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Connections in towers for wind converters, Part II: The friction connection behaviour

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ABSTRACT

A novel friction connection consisting of a single lap joint with long open slotted holes is proposed for use in tubular towers for wind converters for in-situ connections. This is a competitive alternative to the common ring flange connection as it has been shown in the European Project “HISTWIN”. Two sets of experiments are analysed: the down-scaled tubular steel tower 4-point bending experiments using high-strength bolts M20 and a single lap joint using plate thickness 25 mm and tension control bolts M30.

The main motivation for this paper is a much higher bending resistance obtained in the 4-point bending experiments compared to predictions based on hand-calculation models.

Results of experiments are used to validate finite element analysis (FEA). Explicit solver and the most realistic geometry of the bolts are the main characteristics of the FEA performed. Very good agreement between the experiments and FEA results is obtained, which provides credibility of the computational approach used to thoroughly examine experimental results. New evidences of the friction connection behaviour are provided: a short-term loss of preloading force due to external loading, transfer of shear force in the single lap joint and influence of the slotted hole on the joint resistance.

Results obtained from hand-calculation models are used to predict the loss of preloading, the bending resistance of the connection and meridional stresses in the tower shell in the vicinity of the connection, which are compared to the experiments and the FEA. Recommendations related to use of the hand-calculation models in the design are provided.

1. Introduction

Recently finished RFCS (Research Fund for Coal Steel) projects: HISTWIN “High-strength tower in steel for wind turbines” [1] and HISTWIN2 “High steel tubular towers for wind turbines” [2], have mainly focused on the use of technical innovations to increase competiveness of steel tubular towers. One important innovation is the use of the friction connection with long open slotted holes (the friction connection) for in-situ execution. This connection has been shown as a competitive alternative to the ring flange connection of the steel tubular tower for the hub-height up to 80–100 m. The connection cost is about 80% lower for an adequate resistance [1]. The feasibility tests within [1,2] proved that the bolts can be pre-installed in the upper segment and easily slide on the top of the lower segment, see Fig. 1.

In the friction connection, the outer shell is provided with the normal clearance holes on the side of the bolt head while the inner shell has open slotted holes, where the width of the hole is equal to the normal clearance hole diameter, see Fig. 2. The cover plates with normal clearance holes on the inner side are used to facilitate the assembling process by holding the bolts in position to ensure the execution gap between the shells.

Two sets of experiments on the friction connections were performed within the scope of the HISTWIN project [1]: the down-scaled 4-point bending experiments, see Fig. 3, and experiments on the single lap joint using a plate thickness of 25 mm, which represents the real-scale connection segment of a typical tubular tower, see Fig. 4. The down-scaled experiments were performed using two alternatives: the ring flange connection and the friction connection [3]. In a companion paper [4] results of these experiments are used to calibrate and validate

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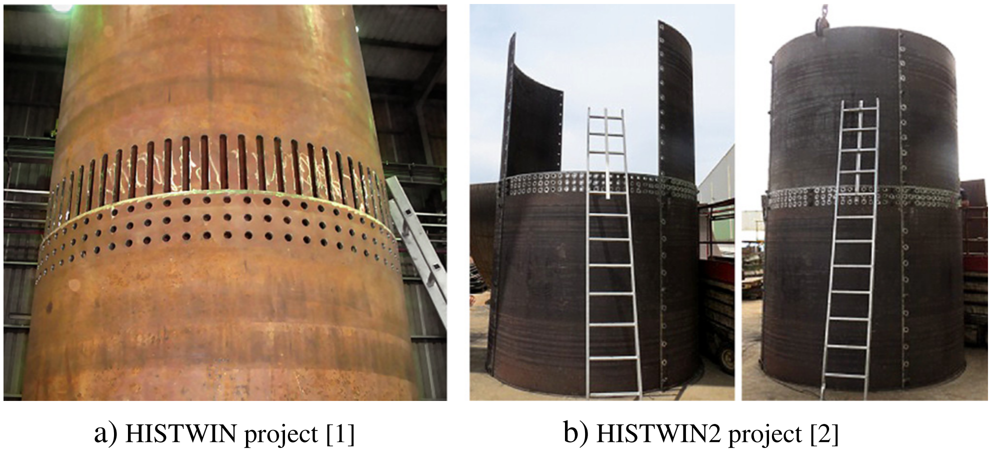

Fig. 1. Feasibility tests performed in previous projects.

results obtained in finite element analysis (FEA) focusing mainly on the ring flange connection. In the single lap joint experiments, plates with open slotted holes and holes with normal clearance are considered [5]. Time dependent loss of the bolt preloading force in the friction connections with long open slotted holes has been reported in Heistermann et al. [6].

Unexpectedly high ultimate slip resistance in the down-scaled experiments of the friction connection subjected to bending is reported in [1,4]. This behaviour is analysed in this paper considering the experiments and advanced FE analysis. Also, the structural aspects that influence change in the preloading forces are analysed.

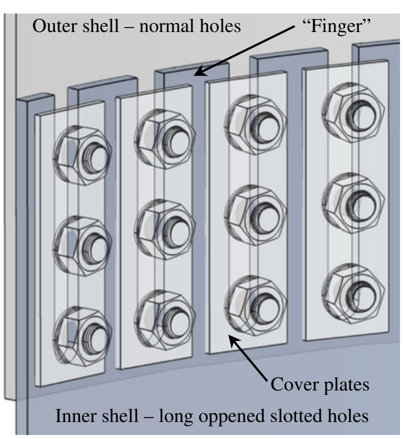

Fig. 2. Components of the friction connection.

2. Experiments

2.1. Down-scaled 4-point bending specimen

Down-scaled experiments of the friction connection using 4-point bending test set-up are performed by RWTH Aachen University [3], as shown in Fig. 3. Experiments have been conducted on 8 mm thick shells with a diameter of 1 m and the total span of about 7 m, connected by bolts M20, grade 10.9. The main objective of the experiments is to investigate the behaviour of the friction connection in bending and to test the feasibility of the assembling. A detailed description of the 4-point bending test set-up is given in the companion paper [4].

2.2. Single lap joint

Series of experiments on the flat segment of the real-scale friction connection with long open slotted holes were performed at Luleå University of Technology [5]. A typical specimen layout and the test set-up are shown in Fig. 4a. Tension control bolts (TCB) M30, shown in Fig. 4b, were used with grade S10T (equivalent to grade 10.9). These are useful because of the ability to preload the bolt only from one side of the connection. The spline, shown in Fig. 4b, holds the bolt during preloading and it shears off when the torque corresponding to the bolt preloading force is reached. The average bolt preloading force of approximately $F_p = 370$ kN was observed in each bolt at the start of the experiments.

Thickness of the connecting plates was 25 mm (the plate with normal clearance holes and the plate with long open slotted holes). Faying surfaces were coated using the ethyl silicate rich paint that is already widely used as a primer for wind towers. The slip factor $\mu = 0.45$ of such faying surface was determined in friction tests according to EN

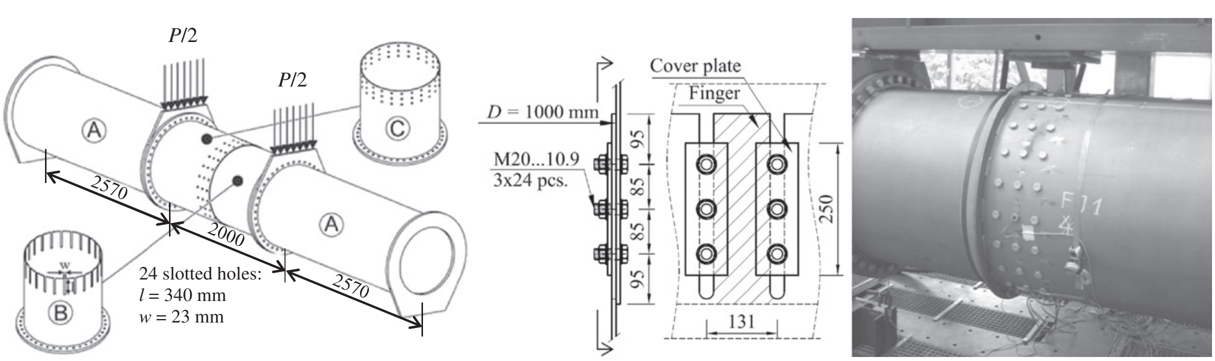

Fig. 3. Specimen of 4-point bending test set-up and detail of friction connection.