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INJECTION ANCHORS FOR USE IN MASONRY STRUCTURES

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Abstract

Fastenings in masonry are often made using injection anchors. Injection anchors consist of a threaded rod that is bonded in a drilled hole by mortar.
Masonry is an inhomogeneous base material with many variations with respect to unit material, strength and hole configuration. These factors influence the load transfer mechanism of injection anchors. To study the load transfer mechanism, the failure mode and the failure load of injection anchors in masonry, numerous tests and non-linear finite element investigations have been performed. This paper presents the results of the research, shows the significant parameters influencing the failure load of injection anchors in masonry, explains their behaviour and proposes an analytic procedure with which the maximum load of single anchors can be calculated.

Key Words

Fastenings in masonry, injections anchors, anchorage with injection anchors

1 Introduction

1.1 Injection anchors with Technical Approvals

Injection systems for use in masonry structure that have Technical Approvals consist of a mesh sleeve made of metal or plastic, a threaded rod, a washer, a hexagon nut and an injection mortar, which is injected with a cartridge or a bag through a mixing nozzle. Some examples of approved injection systems are shown in Figure 1.
In solid units or in areas of unit webs the injection fastening systems transmit load by bond. In perforated units, the load can also be transmitted by mechanical interlock. The mortar passes through the openings of the mesh sleeve into the hollows of the unit.
Injection anchors generally fail by unit cone failure, so that the strength of the base material determines the maximum load. In solid units a failure at the mortar-unit

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interface also is observed. In this case the bond strength between mortar and unit is smaller than the strength of the base material.

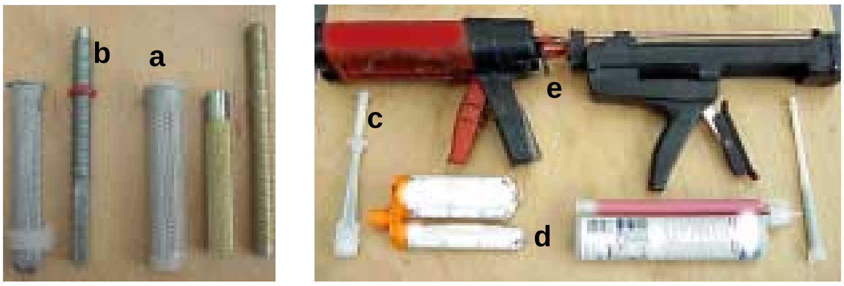
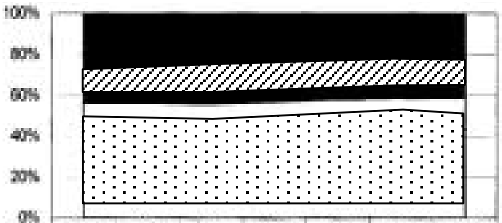


Figure 1: Injection systems with Technical Approvals: a) mesh sleeve, b) threaded rod, c) mixing nozzle, d) injection cartridge, e) injection tool

1.2 Masonry in Germany and Europe

Masonry is a very diverse material. Three materials are typically used for its production: clay, Calcium silicate and concrete, whereby concrete can be differentiated in normal, lightweight and aerated concrete.

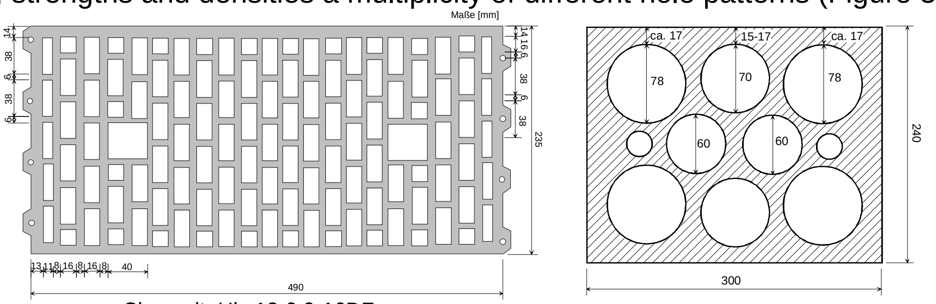


	1992	1994	1995	1996	1997	1998	1999
Calcium silicate	34,1	33	30,6	30,7	29,5	28,9	28,8
concrete	9,3	10,5	13,8	12,4	12,3	12,5	12,6
gas concrete	14,2	14,9	14,4	14,2	15	14,7	15,1
clay	42,4	41,6	41,1	42,7	43,2	44,8	43,5

Figure 2: Market shares of unit manufacturers, Fassade (2001)

In Figure 2 the market shares of the individual kinds of unit are represented for the years 1992 to 1999. Clay and Calcium silicate masonry with altogether 72% are the most popular unit materials in Germany. The requirements for dimensions, hole configuration, strength and density of masonry units are given in DIN Standards.

Masonry can be classified for each material between solid units and hollow units, whereby solid units can have hollow spaces limited to 15% of the contact surface. In the case of hollow units, usually only the permissible hollow fraction is standardized. Thus there exists among the possible formats, strengths and densities a multiplicity of different hole patterns (Figure 3).



Clay unit: Hlz 12-0,9-16DF

Calcium silicate unit: KSL 12-1,2-10DF

Figure 3: Examples of hollow units as defined by a DIN Standard

Additionally a lot of units are produced according to Technical Approvals of the Deutsche Institut für Bautechnik (DIBt).

Considering all of Europe, the unit variations are even greater. There exists a European Standard EN 771 with different parts for each unit material (e.g. EN771-1

(2000) contains clay masonry units, EN771-2 (2003) Calcium silicate masonry units, etc.), but the Standard does not provide a classification of the units with respect to allowable hollow space or other properties. It is written, that classification systems may be given in national annexes. In National Standards, e.g. of Switzerland are no classifications given, but only minimum values for the compressive strength. In other countries classifications exist, but these differ in categories or are based on different unit properties. Another point are regional preferences concerning the unit type. In the Netherlands Calcium silicate units and clay bricks are usually used, in France concrete units are preferred. In the north of Europe small format units dominate the market, in the south larger units are used.
These are the reasons why masonry is such an inhomogenous, complex base material with numerous variations in the general design. This variety presents a special challenge for the development of a practical, analytic model for fasteners.

2 Experimental investigations

2.1 General

Most of the laboratory tests are done as centric pull-out tests. The principal test device is shown in Figure 4.

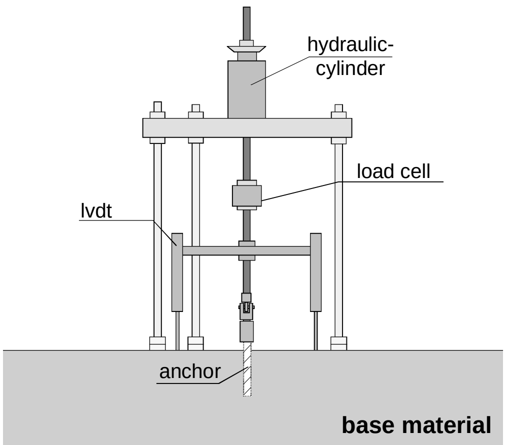


Figure 4: Test device for pull-out tests

The load and the displacement were measured continuously. The loading rate was selected such that the load maximum was reached after 1 to 3 minutes.
In solid units the anchor usually fails by bond failure between mortar and base material or by a combination of unit cone and bond failure.
In perforated units generally cone failure occurs.
Small bricks can be split by anchor loading.
Sometimes steel failure or bond failure between steel and mortar is observed.
The following sections focus on the failure modes cone failure, bond failure between mortar and unit and combination of both. For these failure modes the maximum load is determined by the masonry properties and the bond strength.

2.2 Load transfer mechanism

An injection anchor transmits load by bond in areas of web and/or by mechanical interlook made possible by the hollows of perforated units (Figure 5).
At the University Stuttgart some laboratory tests were performed to find out if one of the load transfer mechanisms is dominant or if there are differences in the failure load depending on the transfer mechanism.
In the test procedure the mesh of some sleeves were closed in the areas of webs, so that no bond could developed. These anchors were set in perforated blocks with a outer web thickness h_{web} = 30mm. There were no additional interior webs involved. Other anchors were set in solid units with reduced embedment depths to 30 mm, so that no mechanical interlock was possible. Some control tests were performed under standard installation conditions.

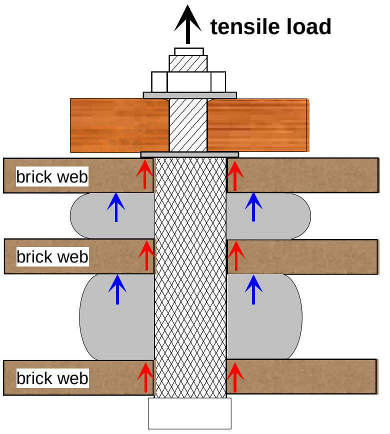


Figure 5: Load transfer mechanism

In Figure 6 it is shown that the failure loads of all three test series are similar. There is no significant difference between the peak loads for the three test series. All tested anchors failed by unit cone.

Comparing the load – displacement curves in Figure 7 one sees that mechanical interlock needs larger displacements to be activated than bond. The displacement depends on the shape of the hardened mortar. The curve for standard tests with both load transfer mechanisms looks very similar to the load-displacement curve appertaining to the bond mechanism.

These results show that bond is the main load transfer mechanism in both solid and perforated units in case of cone failure. This behaviour is similar to the behaviour of bonded anchors in concrete.

The mechanical interlock can be activated if the bond fails before reaching the tensile strength of the unit. In this case the load increases to a first load maximum, than decreases until the hardened mortar contacts the web and transfers load by mechanical interlock. The unit breaks by cone failure. This behaviour was observed in other laboratory tests. The change from the bond to the mechanical interlock also can be continuously.

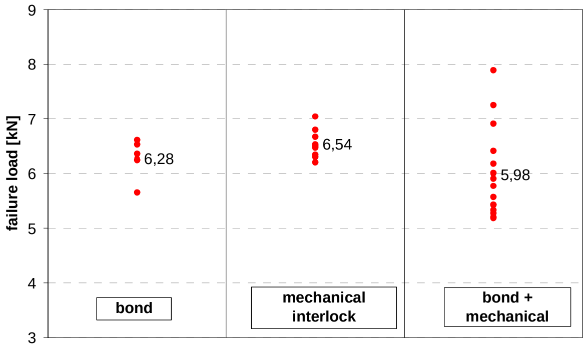


Figure 6: Failure loads with different kinds of load transfer mechanism, h_{web} = 30 mm

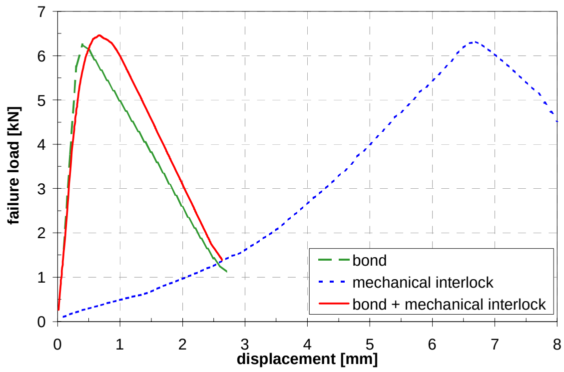


Figure 7: Load-displacement curves of different kinds of load transfer mechanism, h_{web} = 30 mm

The characteristic parameter that determines bond behaviour is the bond strength. The bond strength τ_u is defined for bonded anchors in concrete by the failure load divided by the contact surface between the mortar and the threaded rod (see Meszaros (2002)). The calculation of bond strength for injection anchors in masonry requires some modifications. Usually bond failure happens between mortar and unit. Thus the contact area is defined by the surface of the borehole. The contact area in masonry also includes the embedment depth or the web thickness. How to define the effective embedment depth for different hole cofigurations is described in the following sections.

2.3 Influence of web thickness

In Figure 8 the influence of the web thickness in perforated Calcium silicate blocks and of the embedment depth in solid Calcium silicate units is shown.

The web thickness includes only the outer web because the hole configuration was chosen such a way that no interior webs were involved. The embedment depth in solid units is the length of the reduced mesh sleeve. Usually the sleeve length is about 75 mm to 100 mm and is constant for the injection system.

From Figure 8 it can be concluded that regardless or whether the anchor is set in solid units or in perforated units, the failure loads are in the same range for equivalent web thicknesses or embedment depths.

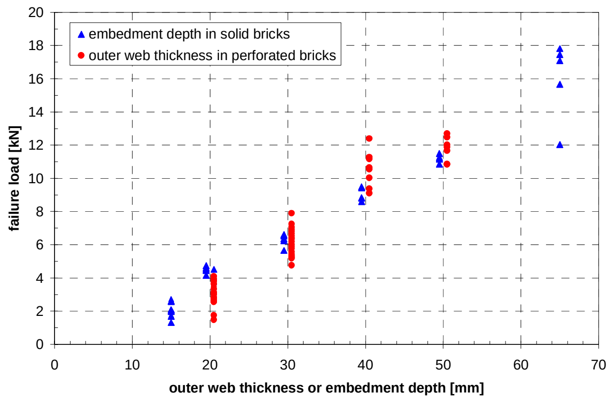


Figure 8: Influence of web thickness/ embedment depth on failure load in Calcium silicate units

A second conclusion is that the failure load increases linearly with the web thickness (embedment depth). Both results confirm that the load is transferred by bond between mortar and unit. In solid units no mechanical interlock exists, only the bond can be used for load transfer. Similar results in perforated units with similar web thicknesses show that the failure load can be handled in the same way as the failure load in solid units. A linear increase of the maximum load with increasing embedment depth is typical for bonded anchors in concrete, which transfer load only by bond.

2.4 Influence of additional webs in perforated units

In the previously described investigations, the hole configuration of the perforated units in which the pull-out tests were done, is characterised by an outer web and a subsequent large hole so that the anchor could not embed in interior webs.

The aim of the tests described in this chapter was to find out how the failure load is influenced by additional interior webs. The injection anchors were set in Calcium silicate units and lightweight concrete units, in which an interior web was cut but not totally passed through. The borehole was cleaned very well. In Figure 9 and 10 the setting positions of the anchors and the results of pull-out tests in units made of Calcium silicate and lightweight concrete are shown. The effective web thickness is the sum of the thickness of the outer web and of the cut part of the interior web. The failure load increases linearly with increasing effective web thickness. This agrees with the results of section 2.3.

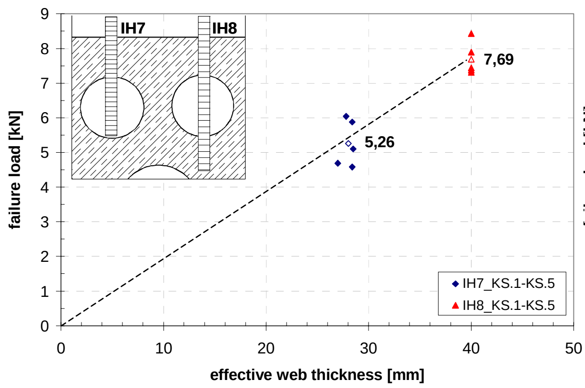


Figure 9: Influence of interior webs on failure load in Calcium silicate units

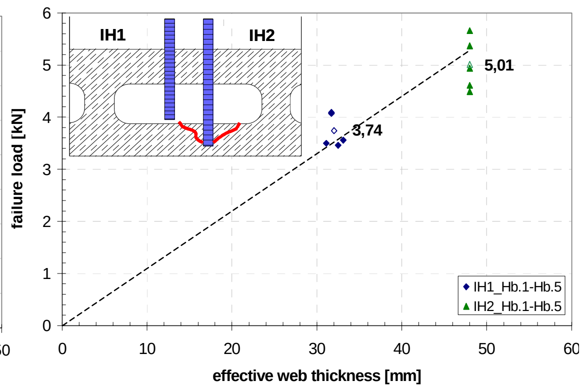


Figure 10: Influence of interior webs on failure load in lightweight concrete units

The interior web can transfer load by bond if the borehole is cleaned well before injection of the mortar. Its contribution is observable in the inner cone failure which is marked in Figure 10. In the case of no borehole cleaning it is possible that the drilling powder prevents the development of bond between mortar and unit. Then the inner web should not be added to the effective web thickness.

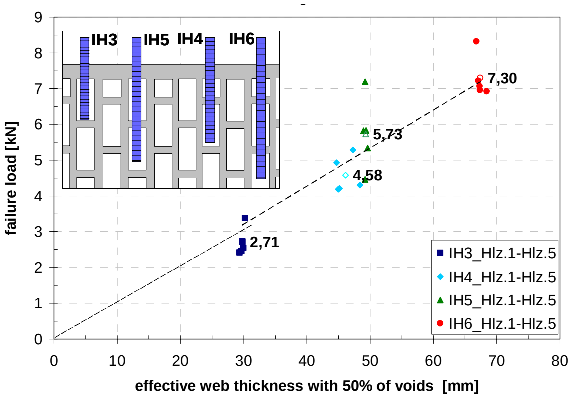


Figure 11: Influence of interior webs on failure load in perforated clay units

More tests were done in perforated clay units. One difference to the two unit types above is that the interior webs are very thin and borehole drilling always entails drilling through the webs. Another difference is that the width of the voids in clay unit is about equal to the drilling diameter. So the unit surface inside the void can become bonded with the injection mortar i.e. if borehole cleaning is performed. In Figure 11 the void surfaces are considered in the effective web thickness. The effective web thickness is calculated as the sum of the cut outer and inner webs plus 50% of the void length along the embedment depth of the anchor. The influence of the effective web thickness on the failure load is comparable to the other unit types.

2.5 Influence of unit strength

The unit properties often determine the maximum load of injection anchors in masonry. The anchor fails by unit cone failure, which is caused by exceeding the unit tensile strength. Since measurement of the tensile strength of units is difficult and expensive, a relation between tensile strength and compressive strength is used. The compressive strength of units usually is determined using the gross unit area. This is acceptable for solid units. In perforated units, it is not the strength of the whole unit, but the strength of the single webs that is of interest for this research. For this reason, the compressive strength is always based on the net unit area.

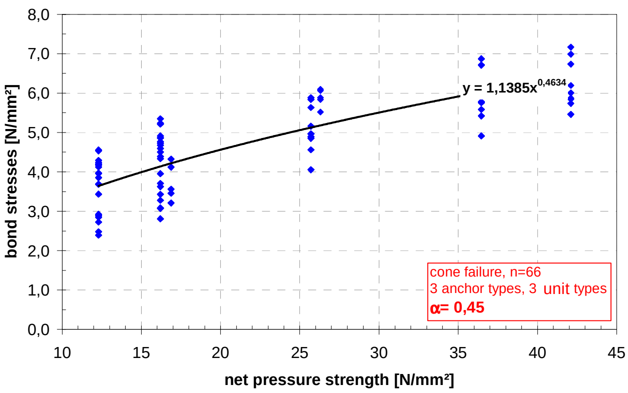


Figure 12: Influence of unit strength on bond stresses in Calcium silicate units

In Figure 12 the bond strengths are shown on the ordinate and the net compressive strengths on the x-axis. The results come from tests in different Calcium silicate units with different anchor types. The effective embedment depth which is necessary for the calculation of the contact area is calculated as it is described in chapter 2.4. The circumference of the contact surface between mortar and unit is assumed to be the borehole diameter. The regression line shows that the unit strength influences the failure load to the power of $\alpha = 0{,}45$. Similar diagrams can be created for lightweight concrete units and clay units. In clay bricks $\alpha = 0{,}45$, in lightweight concrete $\alpha = 0{,}20$. The smaller power in lightweight concrete results from the large-pored structure and the small cement concentration of this base material.

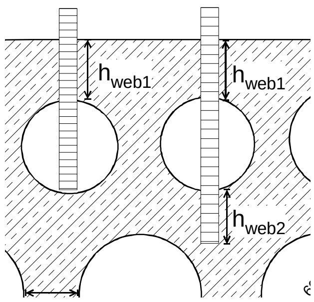
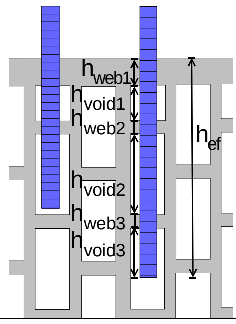
3 Design of single injection anchors in masonry

3.1 Definition of the effective embedment depth h'_{ef}

As is shown in chapter 2.3 and 2.4 the effective embedment depth of injection anchors in perforated units depends not only on the anchor type but also on the hole configuration of the base material. The definition of the effective embedment depth can

be classificated in four groups. The first criterion is the size of the hollows along the anchor. In chapter 2.4 a distinction was made between units with large hollows with diameters larger than the borehole diameter (category 1, e.g. Calcium silicate units) and small hollows with diameters equal to or smaller than the borehole diameter (category 2, e.g. perforated clay units). The second criterion is the participation of cut, but not totally penetrated webs. If no guarantee for their participation in load behaviour can be given, they must not be added to the effective embedment depth (category A). A guarantee can be given e.g. by a carful borehole cleaning (category B). An example of how to determine the effective embedment depth is given in table 1.

Table 1 Determination of the effective embedment depth h'_{ef}

		1	2
		$d_{hole} > d_{borehole}$ e.g. Calcium silicate unit	$d_{Loch} \le d_{Bohrloch}$ e.g. perforated clay unit
			
A	without interior webs	$h'_{ef} = h_{web1}$	$h'_{ef} = \Sigma h_{web}$
B	with interior webs, guaranteed participation	$h'_{ef} = h_{web1} + h_{web2}$	$h'_{ef} = \Sigma h_{web} + 0{,}5 \cdot \Sigma h_{void}$ and $\Sigma h_{void} \le h_{ef} - \Sigma h_{web}$

3.2 Uniform bond model

The uniform bond model assumes a constant distribution of bond strength τ_u along the effective embedment depth. The bond strength depends on the mortar type and the base material and is to be determined by specially defined reference tests. The design model calculates the failure loads of single fastenings with injection anchors in solid and perforated masonry under centric loads. The failure load can be calculated using Equation 1.

$$N_u = \tau_u \cdot h'_{ef} \cdot \pi \cdot d_b \qquad (1)$$

N_u	failure load of a single anchor far away from an edge;
τ_u	mean value of bond strength, determined by reference tests;
h'_{ef}	effective embedment depth, defined by Table 1;
d_b	diameter of the borehole

The tests for determination of the bond strength should be done in perforated units with low compressive strengths. The increase of failure load caused by higher compressive strengths can be calculated by multiplying Eq. 1 with the factor in Eq. 2.

$$(\beta_{net,unit} / \beta_{net,unit,test})^{\alpha} \qquad (2)$$

$\beta_{net,unit}$	actual net compressive strength;
$\beta_{net,unit,test}$	net compressive strength in the reference tests determining τ_u
α	power for unit strength influence, depending on the unit type

3.3 Verification of the design model

The design model described in chapter 3.2 was compared with numerious experimental test data with different types of injection systems in different kinds of unit. In the following diagramms the ordinate shows the ratio between the failure load in tests $N_{u,test}$ and the failure load $N_{u,calc}$ calculated by Eq.1. The bond strength τ_u in Eq. 1 is the mean value of 5 to 10 reference tests made with the several injection systems in perforated clay, Calcium silicate and lightweight concrete units.

Figure 13 shows the ratio $N_{u,test}$ / $N_{u,calc}$ as a function the parameters of the design model, i.e. as a function of the effective embedment depth h'_{ef} or the net compressive strength in lightweight concrete units. In Figure 14 are the corresponding diagrams for Calcium silicate units. A similar picture arises from the verification with clay units.

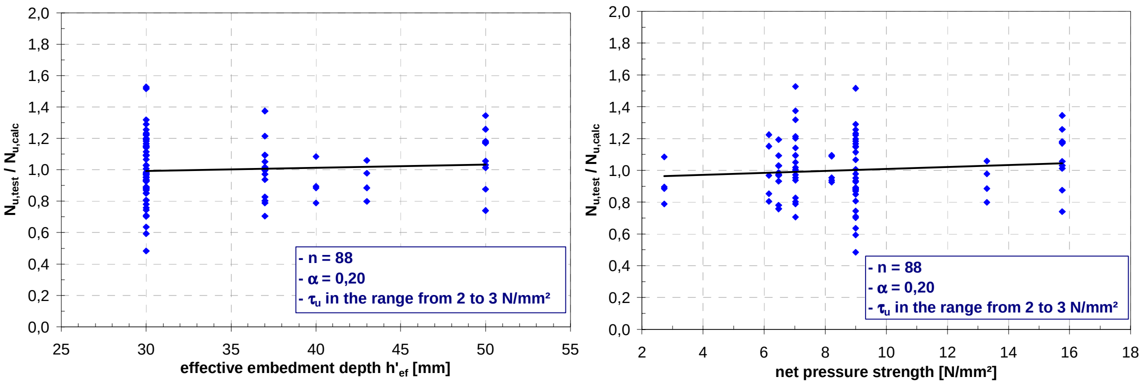


Figure 13: Verification of the design model in lightweight concrete units

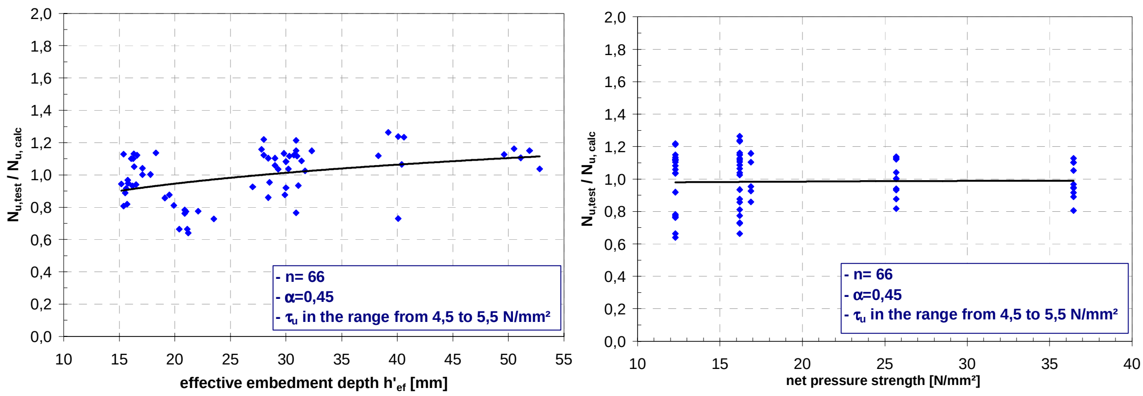


Figure 14: Verification of the design model in Calcium silicate units

The comparison of experimental test data with the calculated failure load gives a good agreement as is shown in Figure 13 and 14.

4 Conclusion

The investigations showed that the behaviour of single injection anchors in masonry is dependent on the bond between the mortar and the base material. This is confirmed by the linearly increasing failure load with increasing effective embedment depth. Load transfer by bond is also observed for bonded anchors in concrete. For this reason a design model for single injection anchors is developed similar to the uniform bond model for bonded anchors in concrete. Some modifications are necessary for use in masonry to account for the highly irregular contact surface between mortar and unit. These modifications are achieved by use of an effective embedment depth.

The influence of the unit strength is based on the net compressive strength. Since this might not be convienient for use in practice, the gross compressive strength can also

be used which yields conservative results. The presented design model is validated with numerious test results. The advantage of the bond model is the general application for fastenings in solid and perforated units.

Future investigations will study fastenings with anchor groups and the influence of edges for completing the design model. Further more, the influence of additional parameters such as unit format, humidity of base material, borehole cleaning will be studied.

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