ABSTRACT

Building frameworks are usually designed for service loads only despite the fact that they are vulnerable to a certain degree to progressive collapse phenomenon caused by local damage as a result of a column loss due to a vehicle impact, explosion, fire or earthquake. The objective was to investigate the behavior of steel and composite joints of building frameworks under typical load combinations and exceptional loading due to accidental loss of a column. The experimental numerical and analytical investigations on building frame joints are carried out following the joint behavior under service action effects and after systematic joint destruction in course of the progressive column loss scenario, taking advantage of the inherent ductile behavior of steel joint components and reinforcement of concrete slab. The requirements for robust joint behavior may be formulated to allow for force redistribution within the structure so that a progressive collapse of the building framework is prevented and structural safety is ensured. The aim was to investigate robustness of joints whose end plates, in line with requirements of current Eurocodes, ensured the joint full rotation capacity. Presented research creates a contribution towards a clarification of some aspects related to joints robustness in view of structural safety and reliability.

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Impact
Aircraft impact
man-made disasters
Explosion
Fire
Earthquakes
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1 EXPERIMENTAL INVESTIGATIONS UNDER THE STATIC COLUMN LOSS SCENARIO

1.1 Descriptions of specimens
As it was humanly impossible to test a full actual composite frame within the project, a substructure was extracted from the actual building and framework to fit the size of the lab. An ordinary building was considered as the distance between the columns being equal to 6 meters. Due to the available space in the lab, the actual length of the full model was taken as approximately 15 meter.

- The main span beams of the system length of 6 meters and two short spans of the length 1.4 m of both steel and composite frameworks were manufactured from IPE300.
- The beams were connected to the side columns (axes B and D) and the middle column placed in the axis C, all made of HEB200.
- The middle column was subjected to removal; its loss changed the static scheme of tested frames.
1.2 Testing procedure for steel specimens

- Four full scale tests were conducted on two steel and two composite frame, one steel and one composite with flush end-plate joints and the similar arrangements of two specimens with extended end-plate joints.

- Two steel specimens were tested only under application of downward displacement of the column whose progressive column loss scenario was simulated.

- The effect of service load was not examined since only the ductility of joint steel part components, and progressive failure modes under bending and catenary action were looked at.

- The goal of this study was to further contribute to the knowledge of their behaviour under exceptional event.
1.3 Testing procedure for steel-concrete composite specimens

- The composite subframe specimens, one with flush end-plate joints and one with extended end-plate joints, were tested in two stages:

- The first stage was the application of concrete blocks simulating a service gravity load associated with the exceptional event scenario.

- The second stage was to maintain the service gravity load and to apply the downward displacement of the column subjected to progressive column loss scenario.
1.4 Results of experimental investigations of flush end-plate joints steel specimen global behavior (TEST 1).
1.5 Results of experimental investigations composite flush end-plate inner joint (TEST 2).
1.6 Results of experimental investigations of extended end-plate joints steel specimen global behavior (TEST 3).
1.7 Results of experimental investigations composite specimen of extended end-plate joints (TEST 4)
1.8 Results of experimental tests investigations

1.9 Steel flush and extended end-plate joints.

1.10 Composite flush and extended end-plate joint global/local behavior (TESTs 1 - 4)
2 NUMERICAL INVESTIGATION OF JOINT BEHAVIOUR VERSUS THAT OF A TEST SPECIMEN

The validation of developed finite element model is carried out using experimental results of steel and composite isolated joints obtained in the Barciewicz PhD research. Developed model contains of the effect of profiled sheeting and reinforcement located in the same place as in the tested specimens and the concrete ribs are modeled with use of brick finite elements. This refined numerical model of joint behavior shows of a better accuracy that the former one. Therefore was used for the representation of physical frame tested to simulate the global behavior for the purposes of this doctoral research.
3 NUMERICAL INVESTIGATIONS OF GLOBAL AND LOCAL BEHAVIORS OF COMPOSITE JOINTS.

3.1 Flush end-plate specimen joints (FE - experimental composite), M-N curves from FE - experimental

3.2 Steel-concrete composite extended end-plate joints specimen tests (hogging and sagging bending).
4 ANALYTICAL INVESTIGATIONS BY COMPONENT METHOD

- Properties under exceptional loads for steel joints under hogging and sagging bending using Eurocodes are calculated for pure bending, neglecting the effect of axial force.
- The analytical method of Eurocodes does not give detailed procedure how to approach the case of sagging bending when the reinforced concrete slab is under compression.
- Since such a component has not been discussed in Eurocodes, the present study adopts the proposal given in Demonceau research.

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5 REMARKS RELATED TO ACTIVITIES UNDERTAKEN

5.1 Experimental investigations
- The load transfer path activated by adequate joint performance gives way for the robust behavior of steel and composite frameworks. This path enables the successful load transfer from the initial state to the stable residual state. The path is associated with catenary action that strongly depends on the ductility of the joint components.
- Robust joints have to have sufficient balance between the rotation capacity and strength. The flush end-plates joints are not robust since their low strength, despite of good ductility proven in tests on isolated joints, does not allow for the sufficient development of catenary action in the beam when tested in the framework.
Symmetrical extended end-plates joints seem to be robust, despite of their lesser ductility. It is possible because of their better balance between the strength and rotation capacity that allows for a sufficient development of catenary action in the beam when tested in the framework.

The developed refined numerical model of joint behavior shows of a good accuracy when compared with experimental results of isolated joints, therefore was used for the representation of physical frame tested to simulate the behavior of full scale specimens tested for the purpose of this doctoral research.

5.2 Numerical investigations

- Comparison of numerical and experimental load-displacement characteristics shows that the global behavior of the frame is reproduced with an acceptable accuracy using the refined finite element mesh.
- The catenary action effect identified in tests was investigated with use of developed numerical modeling technique, and the results are useful for further studies.
- The developed refined numerical model of joint behavior shows of a good accuracy when compared with experimental results of isolated joints, therefore was used for the representation of physical frame tested to simulate the behavior of full scale specimens tested for the purpose of this doctoral research.
6 EMERGING FUTURE NEEDS

- Knowledge on joint stiffness, strength and ductility behaviors in reference to standard static column loss scenario needs to be expanded towards to the influence of deformation rate of joints behaving in extreme situations of local damage.
- Tests on the global behavior of frameworks conducted within this study with regard to simulation of static column removal should be extended to account for the impact effect associated with the sudden nature of this phenomenon.

- There is a need for more experimental evidence on the joint behavior under sagging bending of steel columns and composite beams.
- More attention should be allocated towards on innovative constructional details of joints with regard to its ductile behavior, namely position of bolts and welding scenarios minimizing the influence of ductility degradation in the heat affected zones (HAZs) of beam-to-column joints.
There is a need for continued finite element modeling (FEM) especially with reference to dynamic situations.

Investigations carried out in this show that there should be a further effort undertaken towards the application of component method for joint properties in case of combined sagging bending and catenary action.

7 SUMMERY

Tests on the global behavior of frameworks conducted within my PhD study with regard to simulation of static column removal. This study took place at Warsaw University of Technology from 2008 until 2013, and the research was done Experimentally, Numerically and theoretically.

The Postdoctoral research should be repeated with consideration of dynamic effects associated with the column removal. This advanced search is going to be done in the further years during my post-doctoral search.

Therefore, this would need more sophisticated measurement devices, more of high-speed visual recording nature that of mechanical nature, including the fast speed video camera and laser technology and period of 24 – 36 months.

The comparison between the two researches and the preparation of a final research to be added with the overall research and propose appropriate design of the building structural under typical and exceptional load combination.