DOSS Award 2023 J.A. de Gelder

Summary shearcapacity of anchorbolts with a grout filled stand-off

This study investigates the influence of a grout filled stand-off on the shear capacity of steel anchor bolts. Within the current codes NEN-EN 1993-1-8 and NEN-EN 1992-4 various methods with different boundary conditions are described and this causes in practice when determining this shear capacity ambiguities and discussions what the correct method is. In this study the equations from the current codes are described, the differences between them, how engineers deal with this in daily practice and which equations are used by the various software. The equations show that the shear capacity must be reduced due the stand-off and this can best be summarized in a variable β. The research further focuses on the description of β. For this description, daily practice, safety and simplicity of design and the structural behavior of the whole connection are taken into account.

Underneath the current equations there are past experiments conducted by the Stevin Laboratory at TU Delft, Fischer and the University of Florida, among others. These results have been examined and compared with each other and the prevailing codes. For a broader picture, the comparison and an underlying experiment for the determination of shear capacity of bolts when using steel shims in steel-steel joints has also been included. In this situation the same mechanical behavior takes place.

In order to visualize the complex behavior of the interplay of forces in the anchor bolts caused by the shear force and the moment created by the setting space, a FEM model is developed in Diana-FEA. This model is consistent with the experimental results and the investigated equations and can therefore be used to draw conclusions. Several conservative assumptions were made for the boundary conditions of this FEM model in order not to unjustifiably overvalue the actual shear capacity of the anchor bolts. Some examples include: no adjusting nut under the baseplate so that the longest bending length of the anchors is taken into account, the friction factors according to the codes being lower than will have occurred in the experiments, and a more brittle behavior of the anchor material is used than shown in tensile tests.

The FEM model results show that from the current equation for shear capacity of anchor bolts:

- NEN-EN 1993-1-8 is closest to the test results at the higher stand-off around 3*diameter and gives a safe underestimate at lower adjustment spaces.
- NEN-EN 1992-4 shear load without leveling arm has various incorrect boundary conditions and is described with a decreasing β, which can be unwise due to the increase in stand-off height caused by adjusting. During the design process one is not always sure what the exact height of the stand-off will be after erection.
- NEN-EN 1992-4 shear load with leveling arm gives an unnecessarily low estimate of the shear capacity. Because this equation is known to be conservative, it is regularly ignored within, for example, calculation software. Subsequently engineers doesn't apply one of the aforementioned equations and that behavior leads to a large overestimation of the shear capacity and should therefore not be applicable to stand-off filled joints.

The proposal of this investigation is to extend the current equation for shear capacity of bolts and anchor bolts according to NEN-EN 1993-1-8 Table 3.4 with a reduction factor β to which the following boundary conditions apply:

- If the stand-off height is bigger than 1/3*diameter, the shear capacity must be reduced.
- The stand-off height should not exceed 3*diameter or 0.2*the smallest width of the base plate in accordance with NEN-EN 1992-1-1.
- Steel shims may only be used in steel-concrete connections if the connecting surfaces are parallel to each other and no open position is present on any side after erection. A maximum of three plates applies here.

If these boundary conditions are met, the following equations apply for β:

- for a filled stand-off with grout or a single steel shim

$$\beta = 0{,}745 - 0{,}0005 * f_{yb}$$

- for multiple steel shims

$$\beta = \frac{9\mathrm{d}}{8\mathrm{d} * 3\mathrm{t_p}}$$

This proposal allows the following equations to be dropped:

- NEN-EN 1993-1-8 equation 3.3
- NEN-EN 1993-1-8 equation 6.2
- NEN-EN 1992-4 section 7.2.2.3.1

Due to the conservative assumptions in the FEM model there is a capacity left to introduce additional influence factors that accurately describe the behavior. Based on the experimental and modeling results, recommendations for this have been made that require further investigation.