Analysis of steel frames with precast concrete infill panels

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Summary

This paper presents experimental and numerical analyses of a new type of hybrid lateral load resisting structure. This structure consists of a steel frame with a discretely connected precast concrete infill panel with a window opening. The discrete connections are formed by structural bolts on the column and beam in every corner of the steel frame, confining the precast concrete panel within the steel frame. With the finite element program DIANA, the response of 5 full-scale experiments on one-storey, one-bay, 3 x 3 m infilled frame structures, having different window opening geometries, was simulated. The finite element simulations were performed taking into account non-linear material characteristics and geometrical non-linearity. A comparison between the full-scale experiments and simulations shows that the finite element models enable simulating the elastic and plastic behaviour of the hybrid lateral load resisting infilled frame.

Keywords: infilled frame; steel; precast concrete; structural stability; high-rise buildings.

1. Introduction

At Eindhoven University of Technology a hybrid lateral load resisting structure has been designed for the construction of tall buildings. It is an integrated building system consisting of infilled steel frames with discretely connected precast concrete infill panels. Besides the stiffening and strengthening effect of the infill panels on the frame structure, economical benefits may be realised in saving costs on materials and labour, and in reducing construction times. Experimental and numerical research was carried out to provide insight into the behaviour of this structure.

2. Structure

The one-storey, one-bay, 3 by 3 m infilled frame structure (Fig 1) subject to experimental and numerical analysis consists of a simply connected steel frame, constructed of HE180M sections for columns and beams. The precast concrete panels, provided with a window opening, are made of C45/55 and are 200 mm thick. A discrete steel-concrete connection has been developed, enabling steel frames and precast concrete panels to act compositely when subject to lateral loading. This connection is realized by structural bolts on the column and beam in every corner of the frame, confining the infill panel within the frame. The structures are designed to fail by a bolt failure mechanism.

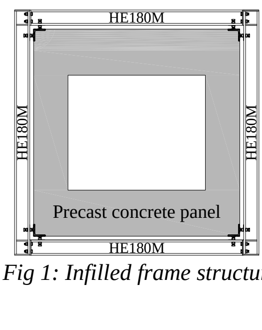

Fig 1: Infilled frame structure

3. Full-scale experiments

Five full-scale tests with different opening geometries were performed to investigate the effect of the size and position of a window opening. In Fig. 2 the load-deflection response of the 5 tested infilled frames is shown. The typical load-deflection response is characterised by a relative high

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initial stiffness, resulting from the tightening and thus prestressing of the steel-concrete connection in combination with uncracked panel behaviour. Next, the lateral stiffness decreases due to crack initiation, and can be considered linear till around 500 kN, followed by a non-linear branch and finally failure. For test 1 to 4, the discrete connections were governing the strength of the structure by the anticipated bolt failure mechanism. For test 5, the infill panel failed first. This failure occurred at the corner of the panel by concrete spalling and reinforcement yielding. All infilled frame structures were able to support a lateral load of 650 kN or more. The experiments showed that the discretely connected precast concrete panels with window openings can significantly improve the performance of steel frames. The observed lateral stiffness of the infilled frames ranges between 5.5 respectively 10.0 times the bare frame stiffness.

4. Finite element modelling

With the finite element program DIANA, the response of the five full-scale tests was simulated. A two-dimensional finite element model was developed. The concrete panel was modelled with plane stress elements. The longitudinal reinforcement and stirrups were modelled with reinforcement bars, embedded in the plane stress elements. The non-linear concrete material model combined the Mohr-Coulomb plasticity model for the compressive regime with a smeared cracking model for the tensile regime. Material nonlinearities such as concrete cracking, tension softening, shear retention, concrete plasticity and reinforcing bar yielding were all simulated. Beam elements combined with the Von Mises plasticity model were used to model the frame members. The beam-to-column connection was modelled by a rigid offset to take the column depth into account, and a two-node torsion spring element representing the stiffness of this connection. The torsion springs were calibrated on the results of full-scale experiments with bare frames, without the infill panels. The discrete steel-concrete connections were modelled with non-linear spring elements with no tension capacity but able to transfer axial compressive forces. Input is the stiffness diagram obtained from a preceding investigation into the structural behaviour of the steel-concrete connection. The finite element simulations were preformed taking into account geometrical non-linearity.

5. Results and discussion

The simulated and experimental global responses of all specimens are presented in Fig. 2. Comparison shows that the FE-models are able to predict the lateral load versus deflection relationship of the hybrid lateral load resisting infilled frame, and the ultimate lateral load carrying capacity for both connection failure (test 1 to 4) and panel failure (test 5). The comparison between local deformations, crack patterns and failure modes indicates that the finite element model used in this study is adequate, and corresponding results are reliable. The numerical investigation will, therefore, be further extended to investigate other configurations of the hybrid lateral load resisting infilled frame.

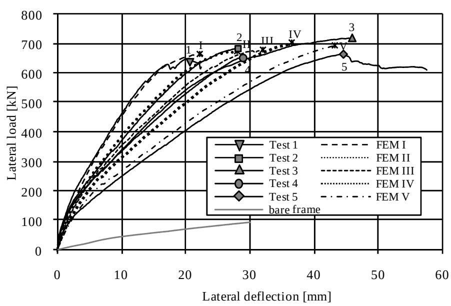

Fig. 2: Load-deflection response infilled frames

6. Conclusions

The experiments show that discretely connected precast concrete panels with window openings can significantly improve the performance of steel frames. The observed lateral stiffness of the infilled frames ranges between 5.5 respectively 10.0 times the bare frame stiffness. All infilled frame structures were able to support a lateral load of 650 kN or more. For four panel geometries, the discrete connections were governing the strength of the structure while for the test with the largest panel opening the infill panel failed first. Finite element simulations were performed taking into account non-linear material properties and geometrical non-linearity. A comparison between the experiments and simulations shows that the FE model is able to predict the lateral load versus deflection relationship, and the ultimate lateral load carrying capacity for all failure mechanisms.