INFLUENCE OF THE SUPPORT OF ADHESIVE ANCHOR SYSTEMS WITH AND WITHOUT SLEEVE IN SOLID CALCIUM SILICATE BRICKS

EINFLUSS DER ABSTÜTZUNG VON VERBUNDDÜBELN MIT UND OHNE SIEBHÜLSE IN KALKSANDVOLLSTEINEN

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SUMMARY

The object of this paper is to determine the influence of the support of bonded anchors in masonry units in axial tensile tests. For this purpose, loading tests are carried out at IWB. Solid calcium silicate bricks with different dimensions as single masonry bricks or in a bond are used as base material. Two anchor systems are used to carry out the tests with varying support distance. These systems consist in bonded anchors (injection mortar and threaded rod) with and without sleeves.

An influence of the support width in tests with masonry units is evident. The ultimate loads decrease and show a change of behaviour the larger the support width becomes.

In tests with bonded anchors in stretcher bond, no influence of the support width is apparent, since a combined failure occurs and the NF bricks failed by splitting.

Further investigations are necessary to understand the behaviour of bonded anchors in masonry units and bonds.

ZUSAMMENFASSUNG

Gegenstand dieser Arbeit ist es, den Einfluss der Abstützung von Verbunddübel in Mauerwerk bei zentrischen Zugversuchen zu ermitteln. Zu diesem Zweck wurden Belastungsersuche am IWB durchgeführt. Als Ankergrund dienten Kalksandvollsteine mit verschiedenen Formaten als Einzelstein oder im Verband. Mit zwei Dübelsystemen wurden Versuche mit variierenden Abstützweiten durchgeführt. Die Systeme bestehen aus Verbunddübel (Injektionsmörtel und Gewindestange) mit und ohne Siebhülse.

Ein Einfluss der Abstützweite ist in Versuchen mit Einzelsteinen ersichtlich. Die Bruchlasten nehmen ab und zeigen einen Wechsel im Verhalten, je größer die Abstützweite wird.

In Versuchen mit Verbunddübeln im Läuferverband ist kein Einfluss der Abstützweite zu sehen, da ein kombiniertes Versagen auftritt und die NF Steine durch Spalten versagen.

Weitere Untersuchungen sind notwendig, um das Verhalten von Verbunddübeln in Mauerwerkssteinen und -verbänden nachzuvollziehen.

1. INTRODUCTION

For decades, one of the most popular construction material has been masonry. Over time, newly developed materials have been used to meet further requirements such as thermal insulation, sound proofing, fire protection, etc.

Since masonry walls are increasingly present in both old and new buildings, research has been conducted in this area and guidelines for bonded anchors and plastic anchors have been established [1-5]. Even though research in this direction is carried out, the current knowledge of the load-bearing behaviour for bonded anchors in masonry is not as great as in concrete. Therefore, it is necessary to carry out further experiments to fill the knowledge gap and apply it to improve the present design model. Understanding the influence of the spacing for ensuring the transmission of the characteristic resistance of single injection anchor (s_{cr}) on the design model is of importance. In EAD 330076, the critical axial distance (s_{cr}) is taken as three times the embedment depth (h_{ef}), however, in most approvals the length or height of the tested brick is taken [5]. This paper investigates the influence of this parameter through experiments. In order to check this parameter, an experimental investigation is carried out in this paper.

2. EXPERIMENTAL PROGRAM

A summary of the performed tests is listed in Table 1. The tests were carried out with various support distances depending on the embedment depth. Bonded anchors with and without sleeves were investigated. The injection mortar consists of two components and is stored in a 2-chamber cartridge. The two components combine and react when dispensed through a static mixing nozzle. In all tests, threaded rods of size M8 with a steel grade of 8.8 were used. Plastic sleeves had a diameter of 12 mm. The embedment depth was for all tests 50 mm. Solid calcium silicate bricks in the dimensions NF, 4 DF and 8 DF with a compressive strength class of 12 N/mm² and a bulk density class of 2.0 kg/dm³ were used as anchoring base. The actual compressive strengths of the bricks were determined according to DIN EN 772-1 at the MPA of the University of Stuttgart and was for NF bricks 21.6 N/mm², for 4 DF bricks 11.0 N/mm² and 8 DF bricks 15.2 N/mm² [6]. Tests were carried out in masonry units as well as in stretcher bonds.

Table 1: Test program

Series	Brick Dimension	Support width
Z-AW-0 h_{ef}	4 DF / 8 DF a)	18 mm
Z-AW-0 h_{ef}-s	4 DF / 8 DF	18 mm
Z-AW-0.5 h_{ef}-s	4 DF	25 mm
Z-AW-0.8 h_{ef}-s	4 DF	40 mm
Z-AW-1.0 h_{ef}	4 DF	50 mm
Z-AW-1.0 h_{ef}-s	4 DF	50 mm
Z-AW-2.0 h_{ef}	4 DF	100 mm
Z-AW-2.0 h_{ef}-s	4 DF	100 mm
Z-AW-3.0 h_{ef}	4 DF	150 mm
Z-AW-3.0 h_{ef}-s	4 DF	150 mm
Z-AW-5.0 h_{ef}	8 DF	250 mm
Z-AW-5.0 h_{ef}-s	8 DF	250 mm
Z-AW-V-0.5 h_{ef}-s	NF (stretcher bond)	25 mm
Z-AW-V-0.5 h_{ef}-s	NF (masonry unit)	25 mm
Z-AW-V-1.0 h_{ef}-s	NF (stretcher bond)	50 mm
Z-AW-V-3.0 h_{ef}-s	NF (stretcher bond)	150 mm

a) DF = thin format, NF = standard format

2.1 PREPERATION OF THE ANCHORAGE MATERIAL

For all test series, the holes are drilled using a rotary hammer with a drilling rig and hardened metal drill bit with the required cutting diameter (d_{cut}) of 12 mm. The drilling rig is used to ensure that the drill holes are perpendicular to the surface. After drilling, the cleaning was done according the manufacturer’s instructions. The mortar was injected directly into the hole or the sleeve (for the sleeve test series) and then the anchors were installed. The tests were performed after the minimum curing time.

2.2 EXPERIMENTAL PROCEDURE

A total of 19 test series with five tests each were carried out. Ten test series had a 4 DF solid calcium silicate brick as anchorage material and four series had an 8 DF solid calcium silicate brick, where the tests were each performed in a masonry unit. Four test series were carried out in a stretcher bond of NF bricks. In order to make a comparison, an additional test series was carried out in NF bricks, which were compressed axially through a hydraulic cylinder with

0.2 N/mm² as shown in Fig. 2. This compression simulated the connection between the single bricks in the stretcher bond. The diameters of the support widths dependent on the embedment depth were 0 h_{ef} (18 mm), 0.5 h_{ef} (25 mm), 0.8 h_{ef} (40 mm), 1 h_{ef} (50 mm), 2 h_{ef} (100 mm), 3 h_{ef} (150 mm), and 5 h_{ef} (250 mm). The bricks and the respective tested support diameters are given in Table 1. All tests were loaded axially by means of a hydraulic cylinder. The load was transferred from the cylinder with an attachment part via a threaded rod. Fig. 1 and 2 illustrate the applied test setups.

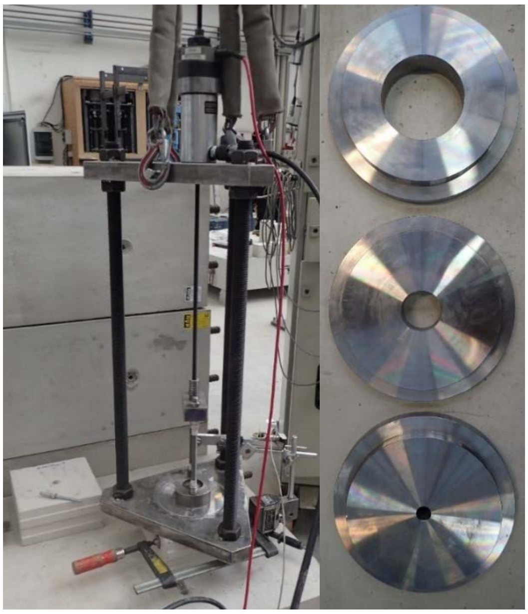

Fig. 1: Test setup for masonry units with different support widths

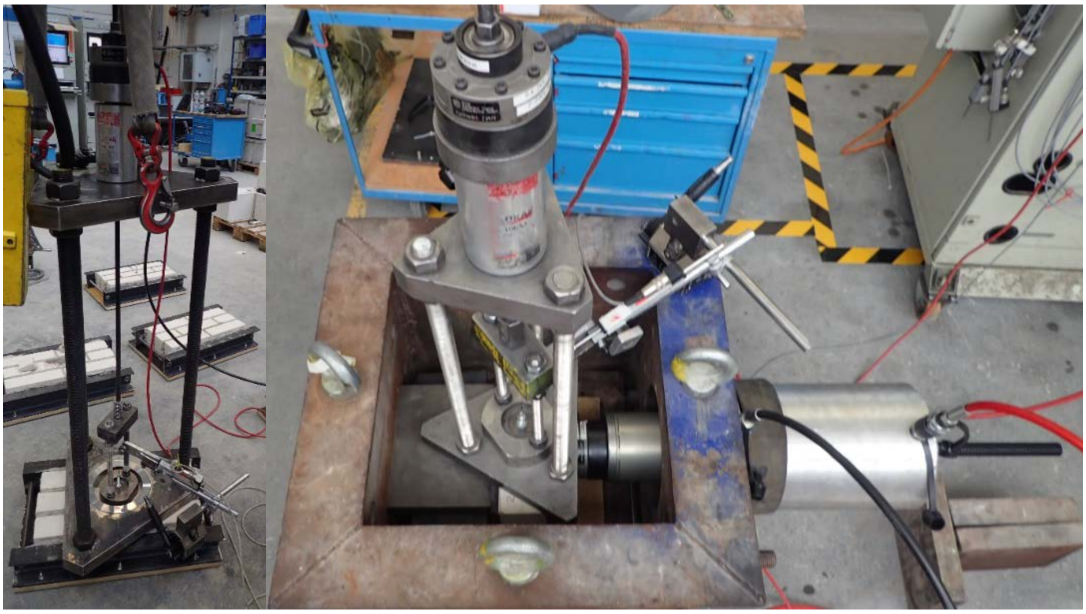

Fig. 2: Test setup for stretcher bond and test setup for clamped NF brick

3. TEST RESULTS

The results of the performed tests are listed in Table 2. The first column contains the names of the series with the letters Z-AW for axial tensile tests with variation of the support width. The following number shows the diameter of the support as a function of h_{ef} and finally s is used for the installation with sleeve. In the other columns the brick dimensions, the mean ultimate load ($N_{u,m}$) and the standard deviation are listed. The ultimate loads were converted to the compressive strength of 4 DF bricks [5]. In the last column are listed the failure modes. In addition to the usual types of failure, such as brick cone breakout (B), pull-out with mortar (P_M), splitting failure (Sp) and mixed failure with cone breakout/pull-out (M) (see Fig. 3); combination failures with splitting were also observed such as M / Sp and B / Sp.

Table 2: Test results

Series	Brick Dimension	$N_{u,m}$ [kN]	Standard deviation [%]	Failure mode
Z-AW-0 h_{ef}	4 DF	9.65	2.8	P_M
Z-AW-0 h_{ef}-s	4 DF	11.85	19.3	P_M
Z-AW-0 h_{ef}	8 DF	8.05	14.4	Sp
Z-AW-0 h_{ef}-s	8 DF	11.38	10.2	P_M
Z-AW-0.5 h_{ef}-s	4 DF	8.72	11.8	P_M
Z-AW-0.8 h_{ef}-s	4 DF	8.33	9.2	M
Z-AW-1.0 h_{ef}	4 DF	8.39	19.4	M
Z-AW-1.0 h_{ef}-s	4 DF	12.02	8.7	M
Z-AW-2.0 h_{ef}	4 DF	6.63	8.6	M
Z-AW-2.0 h_{ef}-s	4 DF	10.71	18.1	M / P_M
Z-AW-3.0 h_{ef}	4 DF	7.15	7.9	M / B
Z-AW-3.0 h_{ef}-s	4 DF	8.45	11.6	M / Sp
Z-AW-5.0 h_{ef}	8 DF	7.40	17.5	M / B / Sp
Z-AW-5.0 h_{ef}-s	8 DF	10.09	6.1	B / Sp
Z-AW-V-0.5 h_{ef}-s	NF (stretcher bond)	3.77	6.6	Sp, M
Z-AW-V-0.5 h_{ef}-s	NF (stretcher bond)	3.55	8.0	Sp, M
Z-AW-V-0.5 h_{ef}-s	NF (masonry unit)	7.31	12.4	M
Z-AW-V-1.0 h_{ef}-s	NF (stretcher bond)	3.60	6.0	Sp, M
Z-AW-V-3.0 h_{ef}-s	NF (stretcher bond)	3.69	5.2	Sp, A

In the tests in single masonry units, mixed failure occurred in approx. 50% of cases, 30% of the tests failed by pull out and 5% failed by splitting, cone breakout or combined failure. Similarly, the stretcher bond bricks failed 60% by splitting and mixed failure. About 20% of the tests failed due to splitting and cone breakout. In the clamped NF bricks, only mixed failure occurred which corresponds to about 20%.

Fig. 3: Mixed failure mode and brick cone breakout

4. DISCUSSION

4.1 TESTS IN MASONRY UNITS

The results of the tests in masonry units show a decrease in ultimate load with increasing of support width. This changes the type of failure from pull-out to mixed failure and then cone breakout occurs. Splitting occurs when the brick is too small or when there are invisible cracks in the stone.

For both fastening systems, with and without sleeve, the ultimate load decreases by about 24% as the diameter of the support (as a function of h_{ef}) is increasing (Fig. 4). While the system without sleeve shows a linear load reduction up to a support width of 3 h_{ef}, the tests with sleeve show a change of behaviour at 2 h_{ef}. This is due to the fact that the sleeve is the weaker component of the fastening system and the connection between mortar and sleeve tends to fail. The fastening system without sleeve can thus activate much more of the calcium silicate brick and is fully utilized from a support width of 3 h_{ef}.

With this behaviour, conclusions can be made about the spacing for ensuring the transmission of the characteristic resistance of single injection anchor (s_{cr}). In this case, s_{cr} lies between 2 and 3 h_{ef} and depends on the anchor system.

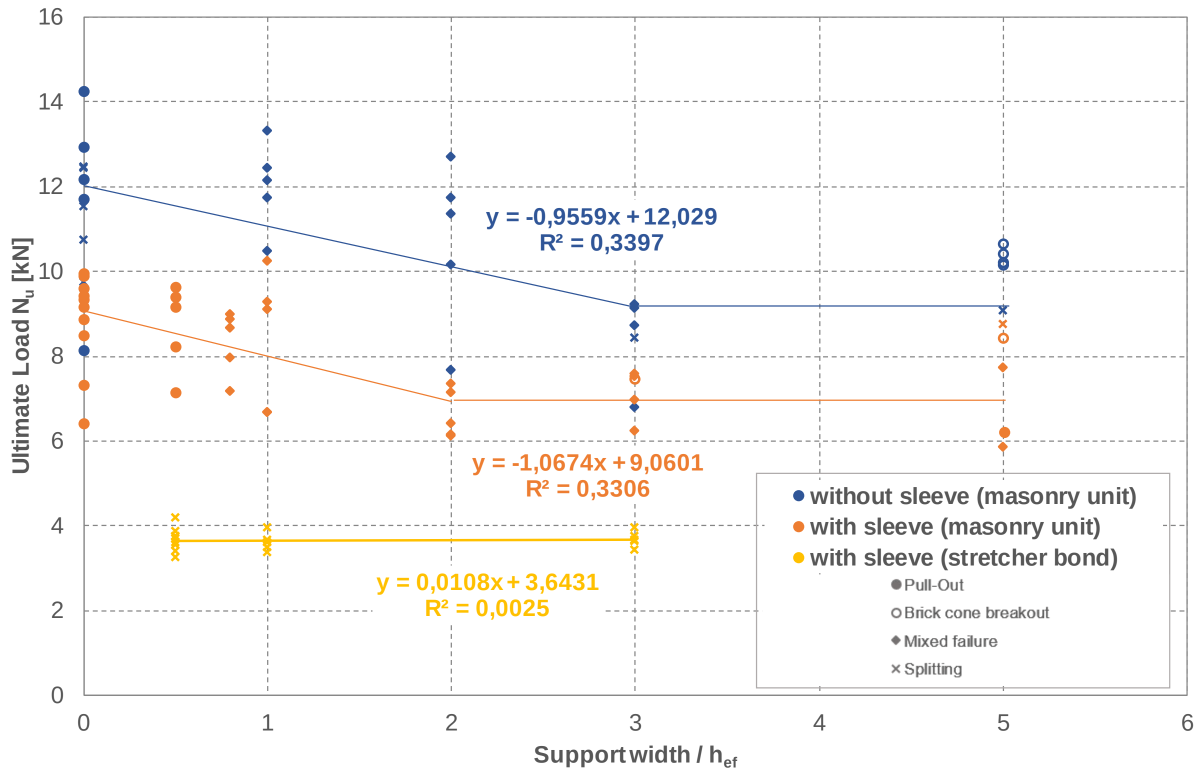

Fig. 4: Failure loads vs. support width/embedment depth

4.2 TESTS IN STRETCHER BOND

The load-displacement behaviour of the anchors in the stretcher bond is not comparable with the tests in the masonry units. The load-displacement curves show two peaks. Depending on the test, the first peak can be the maximum load, as shown in Fig. 5. The presence of two peaks is associated to the combined failure. First, the brick is splitting and then a mixed failure or cone breakout occurs. Therefore, the first peak is assumed to be the ultimate load, since the anchorage base has already failed due to splitting.

Fig. 4 illustrates not only the ultimate loads for single masonry unit but the load for stretcher bond tests as well. This load is converted to the compressive strength of 4 DF bricks. Since the main failure type is splitting, the variation of the support width is insignificant. In order to demonstrate this influence, the tests should be performed in a larger brick dimension.

To simulate the bond, further tests were carried out with single NF bricks (see Fig. 2) with a support width of 0.5 h_{ef}. Mixed failure occurred in all tests. The ultimate load is reached at a displacement of approximately 0.4 mm (see Fig 7). The mean load $N_{u,m}$ is 7.31 kN. Since the type of failure differs from the tests in the stretcher bond, no comparison can be made.

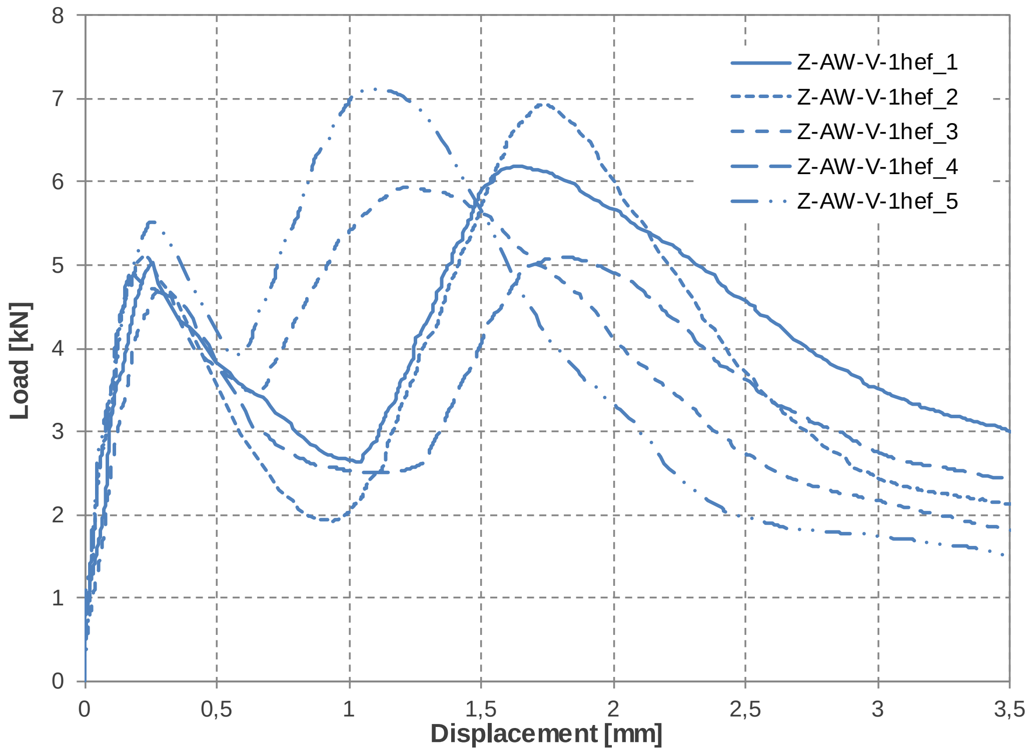

Fig. 5: Load – displacement curves of Z-AW-V-1h_{ef}

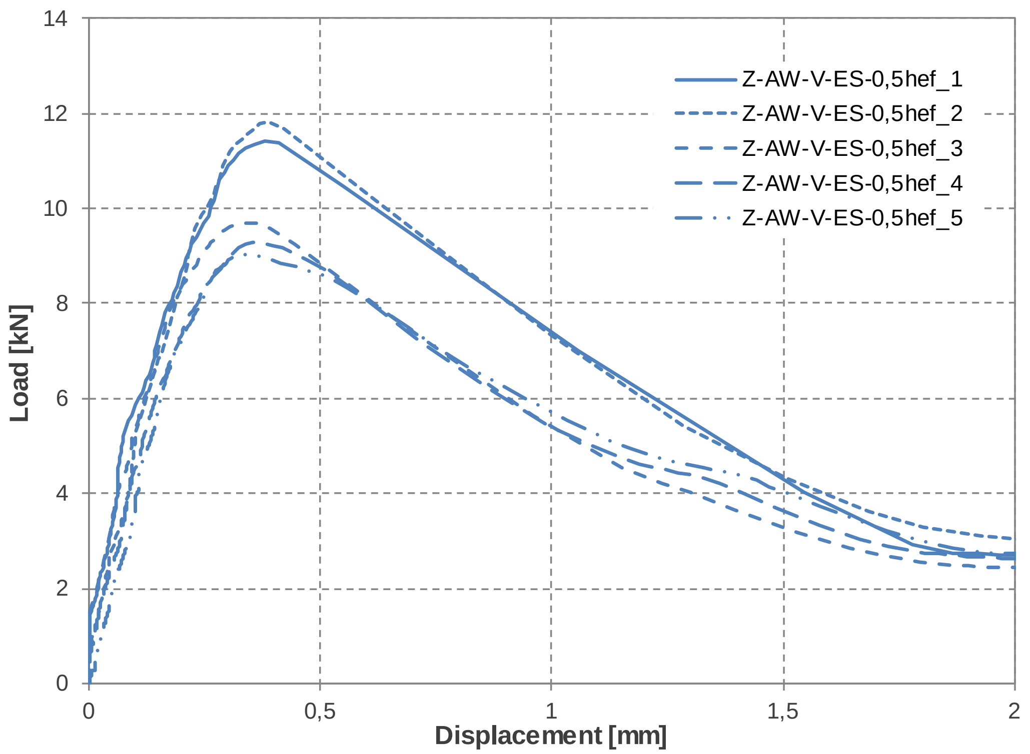

Fig. 6: Load – displacement curves of Z-AW-V-0,5h_{ef} in masonry unit

4.3 COMPARISON OF THE ULTIMATE LOADS

The comparison of the ultimate loads with the support width in single masonry units indicates higher failure loads for the tests without sleeves. It is suspected that this may be due to a higher bond strength based on the fact that failure occurred in the brick-mortar interface. The tests with sleeve have a load reduction of approx. 24% over the entire support width (failure between interface of sleeve and mortar) in relation to the tests without sleeves. This behaviour can be product-specific.

The stretcher bond as anchorage base has no positive influence on the ultimate load, indicating that the brick dimension is the decisive factor. The ultimate load for the bond decreases by 50 to 60% in relation to the tests with sleeve in single bricks.

5. CONCLUSIONS

The tests in masonry units are influenced from the support width. The ultimate loads decrease linearly over the extension of the support and reach the complete cone breakout at 2 h_{ef} or 3 h_{ef} for the tests with or without sleeves, respectively.

The ultimate loads in the stretcher bond tests exhibit no influence from the increase of the support width. Rather it is influenced from the brick dimension, since for NF bricks, the anchors failed all due to the combined splitting and mixed failure mode.

Since several issues remain unaddressed, future research work is suggested. Further tests with group anchorages should be carried out to estimate the critical axial distance (s_{cr}). Also tests with different injection mortars, sleeves and anchor sizes should be carried out to ensure if the assumption that the cone breakout begins at 2 h_{ef} or 3 h_{ef} applies in general. This study was limited to NF bricks for the stretcher bond but could be extended to bigger brick dimensions to exclude splitting failure mode.

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