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Residual stiffness and strength of shear connectors in steel-concrete composite beams after being subjected to a pull-out pre-damaging: An experimental investigation

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ABSTRACT

Horizontal stability of the medium rise steel frame structures is usually ensured by vertical bracings and diaphragm action of composite floors. Load transfer within the composite floor system is made through shear connectors, e.g. headed studs. In an event of explosion, such connectors must reserve sufficient residual stiffness and strength in order to avoid a sudden or delayed collapse of the building. These remaining capacities have not been experimentally studied yet in the literature. This paper presents large scale horizontal push out tests to determine the residual stiffness of the shear connectors after being initially damaged by explosion. The initial damaging is reproduced by a pull-out test using a quasi-static loading. Two types of numerical simulation have also been developed using ABAQUS/CAE software to provide a better understanding of the experimental results.

1. Introduction

The present-day serviceability of steel frame buildings in industry and commerce has exposed the structures with high risk to extreme and accidental loadings, particularly explosion. Many incidents, such as Azote de France Fertilizer factory in Toulouse (AFT), Buncefield in UK and CPR Tank Farm in Puerto Rico to name a few, have damaged structures within a large surrounding area, causing serious casualties and substantial property loss. It is thus increasingly important to design structural buildings with such exposure to withstand the effects of blast loading. The Buncefield investigation led to the recommendations on land use planning and the control of societal risk around major hazard sites in addition to Health and Safety Executive (HSE) to take into account not only direct human harm but also property damage and other harms to communities. Coming after the incident of AFT in Toulouse, a regulation was established to allow the design of concrete buildings that can resist blast actions with an intensity up to 12 kPa. However, steel framed buildings are not permitted to tolerate even with low level of explosion except if the spacing between steel frames is less than 5 m. This consideration is based on inertia effects while robustness of steel structures, i.e. high ductility and redundancy, is not considered. Until recently, either large-scale buildings or concrete structures are included in the regulations while low-to-medium rise steel buildings subject to global explosion have not been studied yet. Consequently, a European project called Blast Actions on Structures In Steel (BASIS) has been proposed to investigate and develop a methodology for the safe design of low to medium rise office buildings subjected to large external explosions.

The research work in BASIS project is based on a reference building of a typical business park office building that fits the description of low to medium rise building. This three-story office structure (See Figs. 1 and 2) was designed based on usual loadings in simple construction using the principle of Eurocodes 1993 and 1994. In this type of frame building, the composite floors are supported by steel columns. The wind actions are transmitted from façades to the vertical steel bracings by the diaphragm action of the composite floor and by shear actions of shear connection. From the reference building design [1], the wind action expected to transmit through the shear connectors was estimated at 10 kN/m. The response of such multi-story steel frame building subjected to blast loading involves complex interactions between building envelope, composite floor, frame system, and connections. The load transfer between the composite floor and its frames depends strongly on the performance of the shear connectors. Headed steel stud anchors welded to steel beam and encased in concrete are commonly used as shear connectors to transfer forces in the composite beam system. Being a part of BASIS project, this paper presents an experimental

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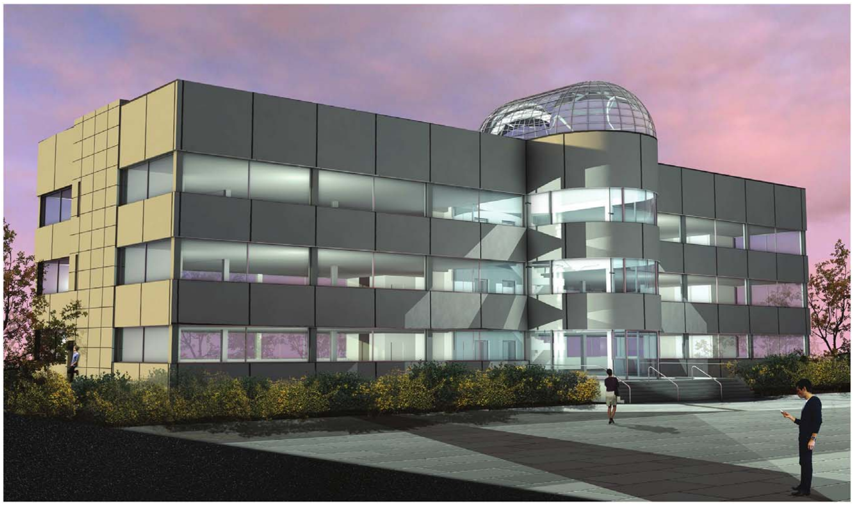

Fig. 1. Architectural façade view.

investigation on the residual shear stiffness and strength of stud connectors after being submitted to blast actions. For the past 50 years, different aspects of the behavior of the headed steel studs such as failure mode, shear capacity and load-slip relation have been assessed throughout empirical studies using small-scale standard or full scale push-out tests. After the earlier push-out tests [2,3], small-scale standard tests were established in CP117 [4], BS5950 [5] and Eurocode 4 [6]. In such tests, the push-out specimen is composed of a profiled steel beam connected to two blocks of concrete by shear connectors. Ollgaard et al. in 1971 [7] used the small scale push-out test setup to investigate the capacity and behavior of stud shear connectors embedded in lightweight and normal weight concrete. Prakash et al. [8] presented modified push-out tests to determine shear strength and stiffness of high strength steel studs, in which the reinforcement, method of casting concrete and test setup were altered from the standard tests with an adaptation to enhance splitting resistance of reinforced concrete. In addition to this, Shim et al. [9] performed push-out tests on specimens fabricated in accordance with Eurocode 4 [6] to determine static behavior of large stud shear connectors (diameter 25, 27, 30 mm stud). On the other hand, Lloyd and Wright [10] conducted a series of large scale push-out tests of composite beam specimens (See Fig. 3) with the objective to recommend a standard configuration for through-deck push-out test. In their study, 42 push-out tests have been performed by varying some parameters such as the width of the slab, the detail of mesh reinforcement, and the number of profiled steel sheet pitches. Having similar test setup to the one described in [10], Smith and Couchman [11] carried out 27 push tests on specimens of composite beam using a new push rig to investigate the effect of variables such as meshed position, transverse spacing of shear connectors, number of shear connectors per trough and the slab depth. In 2009, Hicks [12] also implemented two types of tests on the headed stud connectors welded in profiled steel sheeting and embedded in reinforced concrete slab. One of his setups is a standard push-out test as defined in Eurocode 4 [6] whereas the other setup is a full-scale composite beam illustrated in Fig. 4. Apart from this, Lam [13] proposed a new horizontal push-out test setup using full-scale specimens of

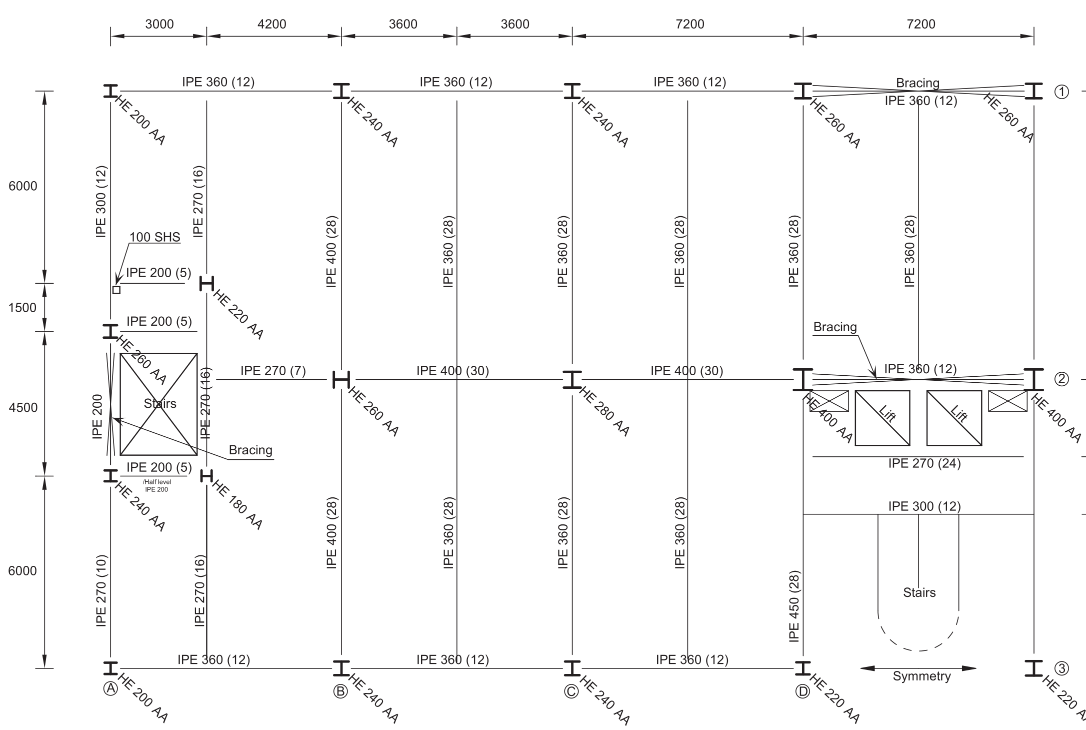

Fig. 2. Level 1 and 2, office areas.