Both unbraced and braced members were tested to gain information on increment of load-bearing capacity. Several different element sizes were used to be able to investigate the different stability failure modes (i.e. local, distortional and global). Results showed that PAC was able to restrain the global and distortional buckling modes of steel elements, thus providing "full bracing" in most practical cases. These results are introduced in two papers (Part I and II), detailing the failure modes, load increments and the effect of composite action. In this paper – Part II – the background and the results of compression tests are presented, and the bending experiments are detailed in Part I [1].

1. Introduction

The applicability and efficiency of polystyrene aggregate concrete (PAC) encased cold-formed steel (CFS) elements was introduced in the first part of the paper [1], where the advantageous behaviour of PAC were also described based on previous research works [2,3,4]. In the first part the behaviour of flexural elements were presented, this paper deals with the behaviour due to axial compression. The first investigation of bracing of CFS elements was reported in the 1940's, since that time several research projects were performed on this topic to support standardised formulae [5,6].

In the recent years Schafer et al. [7,8,9] conducted extended research project in which a design methodology for light-frame cold-formed steel wall systems that properly accounts for the behaviour of wall studs sheathed by similar, dissimilar, and one-sided sheathing was developed. In the framework of this research numerous experiments were done on members subjected to axial compression [7,8] and interaction of compression and bending [9]. They investigated specimens with OSB, gypsum board and mixed sheathing, along with non-braced and half-braced elements. The connection of sheathing and steel members was established by self-drilling screws at discrete points. Results showed that the effect of sheathing is significant, the failure was governed by local mechanism instead of global which was observed in the unbraced experiments, and notable (max. 91%) increment was found in the load-bearing capacity. Telue and Mahendran [10] performed experiments, similar as in [7,8], but additionally they investigated U-sections, too. As they reported, the main failure modes were local phenomena as found by Schafer et al. [7,8]. They also showed that the contribution of sheathing to local buckling of the flanges can be neglected in commonly used cases, but the main load increment is due to the beneficial effect on overall buckling. The observed increment in load-bearing capacity was around 80%, depending on the properties of specimens. Pan and Shan [11] investigated sheathed panels subjected to shear force. Ultimate load, stiffness, energy absorption and ductility were measured. It was found that the effect of sheathing cannot be neglected, it has significant role in the behaviour of the structure. They also pointed out that the sheathing material has significant role in the stiffness of the structure: the specimen with OSB sheathing showed 46% greater stiffness as the same specimen with gypsum board.

Based on the literature review the beneficial effect of discrete bracing is obvious. Unlike the specimens studied before, this paper

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presents continuously braced CFS-members. This means that the bracing effect is present in every cross-section, and is not concentrated to discrete connections. The bracing material has foam-like behaviour, with great deformation capacity and low modulus of elasticity, which is also the contrary of the previously studied materials. In order to understand the complex behaviour an experimental research programme was executed.

The aims of the tests were: (i) to analyse the effect of different PAC-mixtures available as infill for walls to see whether the influence of PAC is significant or not; (ii) to analyse the effect of different CFS-stiffnesses. Based on these aims, two sets of member tests were performed. As a result of the first test series, the material properties could be modified to achieve a more effective structure. After completing the member tests, panel tests were performed to investigate arrangements similar to real structures in loading and build-up and also to confirm the advantageous behaviour of PAC encased CFS column elements in full-scale. In this series of tests new cross-sections were also analysed to broaden the set of available information. The purpose of all the experiments was to get information on the behaviour, the failure mode and the increment of load-bearing capacity.

2. First series of member tests – effect of PAC-mixtures

2.1. Test programme

In the member tests single C-section column elements were investigated in a loading frame shown in Fig. 1. Load transferring elements of 140 mm length were placed to both ends of specimens, to enable loading. These elements were fixed to the C-sections by means of self-drilling screws. Both elements rested on hinges preventing bending moment to develop. The specimens were placed into the loading frame and then were adjusted to the right position. After this, a small amount of load was put onto the specimens, to fix them before the measurement was started. At the post-processing phase, this effect was taken into account, and the load values were corrected, which resulted in a shift in the load–displacement diagrams. The loading was done by a hydraulic jack.

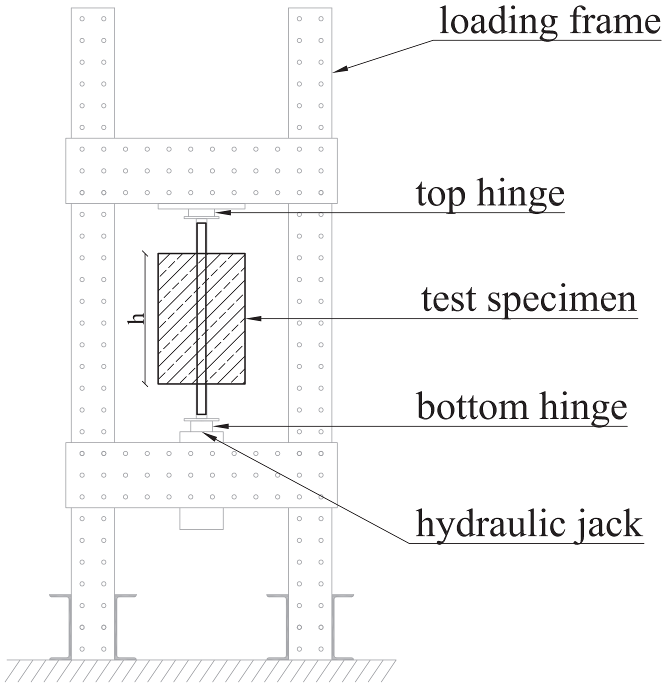

Fig. 1. Loading frame of the member tests.

Table 1
Results of coupon tests (all tests).

Nominal thickness [mm]	Yield strength [N/mm^2]	Tensile strength [N/mm^2]	Corresponding structural specimens
0.9	372	421	First series
0.9	314	391	Second series
1.5	305	380	Second series
0.9	317	379	C90-10-2700
1.5	363	486	C90-15-2700
0.9	311	375	C/I140-10-2700

In this first series of tests a lipped channel section was used with total height of 90 mm, width of 41 mm and 13 mm of stiffeners. The nominal plate thickness of steel was 0.9 mm. To be able to investigate different failure modes (local, distortional and global), three different element lengths were defined; namely 580/880/2280 mm, including the load transferring elements, which resulted in 300/600/2000 mm long investigated zone, respectively. The CFS core was surrounded by 400 mm × 200 mm PAC-block between the load transferring elements. To gain information on the behaviour of stub-columns braced with different PAC-mixtures, two mixtures were used: type A and X [2]. Type A had a nominal bulk density of 380 kg/m^3, with greater amount of cement paste, which provided greater strength to the mixture and also worse heat insulating capacity. On the other hand, type X had a nominal bulk density of 290 kg/m^3, resulting in a softer material better fitting for building physics purposes. Material tests were performed prior to the structural tests, to determine the material properties of steel and PAC. Five coupon tests were carried out for steel (for results, along with all others, see Table 1), and five compressive tests were done on 150 mm cube specimens for PAC. Both the flexural strength and the modulus of elasticity were measured on three prisms 70 mm × 70 mm × 250 mm^3 in dimension (see Table 2, including all results). The experiments were done at age of 42 days.

To be able to evaluate the results, additional experiments were done on unbraced stub-columns, which properties were the same as the PAC encased ones, except the bracing. Each experiment was triplicated, thus results of 27 experiments are reported here. Fig. 2 shows the applied nomenclature.

The instrumentation of specimens consisted of inductive transducers. The axial displacement was measured at the lower

Table 2
Results of material tests for PAC (all tests).

Denotation of mixture	Bulk density [kg/m^3]	Compression strength [N/mm^2]	Flexural strength [N/mm^2]	Young's modulus [N/mm^2]	Corresponding structural specimens
“A”	403.51	0.632	0.346	115.36	First series, all
“X”	285.91	0.392	0.171	270.39	First series, all
WM1	231.14	0.155	0.130	100.51	C140-10-600
WM2	213.51	0.149	0.174	105.43	C140-15-600
WM3	203.43	0.132	0.086	43.30	C140-10-300, C140-15-300
WM4	247.63	0.172	0.087	83.17	C140-2000[a]
WM5	181.01	0.095	0.044	90.14	C140-2000[b]
WM6	236.07	0.151	0.057	36.64	C90-10-2700
WM7	232.80	0.190	0.088	48.90	C90-15-2700
WM8	253.34	0.213	0.101	79.96	C140-10-2700
WM9	242.96	0.187	0.115	85.68	I140-10-2700
WM10	265.58	0.248	0.152	113.00	C140-10-2700
WM11	265.66	0.236	0.175	81.95	C140-10-2700

[a] Specimens equipped with gauges.
[b] Rest of specimens.