RECENT RESEARCH AND DEVELOPMENT IN COMPOSITE STRUCTURES

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Summary:
Composite steel–concrete and concrete-concrete structures represent an efficient and economical form of construction for building and bridge applications. Composite structures, exploring advantages of concrete and structural steel, have been increasingly applied in commercial and parking buildings. This paper presents state of art, achievementsand new experimental works of concrete-concrete and steel-concrete structures. There are described experimental studies on composite beams with partial use fibre reinforced concrete. The researches on composite joints and steel-concrete beams are presented and additionally new method of FE modelling of such structures are shown.

Keywords: composite structures, concrete, steel, experiment, numerical modelling

Introduction

Composite steel–concrete and concrete-concrete structures represent an efficient and economical form of construction for building and bridge applications. Composite structures, exploring advantages of concrete and structural steel, have been increasingly applied in commercial and parking buildings.

In the first part of this article the new approaches in concrete-concrete beams are presented. The second part is voted to steel-concrete beams and joints.

The composite concrete – concrete beams

In concrete-concrete structures many researches are investigated experimentally and theoretically behaviour of HSC and HSC using fibre. In the last decade HPC (or HSC) are more widely used in practice parallel with growing interest of researchers to precisely describe mechanical properties and methods of design of structural members (Bae et al, 2003; Lessard et all 1992).

As reported by (Yamada et al. 1997, 1999), the structural reinforced concrete and prestressed composite beams with the HSC layer tested in Japan under short-time load, may have improved sectional parameters, eg a higher flexural stiffness and greater bending capacity in comparison to homogenous members, made of normal strength concrete. Composite reinforcedconcrete beams presented intermediate behaviour between reinforced concrete beams made of HSC and beams of normal strength concrete.

Experimental analysis of flexural composite beams.

This chapter presented experimental studies presented the selected results of composite beams with partial use fibre reinforced concrete with the cross section of 80 x 120 mm and the effective span of 1100mm , using the above describe concept of strengthening, preparing top concrete layer 40 mm thick (Sadowska-Buraczewska 2012, 2013).

The FRC was elaborated (Sadowska-Buraczewska 2012,2013) based on the cement type CEM I-52,5 with reactive powder and steel- fibre. The static scheme and cross sections of tested beams and also load conditions are shown in Fig.1. Fig. 2 presents the view of the beam under testing.

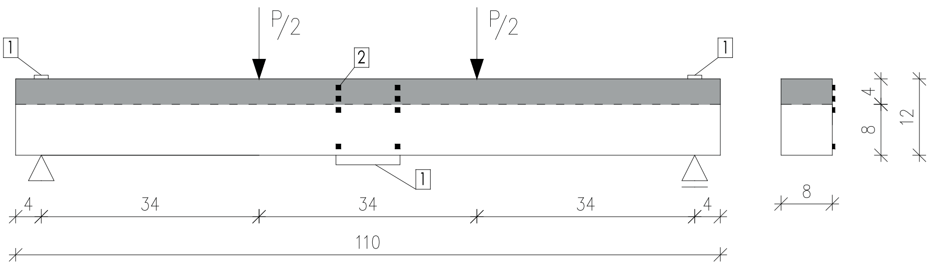

Fig.1. Loading scheme and cross section in tested beams.(Sadowska-Buraczewska,2012)

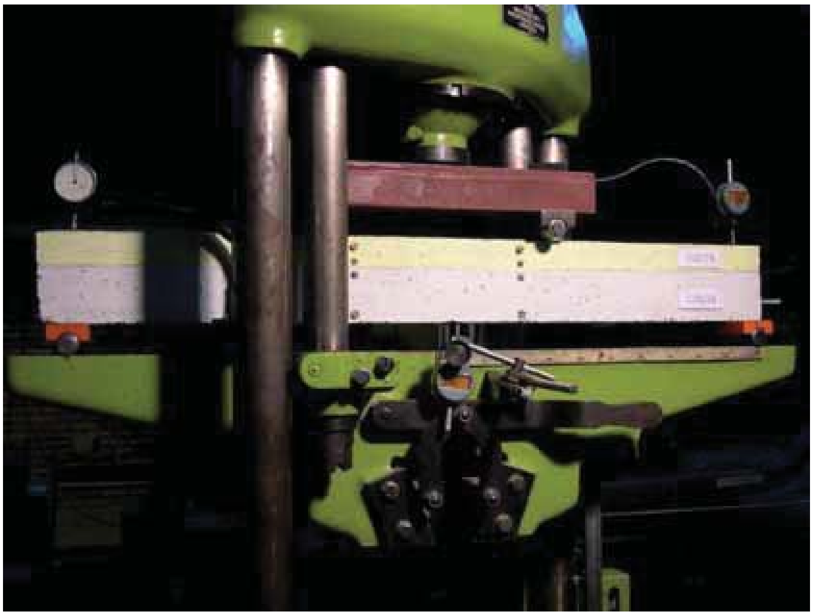

Fig. 2. The beam on the test stand in the testing machine.(Sadowska-Buraczewska,2012)

Analysis of short-time effects under bending

The selected values of deflections are presented in Table 1. The diagram showing experimental relationships between loading force F and compressive strains for FRC beams and also for homogenous control beams HSC and N are presented in Fig.3.

Table 1. Experimental values of deflections [mm] for composite beams made with use of FRC and beams totally made of HSC(Sadowska-Buraczewska,2012)

Force [kN]	Experimental values of deflections [mm] for composite beams made with use of FRC and beams totally made of HSC.	
	FRC	HSC
5	0,36	0,45
10	0,54	0,65
15	1,31	1,50
20	1,74	2,13
25	2,97	3,02
30	3,54	3,73
35	4,02	4,34

The diagram showing experimental relationships between loading force F and compressive strains for FRC (blue) beams and also for homogenous control beams HSC (red) and N (green) are presented in Fig. 3.

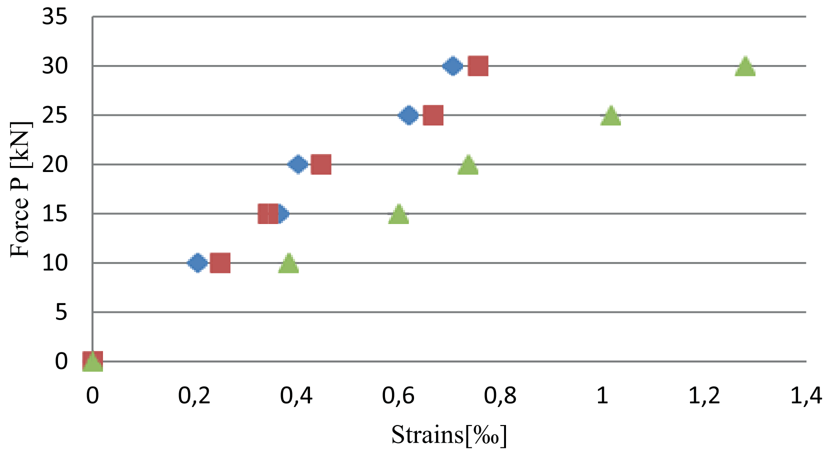

Fig. 3. Experimental relationships between concentrated force and strains for tested beams under short time load (Sadowska-Buraczewska,2012,2013)

The experimental test conducted on reinforced concrete composite beams made of normal concrete and FRC layer in compressive zone tested under short time load show the positive effects of strengthening of such beams in comparison of homogenous normal strength concrete and totally made of HSC.The future studies and efforts will be concentrated on short time and long-term deformations of reinforced concrete beams prepared in natural scale.The results of these investigations proved the effectiveness of composite structures with the partial use of FRC in the compressive zone as a way of strengthening of the structural members wanted a rehabilitation or reconstruction.

Steel-concrete structures

The effective application of steel and concrete leads to the increased strength and stiffness if compared with traditional solutions such as bare steel or reinforced concrete structural elements Due to advantages of composite construction, the scope of application of composite actions in steel frameworks have been widened, finally involving not only the composite actions between the structural floor beams and the reinforced concrete slab, but also taking advantage of composite joints.

The nonlinear analysis of composite structures, carried out up to the failure of limit, is rather difficult due to the complexity of physical phenomena accompanying the structure deterioration process under increasing actions, bond interaction between concrete and steel parts, stress redistribution between the concrete and steel reinforcement after cracking, interaction of the behaviour of steel beam shear studs and concrete, the presence of any profiled metal decking, occurrence of slip between the steel parts and reinforced concrete slab, and due to a variety of all other possible local effects existing in the structure composed of such different materials like steel and concrete, with regard to the overall ductility behaviour (Giżejowski et al., 2010).

Composite joints

Researches

Design rules for steel-concrete structures were developed on basis of worldwide researches efforts since there had been rather limited guidance and lack of expertise in this field (Simoes da Silva et al, 2001). Existing design rules of Eurocode 4 (Eurocode 4, 2005) are not however since they do not cover all possible solutions, especially in design of composite joints (Giżejowski et al., 2010).Recently, the research on the behaviour of composite joints has been done by Kozlowski (Kozlowski, 2000). Gizejowski, Barcewicz and Salah (Gizejowski et al..2010) have conducted laboratory tests in order to investigate the behaviour of steel and steel-concrete composite end-plate beam-to-column joints under bending. The eight tests were carried out. The general arrangement of composite joint specimen is presented in Fig.4.

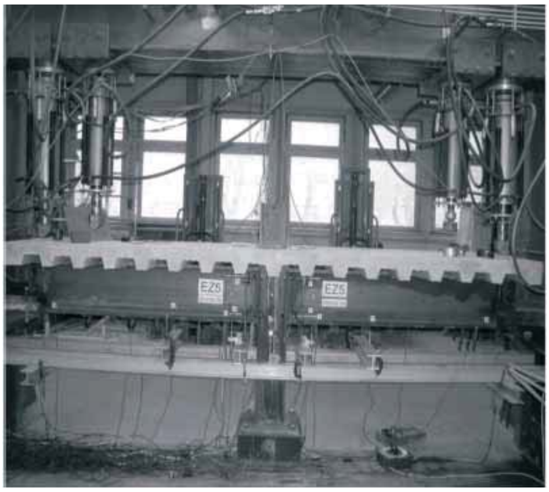

Fig.4. General setup of the test rig (Gizejowski et al, 2010)

Beams elements of all the specimens were made of IPE 300 and columns of HEB 200. All the steel elements were made of steel grade S235JR. The bolt connectors were M20 of class 10.9. The concrete slabwas cast on the dip-profiled sheeting, using the Cofraplus 60 composite flooring. The ribs of the sheeting were arranged in the transverse direction to the supporting beams. The composite action was partially provided by the sheeting and the headed studs SDϕ19 x 100 mm, that were friction welded to the upper flange of the beam.

The results for the bare steel joint with extended end -plate proved that the existence of the concrete slab had a positive influence on the initial stiffness and the ultimate moment capacity.

Design method

According to Eurocode 4 (Eurocode 4,2005) Eurocode 3, part 1-8 (Eurocode 3) may be used as a basis for the design of composite beam-to-column joints and splices provided that the steel part of the joint is within the scope of that section. The structural properties of components assumed in design should be based on tests or on analytical or numerical methods supported by test. In determining the structural properties of a composite joint, a row of reinforcing bars in tension may be treated in a manner similar to a bolt-row in tension in a steel joint, provided that the structural properties are those of the reinforcement.Composite joints should be design to resist vertical shear in accordance with relevant provisions of Eurocode 3. The design resistance moment of a composite joint with full shear connection should be determined by analogy to provisions for steel joints given in Eurocode 3, taking account of the contribution of reinforcement.

The basic joint components for composite beam-to-column connections are:

- Longitudinal steel reinforcement in tension,
- Steel contact plate in compression,
- Column web in transverse compression,
- Column web panel in shear,
- Column web in transverse compression,

The rotational stiffness of a joint should be determined by analogy to provisions for steel joints, taking account of contribution of reinforcement. The rotation capacity of composite joint may be demonstrated by experimental evidence. Account should be taken of possible variations of the properties of materials from specified characteristic values. Experimental demonstration is not required when using details which experience has proved have adequate properties. Alternatively, calculation methods may be used, provided that they are supported by tests.

Composite beams and slabs

Composite steel-concrete beams are formed typically from rolled sections and reinforced concrete slab of a constant thickness or a variable thickness when slab is cast in-situ on profiled sheeting (Johnson, 2004). In case of profiled sheeting used for in-situ casting, it is treated as a lost decking (Type 1) or it is assumed to play the role of additional reinforcement of composite beam subjected to service loads (Type 2).

The system Cofrasolfloor (Floor systems guide,ARVAL,2013) is the example of Type 1 of profiled sheeting. It is made up of steel decks used to provide formwork for the reinforced concrete when it is poured (Fig.5). For slabs on self supporting permanent formwork, the deck is only stressed during the construction stage and is not taken into account in the final floor resistance.

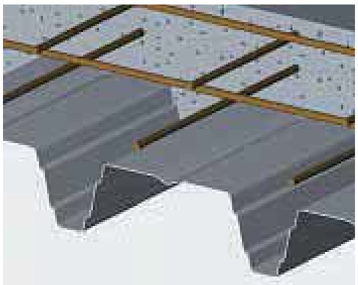

Fig.5. Cofrasol floor (Floor systems guide,ARVAL,2013)

Composite floor systems combine the beneficial features of steel and concrete. Cofraplus (Floor systems guide,ARVAL,2013) is open-rib composite floor decks (Fig.6). These are made up of two open-rib trapezoidal and nestable decks with embossments for easy storage and transportation.

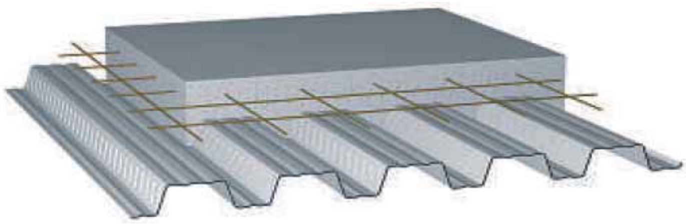

Fig.6. Cofraplus floor (Floor systems guide,ARVAL,2013)

According to Eurocode 4 (Eurocode 4,2005) composite behaviour between profiled sheeting and concrete shall be ensured by one or more of the following means:

a) mechanical interlock provided by deformations in the profile (indentations or embossments);
b) frictional interlock for profiles shaped in a re-entrant form;
c) end anchorage provided by welded studs or another type of local connection between the concrete and the steel sheet, only in combination with (a) or (b);
d) end anchorage by deformation of ribs at the end of the sheeting, only in combination with (b).

A composite floor is designed in two different stages: the assembly and concrete-pouring stage, and then the composite stage. During the assembly and concrete-pouring stage, the deck is used as self-supporting formwork and provides a working platform. In composite stage, the deck is structurally combined with hardened concrete (composite action) and completely or partially replaces the tensile reinforcement of the slab. The design of the profiled steel sheeting as shuttering should be in accordance with Eurocode 3. In composite stage the following methods of analysis may be used for ultimate limit state:

a) linear plastic analysis with or without redistribution;
b) rigid plastic global analysis provided that it is shown that sections where plastic rotations are required have sufficient rotation capacity;
c) elastic-plastic, taking into account the non-linear material properties.

Numerical methods in composite steel-concrete structures

During last years, different FE software packages were used to study the nonlinear behaviour of composite structures. Oven et al. (Oven et al.,1997) developed a two dimensional nonlinear FE model for analysis of composite beams with partial interaction. Baskar and Shanmugam (Baskar and Shanmugam, 2003) proposed 3D FE model to analyse four simply supported composite plate girders. They used 8-node doubly curved thin shell elements to model steel parts and rebar layer to model reinforcement (Fig.7).

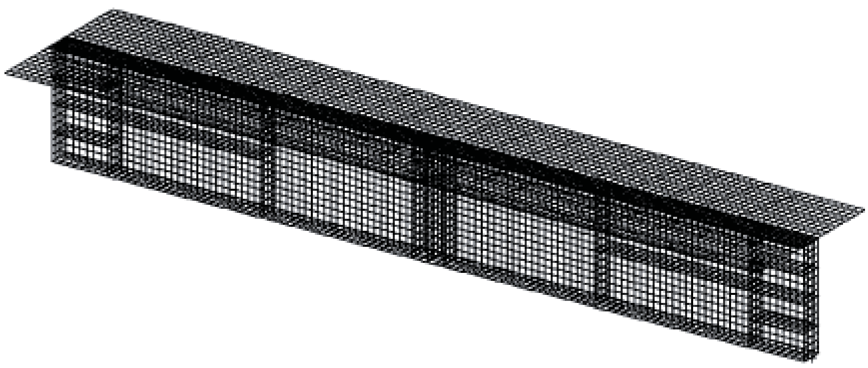

Fig.7. Finite element model of composite girders (Baskar and Shanmugam, 2003)

Lang et al. (Lang et al., 2004) developed a 3D FE model to consider the geometric and material nonlinear behaviour of continuous composite beams. The four- node doubly curved general shell elements were employed to model the concrete slab, the flanges and the web of the steel beam. The stud shear connectors were modelled using 3D beam elements (Fig.8.)

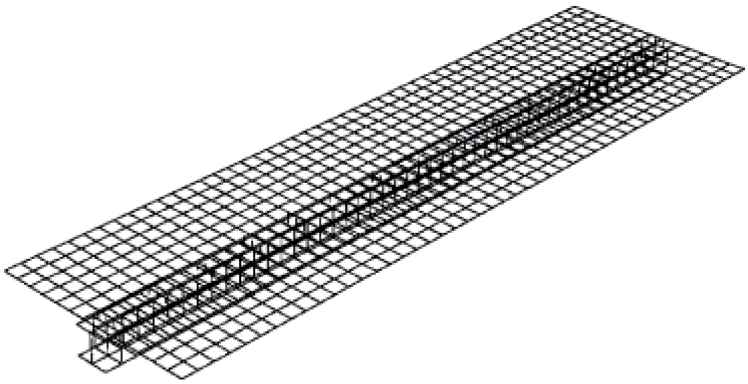

Fig.8. Finite element mesh for composite beam (Lang et al., 2004)

Barth and Wu (Barth and Wu,2006) used a four-node general purpose shell elements S4R to model the steel girder, concrete slab and stiffeners. The steel reinforcement in concrete was modelled by means of REBAR LAYER available in ABAQUS code.Full composite action between the concrete slab and the top flange of the steel girder was considered using beam type multi-point constraints (Fig.9)

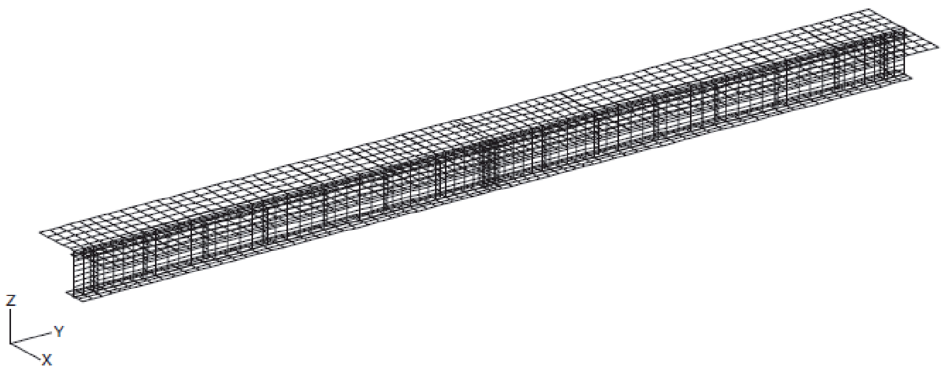

Fig.9. Typical FEA mesh for composite girder elevation (Barth and Wu,2006)

Fu et al. (Fu et al, 2008) developed the continuum elements available in the ABAQUS code to model semi-rigid composite joints with precast hollow core slabs. 3D continuum elements were used to model all parts of the composite joints and the contact was applied between all the joint components (Fig.10)

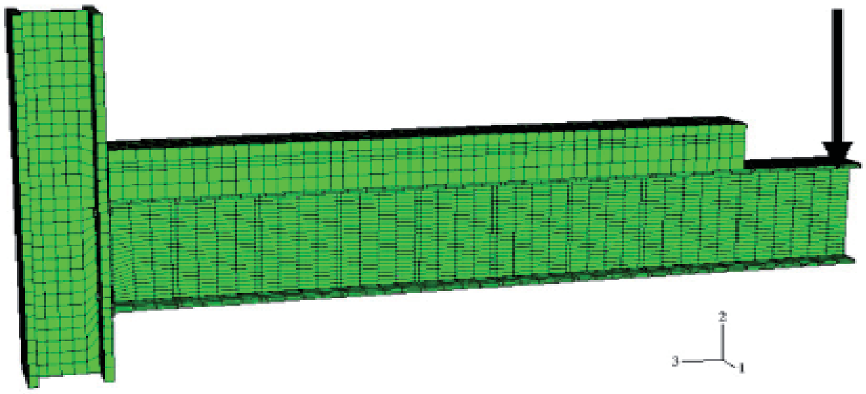

Fig.10. 3-D finite element model of composite connection (Fu et al.,2008)

Giżejowski et al.(Giżejowski et al.,2010) used 4-node shell elements to model steel parts of joint and special REBAR LAYER for modelling of reinforcing bars in the reinforced concrete section. The beam element type B31 were employed to model shear studs. A general 3D view of modelled steel-concrete composite joints is depicted in Fig.11.

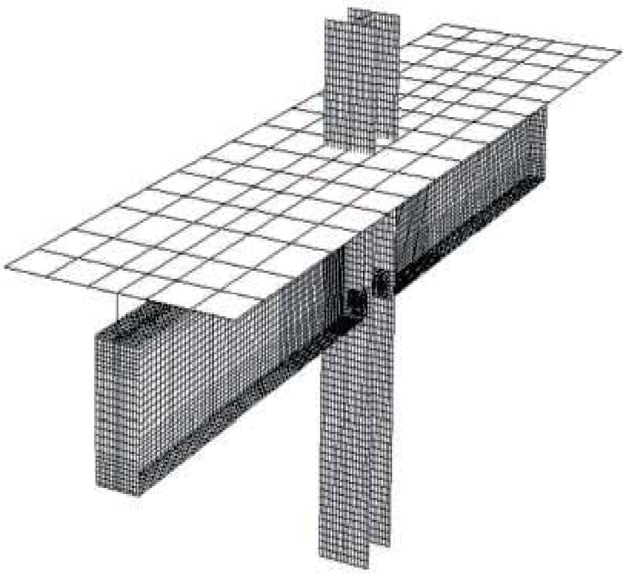

Fig. 11. 3D FE mesh for composite joint (Giżejowski et al.,2010)

Lam (Lam, 2008) used 3D solid elements to build FE model of semi-rigid composite connection with precast hollowcore slabs (Fig.12). Material nonlinearity was included by specifying the stress-strain curves of the material taken from the test specimen.

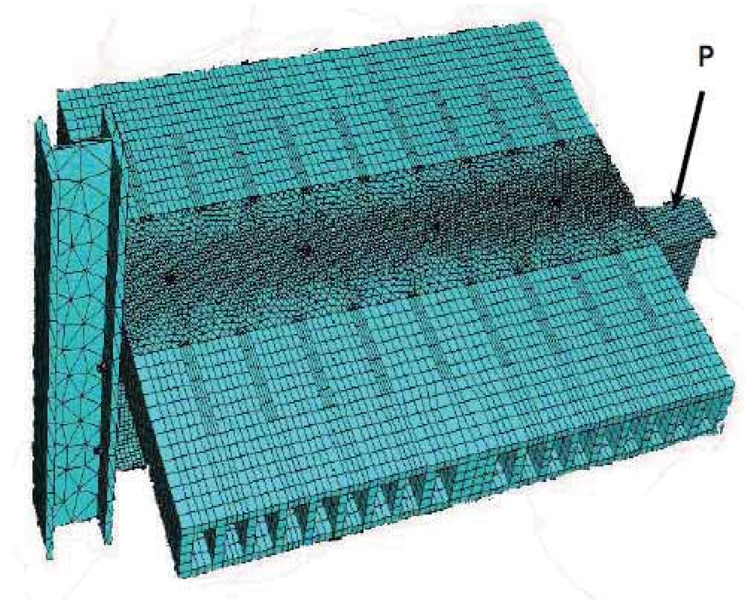

Fig.12. Finite element model of semi-rigid composite joint. (Lam, 2008)

Zeng and Makelamen (Zeng and Makelamen, 2009) conducted a numerical study on semi-rigid composite joint in slim floor frame (Fig.13).

a) b)

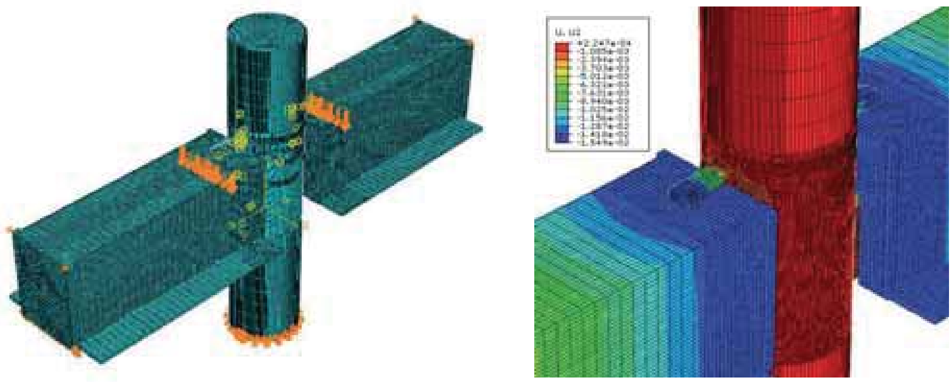

Fig.13. a) Overview of mesh and boundary condition for 3D model of semi-rigid composite joint with composite column; b) Maps of deformations of FE model(Zeng and Makelamen, 2009)

Some main components, such as structural steel and concrete filled in the column, eight-node, first- order solid continuum element (C3D8I) were selected for the modelling. A solid element with incompatible modes has a better performance for such types of problem, including large plasticity calculations, bending, and contact interaction, though these elements take more time, which is expensive. The longitudinal reinforcing bars were modelled via a two-node, first-order truss element (T3D2).

The presented numerical investigations confirm the use of FE model as a potential tool in current design approaches in order to improve the characterization of the real behaviour of composite structures.

Conclusions

This paper has presented state of art, achievements and new experimental works of concrete-concrete and steel-concrete structures. There were described experimental studies on composite beams with partial use fibre reinforced concrete. The researches on composite joints and steel-concrete beams were presented and additionally new method of FE modelling of such structures was shown.

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