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PHYSICAL AND VIRTUAL EXPERIMENTAL INVESTIGATION OF SELF-CENTRING CONCENTRICALLY BRACED FRAMES

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1. Introduction

One of the main structural typologies of steel frames considered by the codes of practice for resisting the lateral forces, are the concentrically braced frames (CBFs). They are characterized by the dissipative performance of the diagonal braces that simulate truss behaviour due to the axial forces that develop during horizontal loading. The seismic response of the CBFs is represented through the cyclic compressive buckling and tensile yielding of the diagonals which induce the development of plastic hinges within the element. Due to the existence of diagonal braces, their lateral stiffness is well above that of the moment resisting frames (MRFs) and are very effective in maintaining the lateral drifts in the design range. Additionally, they represent the most economical structural form for providing lateral seismic resistance [1]. The global performance of the CBFs during high intensity earthquake loading is generally assessed by the frame drifts. After reaching inelastic residual deformations, the braces are unable to provide the initial lateral resistance to the system and the frame experiences residual displacements. To tackle the residual displacements of the frames, innovative damage control procedures have been suggested, such as buckling-restrained braces [2] and self-centring systems [3]. This study presents the experimental findings on the latter method in which post-tensioning (PT) arrangements are used to return the structure to its original position following inelastic deformation demands. The basis for the experimental research is a novel self-centring CBF (SC-CBF) system that has been developed and examined through push-over physical laboratory tests and nonlinear time-history analysis of numerical model [4]. This structural type's main characteristic is the re-centring of the frame following the earthquake loading in the initial vertical position, thus reducing the post-earthquake cost and time for retrofitting. It also reduces the material used for repair since the only elements needing retrofitting remain the diagonal braces that undergo many cyclic loadings and plastic deformations under the earthquake excitation.

2. Experimental studies

Previously, experimental studies have been performed to characterise the behaviour of the individual elements of SC-CBF by investigating several parameters. Shake table tests carried out on bracing members with slenderness values exceeding the limits imposed by seismic codes demonstrated generally satisfactory performance [5]. However, in order to test the overall behaviour of the SC-CBF under horizontal loading and to verify its self-centring behaviour, a more complex testing procedure is required. Therefore, the novel self-centring system that eliminates the residual deformations in the structure by using a post-tensioning arrangement, rocking connections and inelastic behaviour of tubular steel bracing members was tested under quasi-static cyclic tests [6].

The testing proved the self-centring behaviour of the SC-CBF after many cycles of inelastic deformation. It validated the rocking behaviour of the beam-column connection demonstrated by bilinear elastic performance. Also, great structural lateral capacity was observed when combining the

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rocking behaviour with the diagonal bracing members. The complete improvement of the CBF structures' performance was observed after the increase of post-tensioning force in the cables when the gap opening in the rocking connection occurred.

To support the development and validation of the SC-CBF, shake table tests were performed in the framework of the SERA project [7]. The test setup was similar to the one used for quasi-static testing of the structure and comprised a single storey steel frame with a central SC-CBF containing the brace specimens and self-centring system and two external non-braced gravity frames with very low lateral resistance. During the experimental testing procedure, varying observations were indicated related to the structural brace configuration and the ground motion applied. However, some general observations contained negligible residual drifts, excellent functioning of the PT strands, energy dissipation through the braces and rocking connection behaviour between beams and columns, as verified by scratches at the connections.

In order to describe the need for a virtual experimental framework for the investigation of SC-CBF structures, the issues arising from the calibration of the simulated and reference model must be stated. If a calibration model is needed to provide optimal parameters for simulation, it has to focus on the component behaviour that is important from the perspective on the global structural behaviour. However, performing a sufficiently large number of full-scale dynamic experiments for calibration purposes is expensive [8]. The calibration of the physical and numerical model of the SC-CBF would normally consist of: global structural investigation under seismic loading, local brace investigation under seismic loading, brace investigation under virtual quasi-static loading and comparison of errors from dynamic simulation and calibration procedures to evaluate the efficiencies of the calibration methods and quantify uncertainties.

3. Conclusions

This study presents the types of experimental research needed for validation of the structural system and calibration of the numerical models for simulation of the structural behaviour. The various types of experimental procedures are then combined in order to form a complete methodology for estimation of the main characteristics of the novel system and proceeding to a code conforming evaluation procedure.

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