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Structural performance of cold-formed steel trusses used in electric power substations

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ABSTRACT

This paper presents a detailed investigation of the lateral characteristics of cold-formed steel truss structures used in electric power substations. Five full-scale specimens were tested, and their responses were recorded under monotonic and cyclic loading regimes. Of particular interest were the specimens' maximum lateral load capacities and deformation behaviours. A rational estimation of the seismic response modification factor, R, of the truss structures is also provided. In addition, different types of stiffened sections were employed in order to examine the impact of the presence of stiffeners and lips on seismic behaviour, as well as on the lateral resistance of the structure. Detailed comparisons between relevant code methods, finite element modelling and an experimental study were then conducted to suggest an appropriate value for the R factor. A financial evaluation was also performed, to highlight the advantages of employing cold-formed steel trusses in the electric power substation industry. The results show that the cold-formed steel structural system is a reasonable alternative to the currently used hot-rolled steel structures, and that its use decreases the cost of the structures by almost 50%.

1. Introduction

Use of cold-formed steel (CFS) structures has recently grown dramatically in residential and industrial buildings, with it becoming an appropriate alternative to conventional methods due to its enormous advantages, such as its high quality and ease of construction, and its relatively light weight. Electric power substations (EPS), which are usually located in the vicinity of cities, are mainly equipped with truss structures built up from hot-rolled steel angles, which have much greater weight and expense. Considering the advantages of CFS structures, the current research aims to evaluate the lateral performance of CFS truss systems, including an estimation of their seismic response modification factors. As there is currently not enough information in the available codes and standards, this research is essential for improving the design of CFS truss structures. In addition, taking into account a real case study, a brief economic comparison between the proposed CFS truss structures and the corresponding currently used hot-rolled truss structures is provided. For this purpose, a device commonly used in EPSs, a 63 kV current-transformer (CT) which is shown in Fig. 1, is scrutinized as a case study. In each electric power substation, there are several other electric devices installed on hot-rolled truss structures. However, investigating only a CT is considered sufficient, since most of the equipment and corresponding structures are similar to CTs.

Over recent decades, numerous analytical and experimental investigations have been performed to maximize the capacity of cold-formed steel sections employed in CFS structures. Pedreschi and Sinha [1] conducted a few experimental tests on full-scale specimens using different configurations to determine the impact of mechanical clinching in steel trusses. Mohan et al. [2] presented an equivalent radius of gyration for cold-formed lipped angles utilized in the trusses of transmission towers. The behaviour of non-symmetric lipped angle columns was also scrutinized by Young and Chen [3]. The design of cold-formed steel angles with unequal legs subjected to axial force was criticized by Young and Ellobody [4], who noted that North American Specifications [5] are currently not conservative for short to intermediate columns. They also proposed some design rules while different buckling modes are the main causes of failure in these sections. Zeynalian et al. [6] also inspected cold-formed steel truss connections experimentally, in order to determine the specimens' maximum load capacity as well as the connections' failure modes. Koen [7] studied the failure modes of four discrete light-gauge steel storage rack uprights, finding that flexural-torsional buckling governs failure in long specimens while flexural buckling governs failure in medium-length specimens. Manikandan and Arun [8] also studied buckling behaviour of cold-formed steel lipped channel columns with intermediate web stiffeners subjected to axial compression. Szafran and Rykaluk [9] performed a full-scale telecommunication tower test. They concluded that the buckling capacities of applied cold-formed steel legs are greater than those estimated via standard descriptions. This might be as a result of the significant rigidity of the connection flanges, which affects the failure mechanism and the overall stability of the tower legs. Reinforcing the angle legs in lattice towers could potentially be effective in increasing strength, as shown by Zhuge et al. [10]. They investigated the most effective leg retrofitting

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Fig. 1. Structure of current transformer (CT).

methods experimentally, using a one-panel angle leg retrofitting model and a nonlinear finite element model.

In this study, the Majlesi 63 kV substation which is already designed and constructed in the southern part of Isfahan (in Iran) is examined. It is a hot-rolled steel CT structure, with details illustrated in Fig. 2.

As shown in the figure, the structure consists of four columns with dimensions of L60 × 60 × 6 mm, and braces with dimensions of L40 × 40 × 4. One plate (PL520 × 520 × 2.4 mm) is bolted at the top, and four plates (PL120 × 120 × 2.4 mm) are welded at the bottom of each column. The top plate was placed there to provide space for the installation of CT equipment, and the bottom plates are for fastening of the structure to the foundation via four M20 anchor bolts. The overall weight of this structure is 118.38 kg. The height of the structure is 2180 mm and the back to back distance between the columns is 420 mm. The braces are connected to the columns with one M16 high-strength bolt at each end. Because the weight of the CT equipment (525 kg) is much higher than that of the CT structure, a common engineering assumption of considering the structural system as an inverted pendulum system is adopted amongst structural designers.

In order to use cold-formed steel in the structure, the CT structure was redesigned based on AISI standard [5]. The design loads which were applied to the CFS truss structure are based on Standard IR457 [11], and are similar to the design loads which were considered for the hot-rolled truss. The design loads include weight, wind, and earthquake applied to both the CT equipment and the CT structure. An additional short circuit load is applied only on the top of the CT equipment. The short circuit is an electrical circuit that allows a current to travel along a wire and induces horizontal load in the wire which is normal to the wire direction.

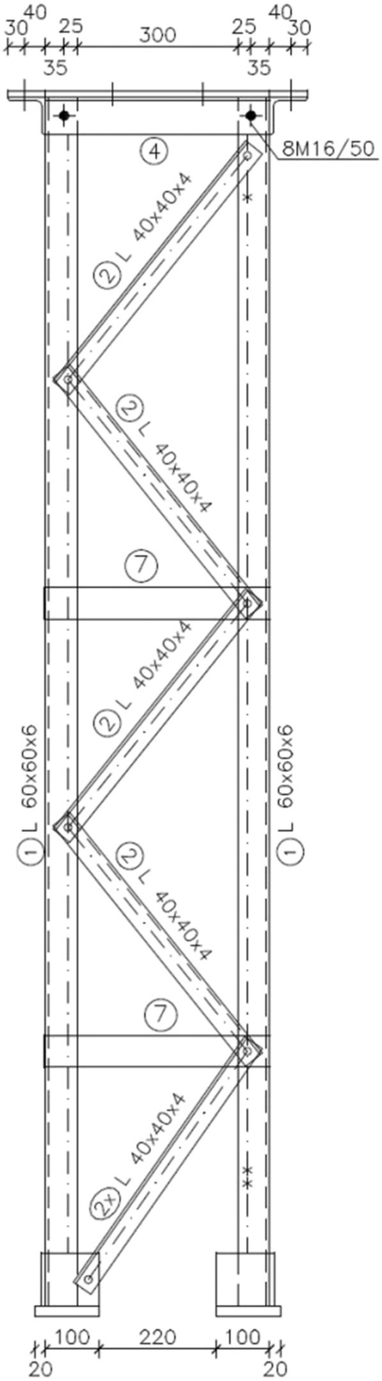

Fig. 2. Details of currently-in-use CT structure (mm).

Considering the geometry of the currently used hot-rolled CT structure, an initial design using cold-formed steel angle sections based on AISI [5] was taken into account. The CFS structure consists of columns of L50 × 50 × 2.4 mm, and braces of L40 × 40 × 1.8 mm in four sides of the truss. Similar to the hot-rolled CT structure, a steel plate of PL 520 × 520 × 10 mm is considered on the top of the structure for installation of the CT equipment. This plate is placed on four horizontal angles, which are also in the same dimensions as the columns, and connected to the columns using 12 M8 high-strength bolts with yield and ultimate strength of 640 MPa and 800 MPa, respectively. At the base, columns are strengthened with two gusset plates (with dimensions of 90 × 70 × 1.8 mm) seated on one base plate of PL 120 × 120 × 15 mm under each column. The anchor bolts connecting the structures to the foundation (test rig) are similar to the hot-rolled CT structure shown in Fig. 3.

2. Experimental investigations

As the first step, four specimens of structures of the current transformer were built in full scale (Fig. 4) in order to investigate the proposed CT truss structure. The first specimen (TR1) was subjected to