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Development of mathematical model for cyclic behaviour of blind bolted HSS column components

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ABSTRACT

This paper presents an experimental and finite element analysis based mathematical modelling of cyclic behaviour of the component of hollow structural section (HSS) columns under bolt tensile loads. This component acts as an important constituent part to the blind bolted connections with HSS columns. Two typical failure modes and their related hysteretic curves are examined experimentally. It is shown that force versus displacement curves under monotonic loading can be regarded as the upper bound of the envelope of the counterpart cyclic response. Moreover, the hysteretic force–displacement curves of test columns with relatively thick tube walls demonstrate significant pinching manner thus less energy dissipative capacity. Based on the calibrated finite element model, the flexibility of tube wall and its influences on the connection response are compared for two failure modes. Parametric analyses are also performed to investigate the influence of geometric parameters on the elastic stiffness and yield strength. The mathematical hysteretic models allowing for the behaviour of the connections in two typical failure modes are proposed that distinguishes the developed model from those reported in the literature. It is demonstrated that the proposed model incorporating degradations of stiffness and/or energy dissipation can achieve a good representation of test hysteretic behaviours.

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1. Introduction

Recent use of blind bolts has been recognized as a solution to tubular members with unavailable free access to inside for installation. These blind bolts, although in different configurations, can exhibit analogical clamping features and loading behaviour of standard bolts with bolt heads, shanks and nuts. Accordingly, the bolted connections can be taken as an alternative to built-up welded counterparts to tubular columns for engineers. Part 1–8 of Eurocode 3 [1] outlines a versatile procedure which permits the assessment of different type of joints by assembling individual components, i.e. component approach. In the case of bolted connection, the components available in the literature are mostly limited to the connections with built-up welded and open section profiles. However, lack of understanding of the behaviour of hollow structural section (HSS) columns under bolt tensile loads limits the design of corresponding structural details with good accuracy [2].

In the modelling of joint rotational behaviour in the structural analysis, the basic deformational behaviour of its constituent connection component has to be clarified in advance. So far, various mathematical models for the connection behaviour have been developed by contemporaneous researchers. Most of these models are derived from the relations for reproducing the elastic–plastic behaviour of materials and correlating with the experimental curves as the range of application agrees with the structural details tested. The monotonic force–displacement curve can be fitted using its different mathematical representation, e.g. Ramberg-Osgood model, Richard-Abbott model [3] and tri-linear model suggested by Eurocode 3 [1], among others. Above mentioned models can be extended in order to be also included in the analysis of the joint component cyclic loading behaviour when stable and reproducible hysteretic loops are considered. Examples can be found in the use of Ramberg-Osgood model [4] and the Richard-Abbott model [5,6] in the simulation of the hysteretic behaviour of the connection. Besides, some sophisticated hysteretic models were also developed later on to include more variables, such as Massing law based unloading and reloading phases by Bernuzzi [7], the strength and stiffness degradations for column-base suggested by Abdollahzadeh et al. [8]. Despite the merits of these models, their application is still limited for the implementation in analysis of the behaviour of the HSS columns undergoing bolt tension load because of lack of sufficient experimental studies.

In light of above mentioned research background, this study aims at developing a mathematical model in capturing the cyclic behaviour of the component of bolted HSS column with relevant geometric parameters. To this end, an experimental test programme is presented in the examination of the hysteretic force–displacement behaviour of the connection. Based on the FE modelling results, a mathematical model is proposed to represent the hysteretic force versus displacement relations in two failure modes of the connections. The applicability of proposed model is discussed accordingly.

2. Experimental test study

2.1. Description of test specimens

Given the behaviour of the connection component of HSS column under bolt tension load is the focus of this study, the test specimens were designed using two T-stubs connected at opposite sides of HSS column so as to ensure the test tensile loads are directly transferred to the connection part, as shown in Fig. 1. Relatively thick flange plate of 25 mm was chosen in the connection to isolate the flexibility of the HSS column wall and tension of the bolt as the main contributors to the behaviour of the test connection. The basic configuration of four groups of connections is listed in Table 1. The geometric parameters of the connections were defined as: outside width (b_0), outside depth (h_0) & wall thickness (t_c) of the HSS column, bolt gauge width (g), diameters of the bolt shank (d_{sh}) and the bolt clearance hole (d_{bh}). The specimen index is expressed as 'St b_0-h_0-t_c-g', e.g. St150-150-8-60 indicates that the specimen with HSS column of $b_0 \times h_0 \times t_c \times g = 150 \times 150 \times 8 \times 60$ (mm). Two computational design parameters related to the connecting face of the HSS column are designated as: bolt gauge width to tube width ratio (β) and the tube wall thickness-to-half wall width ratio (Ψ_0). The Lindapter Hollo-Bolt "HB10", whose size of bolt hole is comparable to standard bolt "M12", was adopted in all connections. The hot-rolled steels with the grade of Q235B of the Chinese national standard GB/T700-2006 [9] were chosen for HSS columns. Relevant material parameters were obtained as the mean value of the test results of three identical coupon specimens extracted from relevant components, as listed in Table 2.

2.2. Test procedure

The experimental tests were performed using a Shimadzu EHF-EM200k2-040 fatigue testing machine of ±200 kN capacity and ±65 mm stroke range. Five test specimens were considered in each test group, in which one specimen was initially loaded monotonically until failure to obtain the basic load–displacement relation and its related property parameters, such as yield strength and ultimate strength; and then the rest four for cyclic loading tests under the frequency of 0.35 Hz and the constant displacement amplitude of approximately 1.5–4.5 times that of yield displacement. In a typical test set-up, the top T-stub web on the one side of the HSS column was clamped in the upper grip located on the rigid cross beam of the test machine to allow the application of tensile action to the connection. Meanwhile, the bottom T-stub web on the other side of the HSS column was fixed in the lower grip of the test machine to provide reaction load, as shown in Fig. 2. Test tensile load was measured by the load cell fixed in the testing machine while the displacement was measured as the mean values of readings from displacement transducers for both T-stubs.

2.3. Test results

The resultant hysteretic response of the connections was evaluated on the basis of the test observation and measured