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# Seismic performance assessment of concentrically braced steel frame buildings with high strength tubular steel columns

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ABSTRACT

In the paper, an analytical and experimental study aimed at supporting new design criteria for the exploitation of steel circular hollow columns made of HSS and subjected to exceptional loads, like earthquakes is presented. In fact, there is an increasing interest in the use of hollow sections of High Strength Steels (HSS). The ambitious targets are to enhance the structural performance of concentrically braced steel frame buildings with tubular columns, and to reduce weight and, at the same time, construction costs. The paper initially describes an experimental study of the seismic behaviour of substructures representing a concentric braced frame of a prototype structure: a steel building with concentric bracings for offices, meetings or exhibitions. The prototype structure was designed in accordance with the capacity design criterion, i.e. by assuming that breaking of connections and buckling of beams and columns must be preceded by yielding of the diagonals in tension. The brace-beam-to-column joints represent the critical component. The objective of the test programme was to characterize the connection behaviour under monotonic, cyclic and random loads. In detail, five tests were carried out on specimens with standard braces and two tests on specimens with weakened braces. Experimental results are shown as force-interstorey drift ratio diagrams. Then, a numerical calibration of a model of these joints was successfully accomplished. After the calibration of the numerical models, in order to evaluate the global response under seismic loading, a numerical analysis of the reference building was performed with the OpenSees programme. Both pushover and dynamic nonlinear time-history analyses were carried out. Experimental and numerical results show that performance-based design approaches can be reasonably extended to concentrically braced frames (CBFs) with high strength tubular steel columns.



## 1. Introduction

The use of High Strength Steel (HSS) circular hollow sections (CHS) is still limited in the construction industry despite their excellent structural and architectural properties, and the rapid development of end-preparation machines. Although the interest in their use is growing among designers, the lack of adequate code recommendations represents a strong restraint.

When employing the capacity design philosophy, the use of high strength steel can be advantageous in seismic design for non-dissipative elements owing to its inherent over-strength. However, in practice, problems as local instability, deformation capacity and over-strength are taken into account in a way that leads to an excessive margin of safety. This approach is due to the limited knowledge of the performance of this type of steels. In fact, although EN1993–1-12 [1] extends its scope to steel grades up to S690/S700MC, limitations still exist at material, structural and design level.

Recently, some studies were carried out on this subject. A few papers have been published on the behaviour of high strength steel employed in structural applications and they are spread over a wide range of topics: connections [2–4]; imperfections and residual stresses of Very High Strength (VHS) steel circular tubes [5]; circular hollow sections and concrete filled tube sections in fire [6,7]; strength of concrete filled steel box columns [8,9].

Besides, some papers were focussed on the introduction of ductile fuses in bracing members with the objective of reducing seismic design loads and, thereby, costs related to steel tonnage, shop fabrication and assembly on site. This goal was achieved by locally reducing the brace cross-section area [10–15] or by introducing ductile components that yield in both compression and tension [16–18].

Another design problem comes from the classification limits imposed by EN 1993–1-1, due to the high yield strength [19]. Studies and tests have shown that the slenderness limits imposed by EN 1993–1-1 might be too conservative for both mild steel up to grade S460 and for HSS, in particular for circular hollow section [20,21]. The

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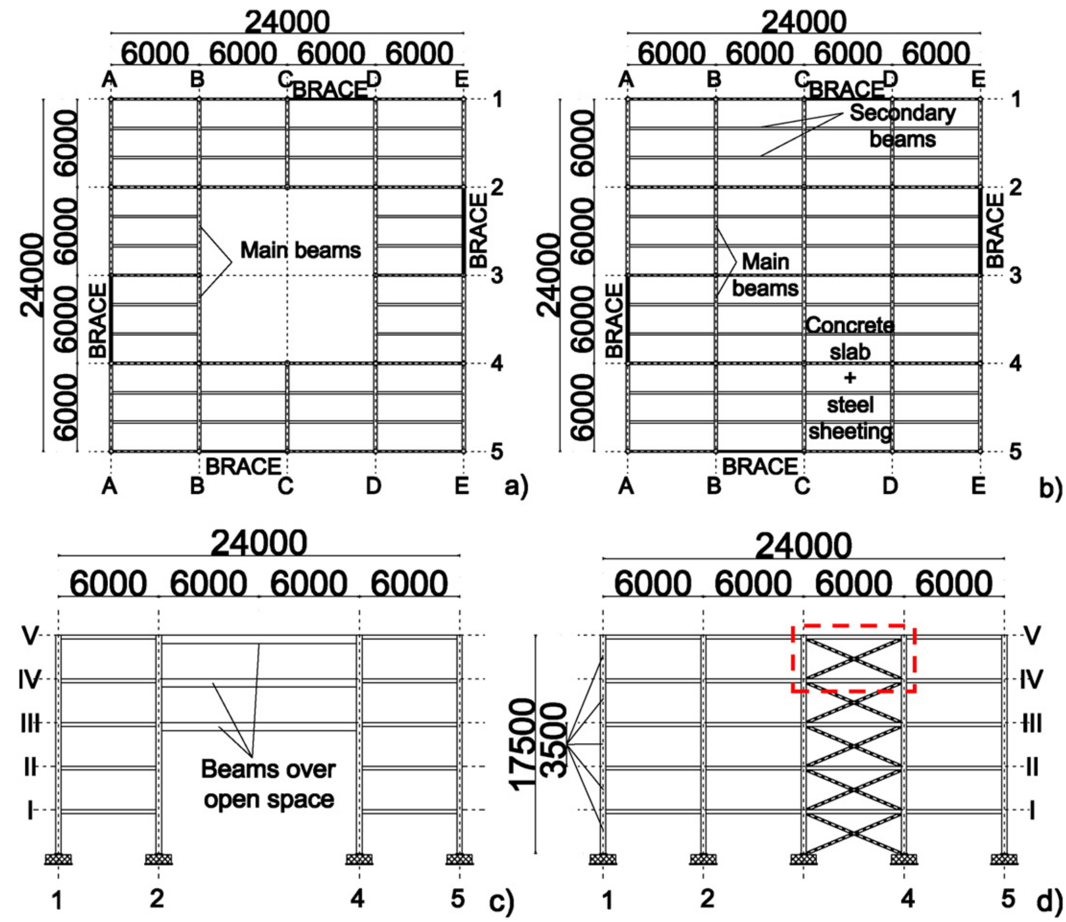


**Fig. 1.** Reference structure; a) plan of 1st and 2nd floors; b) plan of 3th, 4th and 5th floors; c) C—C cross section; d) A-A cross section. Dimensions in mm.

significant differences in slenderness limits recommended in various codes for circular hollow sections (CHSs) under bending [21] add an additional negative element.

In this context, at the University of Trento, two research studies aimed at developing and extending the performance-based design approaches to moment resisting frames with high strength steel (HSS) tubular columns and to concentrically braced frames with high strength steel (HSS) tubular columns were carried out in order to 'promote' the use of high-strength steel circular sections in buildings.

The first project, focussing on frames and called ATTEL, was funded with the aim of investigating both seismic and fire behaviour [2]. The main objectives were the increase of the knowledge both for single structural elements made of high strength steel and for structural assemblies, such as joints.

The second study aimed at developing both analytical and experimental know-how in order to support new design criteria for exploiting HSS circular hollow sections for columns in concentric bracings subjected to exceptional loads, like earthquakes.

The common aim of the two projects is to fill some gaps and to solve existing uncertainties so that both the Italian [22] and European Codes [19,33], are enhanced. This way some of the obstacles to the practical use of HSS would be removed, providing them new market opportunities.

In particular, the second project has the ambition to develop performance-based design approaches, based on the capacity design concept. This philosophy is widely used in seismic engineering in order to avoid brittle failure and to ensure high energy dissipation, and it needs to be extended to HSS tubular CHS structures under earthquake loading.

The specific ambitious target was to enhance the structural performance of concentrically braced steel frame buildings with high

**Table 1**
*Profile type* of braces and overstrength coefficient.

| | *Profile type* | $f_y$ [MPa] | $\Omega_i$ |
|---|---|---|---|
| Floor 1 | UPN 300 | 275 | 1.57 |
| Floor 2 | UPN 300 | 275 | 1.75 |
| Floor 3 | UPN 260 | 275 | 1.67 |
| Floor 4 | UPN 240 | 275 | 1.80 |
| Floor 5 | UN 180 | 275 | 1.71 |

**Table 2**
Coupon tests on steel S275 of UPN180 and on steel L80 of columns.

| Steel — S275 | | | | | | |
|---|---|---|---|---|---|---|
| Nominal values | | $f_{yk}$ [MPa] | | $f_{tk}$ [MPa] | | |
| S275 | | 275 | | 430 | | |
| Actual values | | | | | | |
| Coupon | $f_{y,max}$ [MPa] | $f_{tmax}$ [MPa] | A [MPa] | Lo [*mm*] | Lu [*mm*] | A5 [%] |
| Web 1 | 352 | 474 | 57.57 | 45 | 59 | 31 |
| Web 2 | 350 | 485 | 57.73 | 45 | 60 | 33 |
| Flange 1 | 423 | 507 | 67.28 | 45 | 57 | 27 |
| Flange 2 | 417 | 505 | 60.37 | 45 | 56 | 24 |
| Steel — L80 | | | | | | |
| Nominal values | | $f_{yk}$ [MPa] | | $f_{tk}$ [MPa] | | |
| L80 | | 550 | | 655 | | |
| Actual values | | | | | | |
| Coupon | $f_{y,max}$ [MPa] | $f_{tmax}$ [MPa] | A [MPa] | Lo [*mm*] | Lu [*mm*] | A5 [%] |
| Specimen 1 | 565 | 669 | 58.80 | 45 | 55.5 | 23 |