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# Concrete-filled VHS-to-steel fabricated section stub columns subjected to axial compression

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ABSTRACT

The use of very high strength materials is currently being researched as a way to reduce material use and improve sustainability. In this investigation a total of 32 specimens were fabricated using very high strength (VHS) steel tubes and plates to form stub columns. The VHS-plate fabricated stub columns were tested under axial compression. The specimens comprised 20 fabricated square sections and 12 fabricated triangular sections. The VHS steel tubes used have a nominal yield stress of 1350 MPa and a nominal ultimate tensile strength of 1500 MPa. Mild steel plates and high strength steel plates were used to connect the VHS tubes at the vertices thereby forming square and triangular cross sections. Normal strength concrete with a standard concrete strength grade of 32 MPa was used as concrete in-fill. Finite element models are developed to simulate the behaviour of the VHS-plate stub columns. The finite element models predicted the load–deformation behaviour of the fabricated columns well with the peak strength and post-peak behaviour similar to the experimental results. A parametric study was also carried out to determine the effect of concrete strength, facet plate yield strength and facet plate width to wall thickness ratio. The parametric study shows that there is benefit in concrete confinement through the use of higher strength steel facet plates. This paper also proposes a method for determining the axial compression capacity of fabricated VHS-plate stub columns. The predicted peak strength from the proposed design method is in good agreement with the test results.



## 1. Introduction

Very high strength steel tubes can be manufactured with nominal tensile yield stresses in the order of 1350 MPa. The very high strength steel (VHS) tubes are quenched and tempered and have a nominal tensile yield stress that is more than 3 times that of common steel grades which typically have a nominal tensile yield stress of 350 MPa [1].

At present, VHS tubes have typically found their application in the automotive and mechanical industries where they are used as side door impact bars [2]. The obvious benefits of very high strength steel sections in the construction industry is that they may be able to be deployed in columns for multi-storey buildings through the fabrication of columns of various cross sections consisting of tubes welded to facet plates as shown in Fig. 1a and 1b. This use of the fabricated sections has the advantage of eliminating the need of column formwork when these fabricated sections are concrete filled.

Previous research by Zhao et al. [3] investigated the strength of empty stub columns of fabricated VHS tube to mild steel plate similar to those reported in this current investigation. The research by Zhao et al. [3] extended research carried out by Aoki and Ji [4]. Aoki and Ji [4] investigated the buckling strength of fabricated sections of triangular cross sections using normal strength steel.

This paper proposes a method for determining the axial compression capacity of concrete-filled fabricated VHS-plate stub columns. Both the square and triangular fabricated VHS-plate stub columns are investigated. The fabricated stub columns use both mild steel and high strength steel as facet plates. Normal strength concrete with a standard concrete strength grade of 32 MPa was used as concrete in-fill. Although normal strength concrete has been used in the current study, the use of high strength concrete and high strength steel will also be investigated in future, as part of this research programme. The method for determining the axial compression capacity uses the principle of superposition to take into account the contribution of steel and concrete in the composite stub columns. The effective areas of the steel plates and the VHS tubes used in the columns are also considered to ensure that local buckling effects under compression are taken into account. Finite element (FE) models are developed to simulate the behaviour of the VHS-plate stub columns. The three-dimensional (3D) finite element models are developed using ABAQUS software. The design and FE models also consider the material behaviour of the heat-affected zone (HAZ).

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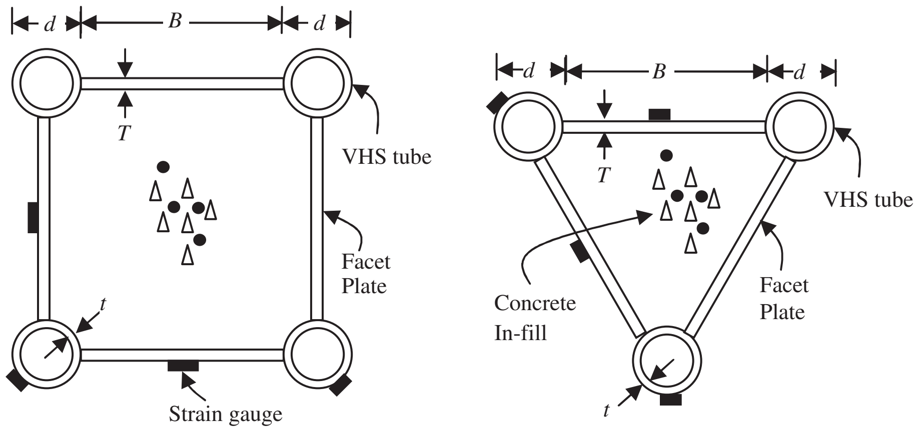


**Fig. 1.** Fabricated VHS-plate square and triangular hollow sections.

A good comparison in load–deformation behaviour is obtained between the FE model and the test results. A parametric study was used to determine the influence of parameters such as concrete strength, yield strength of the facet plates and the facet plate width ($B$) to wall thickness ($t$) ratio. The proposed design method also gives a good prediction of the peak strength in both the concrete-filled square and triangular VHS-plate stub columns.

## 2. Test programme

### 2.1. Fabricated VHS-plate square hollow sections

#### 2.1.1. General

Twenty fabricated VHS-plate square hollow sections were manufactured and tested under compression in this investigation. A fabricated square hollow section is shown in Fig. 1a. Eighteen of the fabricated square section stub columns were concrete-filled using grade 32 MPa concrete prior to compression testing. Two of the fabricated square section stub columns were tested as hollow section stub columns. The properties of the test series of the fabricated square hollow sections tested in this investigation are shown in Table 1. All the tests series except for test series S1H and S3H were concrete filled. Test series S1H and S3H were used for validating the finite element model of the empty fabricated sections.

#### 2.1.2. Material properties

The material properties of the steel used for the different fabricated VHS-plate square hollow section test series are shown in Table 1. The nominal yield stress and nominal ultimate tensile strength of the VHS tube, $f_{ynt}$ and $f_{unt}$ respectively as well as the nominal yield stress and nominal ultimate tensile strength of the facet plates, $f_{ynp}$ and $f_{unp}$ respectively are given in Table 1. For all the specimens, VHS tubes with a nominal yield stress and nominal ultimate tensile strength of 1350 MPa and 1500 MPa respectively were used. Mild steel and high strength steel facet plates were used in the specimens. The mild steel facet plates had a nominal yield stress and nominal ultimate tensile strength of 250 MPa and 350 MPa, respectively. The high strength steel plates had a nominal yield stress and nominal ultimate tensile strength of 400 MPa and 520 MPa, respectively. The corresponding measured yield stress and ultimate tensile strength of the VHS tube, $f_{yt}$ and $f_{ut}$ respectively as well as the measured yield stress and nominal ultimate tensile strength of the facet plates, $f_{yp}$ and $f_{up}$ respectively are also given in Table 1. The yield stress and ultimate tensile strength of the VHS tubes and facet plates were determined using the procedure

**Table 1**
Fabricated VHS-plate square hollow section test series.

| Test series | Number of specimens tested | Very high strength (VHS) steel tube | | | | Plate | | | | Concrete | Height of specimen ($H$) (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $d$ (mm) | $t$ (mm) | $d/t$ | Material properties | $B$ (mm) | $T$ (mm) | $\frac{B}{T}$ | Material properties | Material properties | |
| V1NP1 | 2 | 38.1 | 1.6 | 23.8 | *Nominal values:* | 90 | 3 | 30 | *Nominal values*: $f_{ynp} = 250$ MPa | | 300 |
| V1NP2 | 2 | 38.1 | 1.6 | 23.8 | $f_{ynt} = 1350$ MPa | 120 | 3 | 40 | $f_{unp} = 350$ MPa | $f_c' = 32$ MPa | 400 |
| V1NP3 | 2 | 38.1 | 1.6 | 23.8 | $f_{unt} = 1500$ MPa | 150 | 3 | 50 | *Measured values*: | $f_{cm} = 33$ MPa | 500 |
| | | | | | *Measured values:* | | | | $f_{yp} = 268.9$ MPa | | |
| | | | | | $f_{yt} = 1392$ MPa | | | | $f_{up} = 357.6$ MPa | | |
| V1HP1 | 2 | 38.1 | 1.6 | 23.8 | $f_{ut} = 1515$ MPa | 90 | 3 | 30 | *Nominal values*: $f_{ynp} = 400$ MPa | | 300 |
| V1HP2 | 2 | 38.1 | 1.6 | 23.8 | | 120 | 3 | 40 | $f_{unp} = 520$ MPa | | 400 |
| V1HP3 | 2 | 38.1 | 1.6 | 23.8 | | 150 | 3 | 50 | *Measured values*: | | 500 |
| | | | | | | | | | $f_{yp} = 439.3$ MPa | | |
| | | | | | | | | | $f_{up} = 851$ MPa | | |
| S1H | 1 | 38.1 | 1.8 | 21.17 | *Nominal values*: $f_{ynt} = 1350$ MPa | 90 | 3 | 30 | *Nominal values*: | | 300 |
| S3H | 1 | 38.1 | 1.6 | 23.81 | $f_{unt} = 1500$ MPa | 90 | 3 | 30 | $f_{ynp} = 250$ MPa | Empty | 300 |
| S2Con | 1 | 38.1 | 1.8 | 21.17 | *Measured values*: | 90 | 3 | 30 | $f_{unp} = 350$ MPa | | 300 |
| S4Con | 1 | 38.1 | 1.6 | 23.81 | $f_{yt\text{-}1.6} = 1369$ MPa* | 90 | 3 | 30 | *Measured values*: | $f_c' = 32$ MPa | 300 |
| S5Con | 1 | 38.1 | 1.6 | 23.81 | $f_{ut\text{-}1.6} = 1522$ MPa* | 120 | 3 | 40 | $f_{yp} = 271$ MPa | $f_{cm} = 35$ MPa | 400 |
| S6Con | 1 | 38.1 | 1.8 | 21.17 | $f_{yt\text{-}1.8} = 1330$ MPa* | 120 | 3 | 40 | $f_{up} = 356$ MPa | | 400 |
| S7Con | 1 | 38.1 | 1.6 | 23.81 | $f_{ut\text{-}1.8} = 1522$ MPa* | 150 | 3 | 50 | | | 500 |
| S8Con | 1 | 38.1 | 1.8 | 21.17 | | 150 | 3 | 50 | | | 500 |

NOTE: *$f_{yt\text{-}1.6}$ = measured yield stress in the 1.6 mm thick VHS tubes; *$f_{yt\text{-}1.8}$ = measured yield stress in the 1.8 mm thick VHS tubes; *$f_{ut\text{-}1.6}$ = measured ultimate tensile strength in the 1.6 mm thick VHS tubes; *$f_{yt\text{-}1.8}$ = measured ultimate tensile strength in the 1.8 mm thick VHS tubes.