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An experimentally validated study for open rib profiles steel-concrete composite slabs behavior in partial connection

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ABSTRACT

In this paper the strength of steel deck-concrete composite slabs is studied. Conventional slabs with open and dovetail profiles are studied with different designs, galvanized and stainless steel. Partial connection method (PCM) in Eurocode-4 is permitted for slabs with *ductile* longitudinal shear behavior. Ductility, as explained in the clause 9.7.3(3), depends on the fact that the failure load exceeds the load corresponding to the slip (0.1 mm) in more than 10%; then the slab is classified as ductile. Apparently, the aim of this criterion is to ensure the slab can undergo further deflections until the whole yielding of the cross-section is achieved, as required hypothesis by the PCM. The aim of this paper is to study the stresses developed at the cross-section of composite slabs with open and dovetail profile, in order to evaluate the yielding degree of the cross-section. Based on the results of this study, it is recommended to exclude open profiles from partial connection method (PCM), even if the slab is classified as *ductile* through Eurocode definition. Although all studied specimens are classified as *ductile* according to Eurocode-4 clause 9.7.3(3), the observed stress distribution at cross-section proves that yielding occurs in the slab with re-entrant profile only, whereas slabs with open-rib profiles remain almost elastic until their brittle failure.

Keywords: composite slabs ductility, partial connection method, longitudinal shear resistance, trapezoidal profiles

1 INTRODUCTION

In composite slabs, failure modes are classified as bending, longitudinal shear or vertical shear. Bending or flexure failure occurs in slender slabs (long and shallow), normally with a low resistance and high ductility. Vertical shear failure occurs in compact slabs (short and thick), usually with a high resistance and low ductility. This failure is rarely critical. Shear-bond failure, also known as slip failure, is the most common (1) (2) (3) (4). Although slip is the criterion for classifying the slabs failure as shear-bond mode, slip resistance is not the only factor determining the strength. Other factors are involved such as the vertical separation and the transversal connection, reported in references (5) and (6). Actually, shear-bond failure is a three-dimensional connection failure problem. This paper is focused on longitudinal slip and vertical separation and describes the connection behavior in slabs with conventional open and dovetail profiles by means of finite element modelling.
The longitudinal shear resistance of all slabs is evaluated using four-point bending test according to the Eurocode-4 provisions (part 1-1, Annex B) (7). The loading procedure includes cyclic – representing the load applied over a long period of time– and, after that, a monotonic increasing load until failure. Slabs subjected to cyclic and then monotonic loads, have lower stiffness than slabs subjected to only monotonic load (8). It can be understood that cyclic loading is aimed to break the chemical bond between concrete and steel. Chemical debonding after cyclic test may not be fully achieved, as Salonikios et. al (9) reported, where the lower limit of cyclic loads obtained from monotonic test, is lower than the slab's own weight. This problem is more common in long

slabs. To take a reasonable value for lower limit in cyclic loading, they considered 1/3 of the applied load (excluding the spreader beams' weight and own weight of slab). In general, the chemical bond depends on construction factors such as steel surface condition, temperature of concrete and steel, ambient temperature, humidity curing process etc. (5) and it is assumed neglectable, due to similar maximum load carrying capacity of slabs with or without cyclic loading (8) (10).

Crack inducers simplify the calculations of longitudinal shear resistance by determining a precise shear length. Absence of crack inducers causes greater longitudinal shear resistance especially for long slabs (10). In this research, crack inducers are used in all tests. Slabs are cast fully supported, which means that, when the slab placed on the supports, there is a deflection due to the slab own weight and this is the most unfavorable situation for testing. Test setup consists of two symmetric concentrated line loads located at one quarter of the span (see Figure 1).

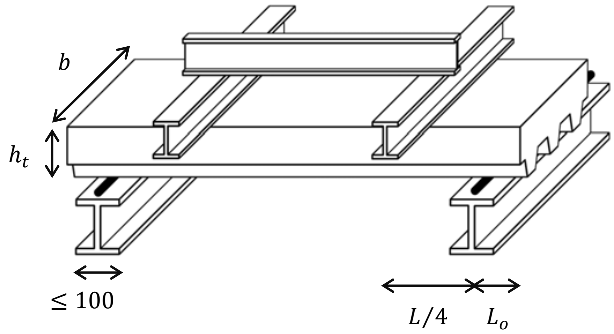


Figure 1 Test setup (7)

2 PURPOSE AND METHOD

Partial connection method (PCM) in Eurocode-4 is permitted for slabs with ductile longitudinal shear behavior. Ductility, as explained in the clause 9.7.3(3), depends on the fact that the failure load exceeds the load corresponding to the slip (0.1 mm) in more than 10%; then the slab is classified as ductile. Apparently, the aim of this criterion is to ensure the slab can undergo further deflections until the whole yielding of the cross-section is achieved, as required hypothesis by the PCM. The aim of this paper is to study the stresses developed at the cross-section of composite slabs with open and dovetail profile, in order to evaluate the yielding degree of the cross-section in each case.

Experimental tests conducted by M. Ferrer et al. (11) are used for validating the finite element models of A80, C60 and W60, which are open-rib profiles. YX66 test on ST-S0.8-150 specimen by Li. X (12) is used for verification of slab model with re-entrant profile. Slabs dimensions and material properties are showed in Table 1.

Table 1 Slab dimensions and material properties

	Steel thickness [mm]	Length Total [mm]	Length Shear [mm]	Length Overhang [mm]	Slab depth [mm]	Steel yield stress [MPa]	Concrete strength [MPa]
A80	0.75	2600	600	100	180	313	24.59
C60	0.8	2600	625	50	100	326	26.86
W60	0.75	2600	600	100	100	326	25.10
YX66	0.8	2200	500	100	147	230	35.00

3 FINITE ELEMENT MODELS

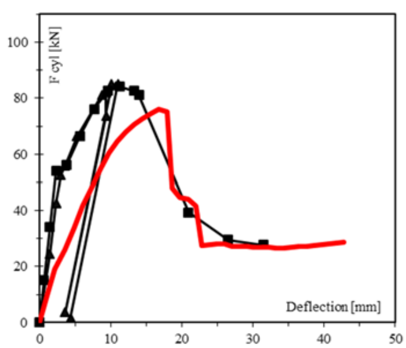
Steel is modelled as an elastic-perfectly plastic material and the cracking capability of concrete is also included if its tensile strength is exceeded. Mechanical properties of materials are showed in Table 1. The interaction between steel and concrete is represented through contact elements and the real geometry of the embossments is also included. The value 0.5 is given to friction coefficient in W60, A80 and YX66 models, and the value 0.1 is set for C60 case, in which stainless steel sheeting was used in the experiments.
Three symmetry boundary conditions have been used: the conventional longitudinal symmetry at the mid span and two lateral symmetries (transversal) on the lateral sides of the rib. Therefore, only a half-span single rib is modelled including the embossments' pattern.
Concrete uplift is resisted as long as the profile embossments are able to provide pulling vertical retention forces, named unclamping forces in this work. Otherwise, steel-concrete detachment occurs and the consequent failure of the slab.
In C60 and W60 cases, embossments are only at flange and, in A80, at flange and web.
The crack inducer is modelled as a discontinuity plane within the concrete mesh. The nodes above the crack inducer shared by the two concrete volumes are merged to transfer compressive bending forces. The shear transfer coefficient for open and closed cracks ranges from 0 to 1 representing smooth and rough cracks. In papers dealing with composite slabs, some of which are presented in Table 2, different coefficients has been used. The coefficients used in this paper are 0.2 and 1.0 for open and closed cracks respectively. After significant trials, the coefficient for closed cracks (between 0.5 and 1.0) was found to have no effect on the slab behavior. In the studied slabs with partial connection, it has been set to 1.0 only for a faster solution. In slabs with re-entrant profile, shear transfer coefficients 0.5 and 1.0 have been used for open and closed cracks, respectively.

Table 2 Concrete model parameters used in similar papers

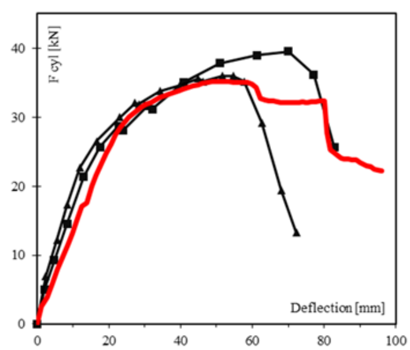
	Shear transfer coefficient for an open crack	Shear transfer coefficient for an open crack
T. Tsalkatidis (13)	0.2	0.6
S. Chen & X. Shi (14)	0.2	0.9
Baskar. R (15)	0.3	0.5
V. Degtyarev (16)	0.3	1.0
Li Liu (17)	0.5	0.9

4 RESULTS

The finite element models match the experimental test result of slabs under cyclic and then monotonic load. As mentioned before, C60 slabs include stainless steel which presents lower chemical bond strength in comparison with galvanized steel, so that initial stiffness has a better coincidence in finite element models and experiments compared with other designs.



A80



C60

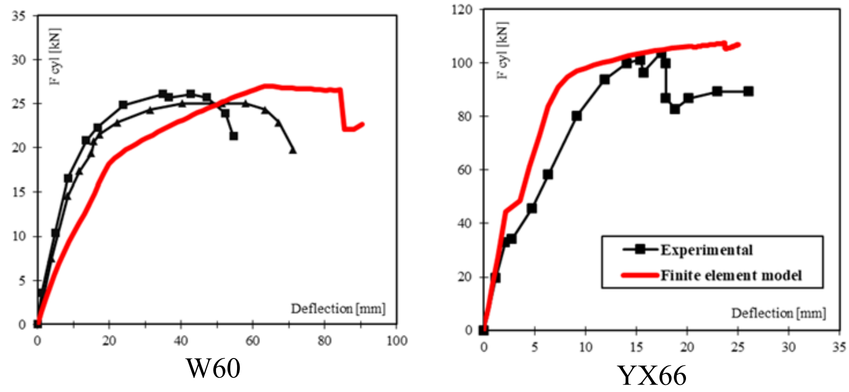
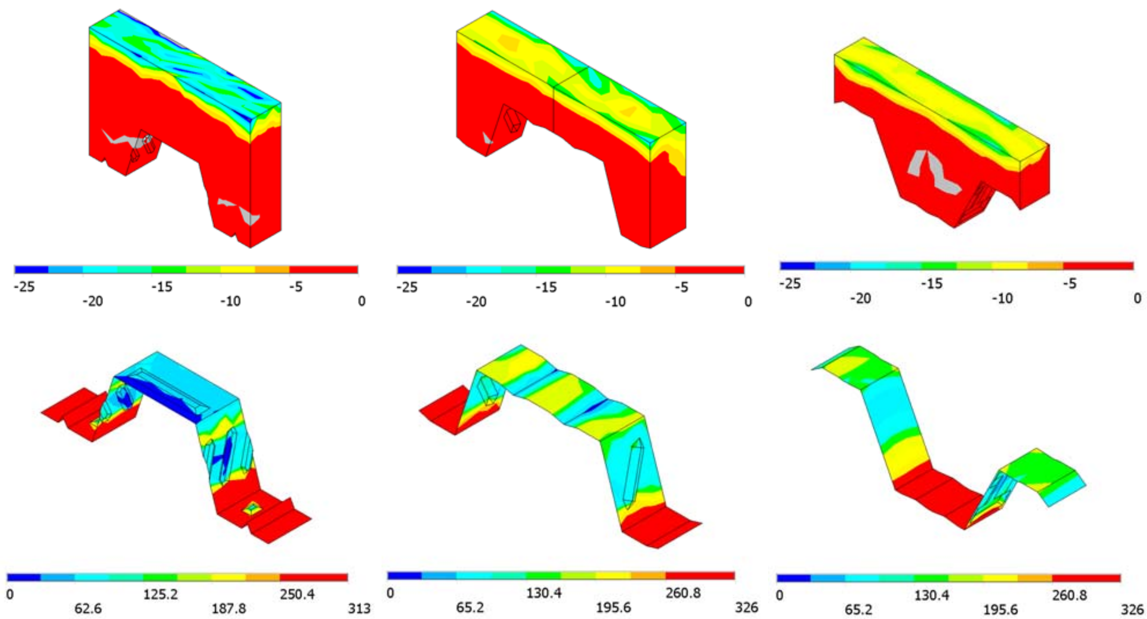


Figure 2 Force-mid span deflection curve from experimental tests and FE result [kN,mm]

5 ANALYSIS AND DISCUSSIONS

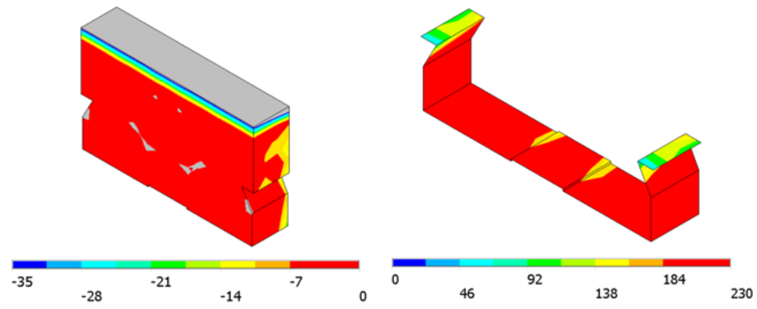
As expected, steel profile provides tensile strength of the composite slab especially at bottom flanges and concrete gives the compressive strength at the top. It is transparent that slab with re-entrant profile shows a better composite action. Concrete crushing stress is exceeded in the re-entrant case (YX66) whereas compression stress in trapezoidal cases is almost below the crushing stress. Figure 3 shows the elastic and plastic regions developed at the most critical sections which are located below the load line.



A80 - short
$F_{max} = 75.99$ [kN]
$d_{mid-span} = 16.81$ [mm]

C60 - short
$F_{max} = 35.18$ [kN]
$d_{mid-span} = 51.14$ [mm]

W60
$F_{max} = 26.97$ [kN]
$d_{mid-span} = 63.17$ [mm]



YX66
F_{max} = 107.32 [kN]
$d_{mid-span}$ = 23.7 [mm]

Figure 3 Stress distributions of materials, 3rd ppl for concrete and von Mises equivalent for steel [MPa]

The stress diagram at the cross-section is a good tool to determine the composite action. In an ideal case where the concrete and steel are fully connected, both materials yield at the ultimate load (steel in tension and concrete in compression). On the opposite null connection case, steel experiences both compressive and tensile stresses while no effective stresses exist in concrete. There is an intermediate case where concrete yields under compression and steel yields under both tension and also compression. This partial connection situation is clearly showed in Figure 4 for YX66 profile which is a dovetail profile. In Figure 4 the compressive yield stress limit of steel is the same as tensile yield limit.

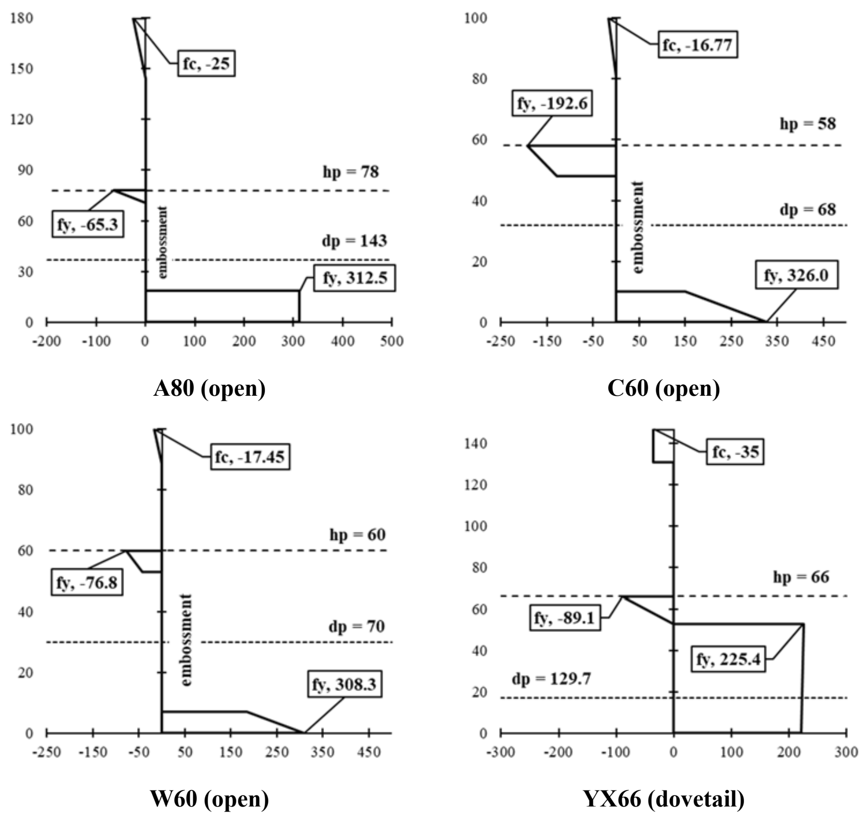


Figure 4 Stress distribution at cross-section by finite element models [MPa]

6 CONCLUSION

Based on the results of this study, open-rib profiles do not seem to accomplish the conceptual ductility hypothesis on which the partial connection method (PCM) is based, even if the slab can be classified as *ductile* through ductility definition in Eurocode-4 clause 9.7.3(3). Although all studied specimens could be classified as *ductile* according to this definition, real ductility is not high enough to allow the complete yielding of the cross-section in partial connection. The stress distribution observed in FEM models at the cross-section proves that plastification occurs in the slab with re-entrant profile only, whereas slabs with open profile remain almost elastic (see Figure 4). This fact has been observed experimentally as well.

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