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Flexural performance of concrete filled tubes with high tensile steel and ultra-high strength concrete

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ABSTRACT

The use of high strength materials in steel-concrete composite members is expected to provide greater resistance meanwhile fulfilling the requirements of sustainable construction. Many of the modern design codes place some limits on the strength of steel and concrete in designing steel-concrete composite members due to limited test data and design experience on their applications in construction. The use of high strength materials was found to have noticeable benefits in high-rise building construction. To extend their applications, a comprehensive experimental program has been carried out to investigate the behaviour of concrete filled steel tubes (CFSTs) with high tensile steel and ultra-high strength concrete at ambient temperature. This paper presented new test results on the structural performance of CFST members subject to flexural loads. High tensile steel with yield strength up to 780 MPa and ultra-high strength concrete with compressive cylinder strength up to 180 MPa were used. The test results seek to clarify if the cross-section plastic moment resistance can be achieved if high tensile steel and ultra-high strength concrete are used in CFST members. The maximum moment resistance from tests were compared with the analytical results predicted by Eurocode 4 method. Then design recommendations were provided so that Eurocode 4 method could be safely extended to determine the flexural resistance of CFST members with high tensile steel and ultra-high strength concrete.

1. Introduction

In today's world, it is important to utilize the natural and manmade resources more effectively to achieve sustainable construction. One way is to adopt sustainable construction that is to use steel structures to replace the conventional concrete structures owing to the fast construction, lighter buildings and less materials and labours employed. However, slender steel structural members are likely to buckle before yielding, thus their cross-sectional resistance could not be fully developed. In such cases, combining the steel and concrete materials to form composite structures and restraining the buckling of steel members could fully exert the advantages of the steel material. This paper investigates the use of high strength steel and ultra-high strength concrete in composite construction to further reduce the construction materials, thus reducing the use of water, energy, manpower, etc., in handling such materials.

Demand for and use of the high strength materials for high-rise buildings began in the 1970s, primarily in the U.S.A. Nowadays, the high strength construction materials are mostly used in Asia region for high rise construction [1]. Long term durability and ductility of high strength materials are two important factors for their adoption in high rise construction. The fact that the high strength materials have been used in countries which have seismic activities such as U.S.A., Japan, Korea and China, indicating that the ductility issues of such materials could be resolved by research and development of new materials subjecting them to cyclic tests and advanced finite element analyses, and most importantly through stringent control of material quality at the factory and the site. As material research and manufacturing technology improve, the use of higher strength concrete and steel materials will continue to increase as wider applications are being sought in the development of mega cities with dense populations.

Set against this background, more research data should be gathered to develop design guides for the use of high strength materials in construction. However, rather limited research and design experience are available regarding the use of high strength materials in composite structures. This paper investigates the flexural performance of concrete filled steel tubular (CFST) members. One would doubt the meaning to study the flexural behaviour of the CFST members as, in reality, the CFST members are seldom subject to pure bending. This may be true for building structures, where CFSTs are mainly used as column members. However, CFSTs are also widely used for bridge construction and in pole structures where they are subject to predominately flexural

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action. Besides, when designing CFST columns under combined axial force and bending moments in high-rise structures, one may have to determine the bending resistance according to the moment-axial force (M-N) interaction curves [2,3] as shown in Fig. 1.

Design guides involving the use of high tensile steel and ultra-high strength concrete in composite construction are rare. Current design guidelines for CFSTs are only applicable for normal strength concrete and steel. For instance, the Chinese code GB 50936 [2] only applies to composite members with concrete cylinder strength from 25 MPa to 70 MPa and steel yield strength from 235 MPa to 420 MPa; Eurocode 4 [3] method is applicable to composite members with normal weight concrete cylinder strength from 20 MPa to 50 MPa and structural steel yield strength from 235 MPa to 460 MPa; AISC 360–10 [4] is for composite members with normal weight concrete cylinder strength from 21 MPa to 70 MPa, light weight concrete cylinder strength from 21 MPa to 42 MPa and structural steel yield strength up to 525 MPa; and the Japanese code AIJ [5] allows the use of high strength concrete with compression strength up to 90 MPa.

In terms of research, there are some work done on CFST columns with high strength materials [6–12], and also flexural CFSTs with normal strength materials [13–18]. However there is rather limited work carried out on flexural CFSTs with high strength materials. For example, Gho and Liu [19] studied the flexural behaviour of 12 rectangular CFSTs with high strength concrete of cylinder strengths between 56.3 MPa and 87.5 MPa and steel yield strengths in the range from 409 MPa to 438 MPa. It was shown that the Eurocode 4 method underestimated the flexural resistance by 11%. Guler et al. [20] experimentally investigated flexural behaviour of 9 square CFSTs with ultra-high performance concrete (UHPC) which had cylinder compressive strength up to 120 MPa. Normal strength steel was used as the tubes. Comparisons indicated that both the Eurocode 4 and the AISC design methods conservatively predicted the ultimate moment capacity. For the study done by Chung et al. [21], 6 square CFSTs were subject to flexural loading. The yield strength of steel was 325 MPa, 555 MPa, and 900 MPa; the compressive strength concrete was 82.5 MPa and 119.7 MPa. It was found that the AISC design method underestimated the flexural stiffness and the maximum flexural resistance.

The foresaid studies have provided significant contributions to the research progress in developing guideline to determine the flexural resistance of the CFSTs using the high strength materials. However, the work is insufficient for CFST members with the ultra-high strength concrete (UHSC) of compressive strength higher than 120 MPa and the high tensile steel (HTS) of yield strength >460 MPa as shown in Fig. 2 where 70 test data in total for the CFST specimens under pure bending were collected from the available literature. This paper presented the experimental work on 8 CFST specimens subject to flexural loads. Test results,

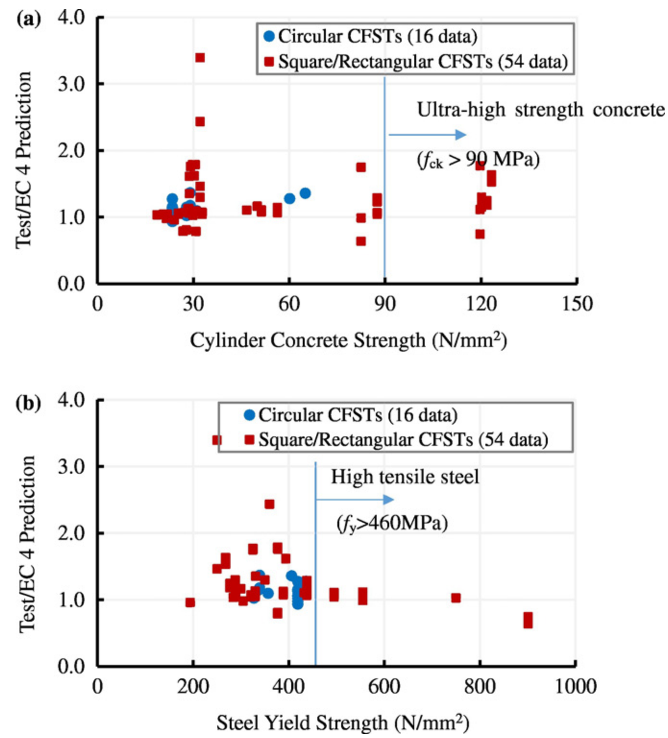

Fig. 2. Database on CFSTs under pure bending moments.

including maximum moment resistance, elastic flexural stiffness, load displacement curves and load strain curves, were presented. Eurocode 4 method was adopted to predict the flexural resistance of CFST members with high strength steel and ultra-high strength concrete and its accuracy is discussed by comparing with the test results and additional data from the literature. The aim is to extend the current guides to design CFST members with high tensile steel and ultra-high strength concrete.

2. Eurocode 4 method for concrete filled steel tubes subject to bending

According to Eurocode 4 [2], the characteristic moment resistance of a CFST cross-section can be calculated by

$$M_{EC4,u} = \alpha_M M_{pl,Rk} = \alpha_M \left[(W_{pa} - W_{pan}) f_y + 0.5 (W_{pc} - W_{pcn}) f_{ck} \right] \quad (1)$$

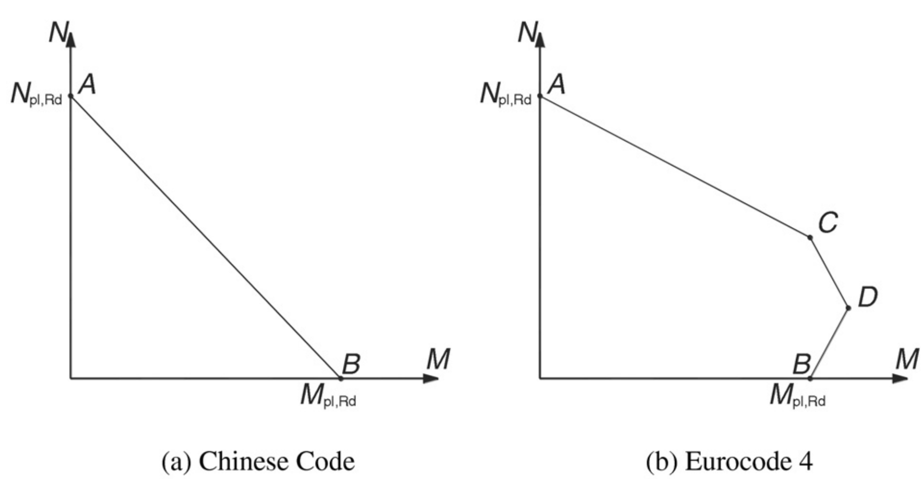

Fig. 1. M-N interaction curves.