Influence of Different Preload Levels and Faying Surfaces on the Slip-Resistant Behaviour of Bolted Connections

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ABSTRACT
The load bearing capacity of slip-resistant connections is mainly influenced by the level of preload in the bolts and the friction - described by the slip factor of the faying surfaces. The highest possible and over the service life of the structure guaranteed slip resistance is desirable in order to keep the number of bolts and the faying surfaces of the complex and therefore expensive connections low and to meet the demand of the industry for maintenance-free connections. In the present paper investigations regarding the influence of different preload levels and faying surfaces on the slip resistant behaviour of bolted connections are presented.

KEY WORDS: slip-resistant connection, preloaded bolted connection, EN 1090-2, slip factor, faying surface.

INTRODUCTION
Bolted connections in structures, such as lattice towers, radio masts and wind turbine towers are designed as slip-resistant connections when they are subjected to heavy impact loads, significant load reversal or fatigue. This type of connection is required, when slip should not occur at serviceability or ultimate limit state.

The slip resistance of high strength bolted connections is mainly influenced by the preload applied in the bolts and the condition of the faying surfaces. Various guidelines/standards specify slip factors for often used surface treatments but in most cases the achieved slip factors for identical surface conditions are not comparable. Different parameters have a great influence on the slip factor. For this reason, slip factors can be determined experimentally e.g. according to Annex G of EN 1090-2, 2011).

According to different standards such as (RCSC, 2009), EN 1090-2, (TL/TP-KOR-Stahlbauten), different levels of preloads are suggested for slip resistant connections which potentially lead to different slip factors for identical surface treatments.

The slip resistance is significantly influenced by the surface pressure and the friction properties of the surfaces, see also (Stranghöner et al., 2013).

A high slip factor can be achieved by blasted surfaces, but the connection may be subjected to different environmental conditions and unprotected surfaces are susceptible to corrosive attacks. To meet the requirements for the corrosion resistance, the surfaces are usually provided with an additional coating.

The slip factors specified in EN 1090-2 are determined for a preload level of F_{p,C}. Nevertheless, EN 1090-2 allows other, lower preload levels as well, but for this case slip factor tests are required.

EN 1090-2 explicitly allows to use the slip factor determined with 10.9 bolts for slip-resistant connections with 8.8 bolts, but not the other way around because a higher preload level tends to cause lower slip factors.

In the frame of the presented investigations, three surface conditions were considered: (1) alkali-zinc silicate coating (ASI), (2) zinc spray metallization (Zn-SM) and (3) a combination of alkali-zinc silicate on one faying surface and zinc spray metallization on the other faying surface. Furthermore, three different preload levels were considered. The tests were performed according to the testing procedure of Annex G of EN 1090-2.

EXPERIMENTAL INVESTIGATIONS

Test Procedure
The slip factor test of Annex G of EN 1090-2 consists of a three steps test procedure by using a predefined standard specimen (M16 or M20), see Fig. 2. In the first step, four static slip factor tests have to be carried out. Based on the literature (Kulak et al., 2001), the specimen geometry does not have significant influence on the slip factor.

The influence of the type of steel of the plates is negligible (Steinhardt et al., 1969), (ORE, 1973), (Cruz et al., 2012), but for friction surfaces with a high slip resistance like grit blasted surfaces, exceeding of the yield stress of the steel plates has to be avoided. For this reason, the use of steel grade S235 with a relatively low yield stress is recommended only for surfaces with low slip factors.

According to EN 1090-2, the preloads in the bolts have to be measured at the beginning of testing and adjusted to an accuracy of ± 5 %.

In case of the presented slip factor tests, the preloads were measured continuously by instrumented bolts, see Fig. 3 (Stranghöner et al. 2015).