WELDA® ANCHOR PLATES INCREASED RESISTANCES WITH LESS REINFORCEMENT

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Avoiding supplementary reinforcement means saving time and money in all phases of a construction project from design to erection.

During the past four years, Peikko has invested a significant amount of resources to a research focused on the assessment of the structural performance of WELDA® Anchor Plates with supplementary reinforcement. The research program involved a basic research which identified the basic behavior patterns of WELDA® anchored in reinforced concrete and an applied research that allowed us to formulate new design recommendations for WELDA® under tensile or shear loading alone as well as under tensile and shear load combined.

The research challenged the current way of calculating the effect of supplementary reinforcement used to increase resistance of anchor plates. It proved that the current standards are very conservative.

First of all, the test results show that when the plate is located close to the edge of concrete member, a shear crack develops from the last row of anchors. Current standards assume that it develops from the first row of studs that are closest to the edge of concrete. The practical implication of this is larger concrete cone resistance increasing shear resistance.

The current assumption is that in case of interaction of shear and tensile forces, it is either concrete or steel resistance, whichever is lower, that sets the limit. This is very conservative. The new analytical approach demonstrates that load can be shared between steel and concrete even at failure load. As a result of this the interaction, the action factor of 0.66 as defined by CEN/TS 1992-4-2 can be increased up to 1.2 for WELDA® Anchor Plates.

The research benefits the construction industry. Thanks to work at the test bench, the new design recommendations allow for significantly greater resistances to WELDA® Anchor Plates in comparison to those that can be assessed in accordance with current European design standards. Both the amount and diameter of supplementary reinforcement can be reduced while increasing resistances compared to current standards.

In practice, this significantly reduces time used to design supplementary reinforcements. Also installing the supplementary reinforcement is quicker. Especially in heavy reinforced structures with big WELDA® and WELDA® Strong Anchor Plates, there is limited space for any additional reinforcement. Being able to use less stirrups and with smaller diameter rebars, the efficiency is significantly increased.

The new design concept of WELDA® Anchor Plates makes them easy, safe and fast to design and install. Thanks to this you can move on to other tasks earlier.

The first approval validating such research-based resistances has already been issued by the Finnish Concrete Association (BY) in 2018.

Let's take a closer look at our thinking!

BACKGROUND

The tensile and shear resistance of WELDA® Anchor Plates is often limited by the anchorage capacity of concrete. The simplest way to improve the resistances of WELDA® in case the concrete capacity is not sufficient is to increase the length of anchors or to place the plate far away from the concrete member's edge. However, this is not always possible for different practical reasons. Alternatively, the anchorage capacity can be increased by using supplementary reinforcement. However, designing, approving and executing of supplementary reinforcement is a time-consuming process.

The structural design of WELDA® Anchor Plate is usually done with Peikko Designer®. It refers to resistances approved in the

European Technical Assessment ETA 16/0430 in accordance with the latest European design standards. These standards typically limit the performance of WELDA® by the load-bearing capacity of concrete surrounding the anchor plate. Under such assumptions, the contribution of the concrete member's reinforcement to the resistance of an anchorage provided by WELDA® is significantly underestimated, if not neglected.

CURRENT DESIGN METHOD

The European Technical Assessment ETA 16/0430 provides information about essential characteristics of WELDA® Anchor Plates. In ETA 16/0430, the structural performance of WELDA® is assessed using methods of the technical specification CEN/TS 1992-4-2. The resistance of concrete is typically limited by the development of a concrete crack between the heads of the anchors and the free edge of the concrete member (Figure 1) and calculated as follows:

$$N_{Rd} = k_{cr} \cdot \sqrt{f_{ck}} \cdot l^{1,5} \qquad (1)$$

where

$\sqrt{f_{ck}}$	represents the tensile strength of concrete
k_{cr}	represents the state of concrete (cracked or uncracked)
l	is the distance between the loaded anchors and the edge or the concrete member

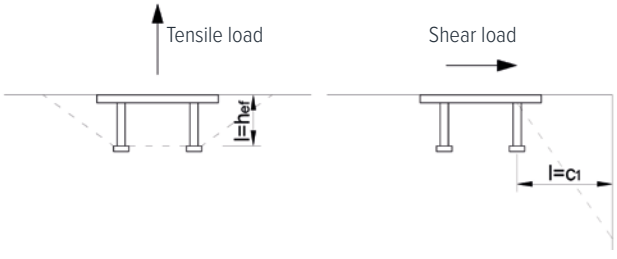


Figure 1. Examples of concrete failure under a) Tensile b) Shear load.

It is a common practice to use supplementary reinforcement in order to increase the capacity of concrete in the anchorage zone. The supplementary reinforcement is typically provided in the form of stirrups that are intended to tie the potential breakaway cone to the rest of the concrete body (Figure 2). The stirrups are continuous inside the concrete cone and anchored outside it. The resistance of a headed anchorage combined with supplementary reinforcement is determined by CEN/TS 1992-4-2 as:

$$N_{Rk,a} = \sum \frac{l_1 \cdot \pi \cdot d_s \cdot f_{bd}}{\alpha} \qquad (2)$$

Where:

l_1 = Anchorage length of supplementary reinforcement
d_s = Diameter of reinforcement bar
f_{bd} = Design bond strength of concrete
α = Influencing factor

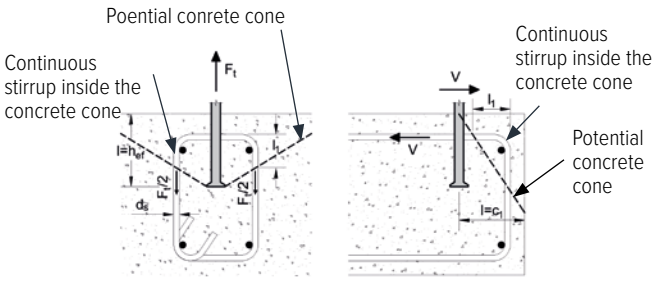


Figure 2. Headed bar coupled with supplementary reinforcement.

Practical experience shows that Eq. (2) provides only a very modest increase to the resistance of WELDA®. At the same time, recent research demonstrated that the Eq. (2) tends to severely underestimate the structural performance of WELDA® Anchor Plates combined with supplementary reinforcement (see references [4]-[7]).

EXPERIMENTAL RESEARCH

An extensive research project was carried out from 2015 to 2018 in cooperation between Peikko Group and the research institute IWB Stuttgart in Germany. The motivation of the research was to develop a detailed understanding of the behavior of WELDA® Anchor Plates combined with supplementary reinforcement and subsequently to develop reliable recommendations for a cost-efficient design of such plates. The project included about 100 laboratory tests of WELDA® anchored in concrete under tensile, shear and combined loading. For each of the load types, specimens with low, moderate and high amount of supplementary reinforcement were tested. These covered all possible failure modes that might occur in practice. Detailed measurements of the test specimens' load deformation behavior allowed to develop, analyze and validate a new analytical approach for the design of WELDA® Anchor Plates combined with supplementary reinforcement.

NEW ANALYTICAL APPROACH

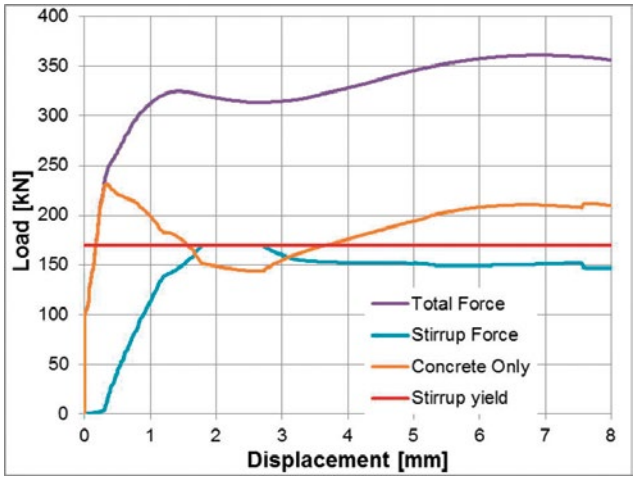
The new analytical approach has been developed by the consulting office IEA (Ingenieurbüro Eligehausen und Asmus) in Stuttgart (see reference [6] and [7] for further details). Within this analytical approach, the resistance of the anchorage is formulated as:

$$N_{Rm} = 0,5 \cdot N_{Rm,c} + N_{Rm,re} \leq \Psi \cdot N_{Rm,c} \qquad (3)$$

where

$N_{Rm,c}$ is the resistance of concrete
$N_{Rm,re}$ is the resistance of supplementary reinforcement (limited ether by the steel or anchorage capacity of the reinforcement bars)
Ψ is an empirical factor

a



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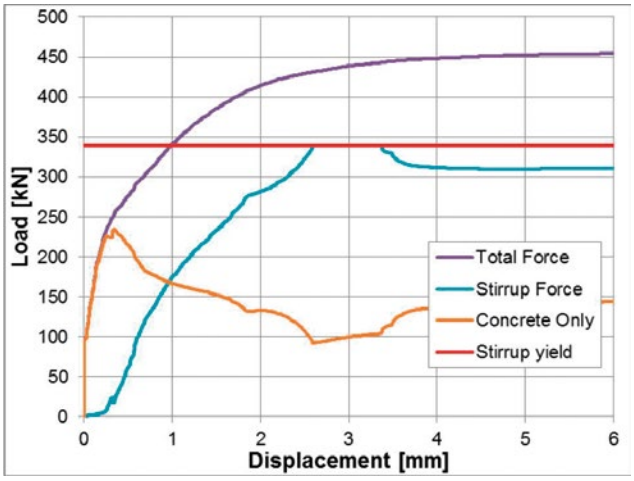
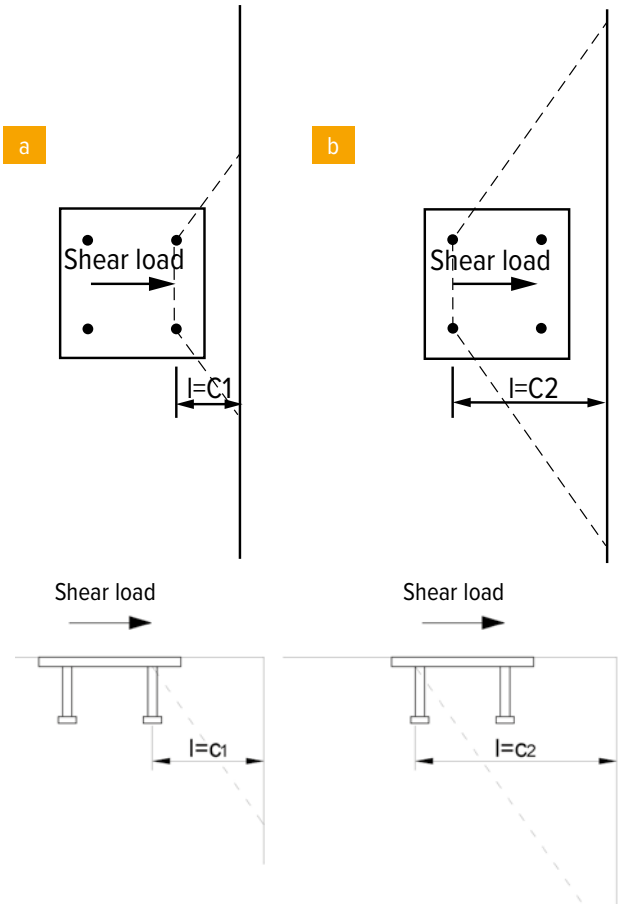


Figure 3. Measured contribution of concrete and steel to the total load-bearing capacity of the anchorage in WELDA® Anchor Plate with a) low b) high amount of steel supplementary reinforcement.

Figure 4. Shear crack acc. to a) CEN/TS 1992-4-2 and b) research.



Contrary to the current design concepts that assume the resistance of the anchorage as the lower of the concrete (Eq. 1) or steel (Eq. 2) resistance, the new analytical approach assumes that these two resistances can be combined. This is justified by experimental measurements (Figure 3) that clearly demonstrate that load can be shared between steel and concrete even at failure load. An upper limit of resistance is defined as a multiple of the concrete resistance, where the factor Ψ has been calibrated in tests with large amount of reinforcement.

The model in Eq. (4) is also applicable for the shear resistance of a plate located close to the edge of a concrete member. However, while ETA 16/0430 assumes that the shear crack develops from the first row of studs that are closest to the edge of concrete, the tests allowed to validate that if supplementary reinforcement is provided, the crack develops from the last row of anchors.

Another improvement yielding from the research is the verification of the resistance of the plate under combined tensile and shear loads. The verification is performed analogous to CEN/TS 1992-4-2 as:

$$\left(\frac{N_{Ed}}{N_{Rd}}\right)^{\alpha} + \left(\frac{V_{Ed}}{V_{Rd}}\right)^{\alpha} \leq 1.0 \qquad (4)$$

However, while the interaction factor defined by CEN/TS 1992-4-2 is α=0.66, the present research allowed to justify the α factor with value up to 1.2 for WELDA® Anchor Plates combined with supplementary reinforcement.

NEW DESIGN METHOD APPROVED BY AUTHORITIES

The extensive experimental research allowed to create a statistical database of test results that was sufficient to develop reliable design recommendations for WELDA® Anchor Plates. These design recommendations have been used to validate tensile, bending and shear resistances of standard models of WELDA®.

Standard WELDA® models have now been approved by the approval BY:13 M2 issued by the Finnish concrete association. The approval also allows to use the factor α=1.2 for the verification of the WELDA® Anchor Plates under combined load in accordance with Eq. (4).

A comparison of resistances of a WELDA® plate without supplementary reinforcement, with supplementary reinforcement acc. to CEN/TS 1992-4-2 and with supplementary reinforcement acc. to the new research based approval BY:13 M2 is in Figure 5 and Figure 6.

Figure 5. Comparison of resistances of WELDA® Anchor Plates calculated using standard and research-based design concepts.

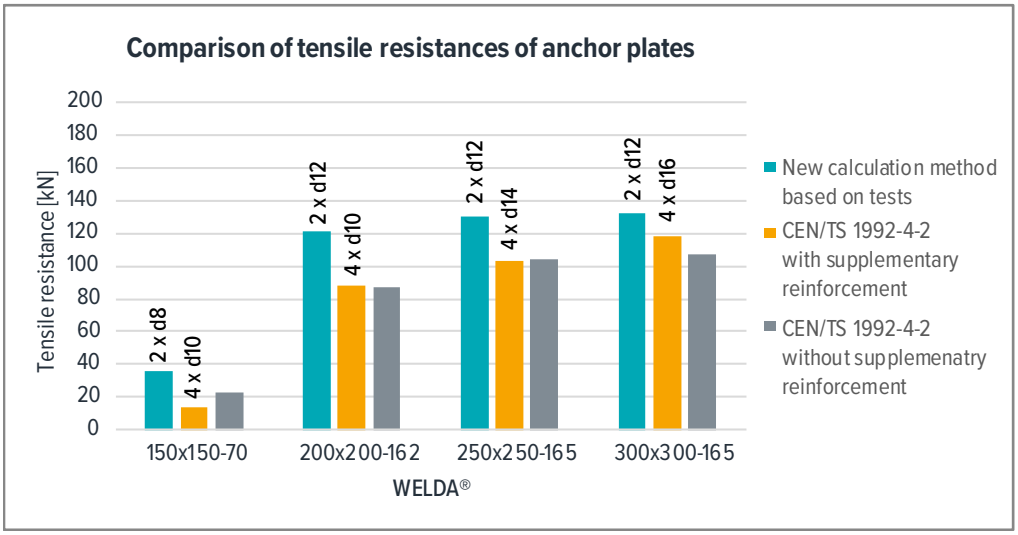
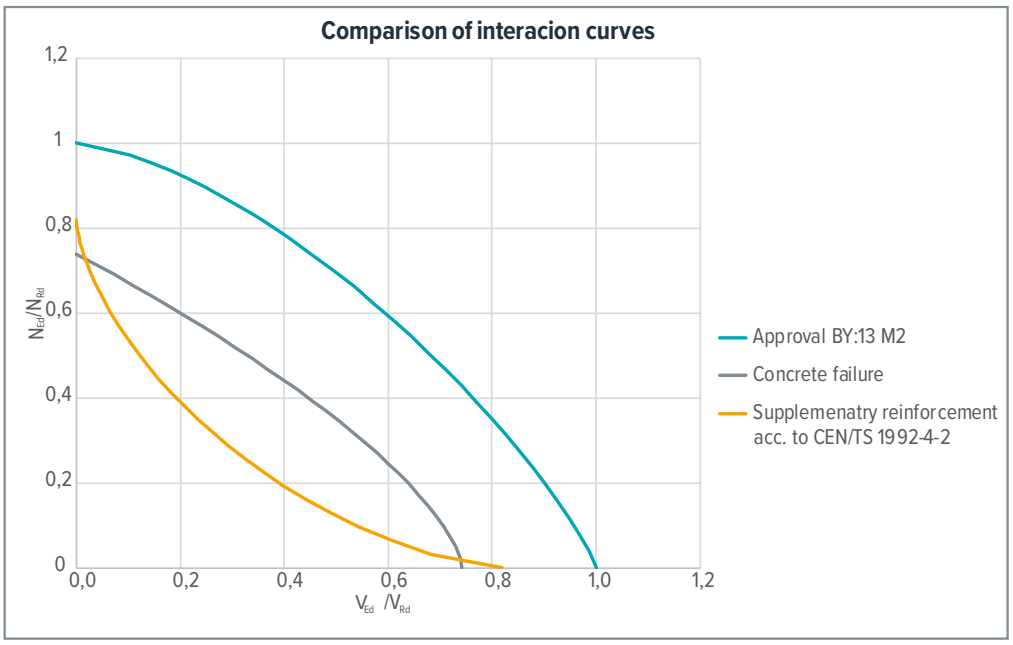


Figure 6. Comparison interaction curves for anchor plates with supplementary reinforcement.



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