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# Impact behaviour of pre-compressed hollow and concrete filled mild and stainless steel columns

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ABSTRACT

This paper investigates the behaviour of hollow and concrete filled steel (CFST) mild and stainless steel columns subjected to transverse static and impact loading with a pre-compressive axial load. Transverse load was applied at the mid or quarter point of the columns. A total of three test series were carried out recently at the University of Western Sydney and the University of Wollongong to obtain the performance of mild and stainless steel hollow and CFST columns subjected to lateral static as well as impact loading with or without pre-compressive load. The test results reported in this paper are from the third test series, where both axial and lateral loads were applied to the columns. This paper also investigates the finite element (FE) modelling of hollow and CFST mild and stainless steel columns due to static and impact loads. Three-dimensional nonlinear FE models were developed using ABAQUS, where nonlinear material behaviour, enhanced strength corner properties of steel, pre-compressive loads were all included to simulate the static and impact experiments. The main objective of this paper is to compare the performance of experimental results with numerical results for mild and stainless steel hollow and CFST columns. Moreover, the behaviour of in-filled tubes under impact loading is also compared with that of hollow sections. Close agreement is achieved between the experimental and finite element results in terms of load–deflection response and ultimate strength. This paper also compares the results of hollow and CFST stainless steel columns with those of mild steel columns due to both static and impact loading. Generally, the stainless steel specimens showed higher strength and improved energy-dissipating characteristics compared with the mild steel columns.



## 1. Introduction

Concrete filled steel tubular (CFST) columns are being used extensively as the main structural components for resisting both vertical and lateral loads in various types of buildings and bridge columns. A CFST column is generally formed by pouring concrete into a steel tube section after it has been secured and positioned on site. In this study before pouring concrete, pre-compressive load was applied through the axial direction by a post tensioning system using a threaded tension bar, nuts and end plates. A typical cross-section for concrete filled steel columns is illustrated in Fig. 1.

In recent decades, CFST columns have been used increasingly in bridges as piers due to their excellent structural and constructional performance. Bridge piers may unavoidably suffer from various types of impact loads during their whole life cycle. For example, they may be laterally impacted by vehicles, vessels or ships. An accident of a vehicle–bridge collision is shown in Fig. 2 examined by Fujikura et al. [1]. It is apparent that bridge piers are required to resist axial loads when an impact occurs.

Concrete filled mild steel columns have been used recently in many Australian tall buildings including Casselden Place and Commonwealth Centre in Melbourne, Riverside and Myer Centre in Adelaide and Market Plaza in Sydney. On the other hand, stainless steel as a construction material has been used very minimally in the construction industry in Australia as well as throughout the World; some examples include the Australian Parliament building's flag pole, Stonecutter's bridge in Hong Kong, Double Helix Bridge in Singapore, Hearst magazine building in USA and the Gateway Arch in St Louis. Considering the advantages of stainless steel, it has great potential to be used widely.

In the past, a large number of studies have been carried out on CFST members under both static and cyclic loads, and a number of design codes have also been published. In recent years, extensive studies have been conducted on stainless steel tubular members with an aim to resist large scale loading like impact, blast, collision etc. due to their high corrosion resistance, ease of construction and maintenance, strength and ductility as well as aesthetic appearance. However investigations of concrete filled stainless steel columns due to impact loading are rarely found in the literature. Concrete filled carbon steel columns

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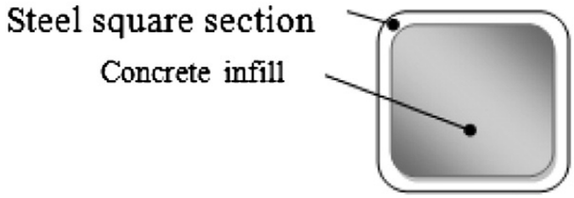


**Fig. 1.** Typical concrete filled steel tube (CFST) section.

have been studied by Uy [2–4], Han and Yao [5], Mursi and Uy [6], Sakino et al. [7], Uy [8], Liu et al. [9], and many other researchers. Meanwhile, experimental investigations of stainless steel hollow columns were conducted by Gardner and Nethercot [10,11], Liu and Young [12] and Young and Hartono [13]. But very limited research has been undertaken on concrete filled stainless steel columns under lateral impact loading. Uy et al. [14] conducted a series of tests on short and slender concrete-filled stainless steel tubular columns to explore their performance under axial compression or combined actions of axial force and bending moment. It has been enumerated that the performance of the composite columns are quite good and have the potential to be used extensively. The test results have been compared with several existing design methods for conventional concrete filled carbon steel tubular columns. Tao et al. [15] employed a nonlinear analysis of square concrete filled stainless steel tubular columns under axial compression. A three-dimensional nonlinear finite element model was developed using ABAQUS and compared with the carbon steel composite columns. A simple model to calculate the ultimate strength of square stainless steel composite stub columns was proposed.

Uy and Remennikov [16] presented the experimental work of mild and stainless steel composite columns subjected to lateral impact loading. The main focus of this research was to determine the advantages of using concrete infill in hollow steel sections on the energy absorption capacity. The dynamic increase factors that were presented ranged quite extensively from 0.85 to 1.42. The results also indicated a significant increase in not only capacity but also ductility and energy absorption capacity of hollow steel sections utilising concrete infill. A recent investigation by Uy [17] on the use of stainless steel for composite applications involved some initial experimental testing assessing the stability and ductility of high performance stainless steel sections. The scope of testing involved four stainless steel columns under axial loading. Testing assessed the local buckling effects and global member behaviour, both with hollow and concrete filled sections. Ellobody and Young [18,19] presented experimental research and theoretical design of concrete filled cold-formed hollow stainless steel structures. Testing involved investigating the effects of shape, plate thickness and concrete strength for columns subjected to uniform axial compression. Square and rectangular tubular sections were tested with the results compared with American and Australian design standards. The results indicated overestimation of strengths for higher strength concrete columns for both design codes. Further to this research, Ellobody and Young [19] developed a non-linear finite element model verified by the previous experimental research. Proposed design methods and equations proved more accurate than the provisions outlined in the American and Australian design standards. Bambach et al. [20,21] investigated the performance of hollow and concrete filled steel members under lateral impacts at the beam mid-span, and a design procedure was also developed. It has been shown that concrete filling provides an increase in section moment capacity by up to 83% for slender sections, and a reduction in transverse failure deflection in non-compact sections. Zeinoddinini et al. [22] investigated the axially pre-loaded steel tubes subjected to lateral impact at mid span. It has been seen that the steel tubes are considerably vulnerable to lateral impact, when axial compressive preloading increases above 50% of the corresponding squash load. Kong et al. [23] studied the comparative behaviour of square hollow section (SHS) tubes filled with rigid polyurethane foam (RFP) and concrete subjected to transverse impact loading both numerically and experimentally. It has been mentioned that stainless steel tubes have a higher impact resistance and energy absorption capacity than mild steel tubes. It has also been shown that the energy absorbing capacity of RFP filled tubes was higher than hollow section but concrete filled columns have the highest energy absorbing capacity of all. Yousuf et al. [24] investigated the behaviour and design of hollow and concrete filled mild steel columns due to transverse impact loading both experimentally and numerically. The results indicated that the hollow sections failed by local buckling well before the global failure occurred, and the effect of concrete infill in mild steels greatly enhanced the resistance to local buckling. It has demonstrated the adequate performance of concrete filled steel columns in terms of energy absorption and ductility. Yousuf et al. [25] studied the behaviour and design of hollow and concrete filled stainless steel square columns both experimentally and numerically due to transverse impact loading. The results of stainless steel columns were compared with those of mild steel columns presented in Yousuf et al. [24]. It has been shown that the static and impact strengths of

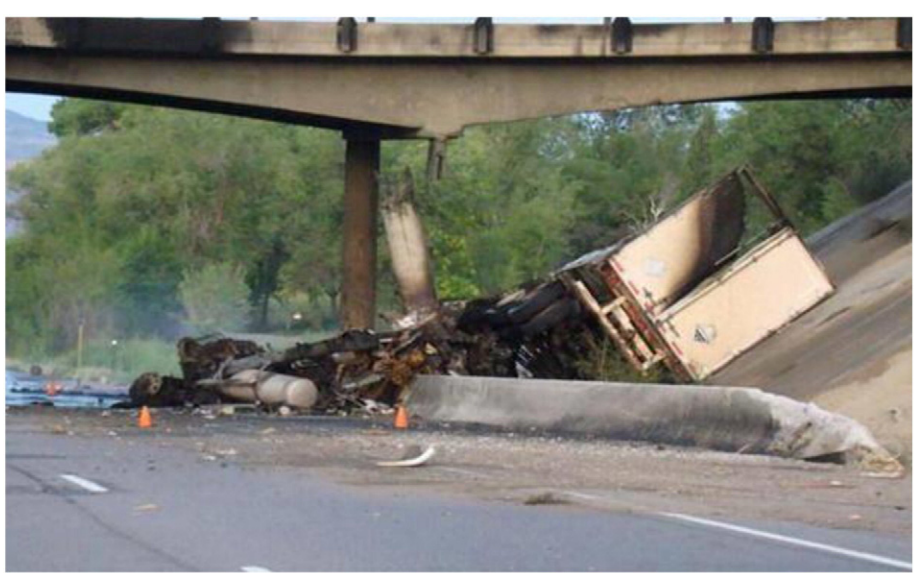

**Fig. 2.** A picture for vehicle-bridge collision (Fujikura [1]).