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DRILLED-IN INSERTS IN MASONRY CONSTRUCTION

by

M. A. HATZINIKOLAS

R. LEE

J. LONGWORTH

J. WARWARUK

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THE UNIVERSITY OF ALBERTA

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M.A. Hatzinikolas[1], R. Lee[2], J. Longworth[3] and J. Warwaruk[4]

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Department of Civil Engineering

Edmonton, Alberta

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1 Director of Technical Services, Alberta Masonry Institute, Edmonton, Alberta
2 Research Assistant, Dept. of Civil Engineering, University of Alberta, Edmonton, Canada
3 Professor of Civil Engineering, University of Alberta, Edmonton, Alberta
4 Professor of Civil Engineering, University of Alberta, Edmonton, Alberta

Abstract

Drilled-in inserts are extensively used in masonry structures to transfer various types of loading. The present Canadian masonry code does not contain provisions for the design of such inserts.

The present study is concerned with the ultimate capacity and behavior modes of failure of drilled-in inserts in burned clay brick and concrete block masonry.

The experimental program consisted of a total of 440 tests under direct shear, direct tension and combined shear and tension. Six different types of expansion inserts and one type of adhesive insert were tested. Variables included type of masonry, insert diameter, embedment length and edge distance. The behavior of the specimens was monitored by measurements of load, longitudinal and lateral displacements.

Based on the test results and observations, the effects of the parameters on failure modes and specimen behavior are described. Empirical relationships are established to predict insert capacity and rational procedures are proposed for insert design.

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List of Symbols

A_s = cross-sectional area of insert

A_{sg} = gross cross-sectional area of insert

A_{sn} = cross-sectional area at the root of the thread

d = insert diameter

d_n = diameter at root of the thread

f'_b = unit compressive strength of brick or concrete block

f'_m = compressive strength of masonry

f_{ut} = ultimate tensile strength of insert material

f_y = yield strength of insert

K = edge distance factor

L = embedment length

T = applied tension load

T_a = allowable tension load

T_u = ultimate tension capacity

V = applied shear load

V_a = allowable shear load

V_m = shear strength of masonry

V_s = shear strength of insert

V_u = ultimate shear capacity

1. Introduction

1.1 General Remarks

Drilled-in inserts are commonly used in masonry structures to support a variety of fixtures and to provide support for angle iron and other structural connections. Drilled-in inserts are also used as an alternative to anchor bolts where these bolts may have been omitted during construction or where, due to construction procedures, proper placing of anchor bolts cannot be achieved.

Despite the extensive use of drilled-in inserts, current design codes[1,2] do not contain provisions for the design of such inserts. Although some studies[3,4] have investigated the strength and behavior of anchor bolts in masonry construction, no results of experimental investigations of drilled-in inserts have been published in Canada.

In this study, various types of drilled-in inserts which are commerically available in the Edmonton area were studied. As inserts are usually used to transfer direct shear force, direct tension force or a combination of both, these three load conditions were included in the study.

1.2 Drilled-in Inserts

Drilled-in inserts may be classified into two categories: metal expansion inserts and adhesive inserts. The characteristics of these two categories are shown in

Figure 1.1. Metal expansion inserts displace and compress the base material while expanding. They obtain their holding power through frictional force along the wall of the hole and a keying action between the grout and the insert. On the other hand, the adhesive inserts do not compress or exert any expansion forces on the base material. The holding power is developed from the adhesive bond between the insert and the grout by means of an adhesive mixture.

1.3 Object and Scope

The main objectives of this study are:

1. To determine experimentally the ultimate capacity of drilled-in inserts in burned clay brick and concrete block masonry when subjected to various combinations of shear and tension loads. Parameters included insert diameter, embedment length and edge distance.
2. To develop a rational procedure for the design of drilled-in inserts in masonry.

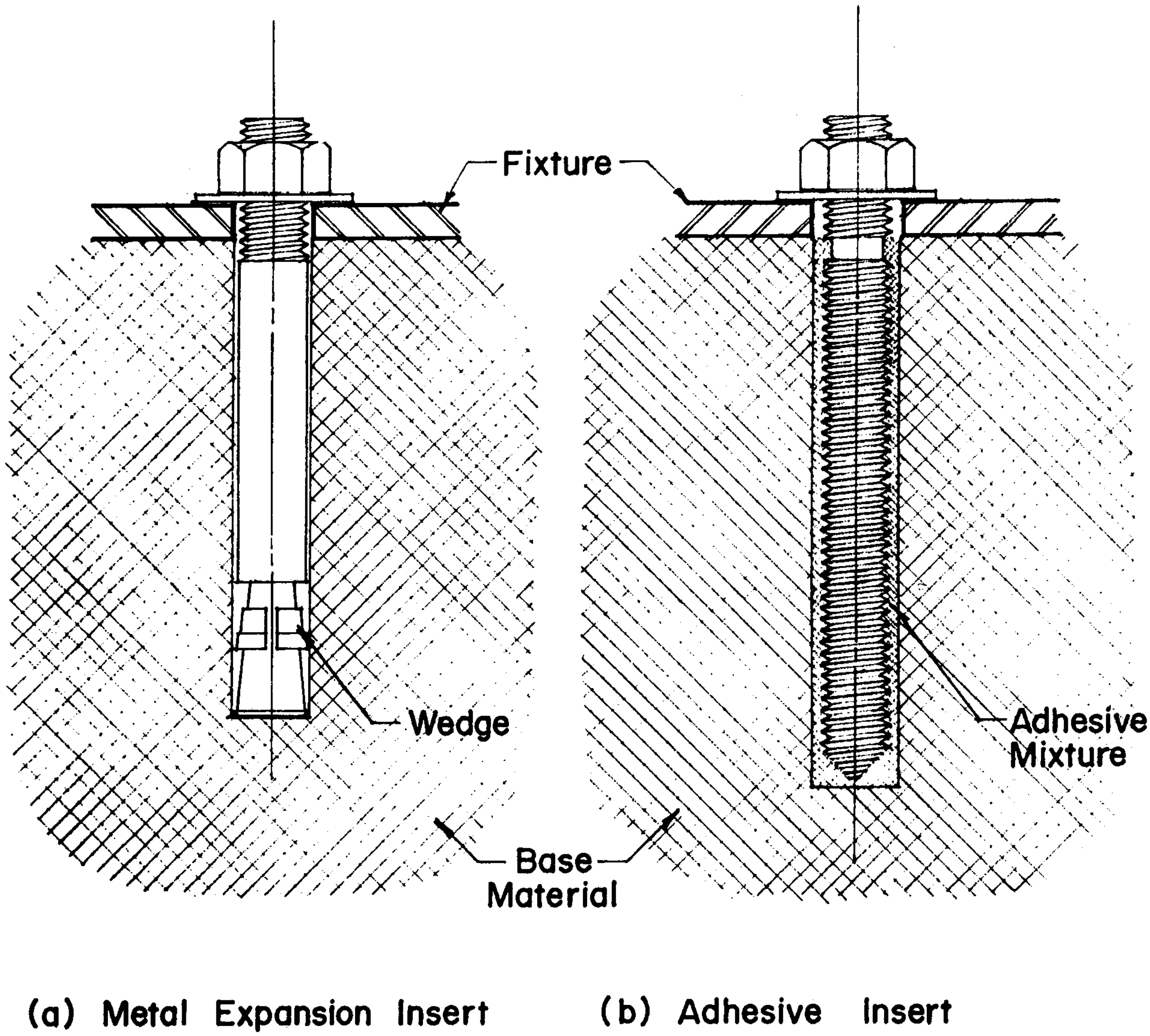

Figure 1.1 Installation of Drilled-in Inserts

2. Experimental Program

2.1 General Remarks

Tests were conducted on seven types of drilled-in inserts whose nominal diameters varied from 5 mm to 24 mm. These inserts were placed in burned clay brick and concrete block wall specimens. The test program consisted of 227 direct shear tests and 161 direct tension tests. Fifty-two combined tension and shear tests were performed on small size diameter inserts. Three tests were conducted for each loading condition. The distance from the insert to the loaded edge of the masonry, i.e., edge distance, varied from 50 mm to 650 mm in burned clay brick specimens, and from 95 mm to 695 mm in concrete block specimens. All inserts were installed at mid-height of a brick or block and at the center of a core as shown in Figure 2.1.

2.2 Materials

2.2.1 Drilled-in Inserts

Tests were performed on metal expansion inserts and adhesive inserts. Within these two categories, seven different types were tested in this program, sketches of these types are shown in Figure 2.2. The inserts are categorized as P, S1, S2, W1, W2 and WS for the expansion inserts and A for the adhesive inserts. Physical properties of the inserts and as-installed embedment lengths are given in Table 2.1. For metal expansion inserts, the area of the critical shear section will either be the gross area of the insert, A_{sg}, or the area at the root of the thread, A_{sn}, depending on the location of the thread relative to the masonry face. In Figure 2.3(a), the gross cross-sectional area, A_{sg}, is subjected to the applied shear load while in Figure 2.3(b), the area at the root of the thread, A_{sn}, is subjected to the applied shear load. The following is a general description of each type of insert.

Type P

This is the zamac pin bolt (ZPB) manufactured by Hilti. It is a light duty insert whose holding power is developed when the expanded insert body bears against the hole wall as a result of hammering the steel pin into the insert body.

Type S1 and Type S2

S1 is the sleeve anchor (SVA) manufactured by Hilti and S2 is the sleeve anchor (HN) manufactured by Phillips. The expansion is achieved by the tapered plug (wedge) forcing the sleeve outwards as the nut is tightened. The ribs on the sleeve are designed to obtain positive holding power.

Type W1 and Type W2

W1 is the kwik bolt (HSA) manufactured by Hilti and W2 is the wedge anchor (WS) manufactured by Phillips. For these inserts, torque applied to tighten the nut creates a tension force which presses the cone (tapered mandrel at the end of the insert) and the expansion sleeve (spring steel expansion wedges) against the base material. Holding power is developed through friction along the wall of the hole and the keying or wedging action of the wedge.

Type WS

This is the mechanical expansion anchor (HSL) manufactured by Hilti. It is actually a wedge as well as a sleeve insert in which the expansion forces can be controlled externally by the applied torque. It achieves its holding power by means of friction and keying action on the wall of the pre-drilled hole. As the insert is tightened, the expansion sleeve is expanded radially by the internally threaded cone. This results in a positive gripping action between the expansion sleeve and the base material.

Type A

This is the adhesive anchor (HVA) manufactured by Hilti. It is a stress-free insert since it does not stress the base material during the setting procedure. The holding power is obtained solely from the adhesive bond between the base material, adhesive mass and the threaded rod. Adhesion is achieved by cold hardening unsaturated liquid polyester resin which is mixed with quartz sand coated with benzol peroxide (hardening agent). The adhesive cartridge unit containing all the ingredients required to bond the insert to the masonry is first placed into the hole. The anchor rod is then driven into the hole under rotary hammer action and breaks the adhesive cartridge allowing its contents to be mixed by the rotary hammer action and distributed evenly throughout the anchor hole. The quantity of each component furnished ensures the entire space between the insert and the wall of the hole is filled with the adhesive mixture.

2.2.2 Wall Specimens

Burned clay brick and concrete block masonry units used to construct the walls were 190 mm wide and 390 mm long, and had two cores of similar dimensions. The burned clay unit were 90 mm high and had a compressive strength ranging from 35 MPa to 57 MPa. The concrete masonry units were 190 mm high and had a compressive strength of 19 MPa. The walls were constructed in running bond resulting in dimensions of 800x800x200 mm. The walls are shown schematically in Figure 2.4. Type S mortar was used in fabricating the walls. The cores were filled with concrete grout which was allowed to cure for at least 28 days prior to the installation of the inserts. The compressive strength of the grout varied from 15.2 MPa to 31.8 MPa.

2.3 Test Procedures

All 227 shear tests employed the setup illustrated in Plate 2.1 and shown schematically in Figure 2.5. The shear load was applied by a manually controlled hydraulic jack through a rod and fitting to the insert. The wall was restrained at the bottom by an angle iron and at the loading surface by a clamped hollow tube section.

The setup for the direct tension tests avoided restraint on the masonry unit into which the inserts were fastened. Plate 2.2 and Figure 2.6 illustrate direct tension test setup for small size inserts. For large size inserts, the arrangement shown in Plate 2.3 was used so as to reduce compressive stresses in the region of the insert.

For the combined tension and shear tests, tension loads were applied by means of a simple device consisting a fulcrum and two lever arms producing a mechanical advantage of 18. A predetermined tension load, in the form of a dead weight, was applied to the insert usually before the shear load was introduced. Plates 2.4 and 2.5 show the test setup.

All the inserts were installed at the maximum embedment depth. Prior to installing the inserts, the pre-drilled holes were cleaned using compressed air to remove all fragments and dust. For the adhesive inserts, the adhesive mixture was allowed to cure in accordance with the manufacturer's specifications prior to testing. For the expansion inserts, the nuts were hand tightened and then wrench tightened according to the manufacturer's specifications. A number of various size inserts were placed in each wall specimen. Since the damage produced in testing the small size inserts was usually too small to affect subsequent tests, small size inserts were tested before the larger size inserts. This procedure permitted an optimum number of tests to be performed using one wall specimen. If a wall was damaged seriously in a test, or if it was considered that the amount of damage might affect further tests, the wall was discarded.

Test data consisted of applied loads and insert displacements. The applied loads were monitored by load cells with 180 kN capacity. The displacements of the inserts relative to the wall were measured by means of a dial gauge or a linear variable differential transducer (LVDT). In measuring insert deflection in a direct shear test as shown in Plate 2.6, one end of the LVDT was clamped and attached to the wall while the other end rested against the fitting applying the shear load.

Table 2.1 Properties of Drilled-in Inserts

Type	Designation	Insert Diameter d (mm)	Diameter at Root of the Thread d_n (mm)	Overall Length (mm)	Emb. Length L (mm)	Ultimate Tensile Strength f_{ut} (MPa)
P	ZPB 3/16x7/8 ZPB 1/4x1	4.70 6.15	- -	28 29	22 22	
S1	SVA 1/4x1 3/8 SVA 5/16x1 1/2	6.35 7.90	3.20 4.90	41 45	28 31	
S2	HN 1624 HN 3830 HN 1240 HN 5842 HN 5860	7.90 9.50 12.30 15.40 15.40	5.35 6.85 8.35 11.15 11.15	72 80 110 120 158	54 64 88 94 120	430
W1	HSA M6x80 HSA M10x90 HSA M10x120 HSA M12x110 HSA M12x150 HSA M16x100 HSA M16x145 HSA M20x125 HSA M20x170	5.95 9.90 9.90 11.90 11.90 15.85 15.85 19.90 19.90	4.35 7.95 7.95 9.30 9.30 12.90 12.90 16.50 16.50	80 90 120 110 150 100 145 125 170	55 68 98 84 124 70 115 86 131	860
W2	WS 1432 WS 3850 WS 5850 WS 3454	6.30 9.50 15.80 19.00	4.60 7.45 12.80 15.20	83 127 127 139	65 104 88 92	620
WS	HSL M12/50 HSL M16/50	17.30 23.35	- -	145 170	113 137	800
A	HVA M8 HVA M10 HVA M12 HVA M16 HVA M20	7.85 9.80 11.80 15.85 19.85	6.55 8.35 10.00 13.80 17.00	110 130 160 190 240	80 90 110 125 170	560 to 780

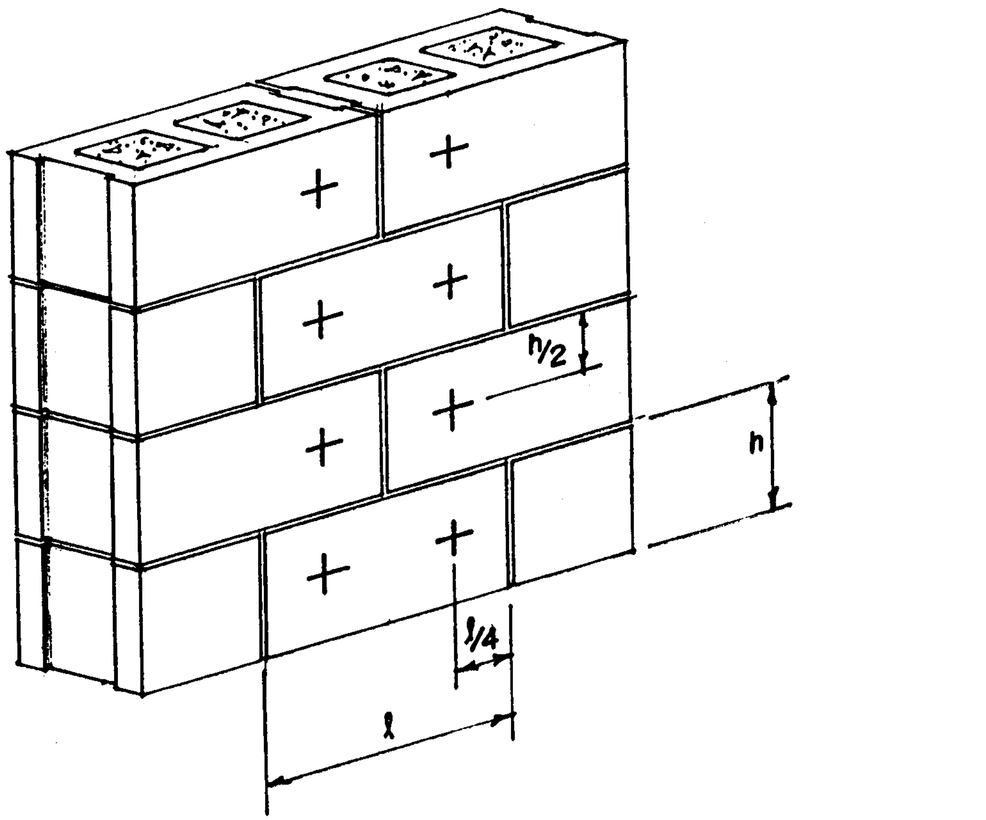

Figure 2.1 Locations of Drilled-in Inserts

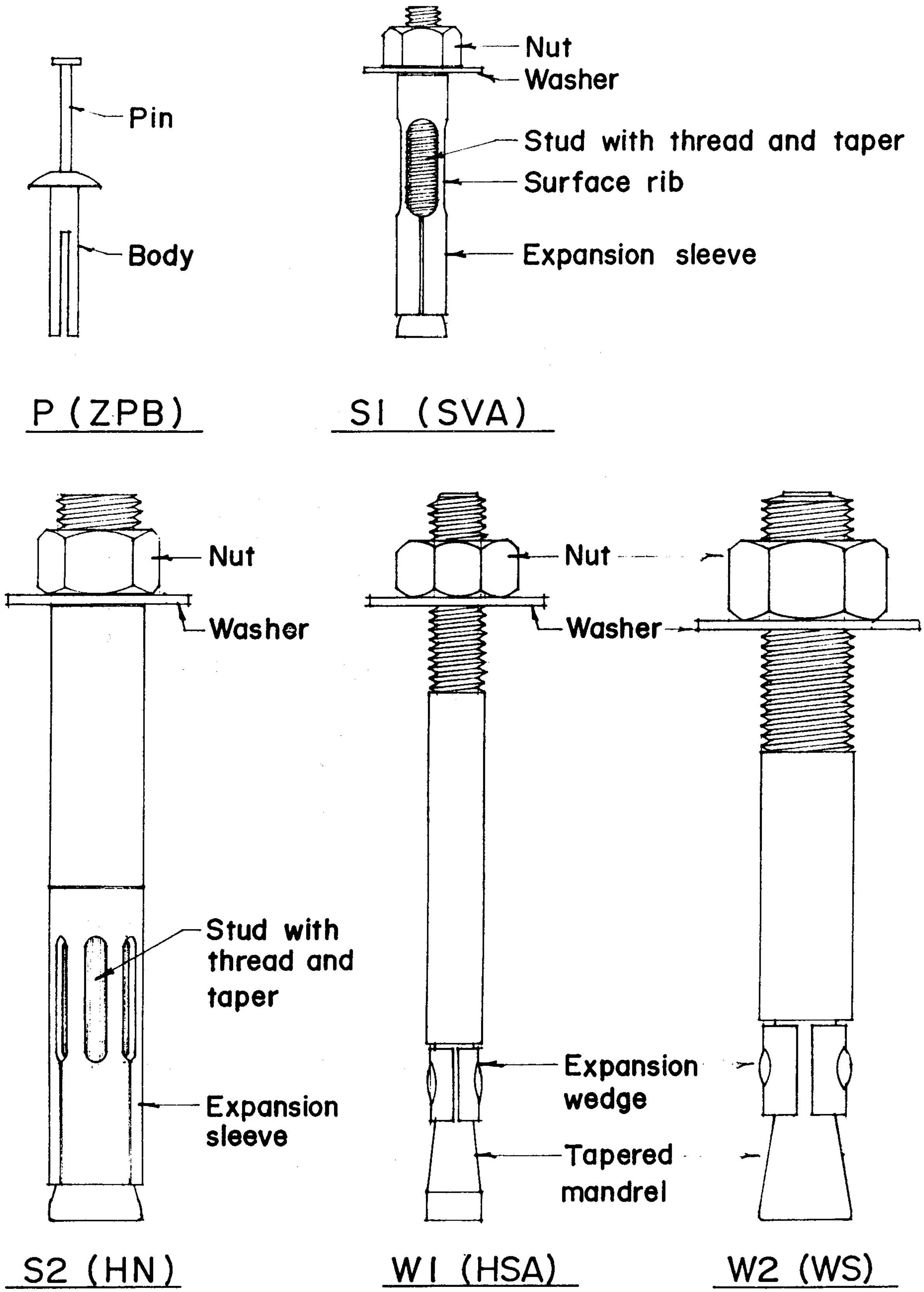

Figure 2.2 Drilled-in Inserts

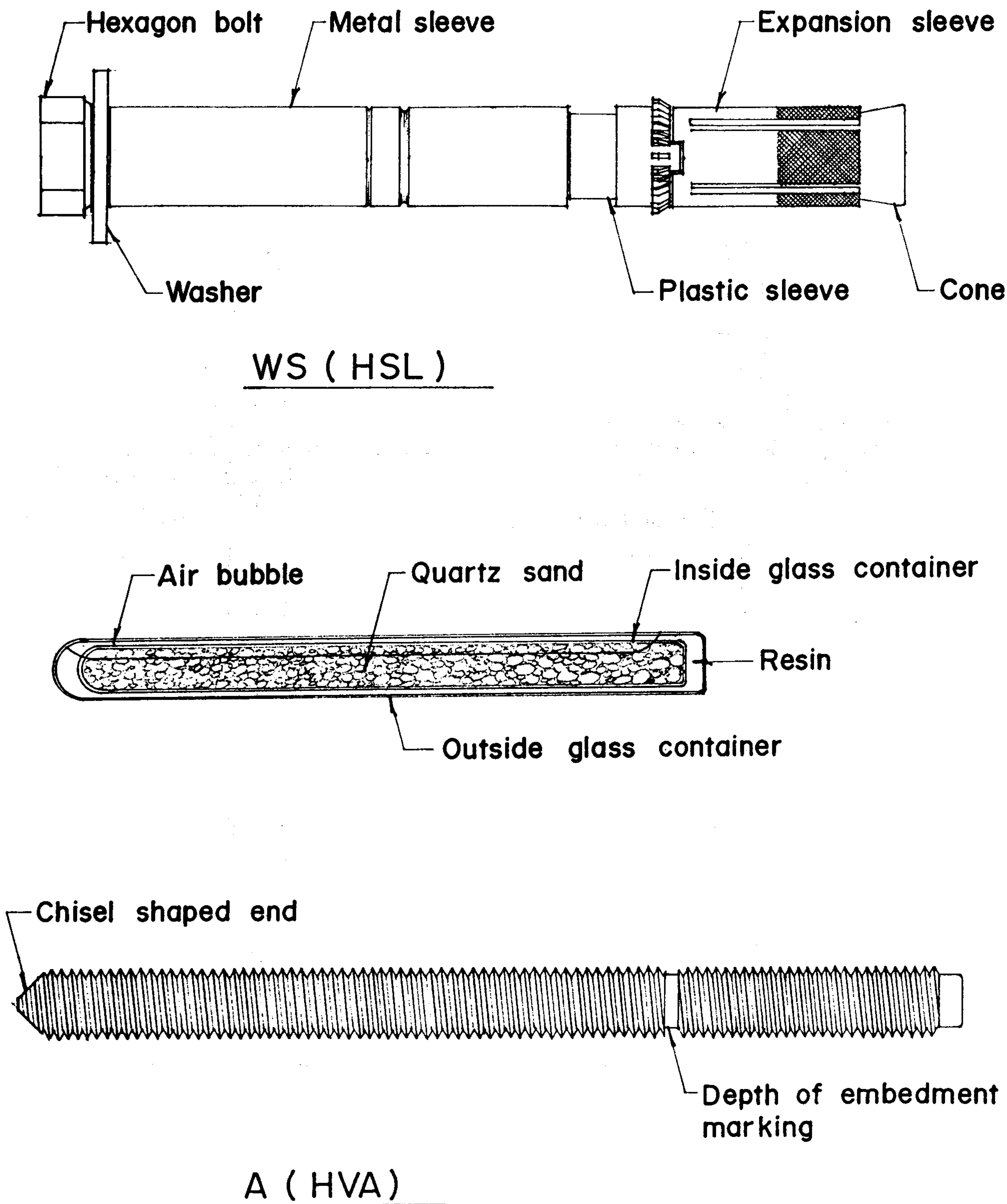

Figure 2.2 Drilled-in Inserts

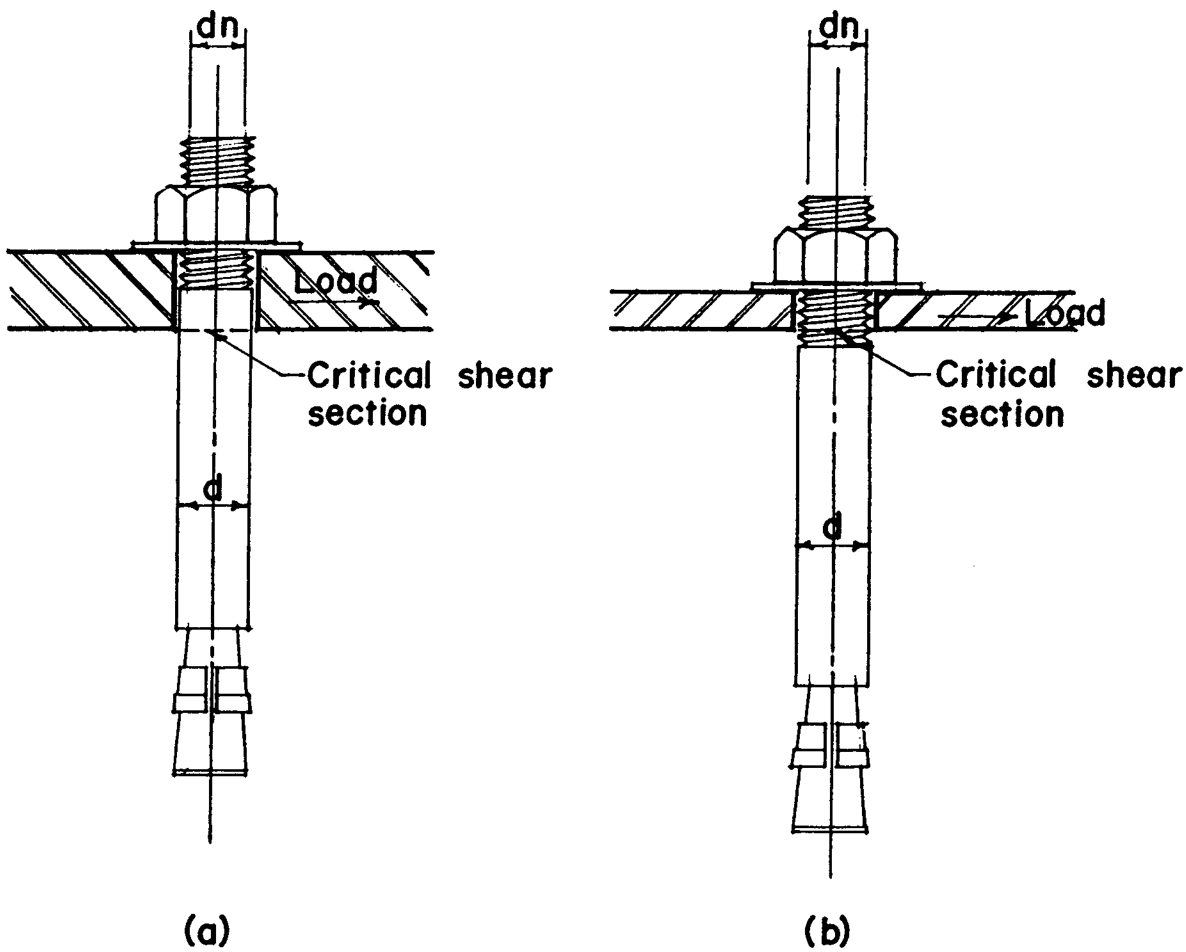

Figure 2.3 Inserts Supporting Lateral Loads

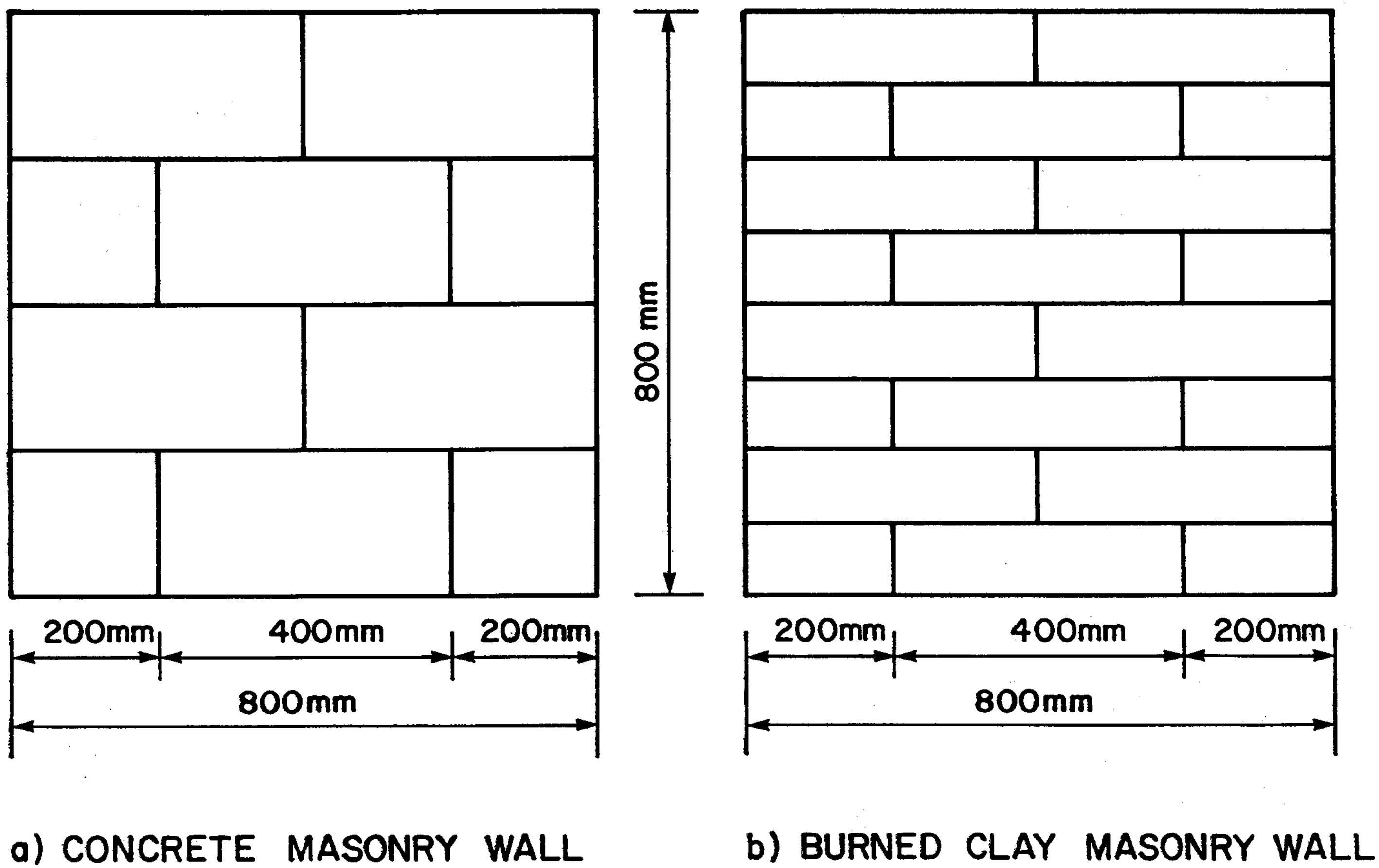

Figure 2.4 Overall Dimensions of Wall Specimens

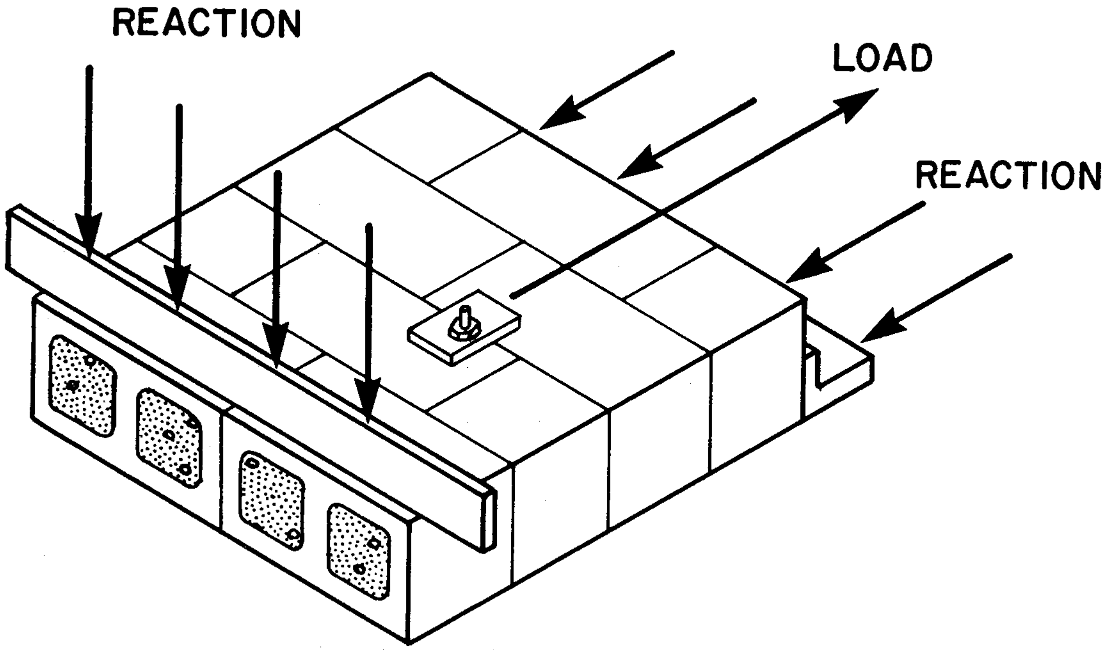

Figure 2.5 Schematic Representation of Shear Test

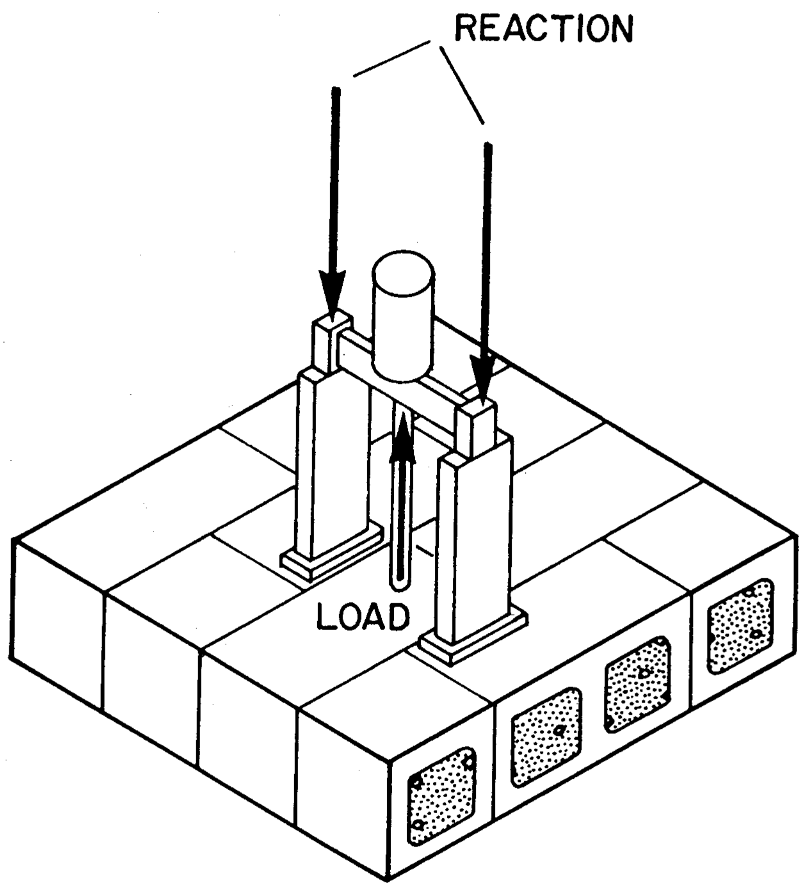

Figure 2.6 Schematic Representation of Tension Test

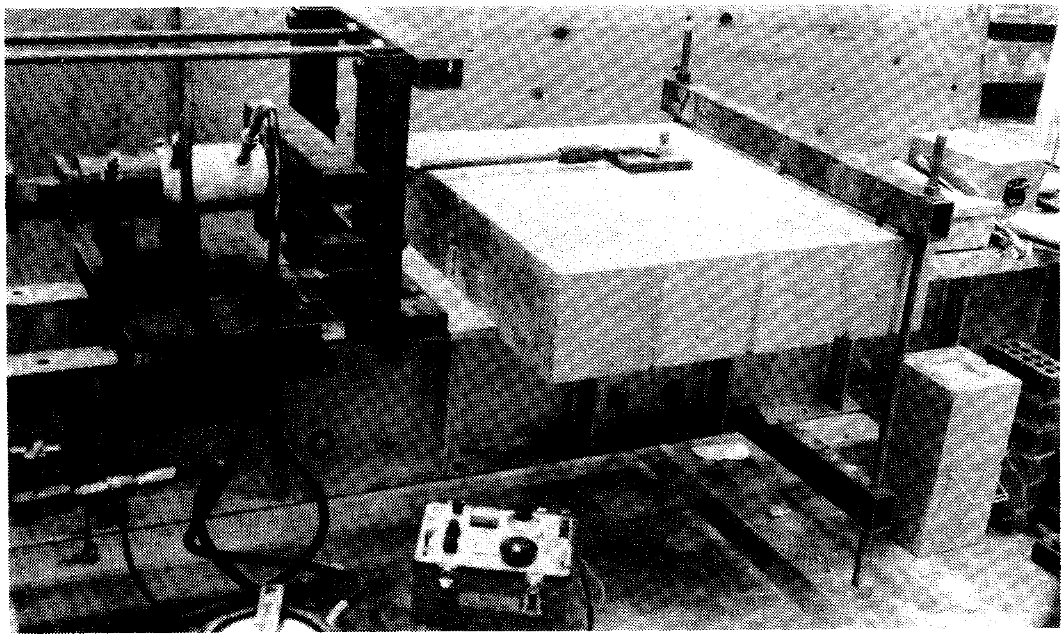

Plate 2.1 Shear Test Setup

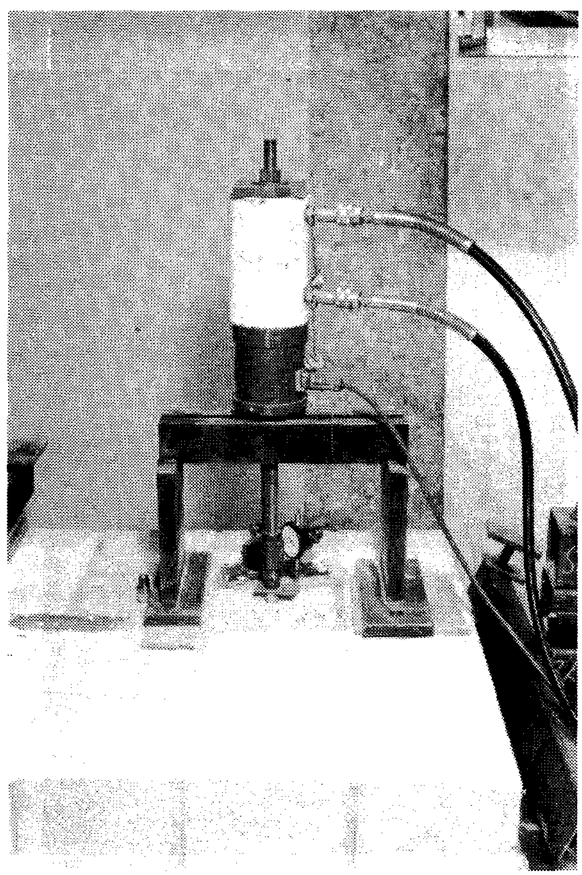

Plate 2.2 Tension Test Setup

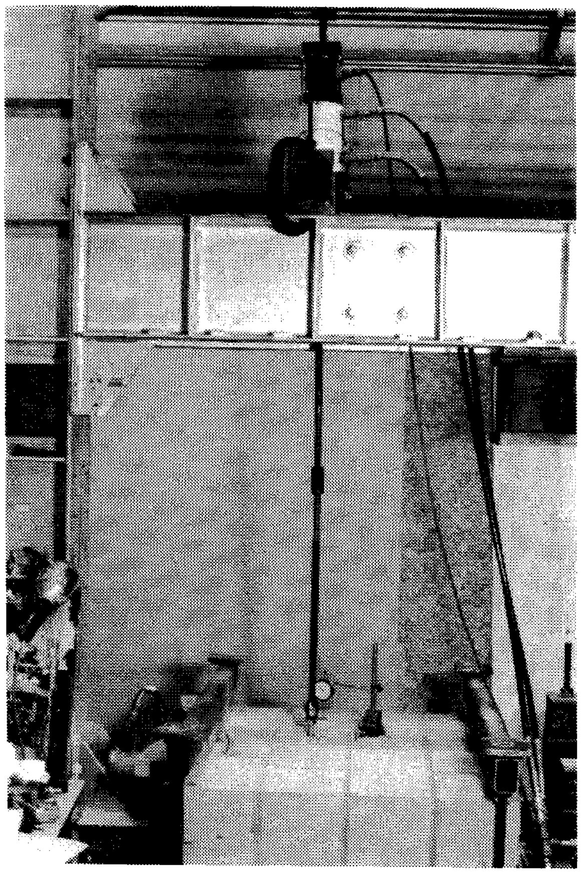

Plate 2.3 Tension Test Setup

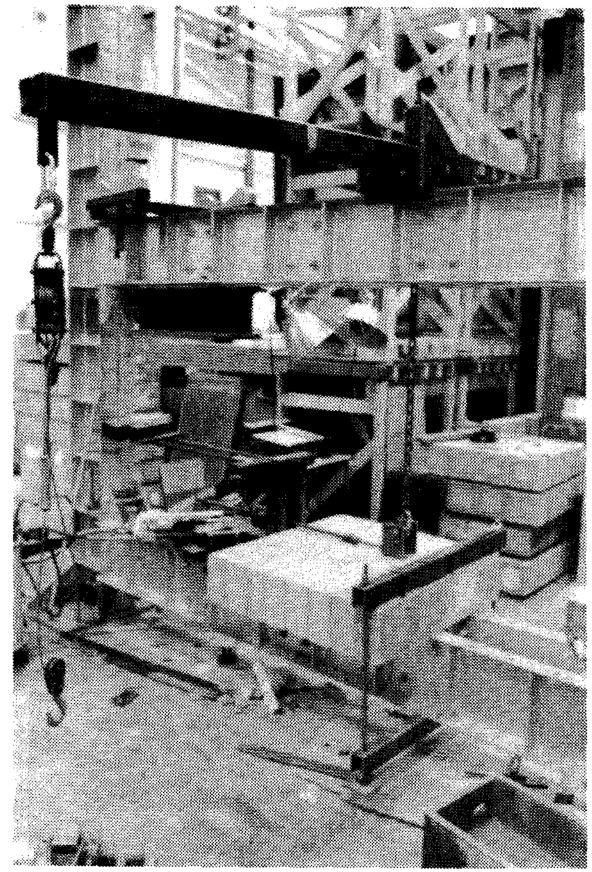

Plate 2.4 Combined Tension and Shear Test Setup

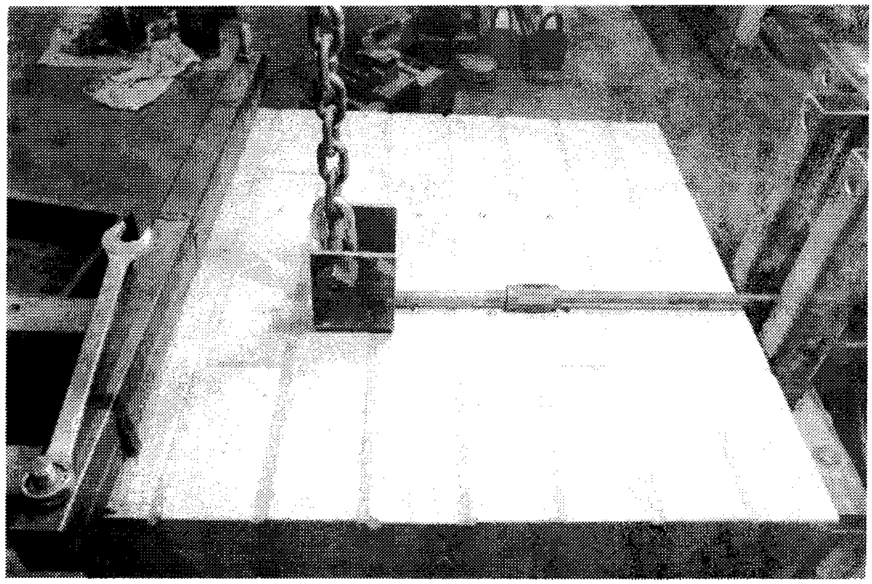

Plate 2.5 Application of Combined Tension and Shear

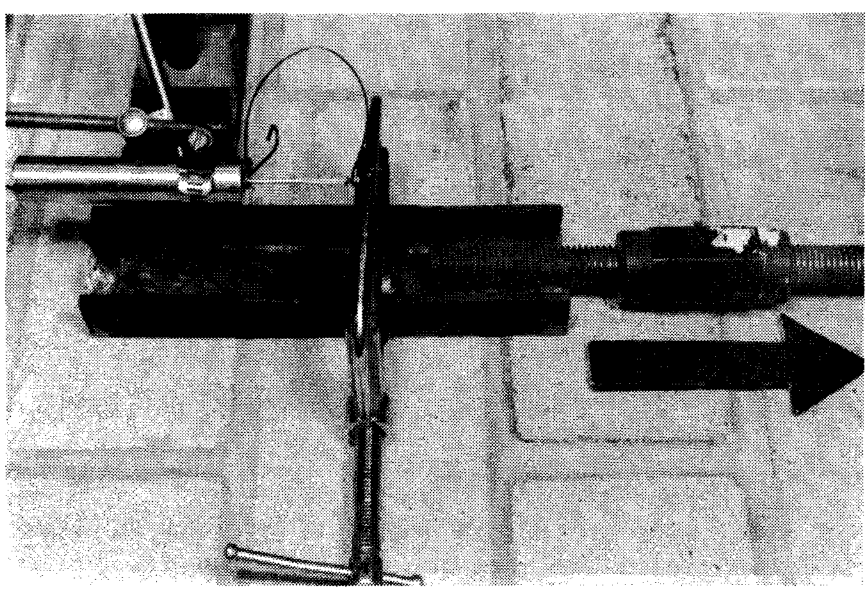

Plate 2.6 Test Setup for Measuring Deflection

3. Test Results

3.1 Introduction

Test results are summarized and presented in tabular, graphic and photographic form.

For the direct shear test, there were two failure modes:

1. Failure of the masonry by crushing of the face shell and cracking along the mortar joints.
2. Failure of the insert with the shank sheared off at the location of the critical shear section.

For the direct tension test, two failure modes were also observed:

1. Failure of the masonry by cracking or face shell lifting.
2. Failure of the insert by pulling out as a result of broken bond for adhesive inserts, or by insert slipping for expansion inserts.

There was considerable variation in the test results for the first mode of failure in both the direct shear and direct tension tests due to such factors as difference in strength of the materials, e.g., masonry units, grout, mortar; as well as workmanship in installing the inserts. There was less variation for the second failure mode in both the direct shear and tension tests.

3.2 Direct Shear Test

The ultimate shear capacities of the inserts in hollow concrete block, grouted clay brick and grouted concrete block masonry are given in Tables 3.1, 3.2 and 3.3, respectively.

3.2.1 Failure Modes

For the light duty expansion inserts (Types P and S1) installed in hollow concrete block, failure always occurred as a result of the block splitting when the edge distance was small or when the size of the insert was large. However, for larger edge distances or smaller insert sizes, the inserts bent significantly and then pulled out of the pre-drilled holes. As a result the sheaths of Type P inserts were usually broken.

For the expansion (Types S2, W1, W2 and WS) and adhesive (Type A) inserts installed in grouted masonry walls, failure was immediate and brittle. For small edge distances, the masonry tended to crack and spall off in the direction of the load as shown in Plate 3.1. For large edge distances, failure occurred either in the masonry or the insert. Masonry failure consisted of crushing of the face shell in the vicinity of the inserts in the direction of the load and cracking of the wall specimen. In most cases, the masonry cracked radially outward from the insert and the cracks usually propogated along either the head or bed mortar joints. Typical masonry failures for shear specimens are shown in Plates 3.2 to 3.5. Insert failure occurred when the shear capacity of the insert material was reached. The insert usually sheared off level with the surface of the masonry with little cracking or crushing as shown in Plates 3.6, 3.7 and 3.8. In a few cases, the insert sheared off slightly above the face as shown in Plates 3.9 and 3.10. As shown in Plate 3.11, crushing of the face shell ahead of the insert shaft and a visible gap behind it was usually observed.

For the same insert size, cracking and crushing in the clay brick masonry walls were usually less severe than in the concrete block masonry walls. This behavior is attributed to the large difference in the strengths of the burned clay brick units and the concrete block units. The difference in the strengths of the brick and block units also affected the failure modes of some inserts. For example, for Type A adhesive inserts, failure of the masonry by crushing and cracking was observed when the insert was installed in concrete block masonry, whereas shear failure of the insert was the major failure mode when the insert was installed in brick masonry. If the compressive strengths of the brick and block units had been the same, similar failure modes would be expected for inserts installed in brick and block masonry.

Adhesive inserts are stress-free inserts whereas expansion inserts compress the grout as they are tightened. This difference between the two types provides a significant effect on the masonry even before the inserts are loaded. As shown in Figure 3.1, the adhesive insert does not deform the grout but only develop adhesive bonding between the grout and the insert. The large initial stress created by tightening the expansion insert produces microscopic cracks in the grout around the wedge of the insert before external load is applied. This leads to different failure modes than those for adhesive inserts. The adhesive inserts sheared off with only minor crushing at the face shell as shown in Plate 3.8. However, as shown in Plate 3.2 for expansion inserts, the wall cracked severely as a result of the propagation of the initial fine cracks.

3.2.2 Load Deflection Characteristics

Typical load deflection curves for each type of specimen are shown in Figures 3.2 to 3.9. The lateral insert deflection increased with decreasing insert diameter for both brick and concrete block masonry. Load deflection curves for the inserts installed in brick masonry are slightly steeper than those for inserts installed in concrete block masonry. This is due to the greater restraint provided by the stronger brick units. The curves indicate that edge distance does not have any effect on lateral deflection.

For Type A inserts, there is no significant difference in the lateral deflection in brick or concrete block masonry although there was a significant difference in the compressive strength of the units. Type W1 inserts appear to be more ductile when installed in grouted concrete block than in grouted brick masonry. The almost identical physical characteristics of Types W1 and W2 are reflected in their similar load deflection curves as shown in Figures 3.5 and 3.6.

Type S2 inserts (Figure 3.7) are more ductile than the Type W1 (Figure 3.4). This is to be expected as the gap between the sleeve and the main shaft for Type S2 inserts may possibly allow some movement when lateral load is applied. Although deflection curves for Types WS and W1 cannot be directly compared because of size difference, comparison of the curves for closest sizes (Figure 3.4 and 3.9) indicates that Type WS is stiffer than Type W1.

The load-deflection relationships are governed by the physical characteristics of the inserts. The sleeve insert, Type S2, is the most ductile insert because of the large gap between the sleeve and the insert shaft that permits significant lateral displacement. Type WS which is a combined sleeve and wedge insert, was the stiffest expansion insert tested.

For same size of insert with different overall lengths, Figure 3.10 indicates that there is no noticeable difference in the lateral load deflection relationship when the inserts were embedded at the maximum available depth based on the insert length. This implies that the ultimate capacity and the load deflection relationship would not be affected by the overall length of an insert as long as its embedment length is greater than the minimum embedment depth required by the manufacturers.

3.3 Direct Tension Test

The ultimate tension capacities of the inserts in hollow clay brick, hollow concrete block, grouted clay brick and grouted concrete block masonry are given in Tables 3.4 to 3.7, respectively.

3.3.1 Failure Modes

For small size expansion inserts (less than 16 mm in diameter), failure occurred when the inserts pulled out by slipping. Usually no cracks were observed in the masonry.

For the adhesive inserts, failure usually occurred when the masonry cracked as shown in Plate 3.12, with cracks running perpendicular to the mortar joints. In some cases, the face shell also lifted. This indicates the high bonding forces produced by the adhesive material as compared to the less effective frictional and wedging forces of the expansion inserts. The strong adhesive bond developed by Type A inserts is also indicated in Plate 3.13 which shows an 8 mm insert with its threads stripped.

For larger size expansion and adhesive inserts, significant cracking occurred in the masonry with cracks usually initiating perpendicular to the bed joints as shown in Plates 3.14 and 3.15 and then following mortar joints or propogating through the brick or block in the next courses as shown in Plates 3.16 and 3.17. As a result a considerable area of the wall surface was affected.

As mentioned earlier, the small size expansion inserts failed by pulling out of the pre-drilled holes. In some cases, the specimen was still be able to hold the applied load; however, the amount of displacement was quite significant. The tension capacity of such specimens was defined as the load corresponding to a longitudinal displacement equal to 25% of the insert diameter. For the larger expansion inserts, the wall usually cracked before this amount of displacement was reached.

3.3.2 Load Displacement Characteristics

Load displacement curves are shown in Figures 3.11 to 3.18. Longitudinal displacement decreased with increasing insert diameter for all types of inserts installed in brick and concrete block masonry. Variations in the displacement curves are probably due to the large variation in workmanship in installing the inserts. It is believed that this factor has greater effect on the direct tension test results than on the direct shear test results. The behavior of small size expansion inserts is greatly affected by the cleaniness of the pre-drilled holes.

As shown in Figures 3.11 and 3.12, the displacement curves for Type A inserts are relatively steep and linear up to the maximum load with failure occurring suddenly as a result of broken bond or wall cracking. However, Figures 3.13 and 3.14 indicate that, for the expansion inserts, the curves flatten out as the amount of pulling force increases. Displacements for adhesive inserts are much less than for expansion inserts of the same size at a given load. Type W2 and W1 inserts exhibit very similar behavior (Figures 3.14 and 3.15). For the sleeve inserts (Type S2), displacement is greater than for wedge inserts of the same size (Figures 3.13 and 3.17).

3.4 Combined Tension and Shear Test

For both the adhesive and expansion inserts, the failure mode depended on the magnitude of the applied tension load. For low tension loads, the insert sheared near the masonry surface as shown in Plates 3.18 and 3.19. For large tension loads, failure occurred when the insert pulled out by slipping for the expansion inserts or when the masonry face shell severely cracked and lifted due to bond broken for the adhesive inserts as shown in Plate 3.20. Although it is not possible to accurately define the shear to tension load ratio which separates the two failure modes, test results indicate that when the shear to tension load ratio is greater than one, shearing failure of the insert occurred and when the ratio is less than one, pull-out failure of the insert predominated. However, some adhesive inserts failed by shearing when the shear to tension load ratio was about 0.6. More tests must be performed before a definite conclusion can be drawn.

3.5 Embedment Depth Test

Direct tension and shear tests were performed for various embedment depths on two expansion inserts (HSA M10x120 and HSA M12x150).

For both inserts the shear capacity varied with embedment length as shown in Table 3.8. When the embedment length was at a maximum with the threaded part of the insert at the face of the masonry, the shear capacity was dependent on the area of the insert at the root of the thread. When the embedment length was reduced so that the unthreaded portion of the insert extended outwards beyond the face of the masonry, the shear capacity was significantly higher because the insert sheared through the gross area. However, as the embedment length was further decreased so that the wedge was close to the interface of grout and brick, the shear capacity dropped because the wedge broke before the insert sheared. Plate 3.21 to 3.25 show the failed specimens and Plate 3.26 shows the exposed portions of the inserts after test.

The lateral deflection curves shown in Figures 3.19 and 3.20 indicate that lateral deflection is reduced when the lateral load is applied to the shaft of the insert rather than to the threaded portion. However, if the embedment depth is too shallow, the restraint provided by the masonry is reduced resulting in a larger lateral deflection.

Table 3.8 indicates that there is little variation in tension capacity with embedment depth. However, when the wedge of the insert was close to the face shell, significant cracking occurred in the masonry. When the wedge was set at the interface of the grout and shell, the face shell cracked severely and then lifted up, resulting in lower failure load. Plates 3.27 to 3.30 show the failed tension specimens.

As shown in Figures 3.21 and 3.22, the longitudinal displacement of the inserts does not appear to be affected by the embedment depth. However, when the wedge is close to the face shell, the load-displacement curve is flattened because load could not be increased once the face shell cracked and lifted up.

The minimum shear capacity of an insert occurs when the threaded portion extends into the masonry.

Table 3.1 Shear Strength of Inserts in Hollow Concrete Block Masonry

Type	Designation	Embedment Length (mm)	Edge Distance (mm)	Failure Load (kN)	Failure Mode
P	ZPB 3/16x7/8	22	25	1.8	M*
	ZPB 3/16x7/8	22	25	2.3	M
	ZPB 3/16x7/8	22	25	1.6	M
	ZPB 3/16x7/8	22	25	1.9	M
	ZPB 3/16x7/8	22	50	3.8	P#
	ZPB 3/16x7/8	22	50	3.5	P
	ZPB 3/16x7/8	22	50	4.4	P
	ZPB 3/16x7/8	22	50	3.7	P
	ZPB 1/4x1	22	25	2.2	M
	ZPB 1/4x1	22	25	1.8	M
	ZPB 1/4x1	22	25	1.8	M
	ZPB 1/4x1	22	25	2.1	M
	ZPB 1/4x1	22	25	1.4	M
	ZPB 1/4x1	22	25	2.3	M
	ZPB 1/4x1	22	25	1.8	M
	ZPB 1/4x1	22	25	2.2	M
	ZPB 1/4x1	22	50	4.9	M
	ZPB 1/4x1	22	50	3.6	M
	ZPB 1/4x1	22	50	4.5	I&
	ZPB 1/4x1	22	50	3.6	M
	ZPB 1/4x1	22	50	4.3	P
	ZPB 1/4x1	22	50	3.1	P
	ZPB 1/4x1	22	50	5.7	P
	ZPB 1/4x1	22	50	4.7	I
	ZPB 1/4x1	22	75	6.3	I
	ZPB 1/4x1	22	75	5.1	I
	ZPB 1/4x1	22	75	6.3	I
	ZPB 1/4x1	22	75	4.9	I
S1	SVA 1/4x1 3/8	28	25	1.7	M
	SVA 1/4x1 3/8	28	25	2.1	M
	SVA 1/4x1 3/8	28	25	1.8	M
	SVA 1/4x1 3/8	28	25	1.8	M
	SVA 1/4x1 3/8	28	50	4.0	M
	SVA 1/4x1 3/8	28	50	4.4	M
	SVA 1/4x1 3/8	28	50	4.1	M
	SVA 1/4x1 3/8	28	50	3.8	M
	SVA 1/4x1 3/8	28	75	5.6	I
	SVA 1/4x1 3/8	28	75	5.2	I
	SVA 1/4x1 3/8	28	75	4.9	I
	SVA 1/4x1 3/8	28	75	5.8	I
	SVA 5/16x1 1/2	31	25	2.1	M
	SVA 5/16x1 1/2	31	25	2.5	M
	SVA 5/16x1 1/2	31	50	3.6	M
	SVA 5/16x1 1/2	31	50	3.5	M

Table 3.1 - continued

Type	Designation	Embedment Length (mm)	Edge Distance (mm)	Failure Load (kN)	Failure Mode
S1	SVA 5/16x1 1/2	31	50	6.0	M
	SVA 5/16x1 1/2	31	50	8.0	M
	SVA 5/16x1 1/2	31	50	4.6	M
	SVA 5/16x1 1/2	31	50	4.6	M
	SVA 5/16x1 1/2	31	75	6.1	M
	SVA 5/16x1 1/2	31	75	6.7	M
	SVA 5/16x1 1/2	31	75	6.3	M
	SVA 5/16x1 1/2	31	75	6.3	M

* M - concrete block cracked
\# P - insert pulled out
& I - pin sheath failed or insert broke

Table 3.2 Shear Strength of Inserts in Grouted Burned Clay Brick Masonry

Type	Designation	Embedment Length (mm)	Grout Strength (MPa)	Edge Distance (mm)	Failure Load (kN)	Failure Mode
S2	HN 1240	88	17.9	250	28.2	I*
	HN 1240	88	17.9	250	29.0	I
	HN 1240	88	17.9	450	18.4	I
	HN 5842	94	17.9	450	40.5	M#
	HN 5842	94	17.9	650	40.8	M
W1	HSA M6x80	55	17.9	250	10.5	I
	HSA M6x80	55	17.9	250	9.8	I
	HSA M6x80	55	17.9	250	8.6	I
	HSA M6x80	55	17.9	250	8.7	I
	HSA M6x80	55	17.9	450	8.1	I
	HSA M10x90	68	17.9	50	9.0	M
	HSA M10x90	68	17.9	250	20.4	I
	HSA M10x90	68	17.9	250	21.0	I
	HSA M10x90	68	17.9	250	20.8	I
	HSA M10x90	68	17.9	250	20.2	I
	HSA M10x90	68	17.9	250	20.8	I
	HSA M10x90	68	17.9	450	20.6	I
	HSA M10x90	68	17.9	450	24.5	I
	HSA M10x90	68	17.9	450	20.5	I
	HSA M10x90	68	17.9	650	22.1	I
	HSA M10x120	98	18.8	250	15.3	I
	HSA M10x120	98	18.8	450	18.4	I
	HSA M10x120	98	17.9	450	21.6	I
	HSA M10x120	98	18.8	650	16.0	I
	HSA M12x110	84	17.9	250	37.4	I
	HSA M12x110	84	17.9	250	40.7	I
	HSA M12x110	84	17.9	250	31.3	I
	HSA M12x110	84	17.9	250	32.3	I
	HSA M12x110	84	17.9	450	37.3	I
	HSA M12x110	84	17.9	450	31.2	I
	HSA M12x110	84	17.9	450	38.2	I
	HSA M12x110	84	17.9	450	31.5	I
	HSA M12x110	84	17.9	650	38.3	I
	HSA M12x110	84	17.9	650	33.6	I
	HSA M12x110	84	17.9	650	34.2	I
	HSA M12x150	124	18.8	250	34.1	M
	HSA M12x150	124	18.8	450	37.1	I
	HSA M12x150	124	18.8	450	37.4	I
	HSA M12x150	124	18.8	650	37.4	I
	HSA M12x150	124	17.9	650	36.1	I
	HSA M16x100	70	17.9	450	44.8	M
	HSA M16x100	70	18.8	450	45.4	M
	HSA M16x100	70	17.9	450	51.1	M
	HSA M16x100	70	18.8	650	45.0	M

Table 3.2 - continued

Type	Designation	Embedment Length (mm)	Grout Strength (MPa)	Edge Distance (mm)	Failure Load (kN)	Failure Mode
W1	HSA M16x145	115	17.9	650	72.8	I
	HSA M20x125	86	18.8	450	58.4	M
A	HVA M8	80	18.8	50	11.6	M
	HVA M8	80	17.9	50	7.8	M
	HVA M8	80	18.8	250	13.1	I
	HVA M8	80	18.8	450	12.7	I
	HVA M10	90	17.9	50	10.0	M
	HVA M10	90	18.8	250	19.9	I
	HVA M10	90	17.9	250	25.4	I
	HVA M10	90	17.9	450	22.0	I
	HVA M10	90	17.9	450	24.0	I
	HVA M10	90	18.8	450	19.2	I
	HVA M10	90	18.8	650	16.6	I
	HVA M12	110	18.8	250	26.2	I
	HVA M12	110	17.9	250	32.0	I
	HVA M12	110	18.8	450	27.3	I
	HVA M12	110	17.9	450	33.1	I
	HVA M12	110	18.8	650	26.4	I
	HVA M12	110	17.9	650	38.0	I
	HVA M12	110	17.9	650	40.0	I
	HVA M16	125	18.8	450	55.9	I
	HVA M16	125	18.8	650	52.4	I
	HVA M16	125	17.9	650	68.2	I

* I - insert sheared
\# M - brick cracked and crushed

Table 3.3 Shear Strength of Inserts in Grouted Concrete Block Masonry

Type	Designation	Embedment Length (mm)	Grout Strength (MPa)	Edge Distance (mm)	Failure Load (kN)	Failure Mode
S2	HN 1624	54	18.8	95	9.5	I*
	HN 1624	54	18.8	295	8.4	I
	HN 1624	54	18.8	495	7.9	I
	HN 3830	64	18.8	295	13.8	I
	HN 3830	64	18.8	495	14.4	I
	HN 3830	64	18.8	695	13.9	I
	HN 1240	88	18.8	95	16.3	M#
	HN 1240	88	18.8	295	25.7	I
	HN 1240	88	18.8	495	18.9	I
	HN 5842	94	18.8	295	35.9	M
	HN 5842	94	18.8	495	34.6	M
	HN 5842	94	18.8	695	45.8	I
	HN 5860	120	18.8	695	49.3	M
W1	HSA M6x80	55	31.8	95	8.8	I
	HSA M6x80	55	31.8	95	9.5	I
	HSA M6x80	55	31.8	295	9.5	I
	HSA M10x90	68	31.8	95	10.0	I
	HSA M10x90	68	15.2	295	14.5	I
	HSA M10x90	68	31.8	295	18.3	I
	HSA M10x90	68	15.2	495	13.1	I
	HSA M10x90	68	15.2	695	16.8	I
	HSA M10x120	98	31.8	95	10.0	M
	HSA M10x120	98	31.8	295	22.5	I
	HSA M10x120	98	31.8	695	20.6	I
	HSA M12x110	84	31.8	95	10.8	M
	HSA M12x110	84	15.2	295	22.6	M
	HSA M12x110	84	31.8	295	20.0	M
	HSA M12x110	84	15.2	495	27.2	I
	HSA M12x110	84	31.8	495	29.0	I
	HSA M12x110	84	31.8	495	25.0	I
	HSA M12x110	84	15.2	695	26.0	I
	HSA M12x110	84	31.8	695	30.6	I
	HSA M12x150	124	15.2	95	14.3	M
	HSA M12x150	124	15.2	295	28.6	I
	HSA M12x150	124	31.8	295	28.4	I
	HSA M12x150	124	31.8	495	30.7	I
	HSA M12x150	124	31.8	695	28.8	I
	HSA M16x100	70	15.2	295	19.8	M
	HSA M16x100	70	31.8	295	25.0	M
	HSA M16x100	70	15.2	495	30.0	M
	HSA M16x100	70	31.8	495	31.7	M
	HSA M16x100	70	15.2	695	26.0	M
	HSA M16x100	70	31.8	695	32.0	M
	HSA M16x145	115	31.8	95	15.0	M

Table 3.3 - continued

Type	Designation	Embedment Length (mm)	Grout Strength (MPa)	Edge Distance (mm)	Failure Load (kN)	Failure Mode
W1	HSA M16x145	115	31.8	295	24.1	M
	HSA M16x145	115	15.2	495	36.0	M
	HSA M16x145	115	31.8	495	40.0	M
	HSA M16x145	115	15.2	695	37.6	M
	HSA M16x145	115	31.8	695	42.2	M
	HSA M16x145	115	31.8	695	42.5	M
	HSA M20x125	86	15.2	295	22.5	M
	HSA M20x125	86	31.8	295	22.5	M
	HSA M20x125	86	15.2	495	49.2	M
	HSA M20x125	86	31.8	495	41.5	M
	HSA M20x125	86	31.8	695	40.0	M
	HSA M20x170	131	31.8	295	20.0	M
	HSA M20x170	131	15.2	495	35.3	M
	HSA M20x170	131	15.2	495	37.9	M
	HSA M20x170	131	31.8	495	37.5	M
	HSA M20x170	131	31.8	695	48.3	M
W2	WS 1432	65	18.8	295	14.0	I
	WS 1432	65	18.8	495	15.1	I
	WS 1432	65	18.8	495	17.9	I
	WS 3850	104	18.8	295	18.4	I
	WS 3850	104	18.8	495	19.2	I
	WS 3850	104	18.8	495	19.5	I
	WS 5850	88	18.8	295	29.3	M
	WS 5850	88	18.8	295	37.6	M
	WS 5850	88	18.8	495	44.1	I
	WS 5850	88	18.8	495	43.9	I
	WS 3454	92	18.8	295	38.4	M
	WS 3454	92	18.8	495	49.5	M
WS	HSL M12/50	113	31.8	295	32.5	M
	HSL M12/50	113	15.2	495	52.2	M
	HSL M12/50	113	15.2	495	57.9	M
	HSL M12/50	113	31.8	495	40.0	M
	HSL M12/50	113	31.8	695	45.0	M
	HSL M16/50	137	15.2	495	44.5	M
	HSL M16/50	137	15.2	495	54.3	M
	HSL M16/50	137	15.2	495	44.1	M
A	HVA M8	80	31.8	95	15.0	I
	HVA M8	80	31.8	295	14.1	I
	HVA M10	90	31.8	95	16.3	M
	HVA M10	90	15.2	295	24.9	I
	HVA M10	90	31.8	295	15.7	I
	HVA M12	110	15.2	95	15.1	M
	HVA M12	110	31.8	95	17.6	M

Table 3.3 - continued

Type	Designation	Embedment Length (mm)	Grout Strength (MPa)	Edge Distance (mm)	Failure Load (kN)	Failure Mode
A	HVA M12	110	15.2	295	26.0	I
	HVA M12	110	15.2	495	28.0	I
	HVA M12	110	15.2	695	27.0	I
	HVA M12	110	31.8	695	27.5	I
	HVA M16	125	15.2	295	42.0	M
	HVA M16	125	31.8	295	40.0	M
	HVA M16	125	15.2	495	46.8	M
	HVA M16	125	15.2	695	56.0	M
	HVA M16	125	31.8	695	50.0	M
	HVA M20	170	15.2	495	50.0	M
	HVA M20	170	15.2	495	31.8	M
	HVA M20	170	31.8	695	67.5	M

* I - insert sheared
\# M - block cracked and crushed

Table 3.4 Tension Strength of Inserts in Hollow Burned Clay Brick Masonry

Type	Designation	Embedment Length (mm)	Failure Load (kN)	Failure Mode
P	ZPB 3/16x7/8	22	3.0	P*
	ZPB 3/16x7/8	22	3.8	P
	ZPB 3/16x7/8	22	3.9	P
	ZPB 3/16x7/8	22	3.7	P
	ZPB 3/16x7/8	22	3.7	P
	ZPB 1/4x1	22	1.5	P
	ZPB 1/4x1	22	1.5	P
	ZPB 1/4x1	22	3.7	P
	ZPB 1/4x1	22	2.6	P
	ZPB 1/4x1	22	1.8	P
	ZPB 1/4x1	22	2.8	P
	ZPB 1/4x1	22	3.7	P
	ZPB 1/4x1	22	1.8	P
S1	SVA 1/4x1 3/8	28	3.7	P
	SVA 1/4x1 3/8	28	3.0	P
	SVA 1/4x1 3/8	28	2.3	P

* P - insert pulled out

Table 3.5 Tension Strength of Inserts in Hollow Concrete Block Masonry

Type	Designation	Embedment Length (mm)	Failure Load (kN)	Failure Mode
P	ZPB 3/16x7/8	22	2.0	P*
	ZPB 3/16x7/8	22	1.6	P
	ZPB 3/16x7/8	22	2.2	P
	ZPB 3/16x7/8	22	2.8	P
	ZPB 3/16x7/8	22	2.3	P
	ZPB 3/16x7/8	22	2.2	P
	ZPB 3/16x7/8	22	2.1	P
	ZPB 1/4x1	22	3.0	P
	ZPB 1/4x1	22	2.3	P
	ZPB 1/4x1	22	1.7	P
	ZPB 1/4x1	22	2.3	P
	ZPB 1/4x1	22	2.1	P
	ZPB 1/4x1	22	2.2	P
	ZPB 1/4x1	22	1.9	P
	ZPB 1/4x1	22	1.7	P
	ZPB 1/4x1	22	1.6	P
S1	SVA 1/4x1 3/8	28	5.2	P
	SVA 1/4x1 3/8	28	4.1	P
	SVA 1/4x1 3/8	28	2.9	P
	SVA 1/4x1 3/8	28	3.2	P
	SVA 1/4x1 3/8	28	3.0	P
	SVA 1/4x1 3/8	28	3.7	P
	SVA 1/4x1 3/8	28	2.7	P
	SVA 1/4x1 3/8	28	2.1	P
	SVA 1/4x1 3/8	28	3.2	P
	SVA 1/4x1 3/8	28	3.0	P

* P - insert pulled out

Table 3.6 Tension Strength of Inserts in Grouted Burned Clay Brick Masonry

Type	Designation	Embedment Length (mm)	Grout Strength (MPa)	Failure Load (kN)	Failure Mode
S2	HN 1240	88	18.8	18.3	P*
	HN 1240	88	18.8	21.6	P
	HN 5842	94	18.8	31.5	P
W1	HSA M6x80	66	17.9	6.3	P
	HSA M6x80	66	17.9	6.6	P
	HSA M6x80	66	17.9	7.4	P
	HSA M6x80	66	17.9	5.6	P
	HSA M10x90	68	17.9	9.8	P
	HSA M10x90	68	17.9	11.3	P
	HSA M10x90	68	17.9	11.4	P
	HSA M10x90	68	17.9	11.4	P
	HSA M10x90	68	17.9	11.4	P
	HSA M10x90	68	17.9	10.3	P
	HSA M10x120	98	18.8	11.8	P
	HSA M10x120	98	17.9	13.9	P
	HSA M10x120	98	17.9	12.0	P
	HSA M10x120	98	17.9	11.4	P
	HSA M12x110	84	17.9	22.2	P
	HSA M12x110	84	17.9	19.6	P
	HSA M12x110	84	17.9	21.3	P
	HSA M12x110	84	17.9	17.0	P
	HSA M12x110	84	17.9	18.0	P
	HSA M12x110	84	17.9	19.7	P
	HSA M12x110	84	17.9	17.2	P
	HSA M12x110	84	17.9	18.6	P
	HSA M12x150	124	17.9	18.1	P
	HSA M12x150	124	17.9	25.1	P
	HSA M12x150	124	17.9	15.7	P
	HSA M12x150	124	17.9	19.9	P
	HSA M12x150	124	17.9	22.9	P
	HSA M16x100	70	18.8	20.8	M#
	HSA M16x100	70	18.8	22.9	M
	HSA M16x100	70	18.8	21.9	M
	HSA M16x145	115	17.9	22.9	P
	HSA M16x145	115	17.9	28.4	P
A	HVA M8	80	18.8	23.2	I&
	HVA M8	80	17.9	22.0	M
	HVA M8	80	17.9	22.0	M
	HVA M8	80	18.8	24.0	I
	HVA M8	80	18.8	24.0	I
	HVA M10	90	18.8	32.6	M
	HVA M10	90	18.8	29.9	M
	HVA M10	90	18.8	33.9	M

Table 3.6 - continued

Type	Designation	Embedment Length (mm)	Grout Strength (MPa)	Failure Load (kN)	Failure Mode
A	HVA M10	90	17.9	24.2	M
	HVA M12	110	18.8	38.5	M
	HVA M12	110	17.9	32.8	M
	HVA M12	110	18.8	41.1	M
	HVA M12	110	18.8	41.6	M
	HVA M12	110	17.9	36.6	M
	HVA M12	110	17.9	42.6	M
	HVA M16	125	18.8	48.5	M
	HVA M16	125	17.9	53.0	M
	HVA M16	125	17.9	56.2	M

* P - insert pulled out
\# M - brick cracked
& I - insert threads stripped

Table 3.7 Tension Strength of Inserts in Grouted Concrete Block Masonry

Type	Designation	Embedment Length (mm)	Grout Strength (MPa)	Failure Load (kN)	Failure Mode
	HN 1624	54	18.8	5.8	P*
	HN 1624	54	18.8	4.8	P
	HN 1624	54	18.8	4.3	P
S2	HN 3830	64	18.8	9.5	P
	HN 3830	64	18.8	8.8	P
	HN 3830	64	18.8	8.3	P
	HN 1240	88	18.8	20.9	P
	HN 5842	94	18.8	31.1	P
	HSA M10x90	68	15.2	10.3	P
	HSA M10x90	68	31.8	10.0	P
	HSA M10x90	68	31.8	11.9	P
	HSA M10x120	98	15.2	14.4	P
	HSA M10x120	98	31.8	10.0	P
	HSA M10x120	98	31.8	17.3	P
	HSA M12x110	84	15.2	27.8	P
	HSA M12x110	84	15.2	22.9	M#
	HSA M12x110	84	15.2	18.8	M
	HSA M12x110	84	31.8	20.9	P
	HSA M12x110	84	15.2	28.4	M
W1	HSA M12x150	124	31.8	25.5	P
	HSA M12x150	124	31.8	11.6	P
	HSA M12x150	124	15.2	29.5	M
	HSA M16x100	70	15.2	18.4	P
	HSA M16x100	70	31.8	15.3	P
	HSA M16x145	115	15.2	21.5	P
	HSA M16x145	115	31.8	22.5	P
	HSA M16x145	115	15.2	14.2	P
	HSA M20x125	86	15.2	17.5	P
	HSA M20x125	86	31.8	17.5	P
	HSA M20x170	131	15.2	19.4	M
	HSA M20x170	131	31.8	26.5	P
	WS 1432	65	18.8	9.6	P
	WS 1432	65	18.8	11.8	P
W2	WS 1432	65	18.8	10.7	P
	WS 3850	104	18.8	18.4	P
	WS 3850	104	18.8	16.3	P
	WS 3850	104	18.8	14.9	P
	HSL M12/50	113	15.2	17.8	M
	HSL M12/50	113	15.2	21.4	M
WS	HSL M12/50	113	15.2	37.1	M
	HSL M16/50	137	15.2	35.7	M
	HSL M16/50	137	31.8	32.5	M

Table 3.7 - continued

Type	Designation	Embedment Length (mm)	Grout Strength (MPa)	Failure Load (kN)	Failure Mode
	HVA M8	80	15.2	21.1	M
	HVA M8	80	15.2	15.6	M
	HVA M10	90	15.2	26.9	M
	HVA M10	90	15.2	20.1	M
	HVA M10	90	31.8	22.5	M
	HVA M10	90	31.8	30.0	M
	HVA M10	90	31.8	28.4	M
A	HVA M12	110	15.2	28.1	M
	HVA M12	110	15.2	33.0	M
	HVA M16	125	15.2	33.7	M
	HVA M16	125	15.2	35.6	M
	HVA M16	125	31.8	26.0	M
	HVA M16	125	31.8	37.5	M
	HVA M20	170	15.2	35.5	M
	HVA M20	170	31.8	47.5	M

* P - insert pulled out
\# M - concrete block cracked

Table 3.8 Embedment Depth Test Results

Type	Designation	Direct Shear		Direct Tension	
		Embedment Length (mm)	Failure Load (kN)	Embedment Length (mm)	Failure Load (kN)
W1	HSA M10x120	103	21.6	97	13.9
	HSA M10x120	78	29.7	78	12.0
	HSA M10x120	57	24.9	56	11.4
	HSA M10x120	35	20.1	37	5.5
	HSA M12x150	128	36.1	125	18.1
	HSA M12x150	105	49.4	105	25.1
	HSA M12x150	85	50.5	80	15.7
	HSA M12x150	65	43.5	58	19.9
	HSA M12x150	46	39.1	39	14.9

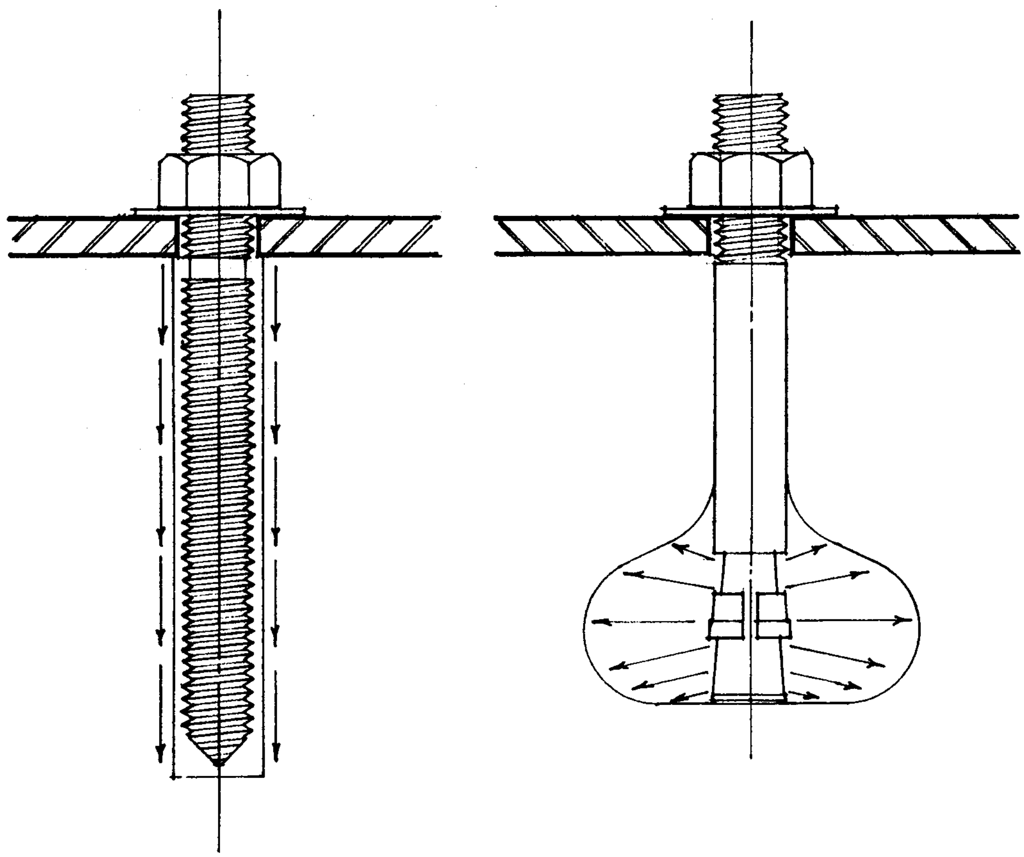

Figure 3.1 Initial Stress before the Inserts are Loaded

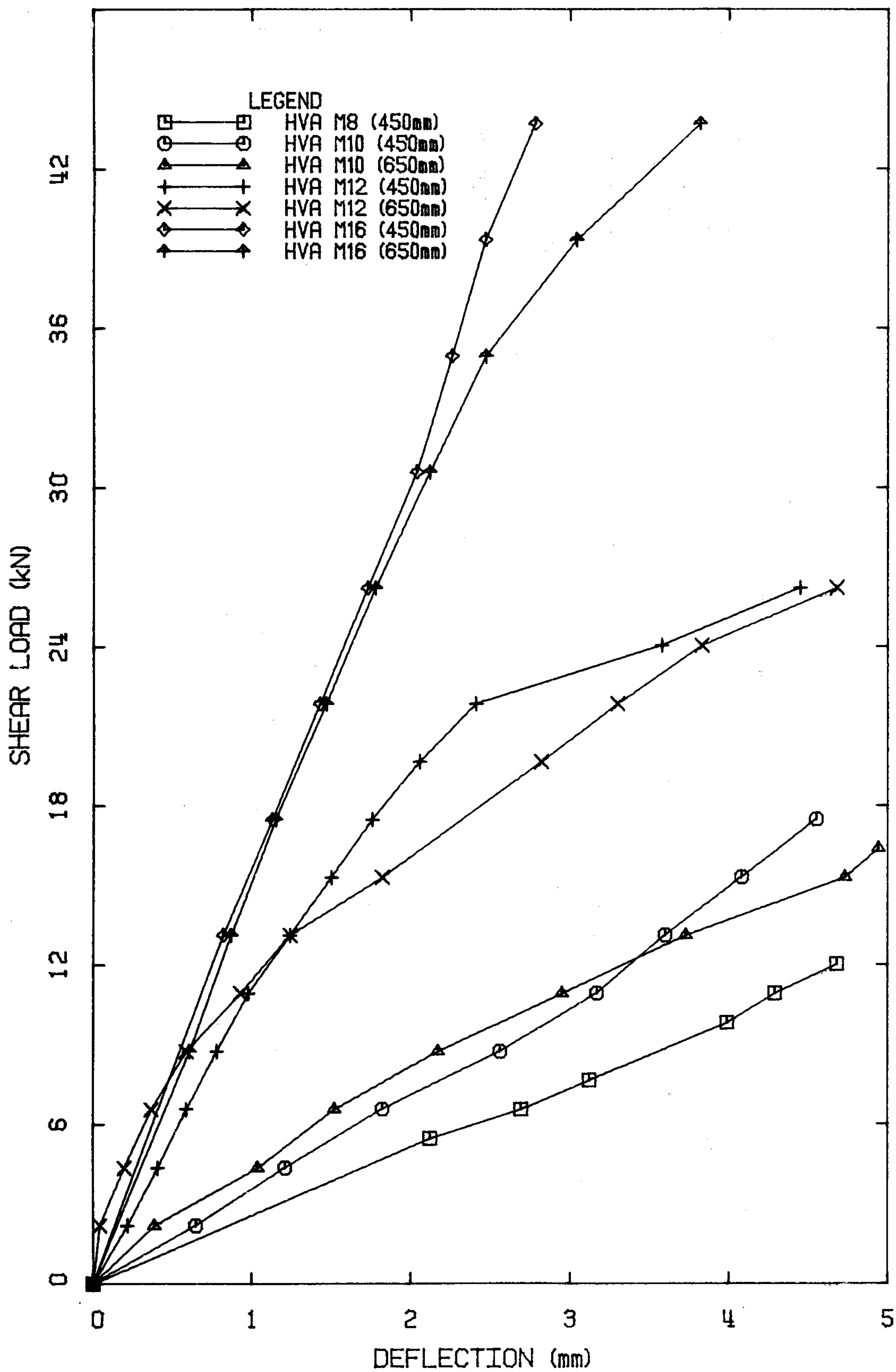

Figure 3.2 Shear Load vs Deflection for Type A Inserts in Grouted Brick Masonry

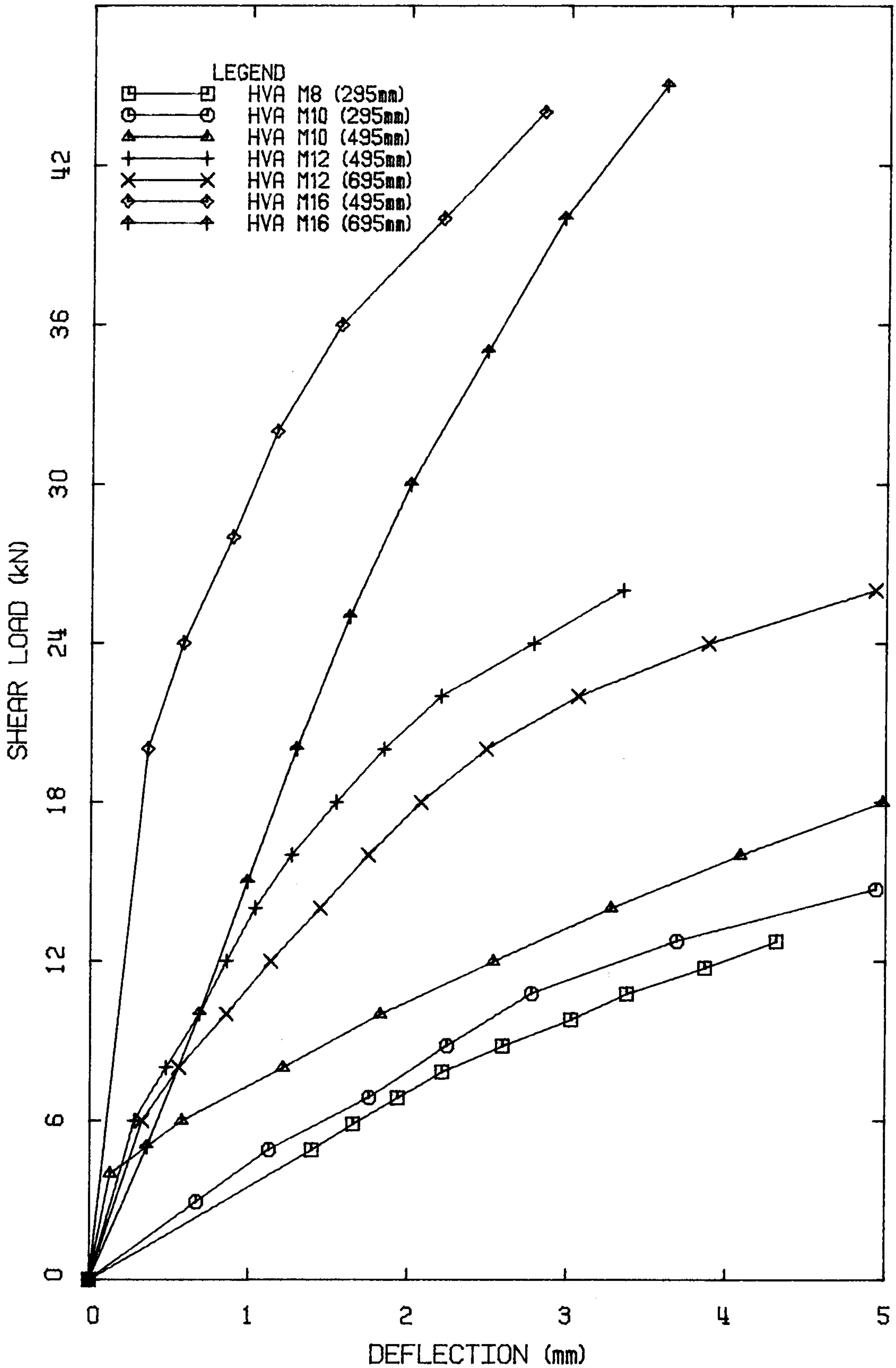

Figure 3.3 Shear Load vs Deflection for Type A Inserts in Grouted Concrete Block Masonry

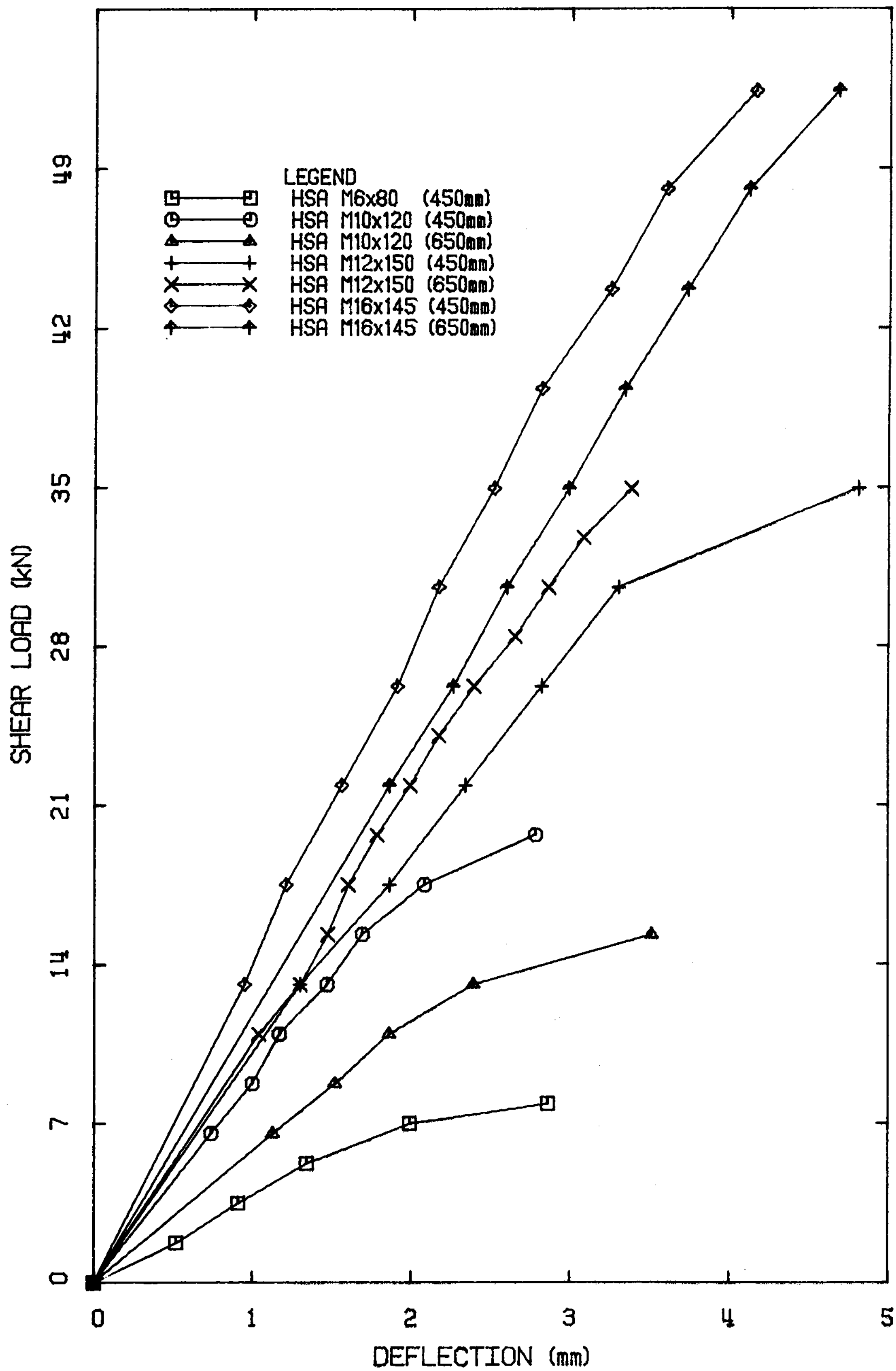

Figure 3.4 Shear Load vs Deflection for Type W1 Inserts in Grouted Brick Masonry

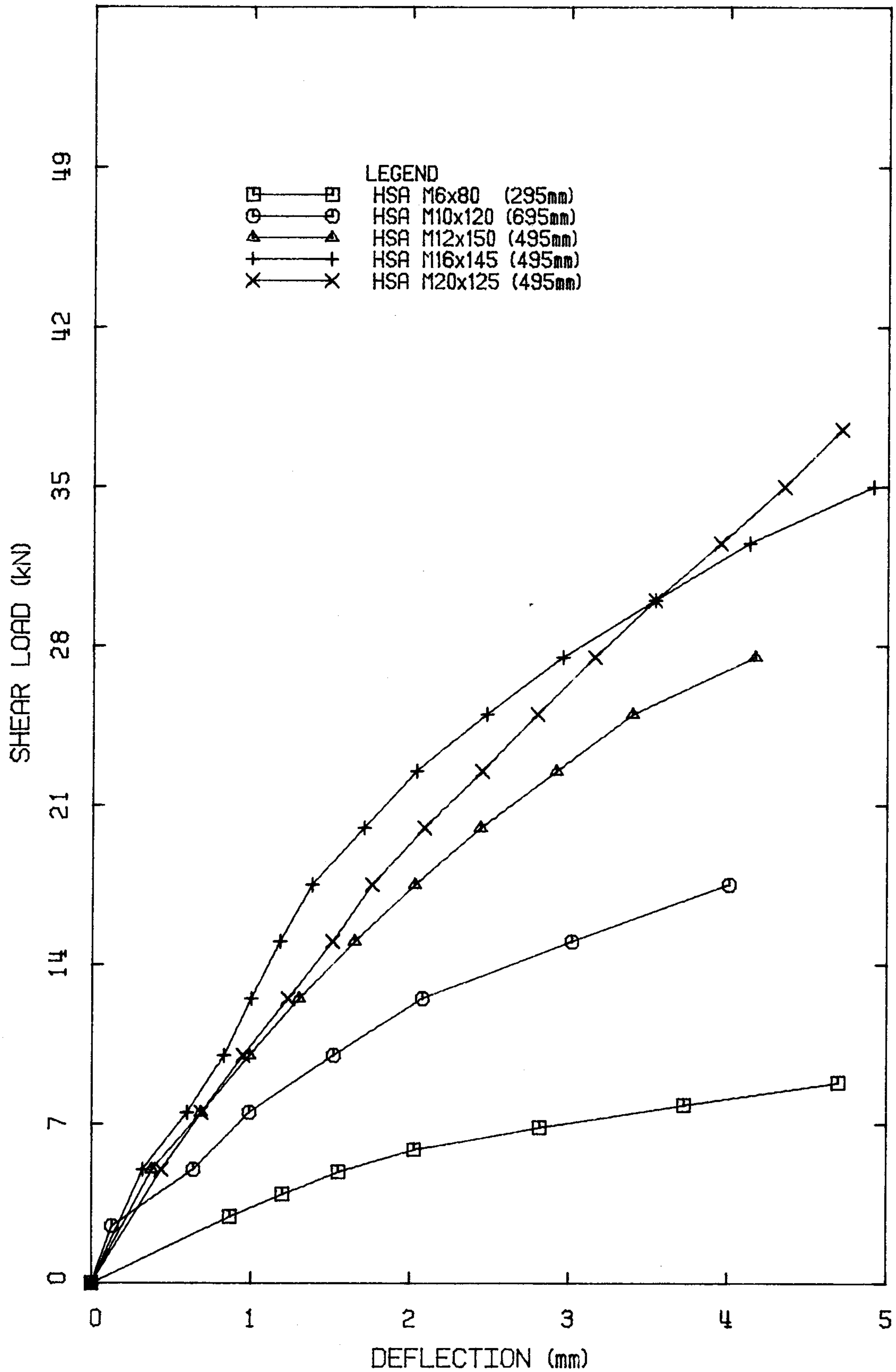

Figure 3.5 Shear Load vs Deflection for Type W1 Inserts in Grouted Concrete Block Masonry

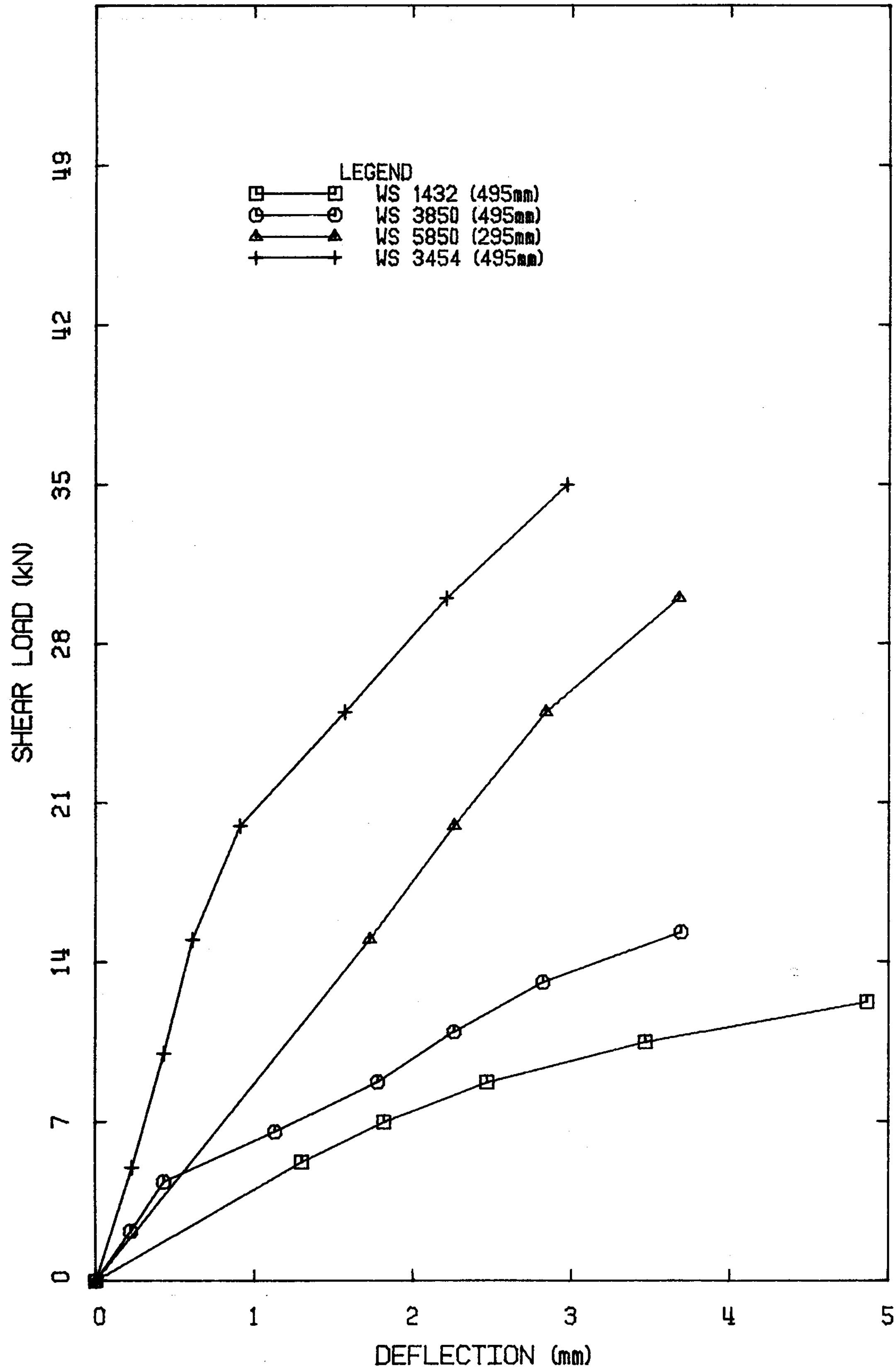

Figure 3.6 Shear Load vs Deflection for Type W2 Inserts in Grouted Concrete Block Masonry

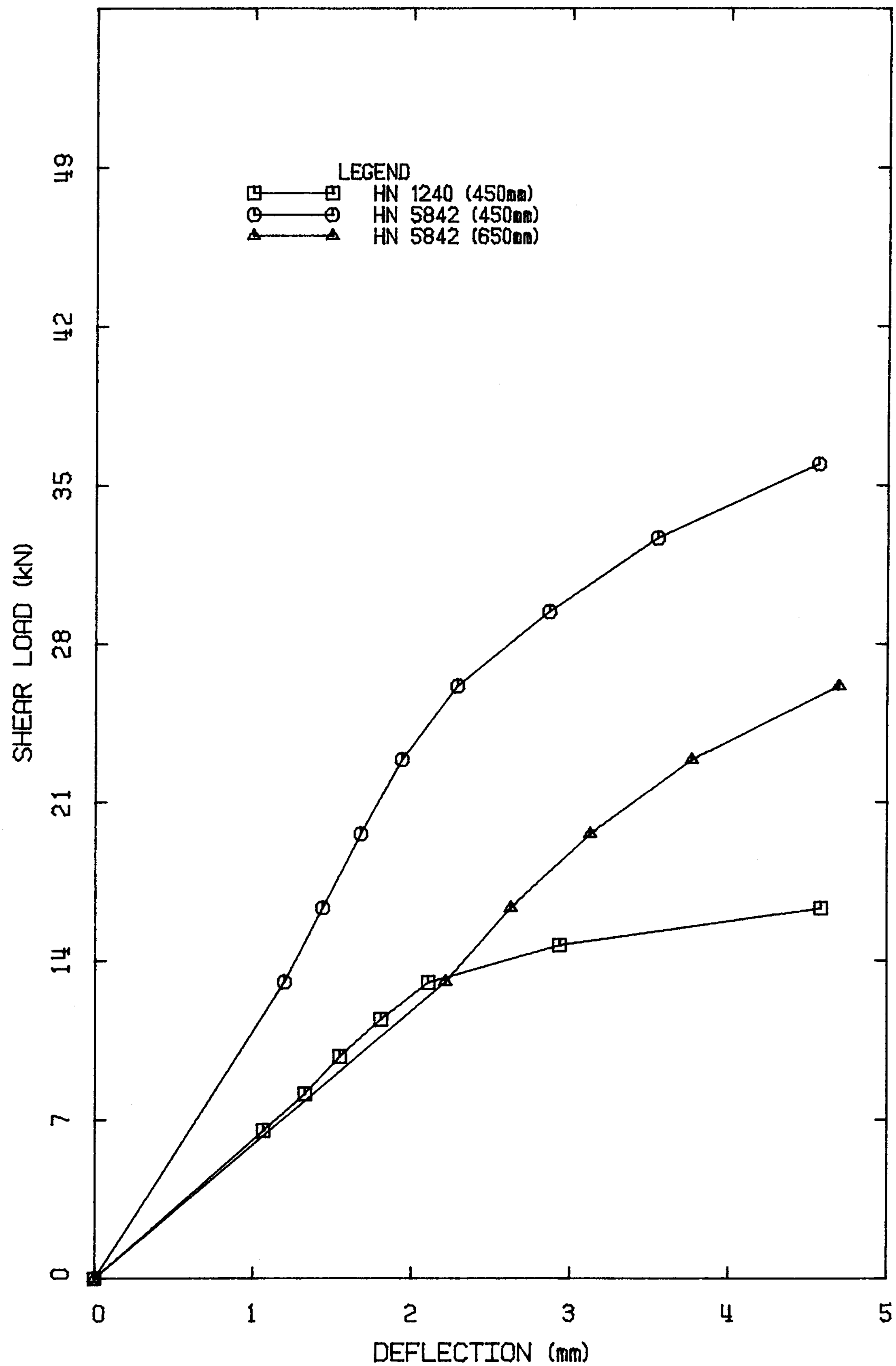

Figure 3.7 Shear Load vs Deflection for Type S2 Inserts in Grouted Brick Masonry

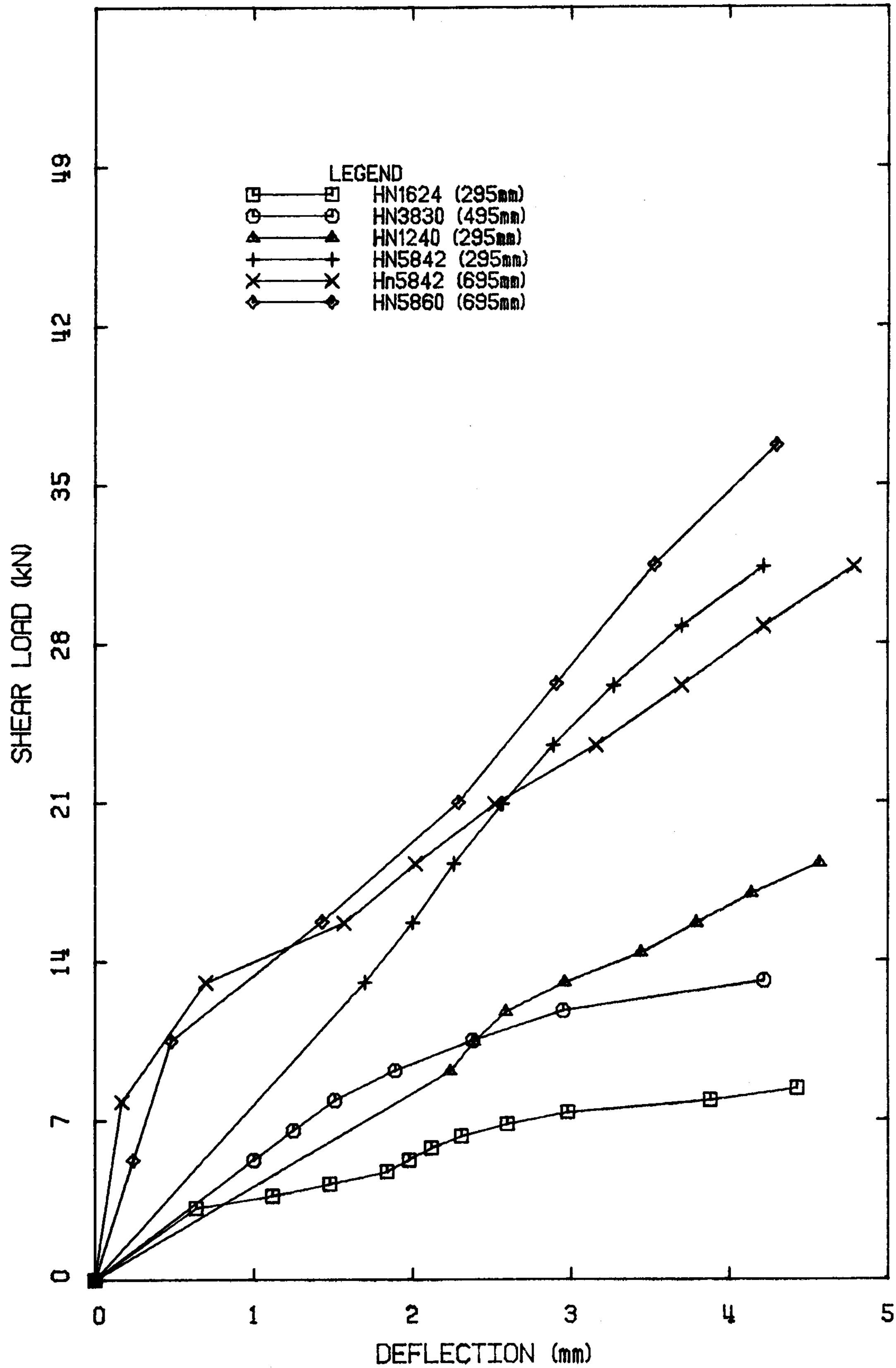

Figure 3.8 Shear Load vs Deflection for Type S2 Inserts in Grouted Concrete Block Masonry

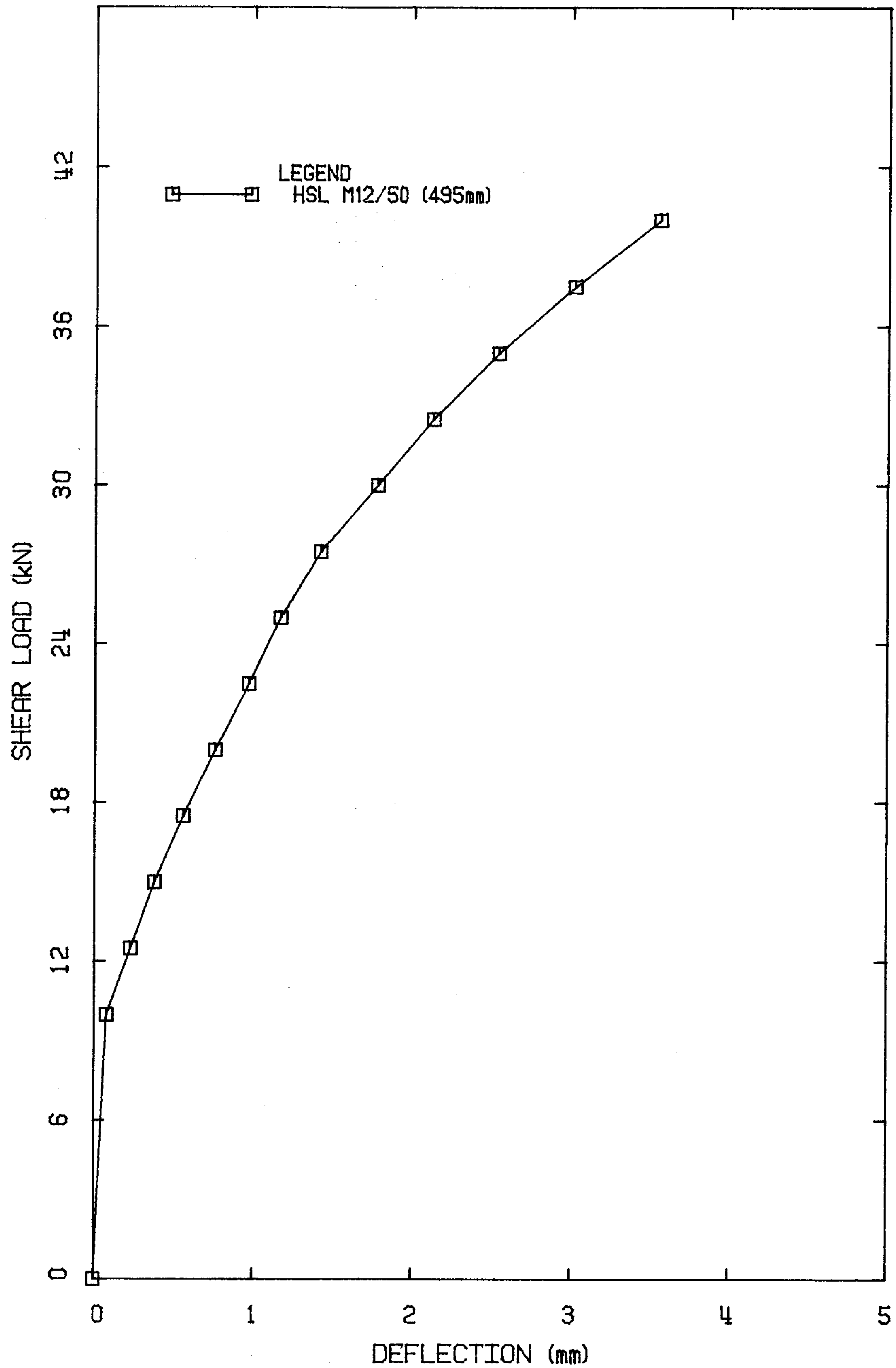

Figure 3.9 Shear Load vs Deflection for Type WS Inserts in Grouted Concrete Block Masonry

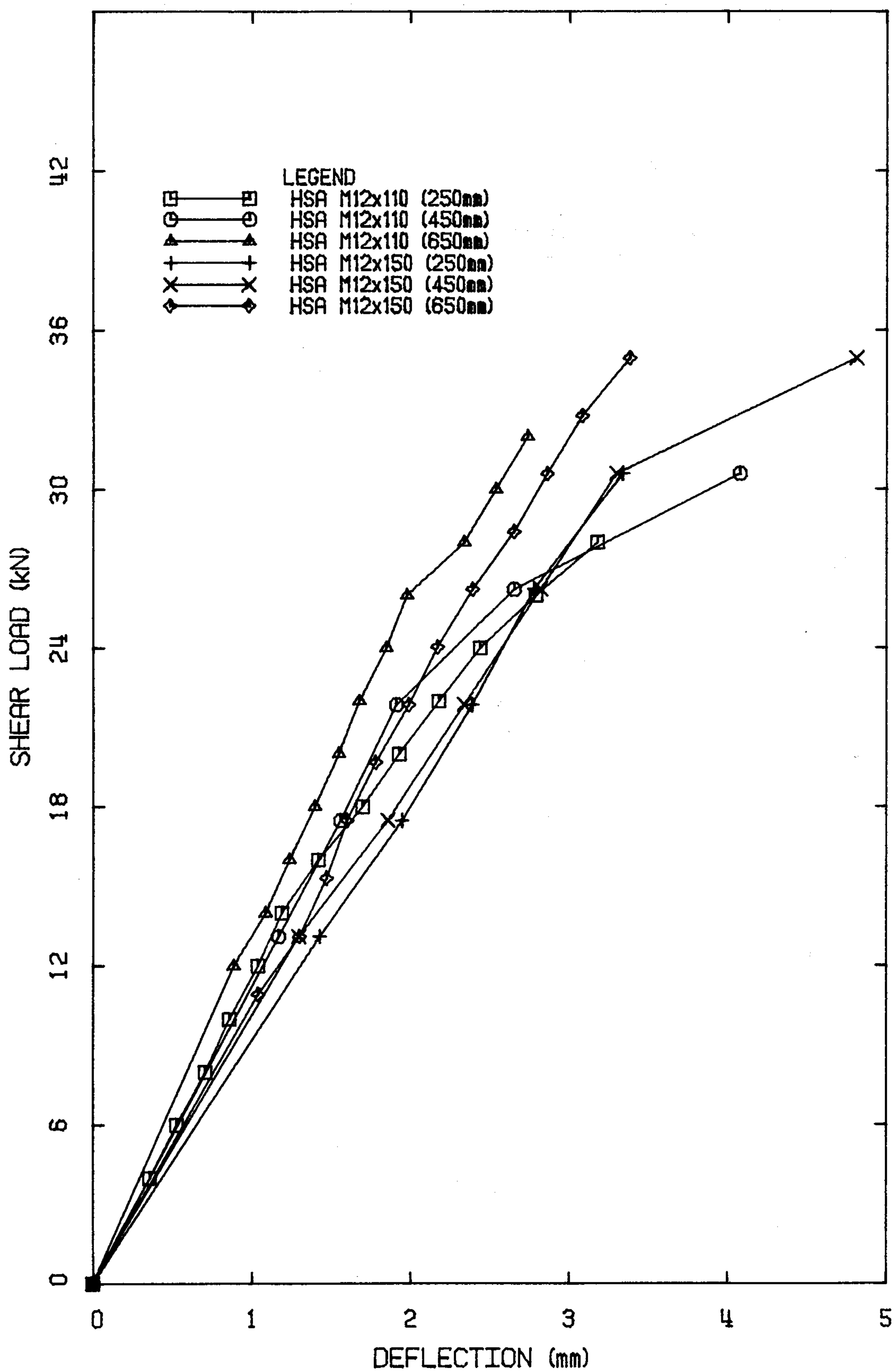

Figure 3.10 Shear Load vs Deflection for Type W1 Inserts in Grouted Brick Masonry

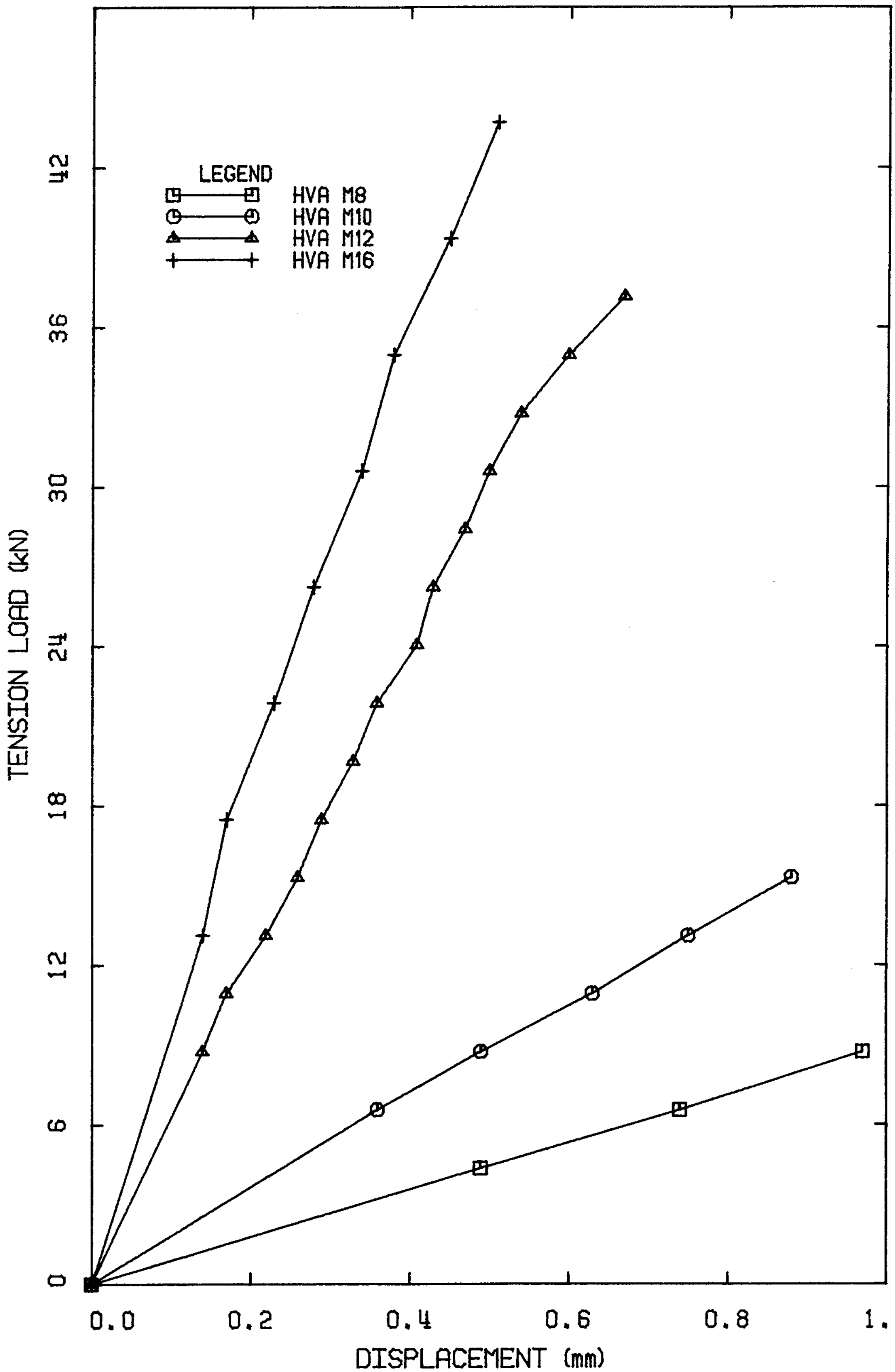

Figure 3.11 Tension Load vs Displacement for Type A Inserts in Grouted Brick Masonry

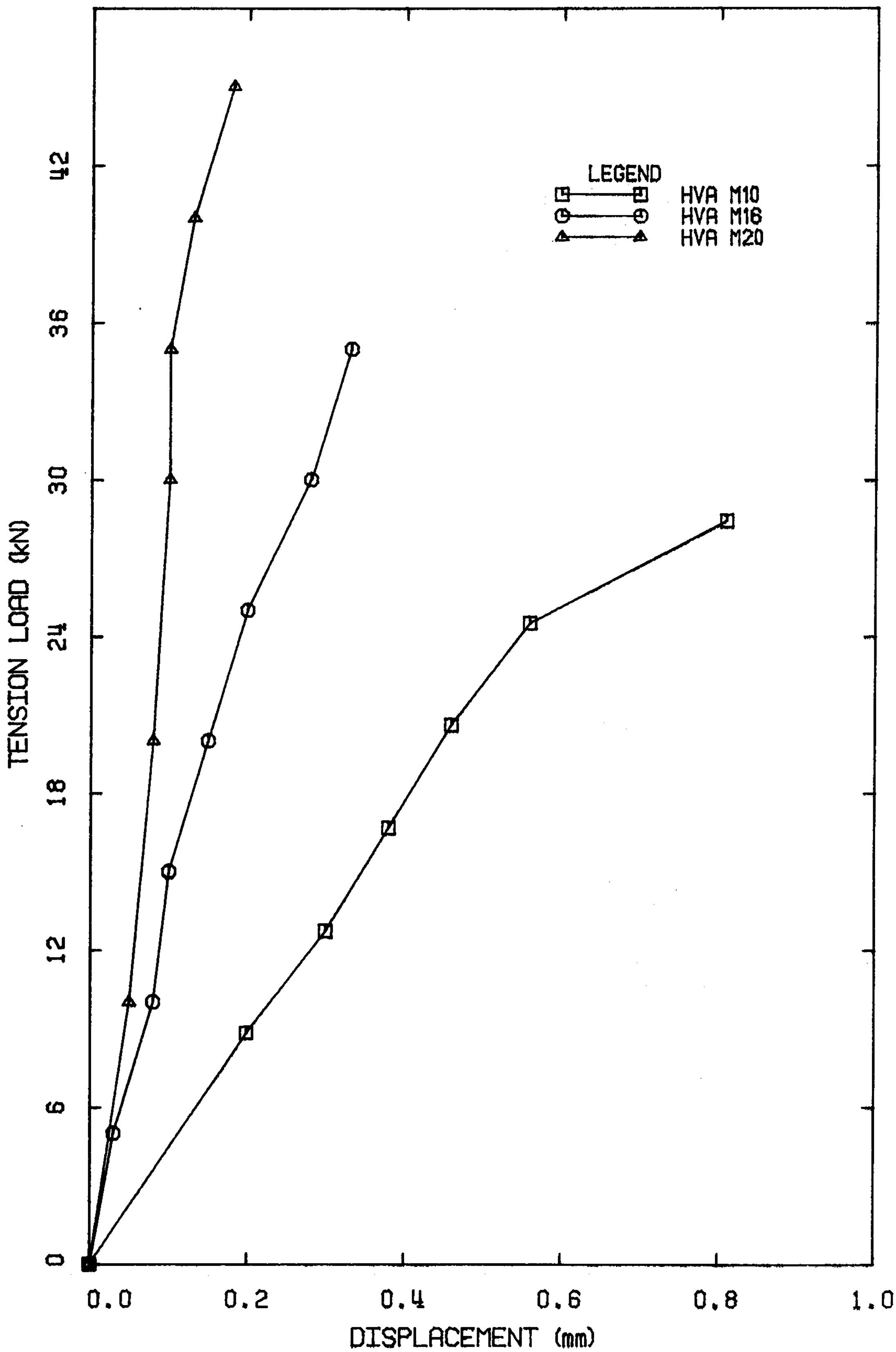

Figure 3.12 Tension Load vs Displacement for Type A Inserts in Grouted Concrete Block Masonry

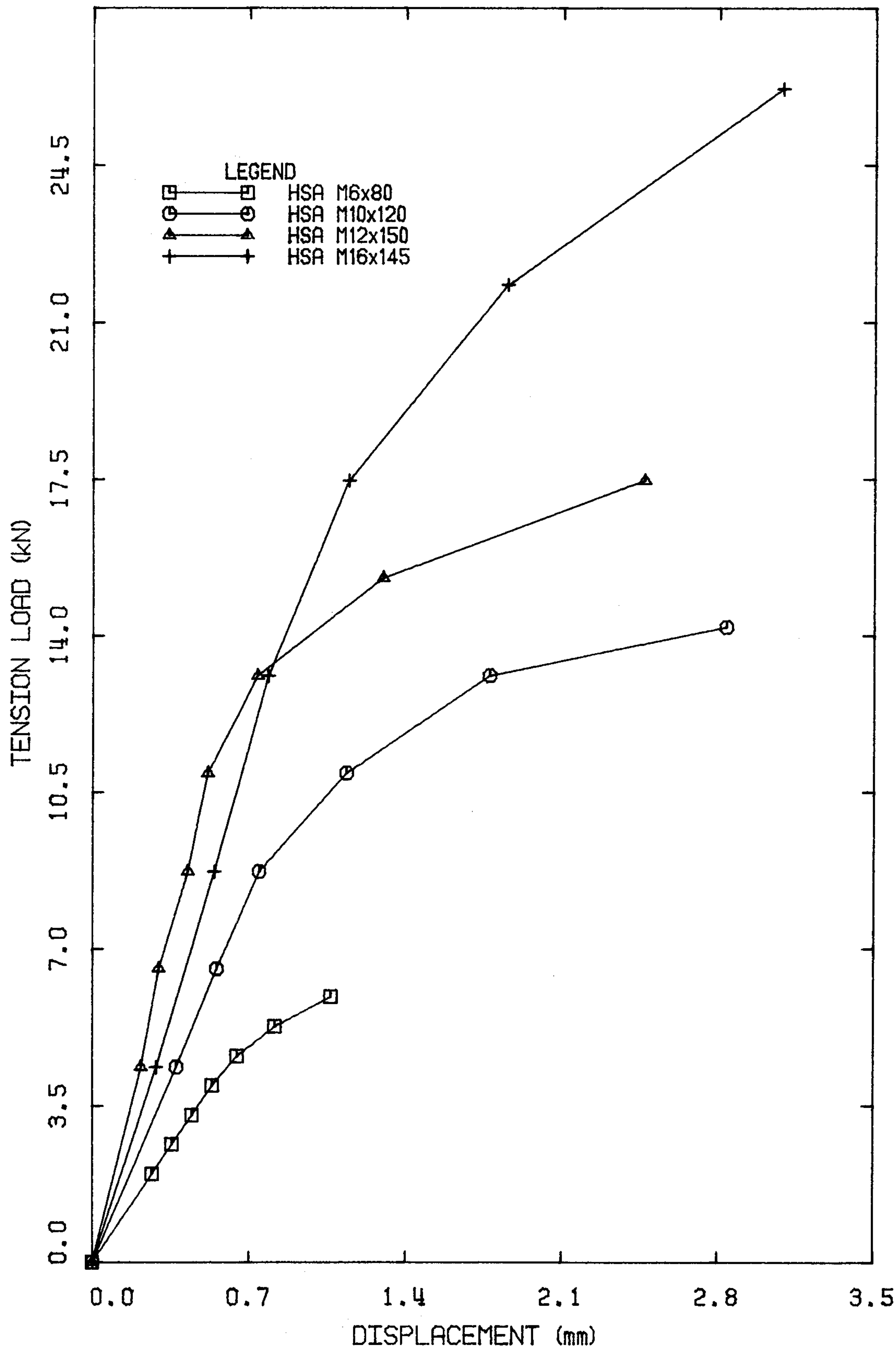

Figure 3.13 Tension Load vs Displacement for Type W1 Inserts in Grouted Brick Masonry

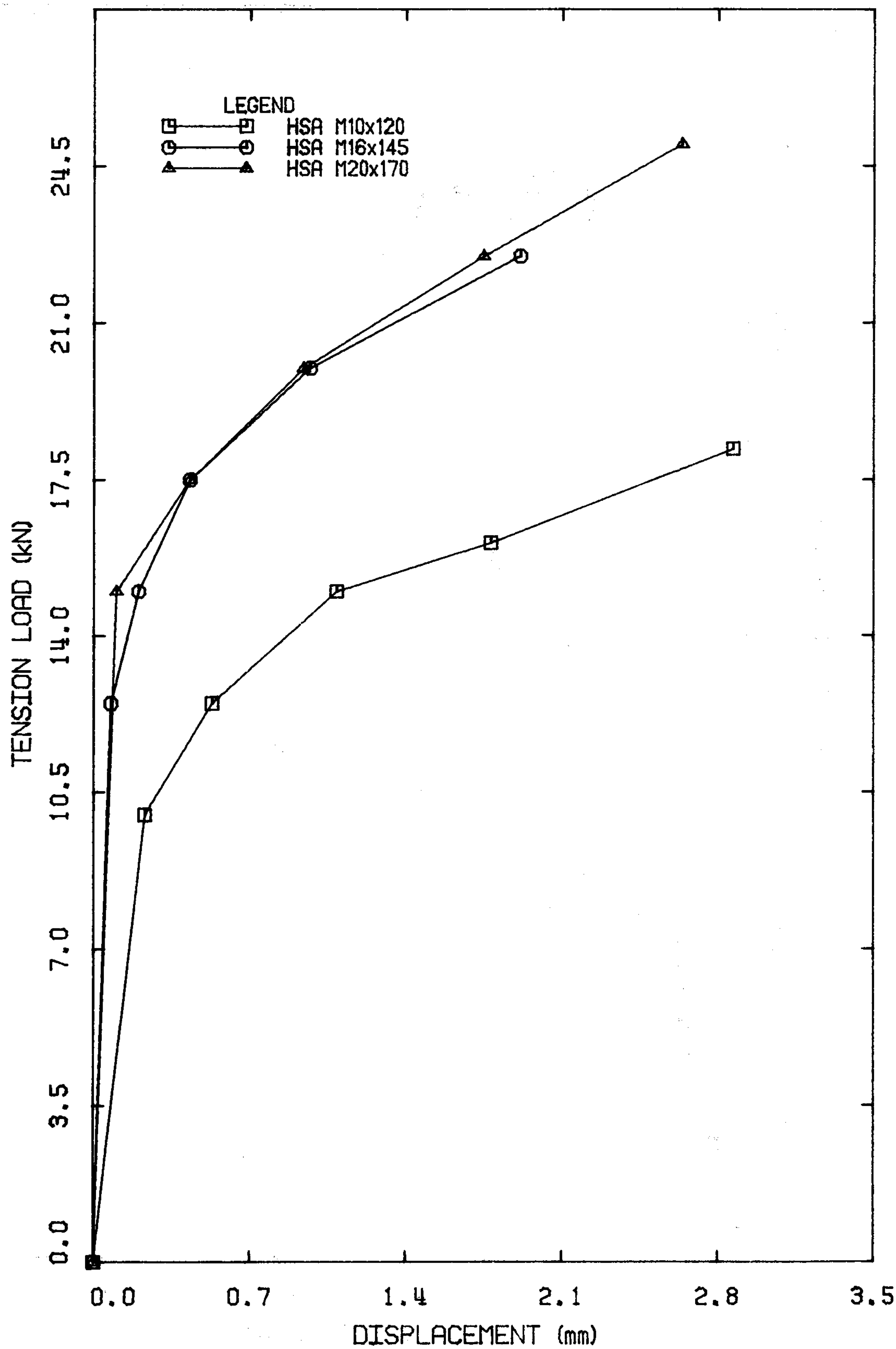

Figure 3.14 Tension Load vs Displacement for Type W1 Inserts in Grouted Concrete Block Masonry

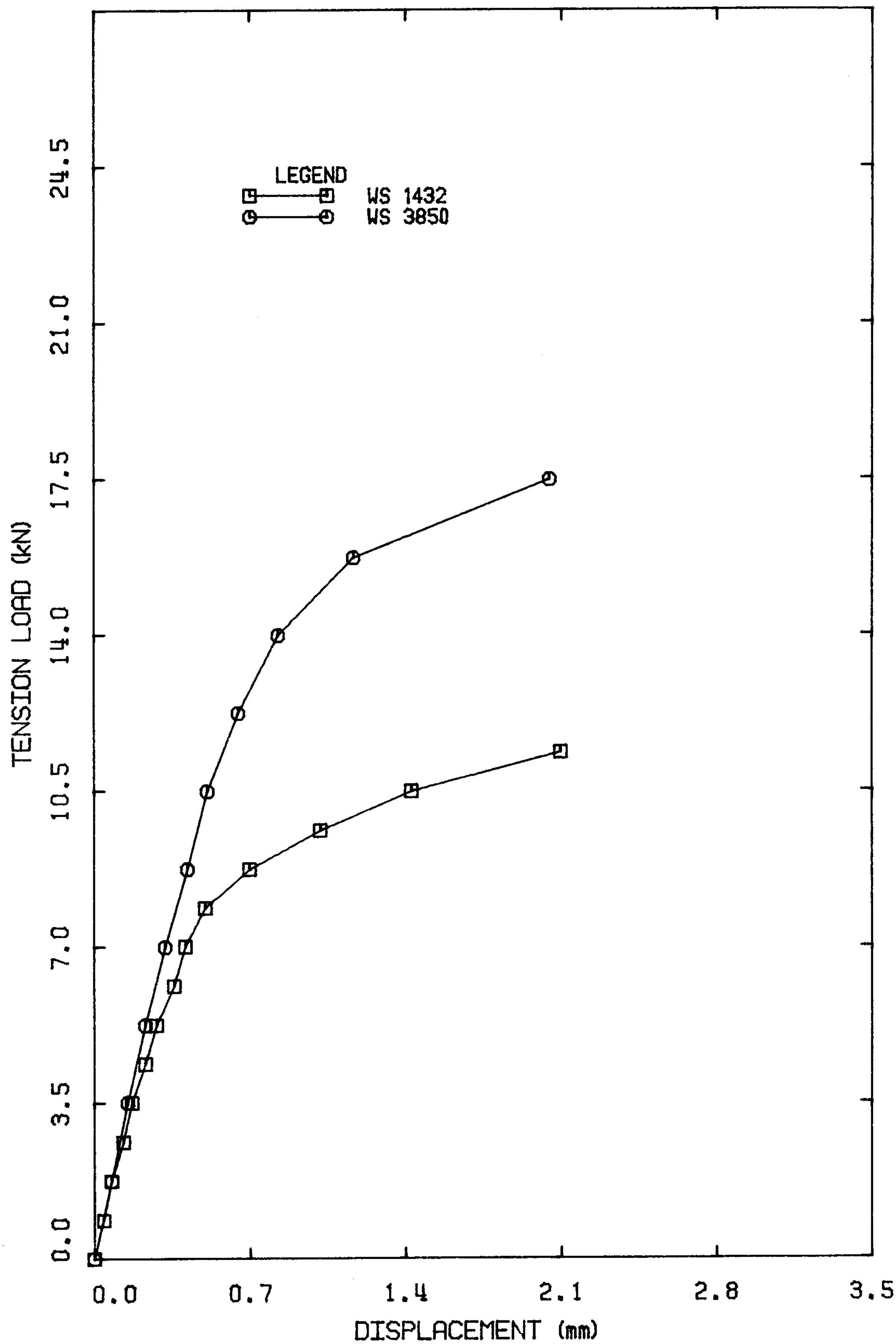

Figure 3.15 Tension Load vs Displacement for Type W2 Inserts in Grouted Concrete Block Masonry

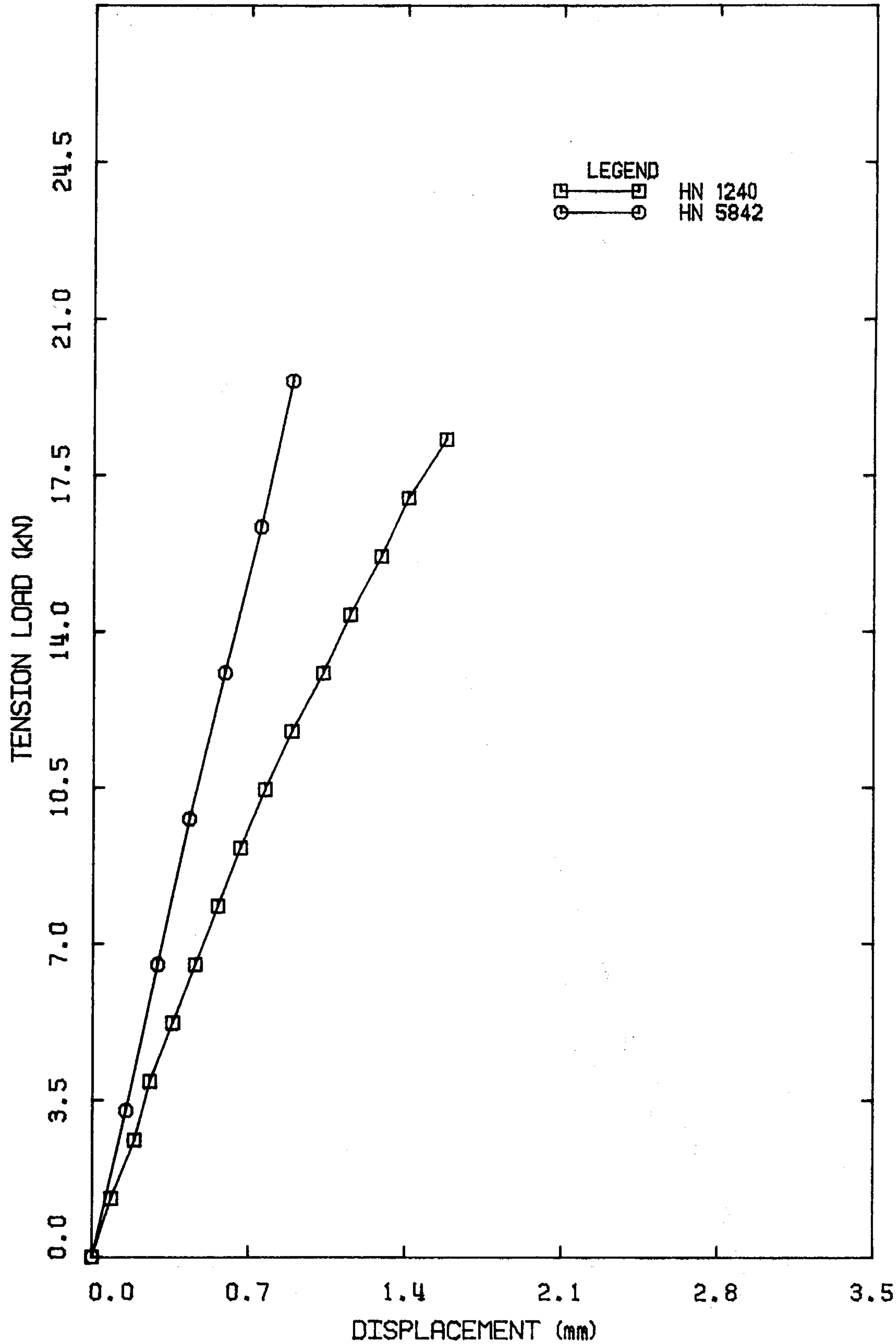

Figure 3.16 Tension Load vs Displacement for Type S2 Inserts in Grouted Brick Masonry

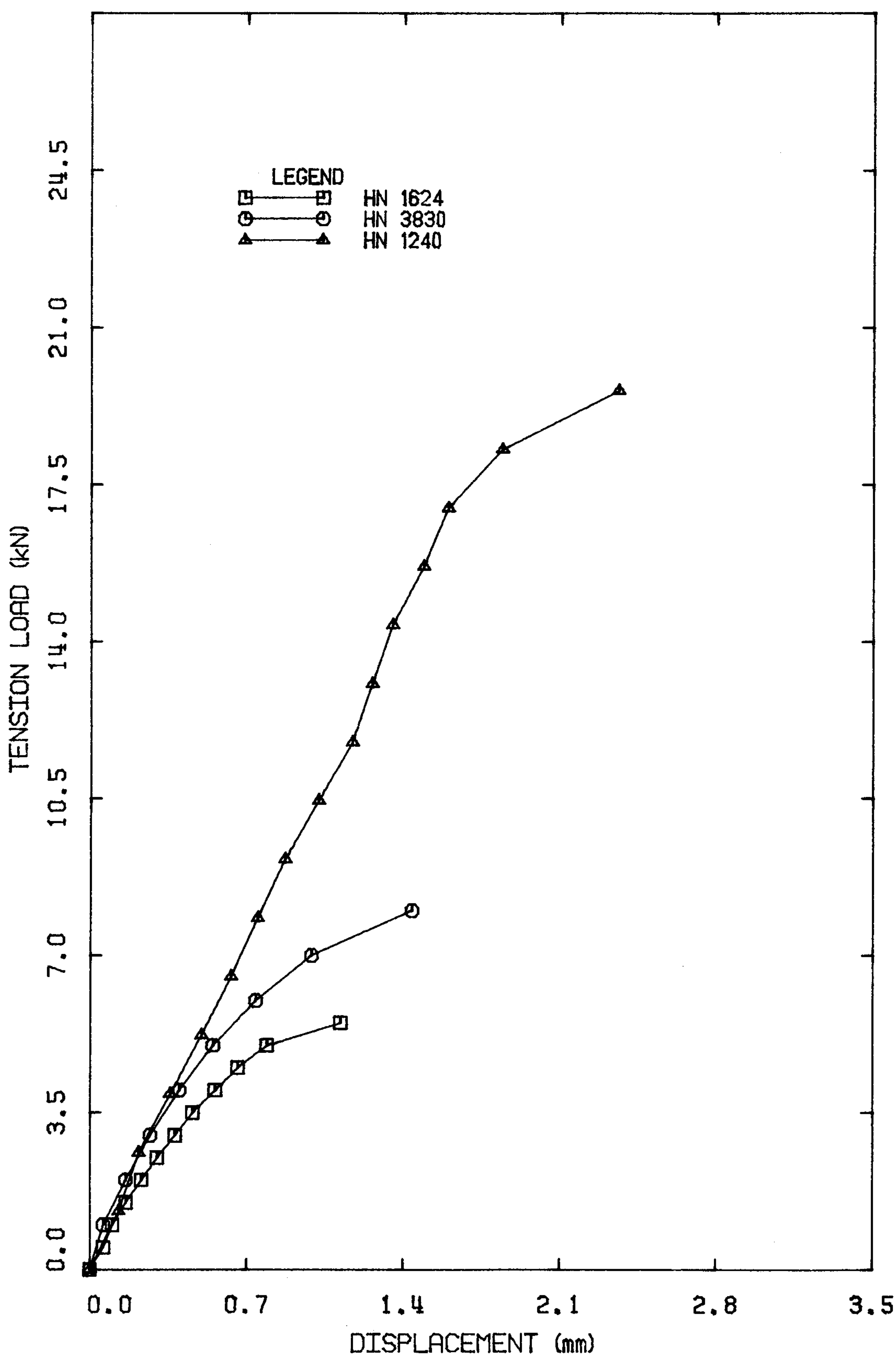

Figure 3.17 Tension Load vs Displacement for Type S2 Inserts in Grouted Concrete Block Masonry

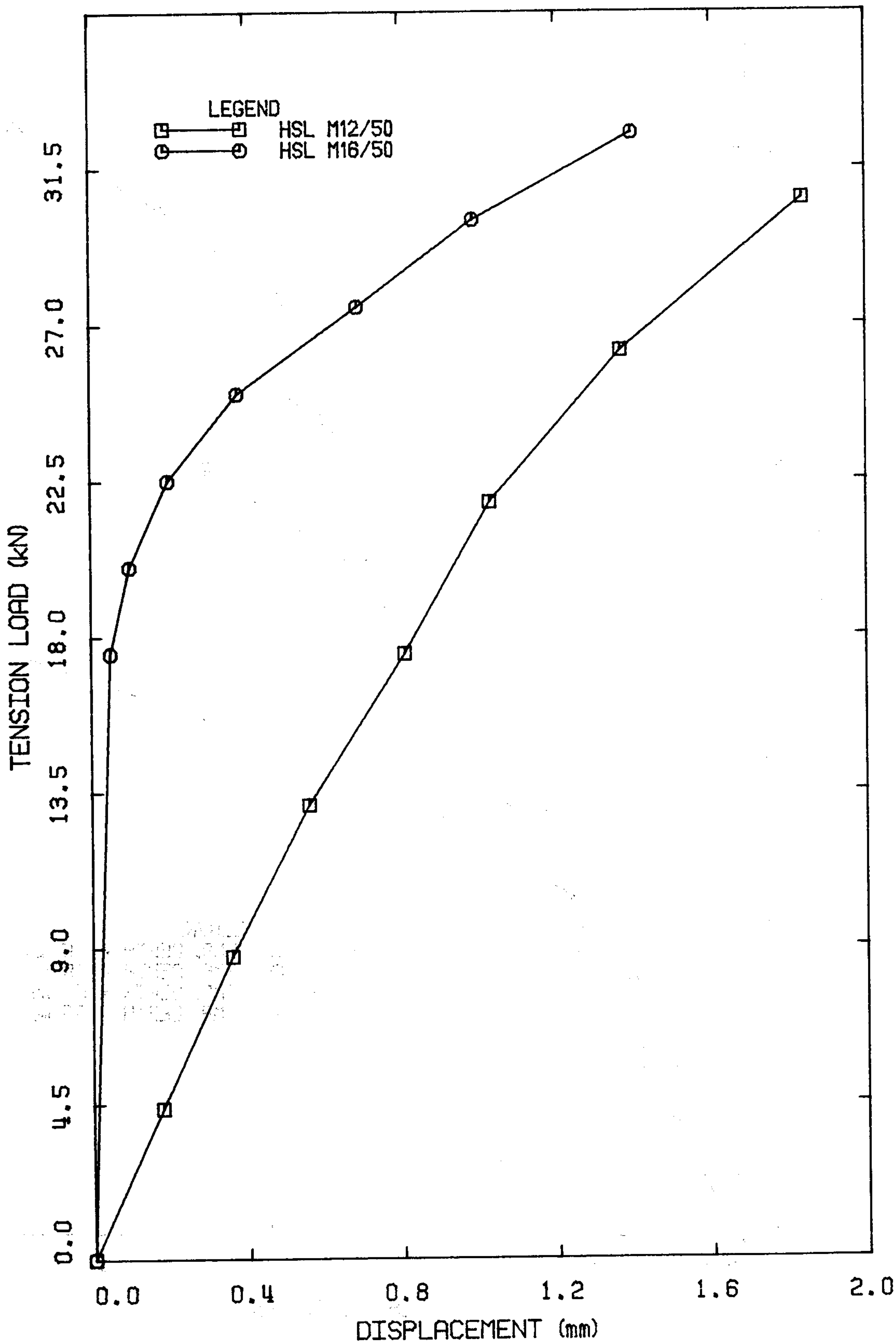

Figure 3.18 Tension Load vs Displacement for Type WS Inserts in Grouted Concrete Block Masonry

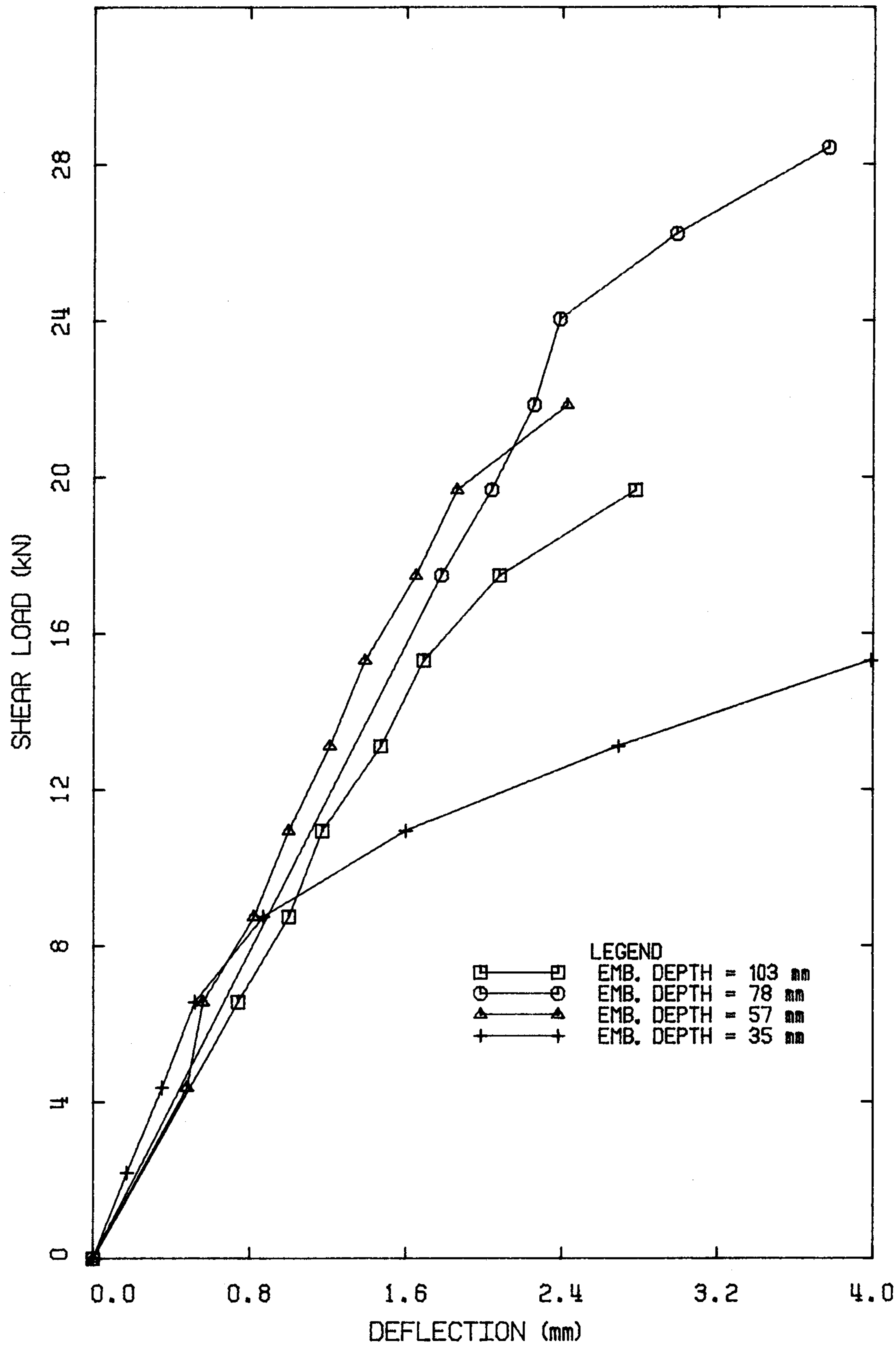

Figure 3.19 Shear Load vs Deflection for HSA M10x120

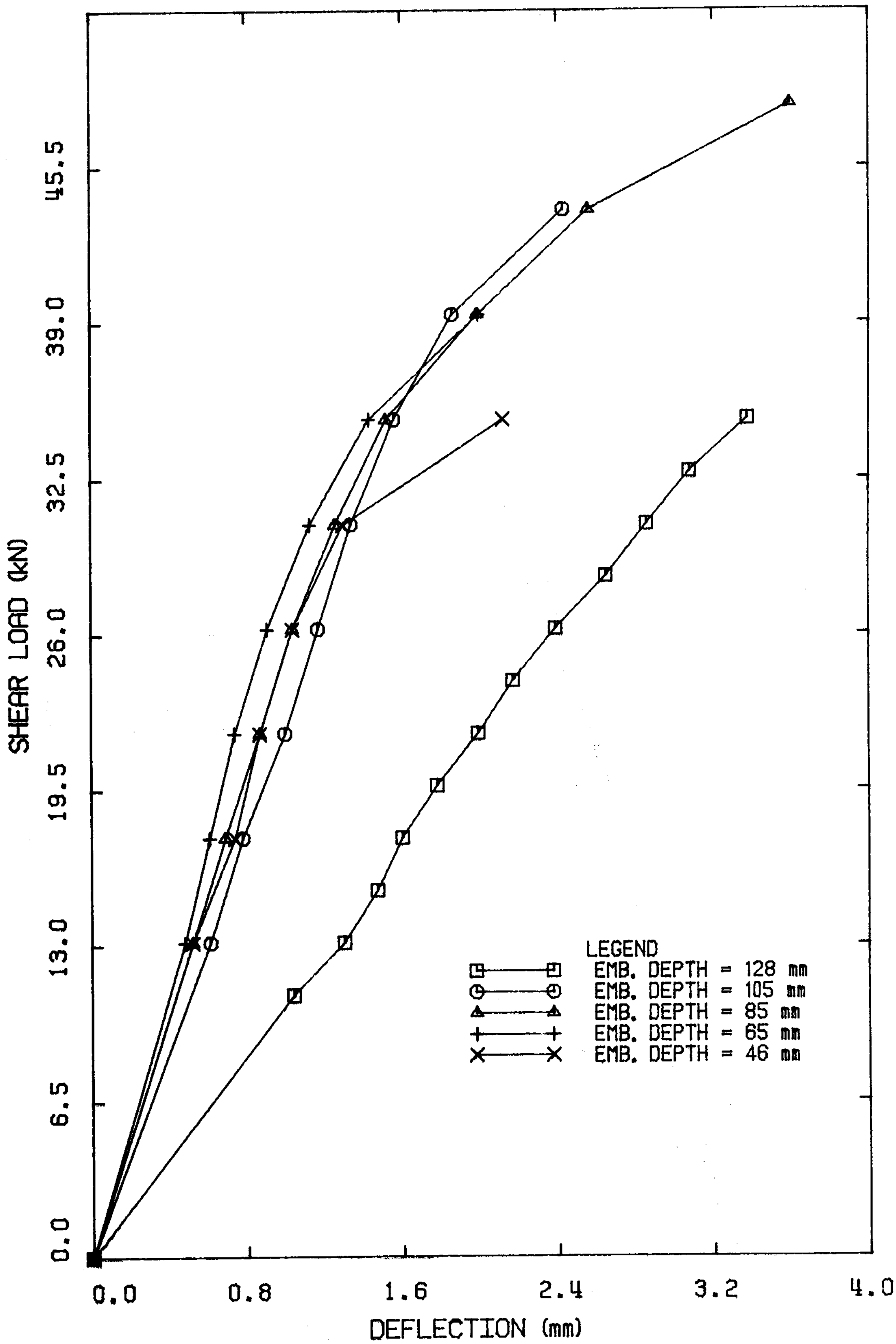

Figure 3.20 Shear Load vs Deflection for HSA M12x150

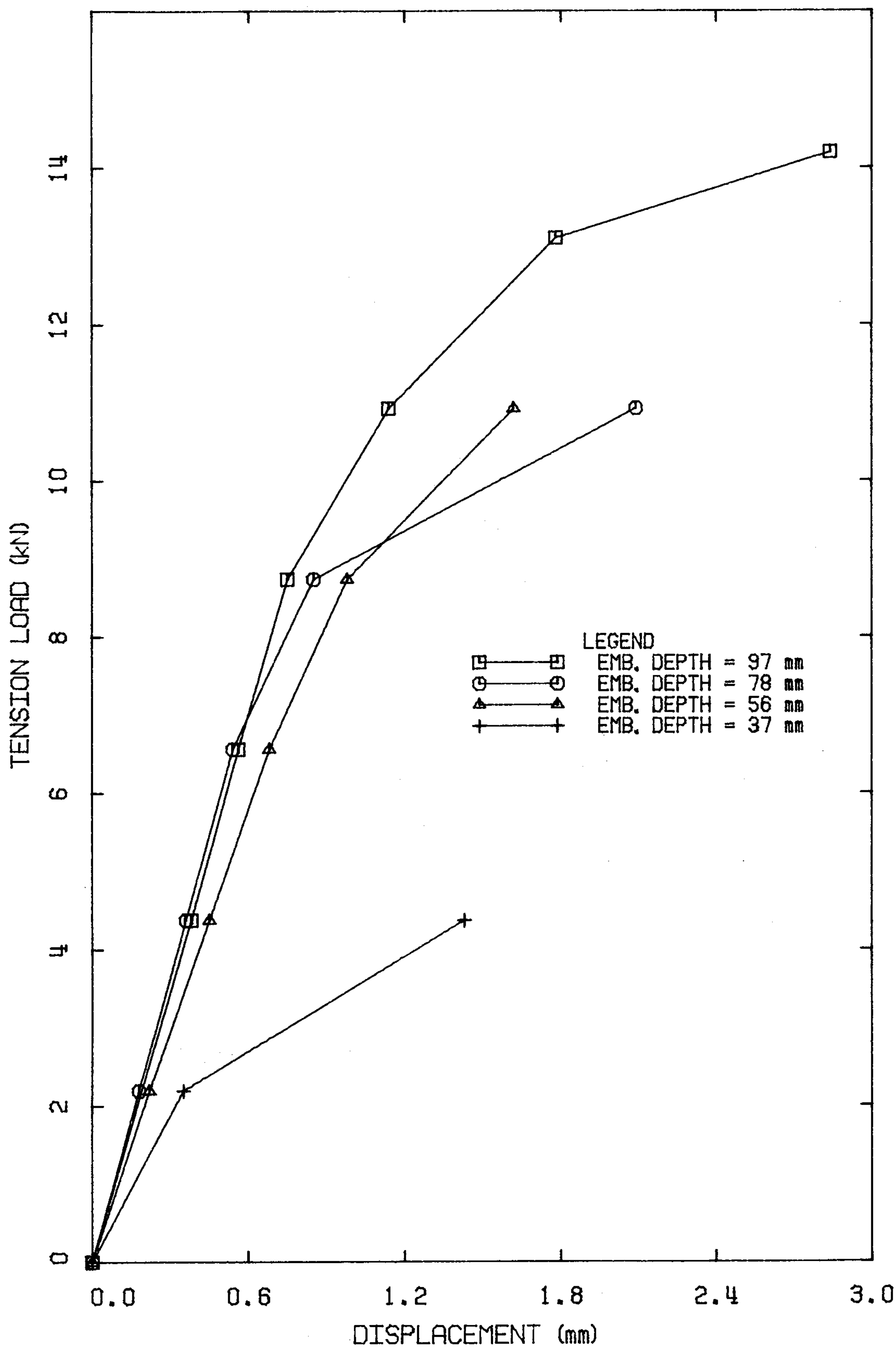

Figure 3.21 Tension Load vs Displacement for HSA M10x120

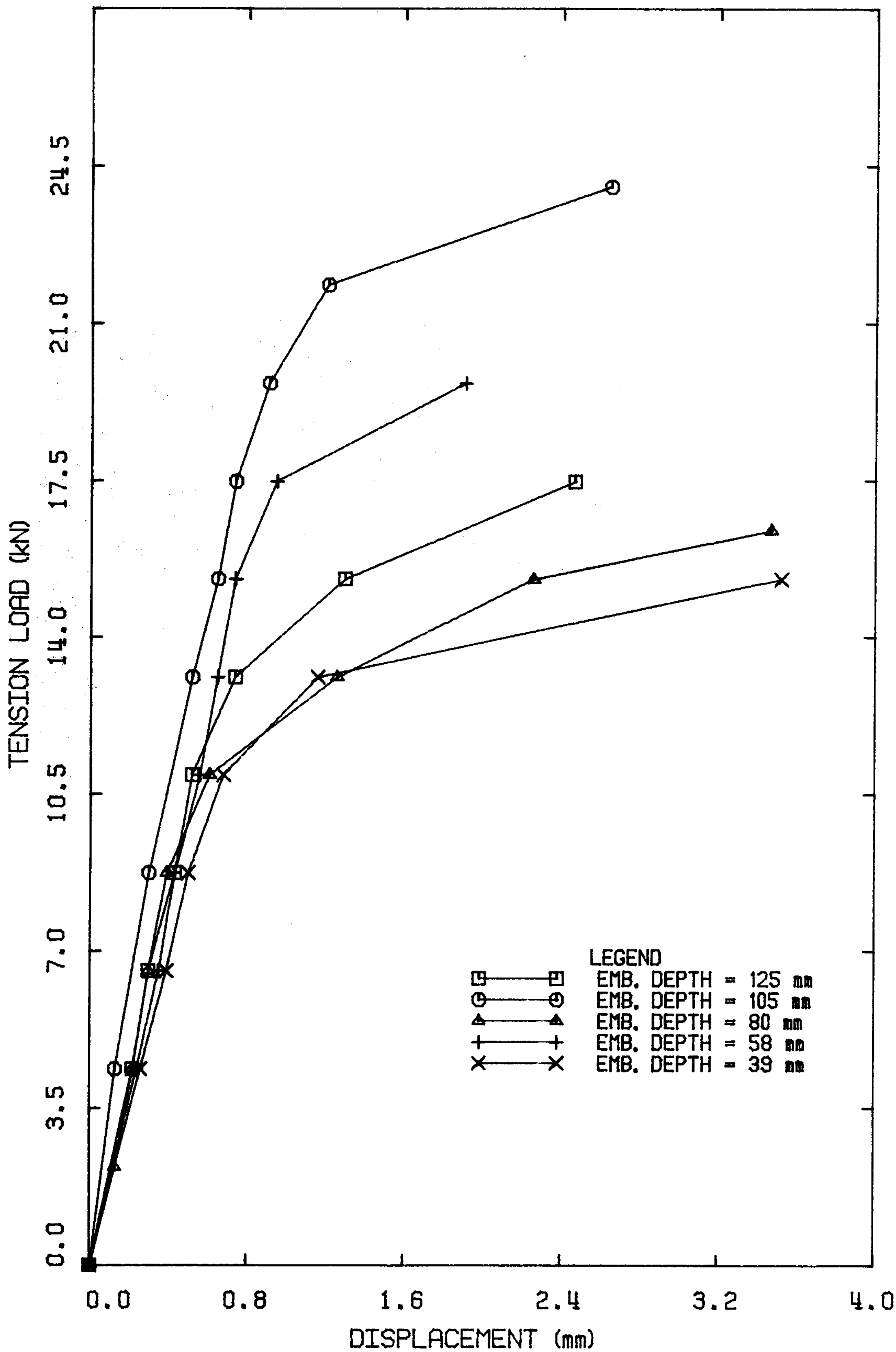

Figure 3.22 Tension Load vs Displacement for HSA M12x150

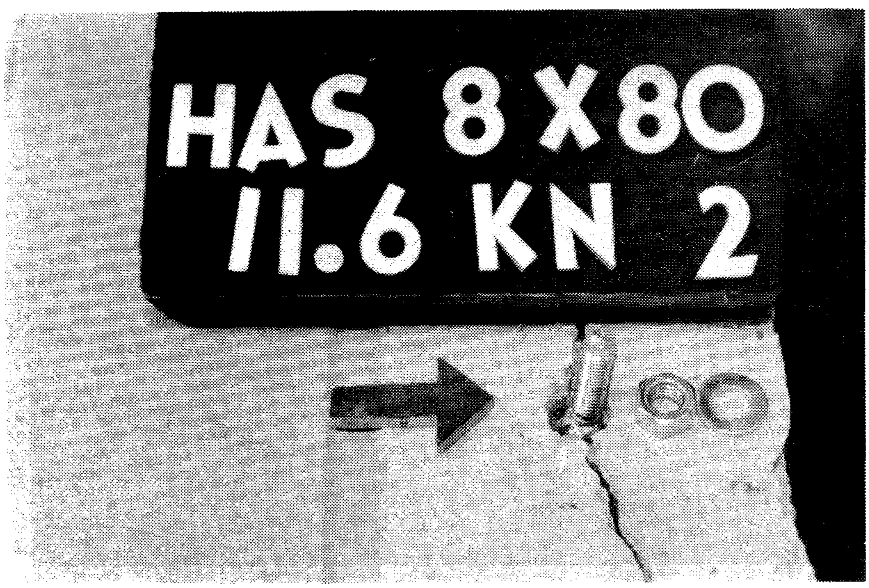

Plate 3.1 Shear Failure in Masonry
(HAS = HVA)

Plate 3.2 Shear Failure in Masonry

Plate 3.3 Shear Failure in Masonry

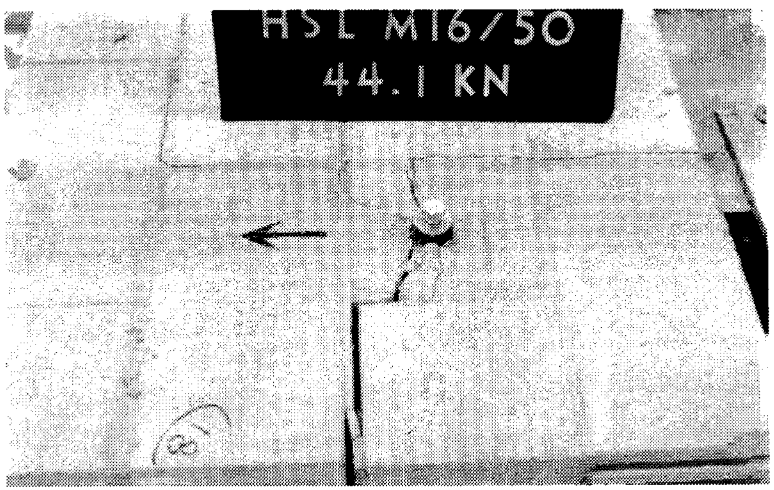

Plate 3.4 Shear Failure in Masonry

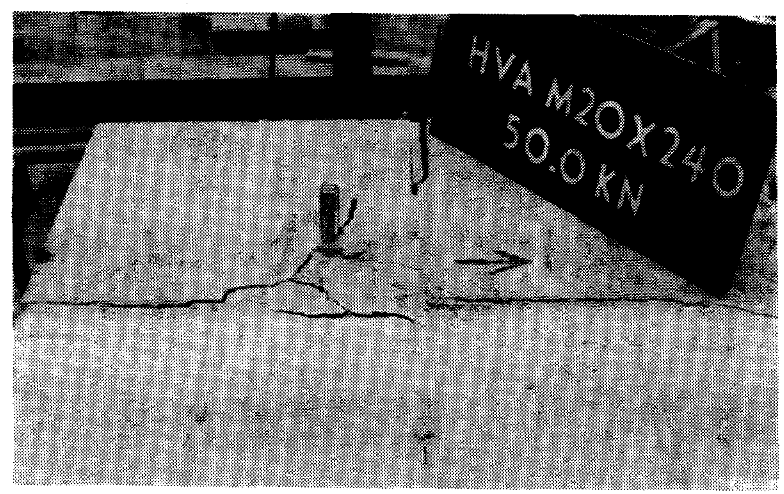

Plate 3.5 Shear Failure in Masonry

Plate 3.6 Insert Failure in Shear

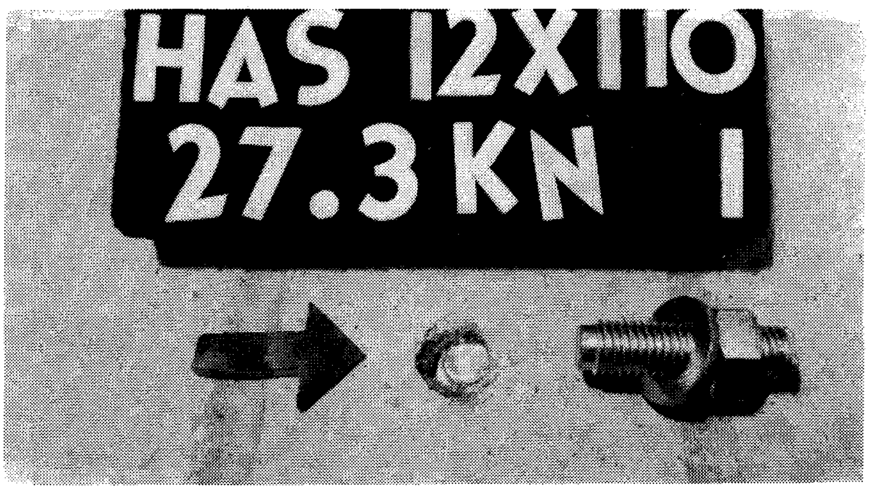

Plate 3.7 Insert Failure in Shear

Plate 3.8 Insert Failure in Shear
(HAS = HVA)

Plate 3.9 Insert Failure in Shear

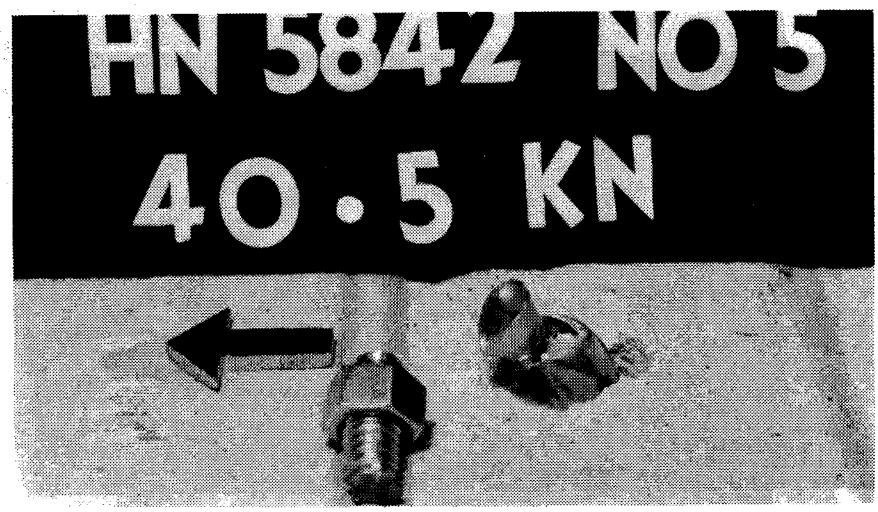

Plate 3.10 Insert Failure in Shear

Plate 3.11 Insert Failure in Shear

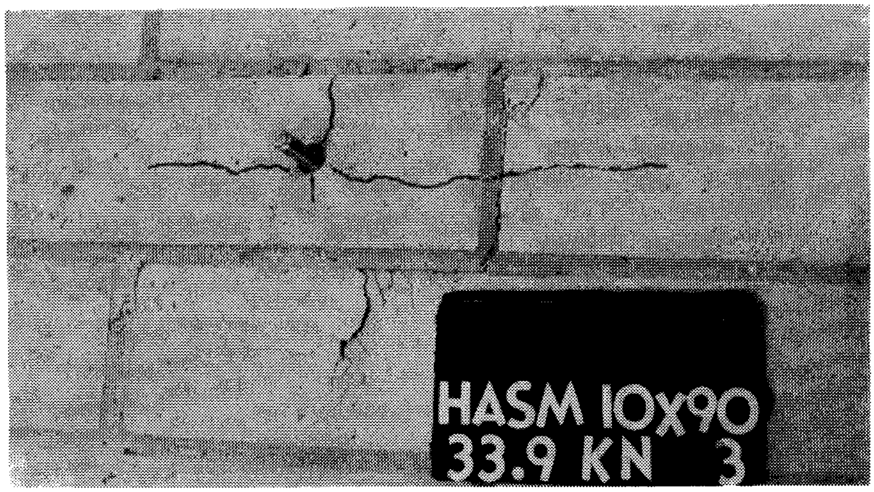

Plate 3.12 Tension Failure in Masonry

Plate 3.13 Threads Stripped in Tension Test

Plate 3.14 Tension Failure in Masonry
(HAS = HVA)

Plate 3.15 Tension Failure in Masonry

Plate 3.16 Tension Failure in Masonry
(HAS = HVA)

Plate 3.17 Tension Failure in Masonry

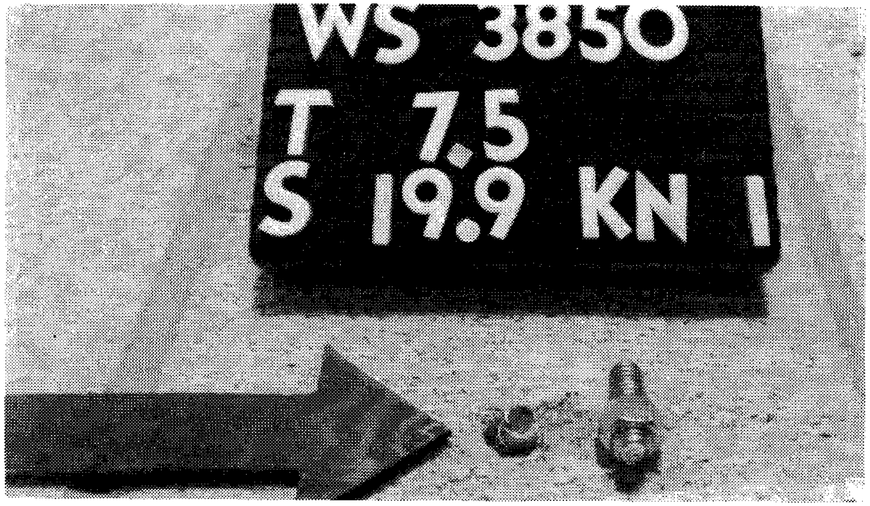

Plate 3.18 Insert Failure Under Combined Shear and Tension

Plate 3.19 Insert Failure Under Combined Shear and Tension

Plate 3.20 Masonry Failure Under Combined Shear and Tension
(HAS = HVA)

Plate 3.21 Shear Failure Under Embedment Depth Test

Plate 3.22 Shear Failure Under Embedment Depth Test

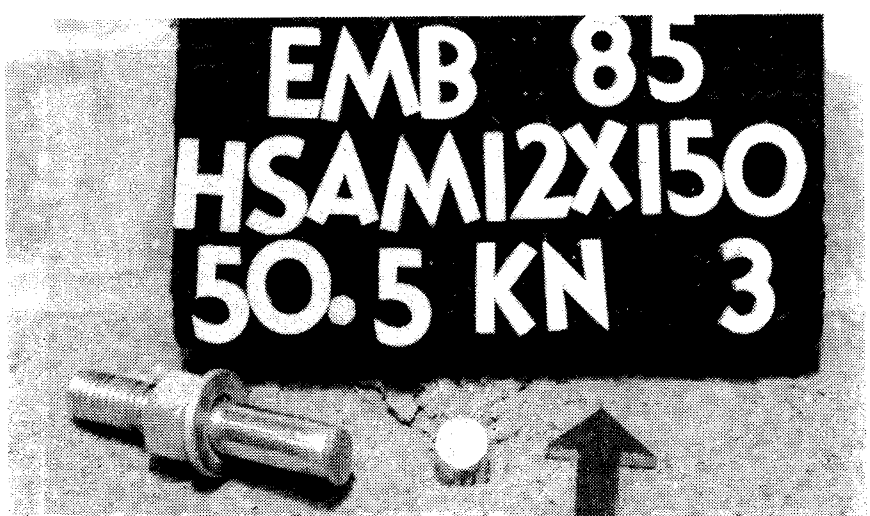

Plate 3.23 Shear Failure Under Embedment Depth Test

Plate 3.24 Shear Failure Under Embedment Depth Test

Plate 3.25 Shear Failure Under Embedment Depth Test

Plate 3.26 Failed Specimens

Plate 3.27 Tension Failure Under Embedment Depth Test

Plate 3.28 Tension Failure Under Embedment Depth Test

Plate 3.29 Tension Failure Under Embedment Depth Test

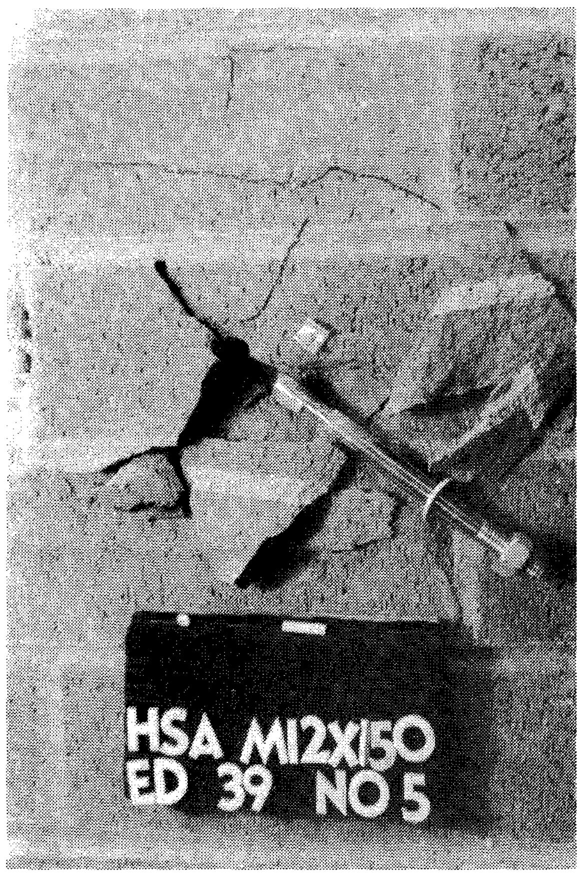

Plate 3.30 Tension Failure Under Embedment Depth Test

4. Analysis of Test Results

4.1 Introduction

Results of the large number of tests are presented in graphical form relative to edge distance, type of masonry (clay brick or concrete block) and type of loading. Although there is some variation in the tensile strengths of the various inserts and the compressive strengths of the masonry units, test results are grouped together as appropriately as possible in order to develop the general behavior patterns of drilled-in inserts in masonry. Earlier studies[3] by the authors on the behavior of anchors embedded in masonry related the anchor shear capacity to the yield strength (f_y) of the anchors and the compressive strength of masonry (f'_m). These relationships have been modified to define the capacity of drilled-in inserts.

4.2 Direct Shear

The shear capacities for various edge distances are plotted in Figures 4.1 to 4.4 for adhesive inserts, and from Figures 4.5 to 4.7 for expansion inserts in grouted brick masonry. For edge distances of 250 mm or higher, the shear capacities were not affected by the edge distance. For an edge distance of 50 mm, the shear capacity was reduced in the order of 50%.

The shear capacities in grouted concrete block masonry for various edge distances are plotted in Figures 4.8 to

4.11 for adhesive inserts, and in Figures 4.12 to 4.15 for expansion inserts. For both the adhesive and expansion inserts, shear capacity is always limited by the masonry strength when nominal insert size is 16 mm or higher. For edge distances of 495 mm or more, the masonry failed by cracking of the entire specimen along bed or head joints. When the edge distance was 295 mm, masonry in front of the insert in the direction of the load tore away from the wall at a substantially lower load. For inserts installed at an edge distance of 95 mm, a reduced capacity in the order of 50% as those installed in brick masonry was observed. Thus edge distance significantly affected the capacity in concrete block specimens.

Test results indicated that shear capacity increased with increasing insert size. The type of grout had no significant effect on the shear capacity. However, the type of masonry (clay brick or concrete block) did have some influence on the capacity of the inserts as well as on the failure mode. The shear capacity is governed by the strength of the masonry unit, i.e., clay brick or concrete block, and limited by the strength of the insert material. The shear capacities are slightly higher in clay brick than in concrete block masonry.

Based on the ultimate tensile strength (f_{ut} in MPa) of the insert material, the shear strength V_s of an insert in kN may be approximated as

$$V_s = \frac{f_{ut}\,A_{sn}}{10^3 \cdot \sqrt{3}} \qquad (4.1)$$

where

A_{sn} = actual cross-sectional area of insert at the root of the thread in mm^2
= $\pi d_n^2/4$

d_n = diameter at root of the thread in mm

Equation 4.1 is based on A_{sn} since the shear load was applied to the threaded portion of the insert in all direct shear tests in this program. The ultimate tensile strength (f_{ut}) of the inserts tested varied from 560 to 860 MPa. Based on these two limits, Equation 4.1 is plotted in Figure 4.16 which includes all the results of inserts failing in shear. The majority of the test data falls within the two limits indicating that Equation 4.1 predicts the insert shear capacity satisfactorily. Equation 4.1 based on the average f_{ut} value of 700 MPa is also plotted in the same figure.

From previous studies[3] by the authors, the shear strength of masonry, V_m in kN, may be defined by the empirical relation

$$V_m = K \sqrt[4]{f_b' \, A_{sg}} \qquad (4.2)$$

where

K = edge distance factor
= 5.25 for edge distance equals to or over 500 mm
= 3.25 for edge distance equals to 300 mm
= 2.25 for edge distance equals to 100 mm

f_b' = unit compressive strength of brick or concrete block in MPa

A_{sg} = gross cross-sectional area of insert in mm^2

The unit strength of brick or concrete block (f_b') is used since crushing or cracking in the masonry always initiated in the masonry units. The factor K reflects the influence of edge distance.

Equation 4.2 may be modified to relate the shear capacity to the actual cross-sectional area at the root of the thread instead of gross area. This will allow direct comparison with Equation 4.1. From the insert diameters tabulated in Table 2.1, it is found that the fourth root of the ratio of gross cross-sectional area to net cross-sectional area ($\sqrt[4]{A_{sg}/A_{sn}}$) ranges from 1.07 to 1.22. For simplification, using a value of 1.1 for $\sqrt[4]{A_{sg}/A_{sn}}$, Equation 4.2 can be rewritten as

$$V_m = 1.1 \times K \times \sqrt[4]{f_b' A_{sn}} \qquad (4.2(a))$$

Equation 4.2(a) is plotted in Figures 4.17 to 4.21 which relate insert capacity to strength of masonry at various edge distances. Considering the number of variables affecting the test results, Equation 4.2 or 4.2(a) is a satisfactory expression for the shear capacity.

Equations 4.1 and 4.2(a) are plotted in Figures 4.22 to 4.28 which show test results for the two masonry types at various edge distances. Equations 4.1 and 4.2(a) provide a reasonable prediction of the capacities of drilled-in inserts.

4.3 Direct Tension

As indicated in Tables 3.6 and 3.7, tension capacities of adhesive (Type A) inserts are higher than those of expansion (Type W1) inserts of the same size. For Type W1 inserts, the tension capacity increased as the insert diameter increased up to 12 mm, beyond which the capacity remained approximately the same. However, the tension capacity of Type A inserts continued to increase for insert diameters greater than 12 mm.

Relationships between tension strength and embedment depth or insert diameter for adhesive inserts in grouted brick and concrete block masonry are shown in Figures 4.29 to 4.32, while those for expansion inserts are shown in Figures 4.33 to 4.36.

Test results indicate that the capacity of adhesive inserts depended on the embedment depth as well as the insert diameter. This is to be expected, as the ability of this type of insert to resist tension load mainly depends on the bond stress on the contact area between the insert shaft and the wall of the hole. However, for expansion inserts having the same diameter, a considerable difference in the embedment depth makes no difference to the tension capacity. The holding power is provided by the keying action at the wedge part of the insert. Thus the capacity depends on the diameter of the insert instead of the embedment depth or the length of the insert.

Figures 4.29 to 4.32 indicate that the tension capacity of adhesive inserts in both brick and concrete block masonry varies almost linearly with the embedment length as well as the insert diameter. On the other hand, Figures 4.33 and 4.34 indicate considerable scatter of tension capacities for expansion inserts in terms of embedment depth. However, Figures 4.35 and 4.36 indicate a rather linear increase in capacity with increase in insert diameter for this type of insert.

Based on the above observations, the capacity of adhesive inserts should be related to the embedment depth and the insert diameter, whereas the capacity of expansion inserts should be related to the insert diameter but not to the embedment depth.

A linear regression fit to the test data yields the following relationships for the two types of insert.

For adhesive inserts

$$T_u = 2.1 + 0.3L \quad (4.3)$$

where

T_u = tension capacity in kN

L = embedment length in mm

and $$T_u = 8.6 + 2.0d \quad (4.4)$$

where

d = insert diameter in mm

For expansion inserts

$$T_u = 0.5 + 1.4d \tag{4.5}$$

Equations 4.3 to 4.5 are plotted in Figures 4.37 to 4.39. The higher capacity of the adhesive inserts is clearly indicated by comparing Equations 4.4 and 4.5 in terms of insert diameter.

4.4 Combined Tension and Shear

For the combined tension and shear tests in this investigation, the inserts were installed at a large edge distance and the diameter was limited to 12 mm in order to avoid masonry failure.

The experimental results are shown in Figures 4.40 to 4.45. To predict the interactive tension-shear relationship, an elliptical interactive curve of the form

$$\left(\frac{T}{T_u}\right)^{5/3} + \left(\frac{V}{V_u}\right)^{5/3} = 1 \tag{4.6}$$

was found to be the best fit to most test data, where

T = applied tension load in kN

T_u = tension capacity in kN

V = applied shear load in kN

V_u = shear capacity in kN

The shear capacity V_u is defined by Equation 4.1 while the tension capacity T_u is defined by the smaller of Equation 4.3 or 4.4 for adhesive inserts and Equation 4.5 for expansion inserts.

Equation 4.6 is also plotted in Figures 4.40 to 4.45. For the adhesive inserts, reasonable agreement with the test data is observed. However, Equation 4.6 is in close agreement with test data for the expansion inserts only for the larger size. This may be attributed to the arbitrary definition of the tension capacity based on a maximum longitudinal slip equal to 25% the insert diameter. It is possible that greater ultimate tension capacities could be reached at larger slip values for the small inserts.

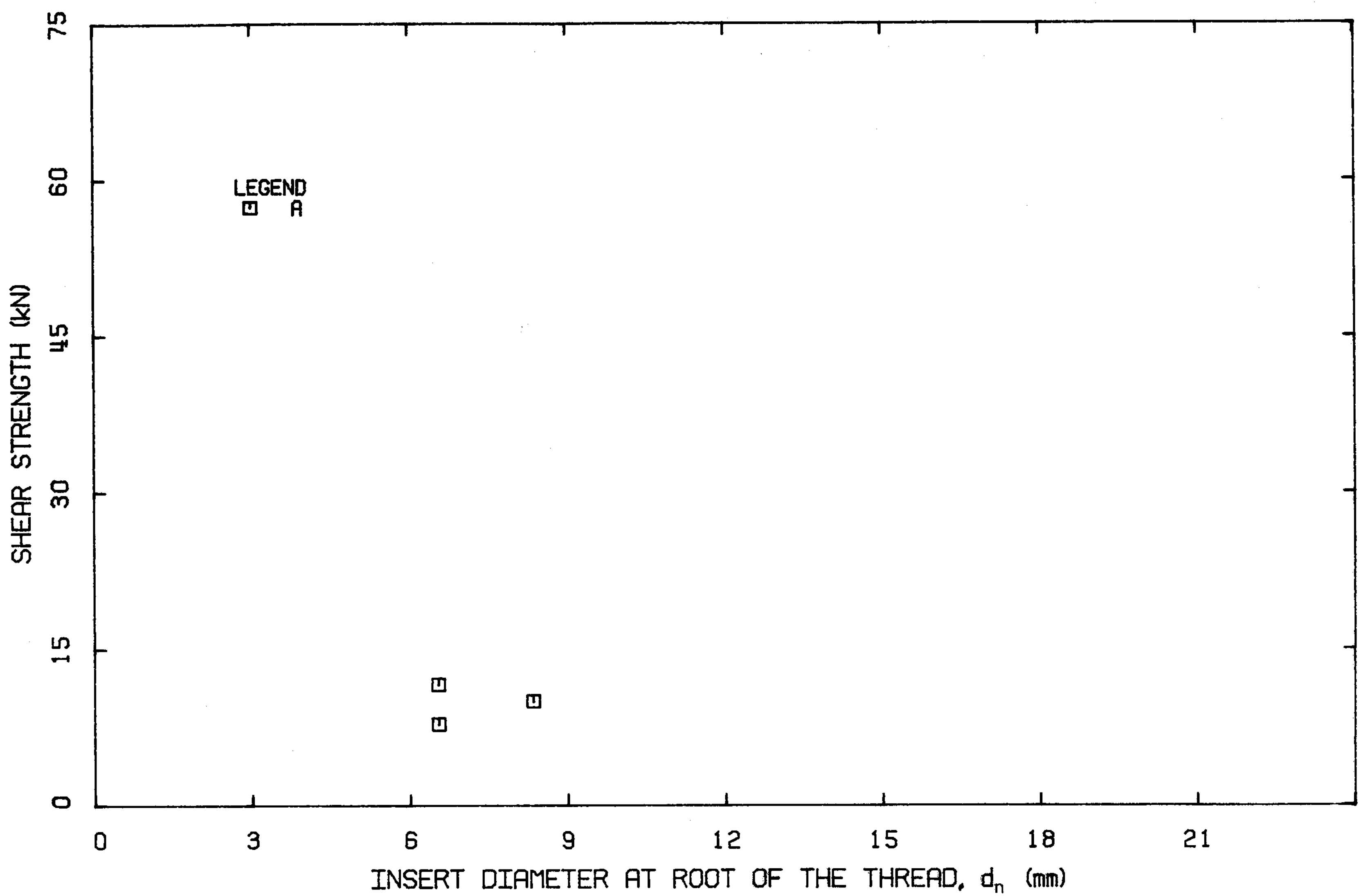

Figure 4.1 Shear Strength of Adhesive Inserts at an Edge Distance of 50 mm in Grouted Brick Masonry

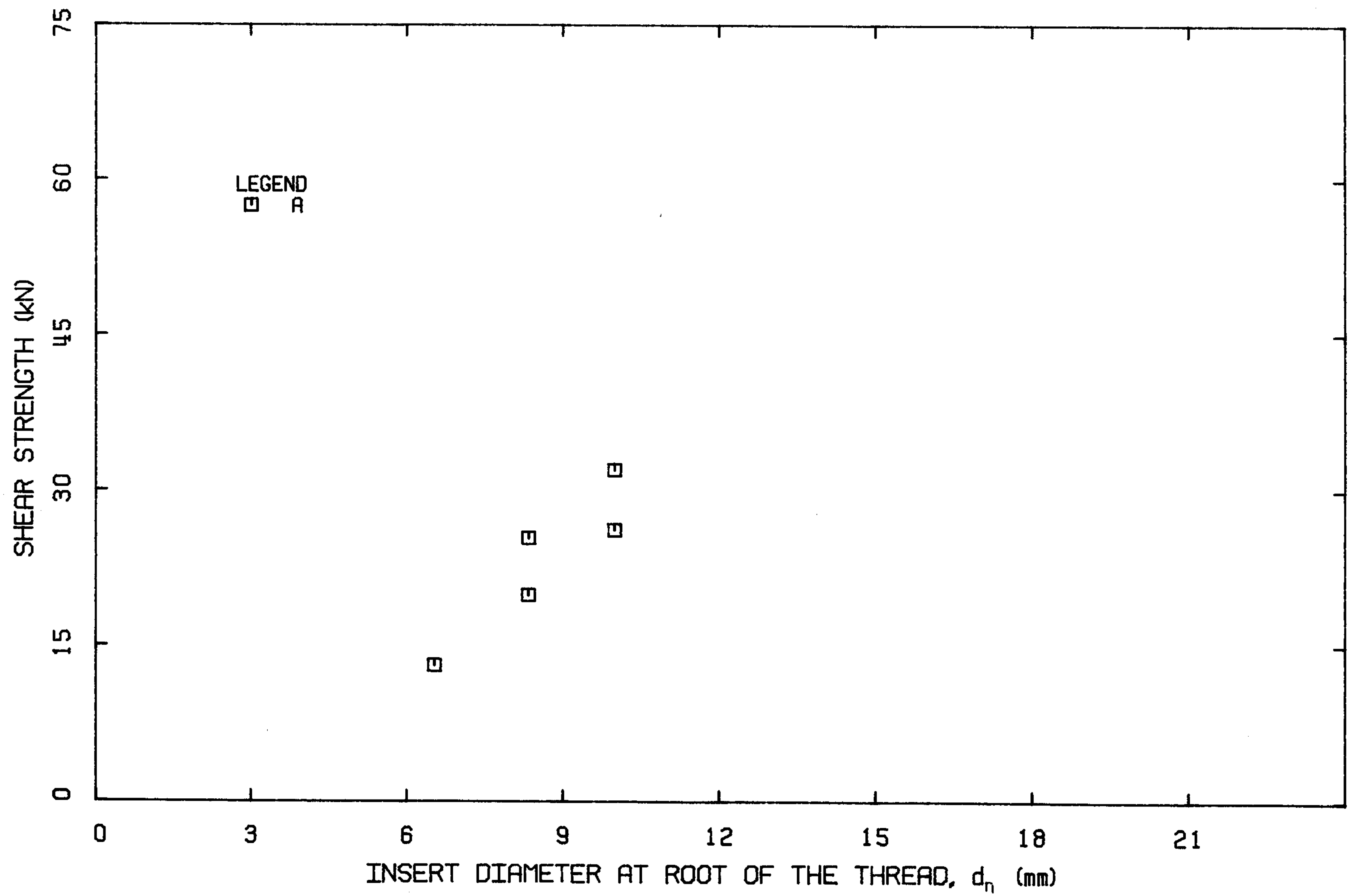

Figure 4.2 Shear Strength of Adhesive Inserts at an Edge Distance of 250 mm in Grouted Brick Masonry

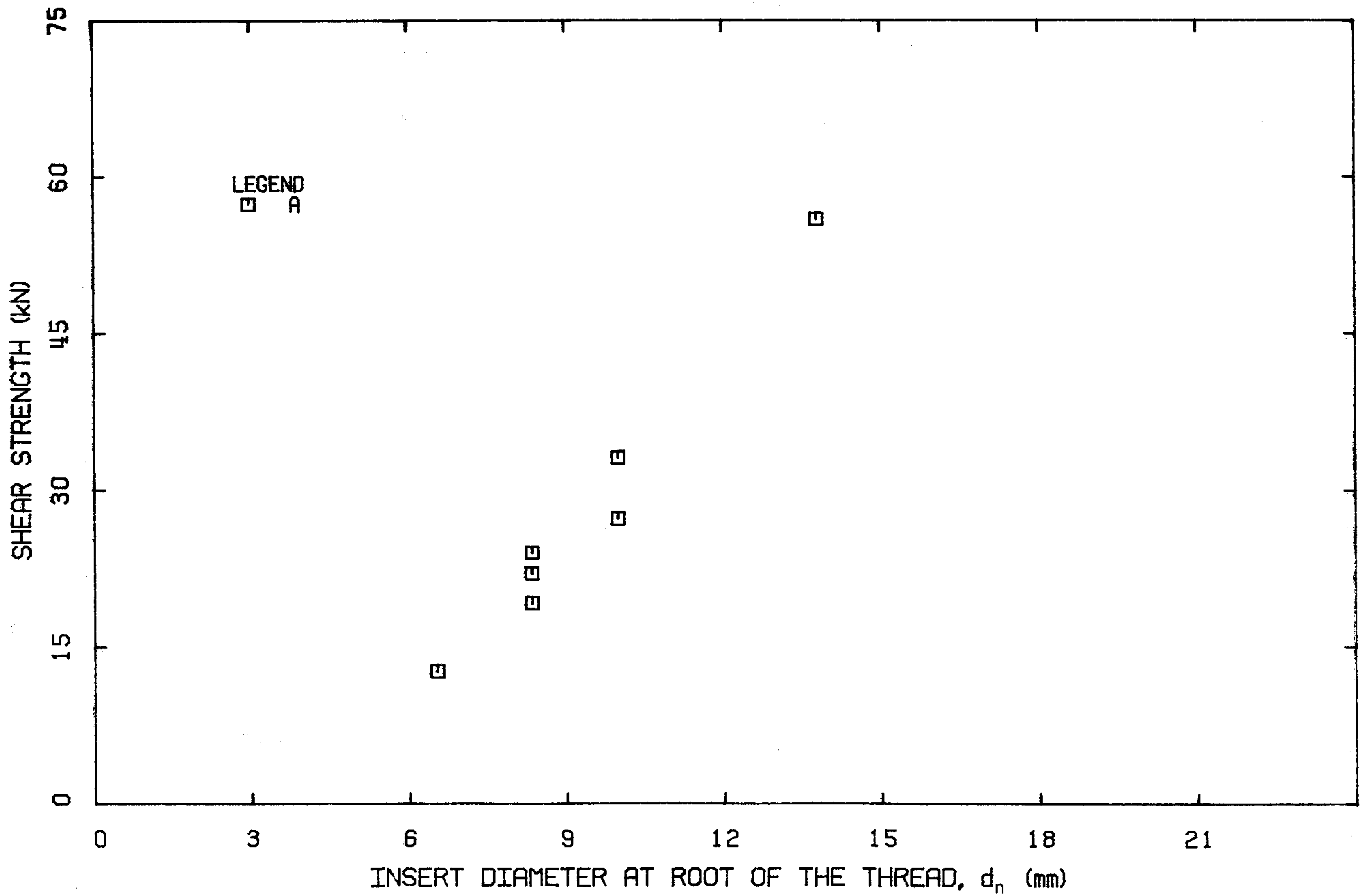

Figure 4.3 Shear Strength of Adhesive Inserts at an Edge Distance of 450 mm in Grouted Brick Masonry

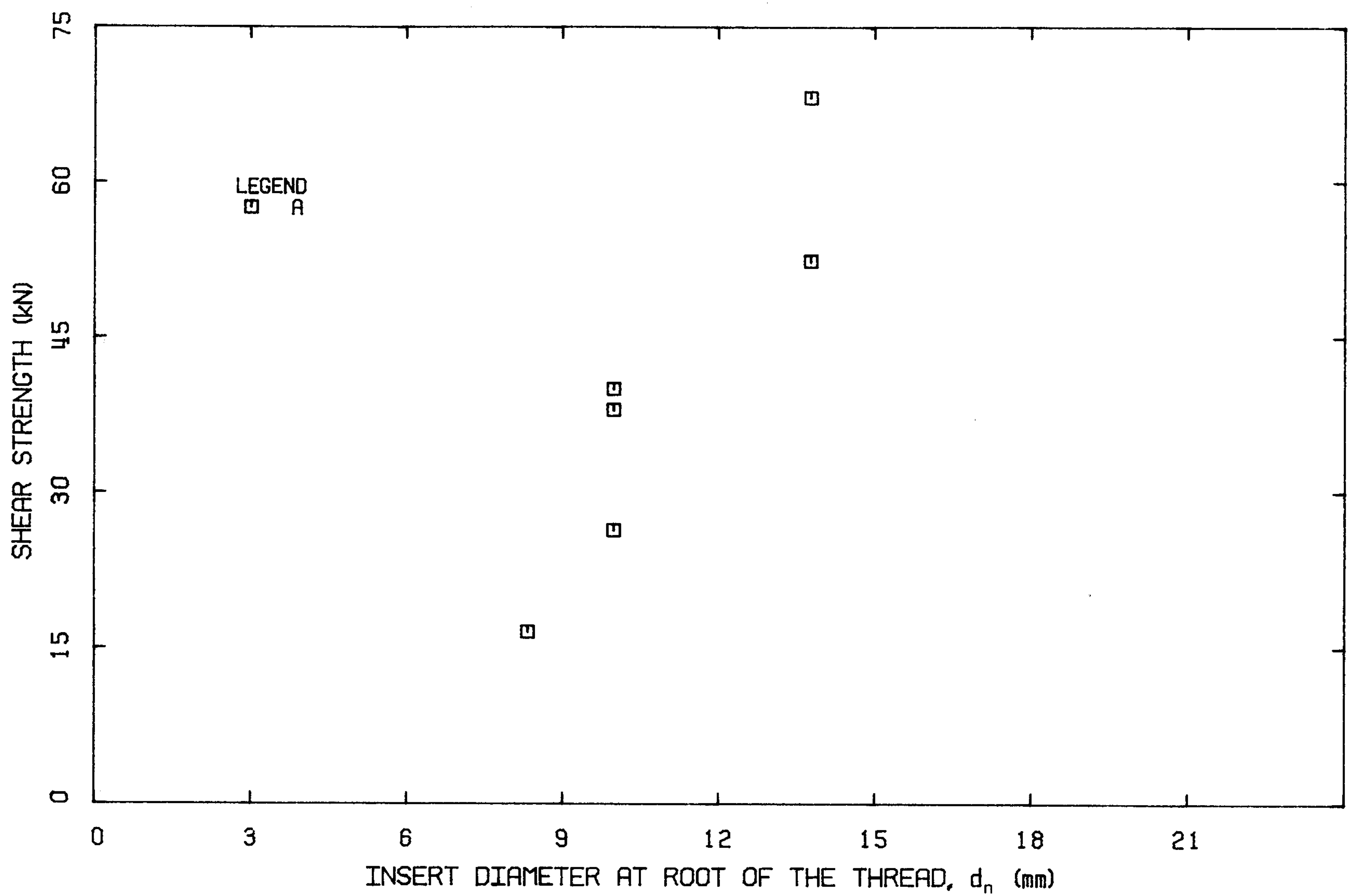

Figure 4.4 Shear Strength of Adhesive Inserts at an Edge Distance of 650 mm in Grouted Brick Masonry

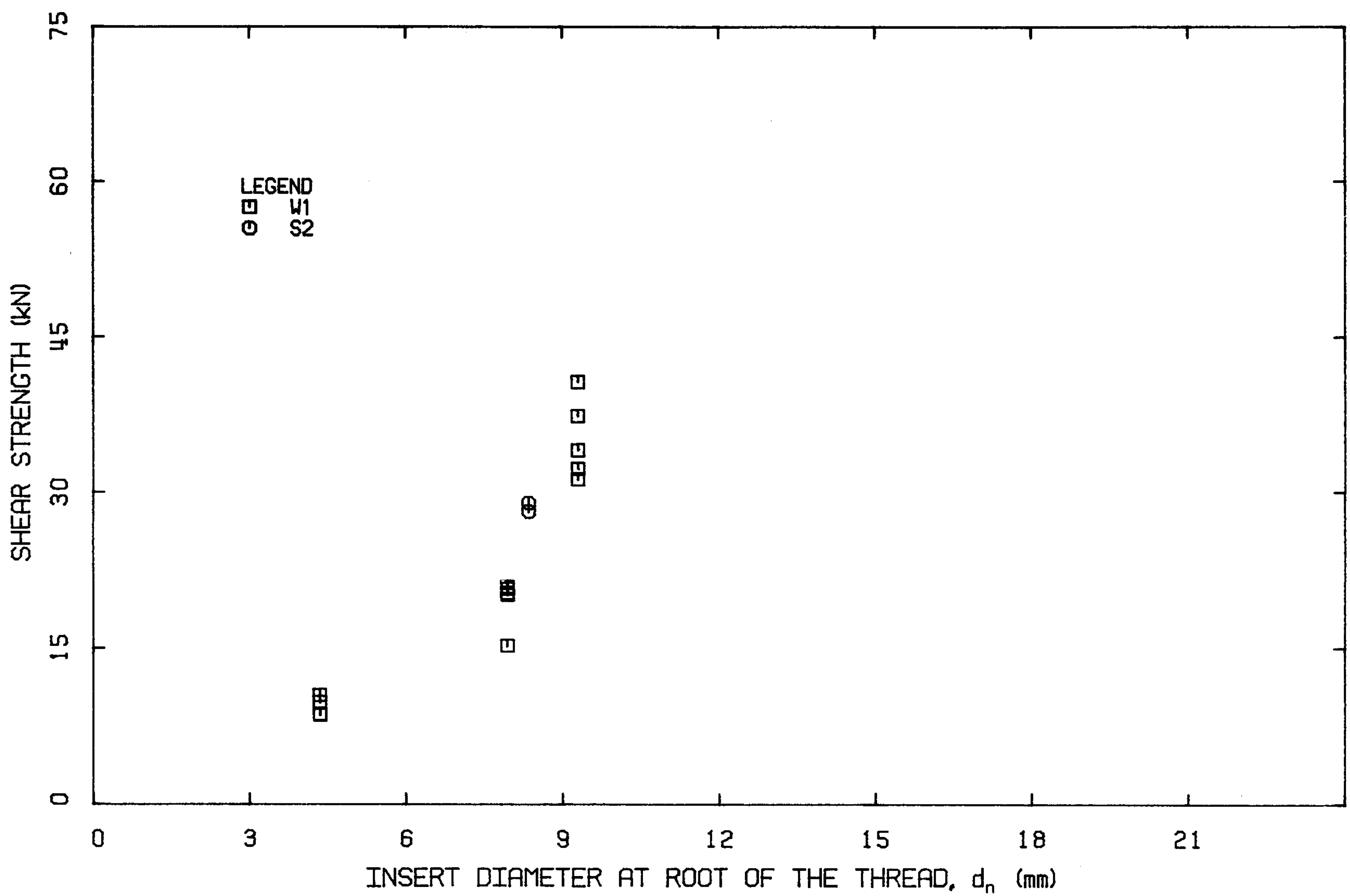

Figure 4.5 Shear Strength of Expansion Inserts at an Edge Distance of 250 mm in Grouted Brick Masonry

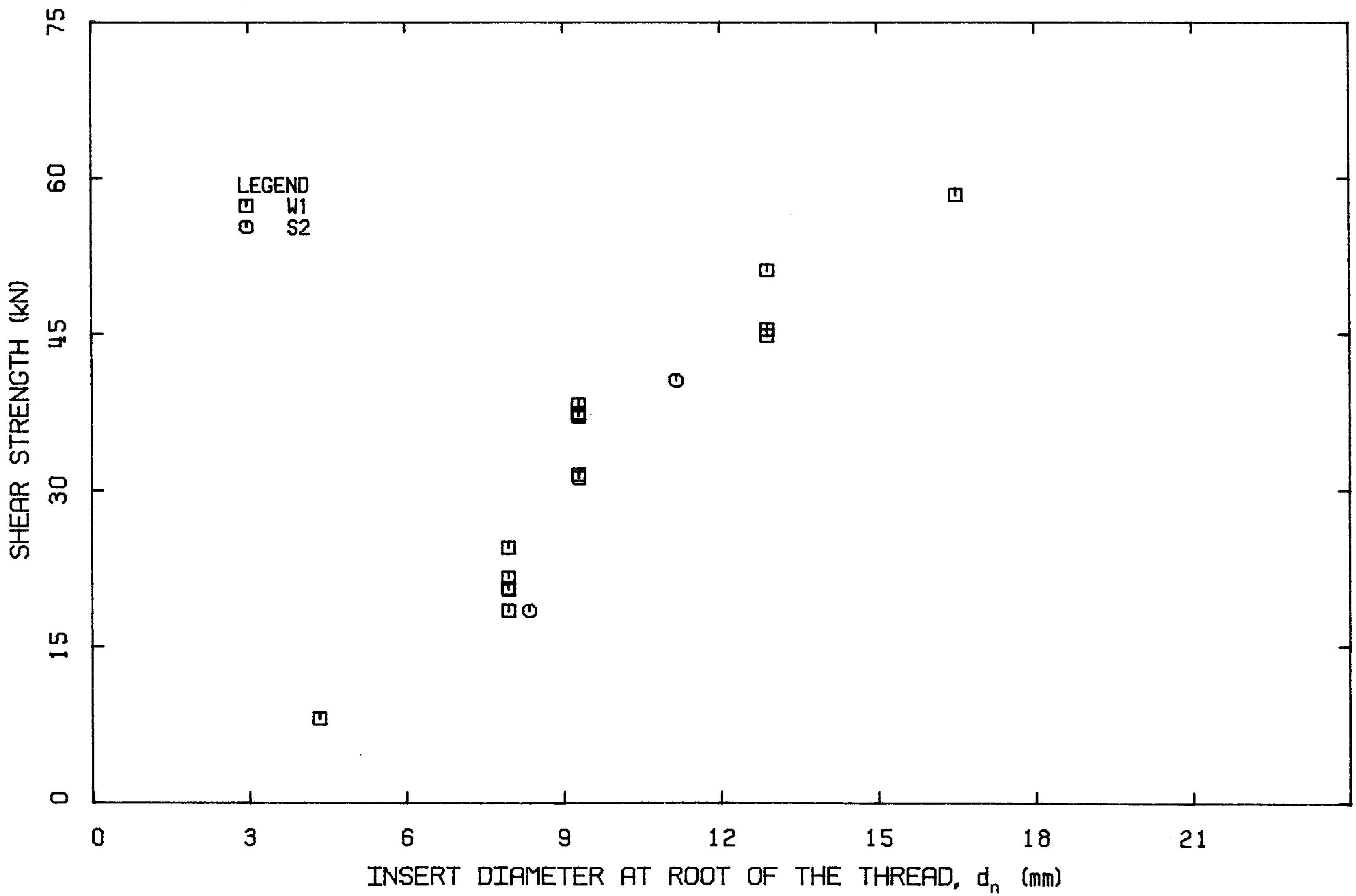

Figure 4.6 Shear Strength of Expansion Inserts at an Edge Distance of 450 mm in Grouted Brick Masonry

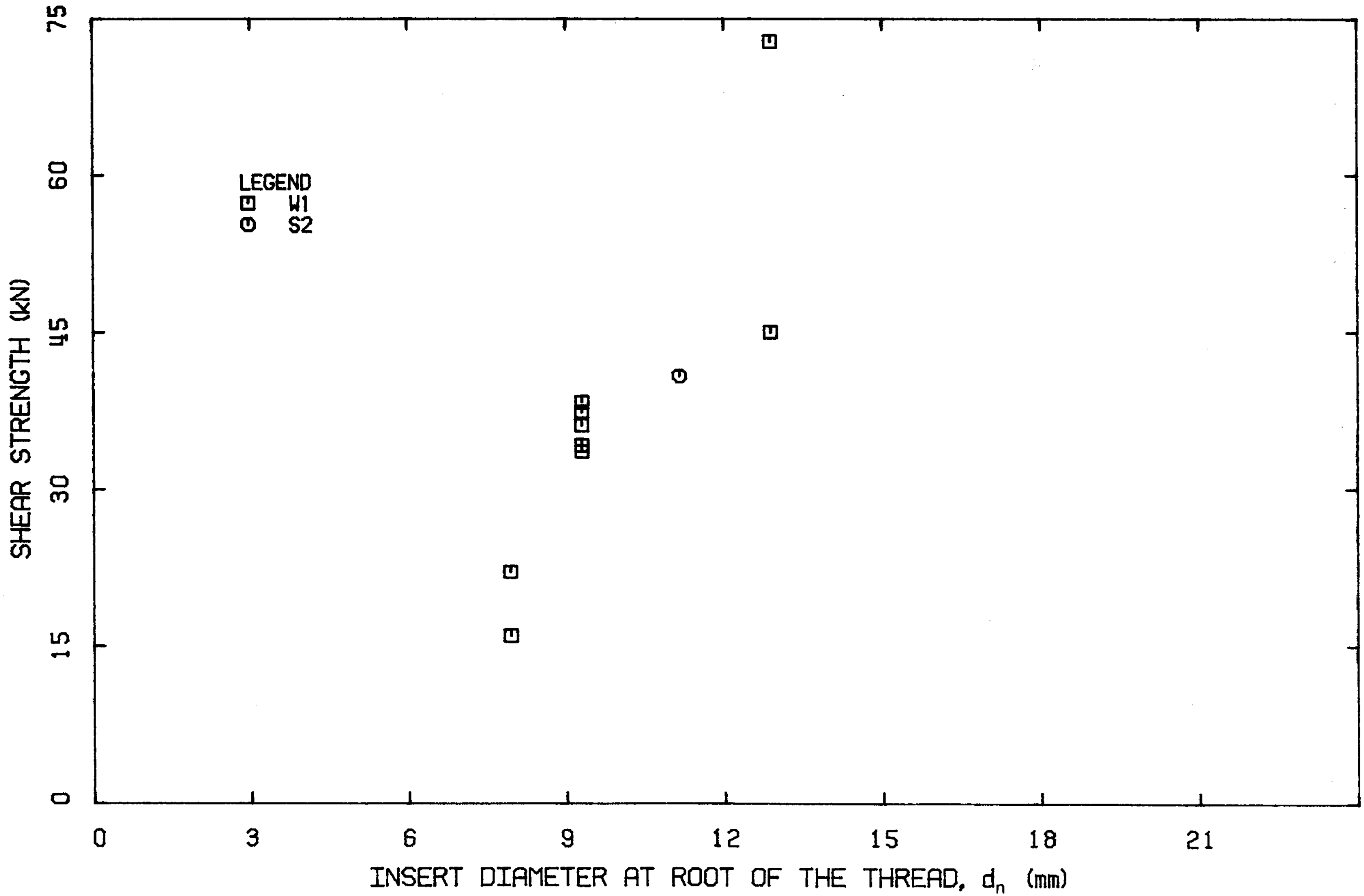

Figure 4.7 Shear Strength of Expansion Inserts at an Edge Distance of 650 mm in Grouted Brick Masonry

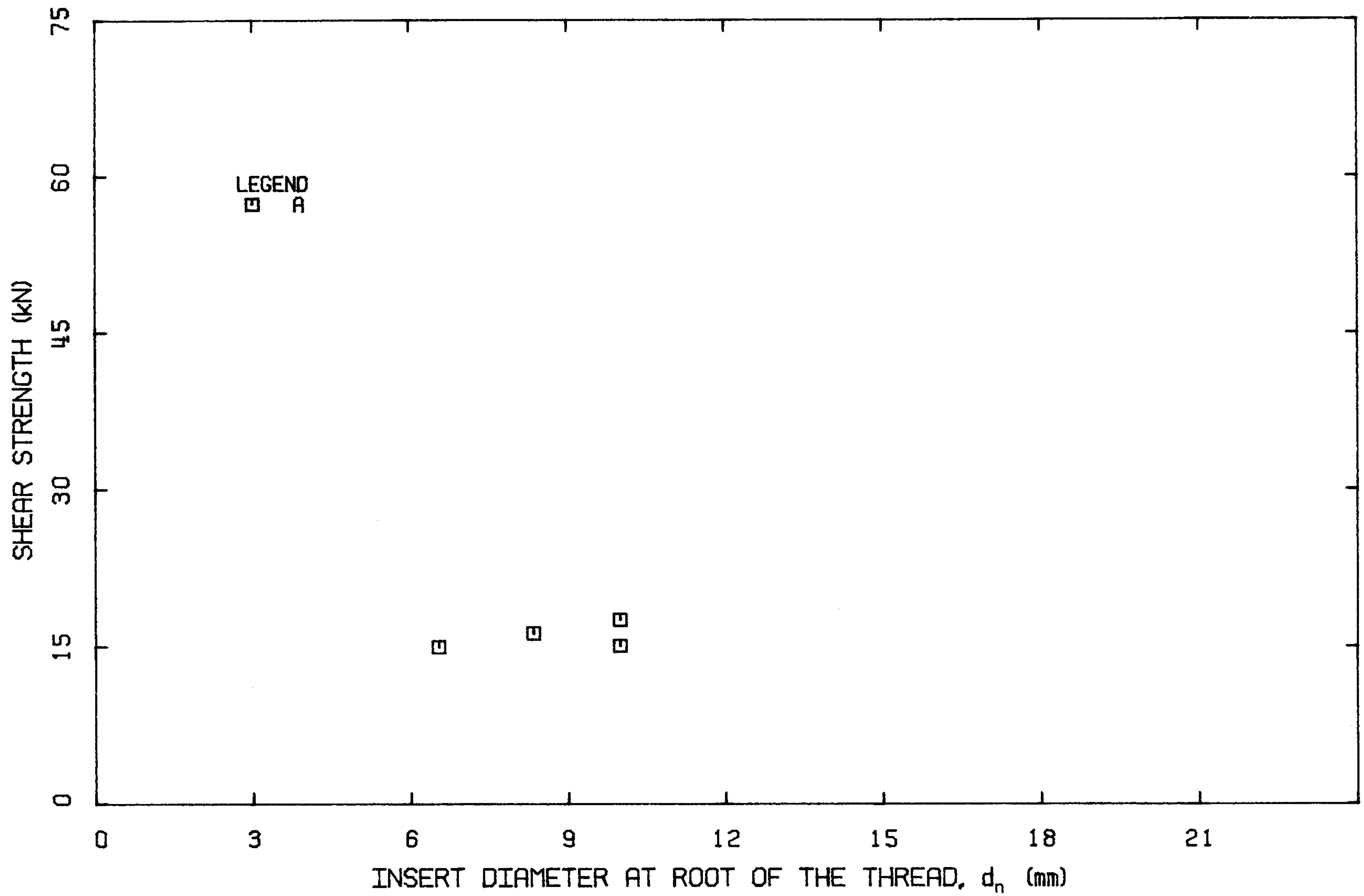

Figure 4.8 Shear Strength of Adhesive Inserts at an Edge Distance of 95 mm in Grouted Concrete Block Masonry

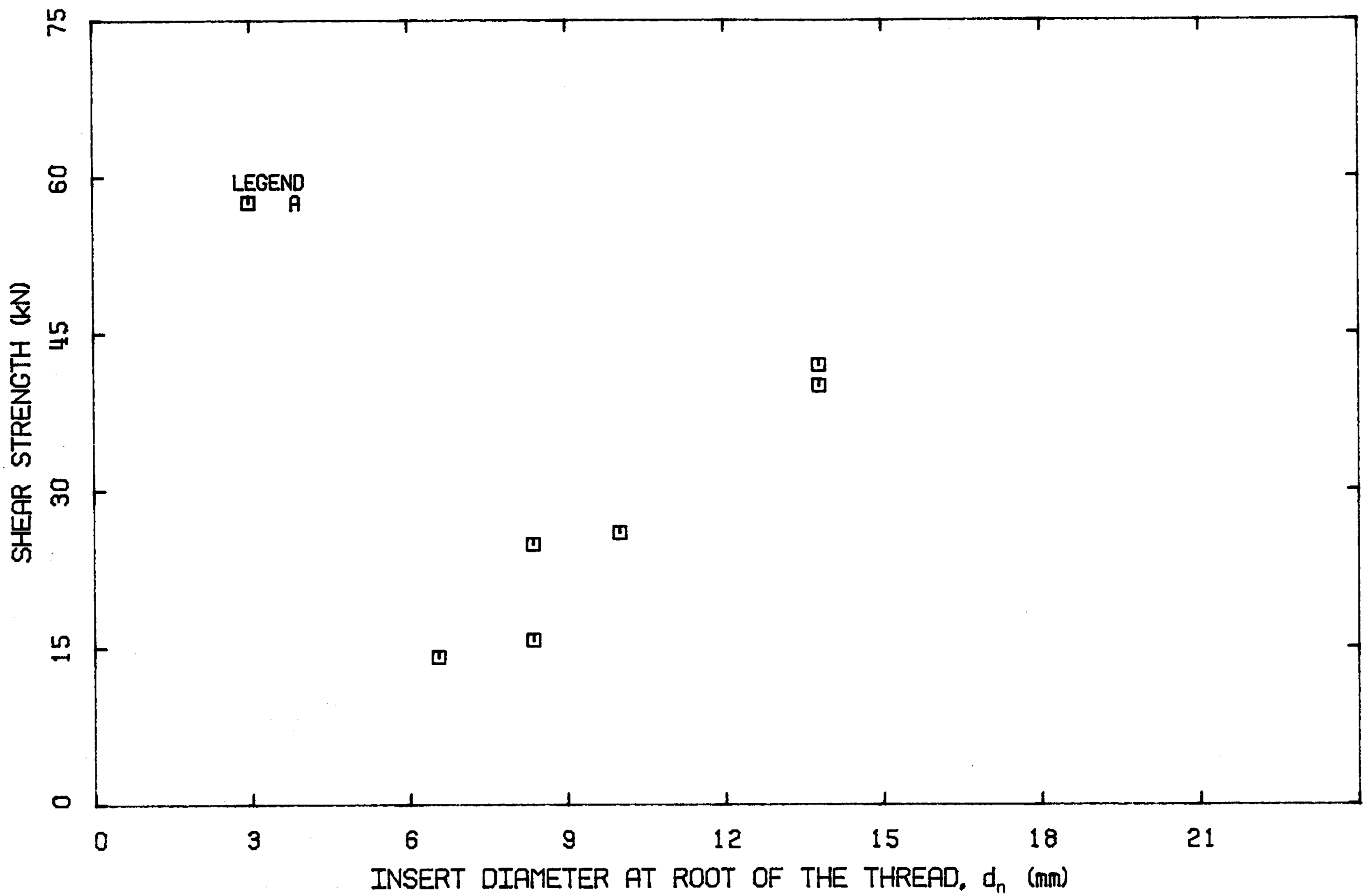

Figure 4.9 Shear Strength of Adhesive Inserts at an Edge Distance of 295 mm in Grouted Concrete Block Masonry

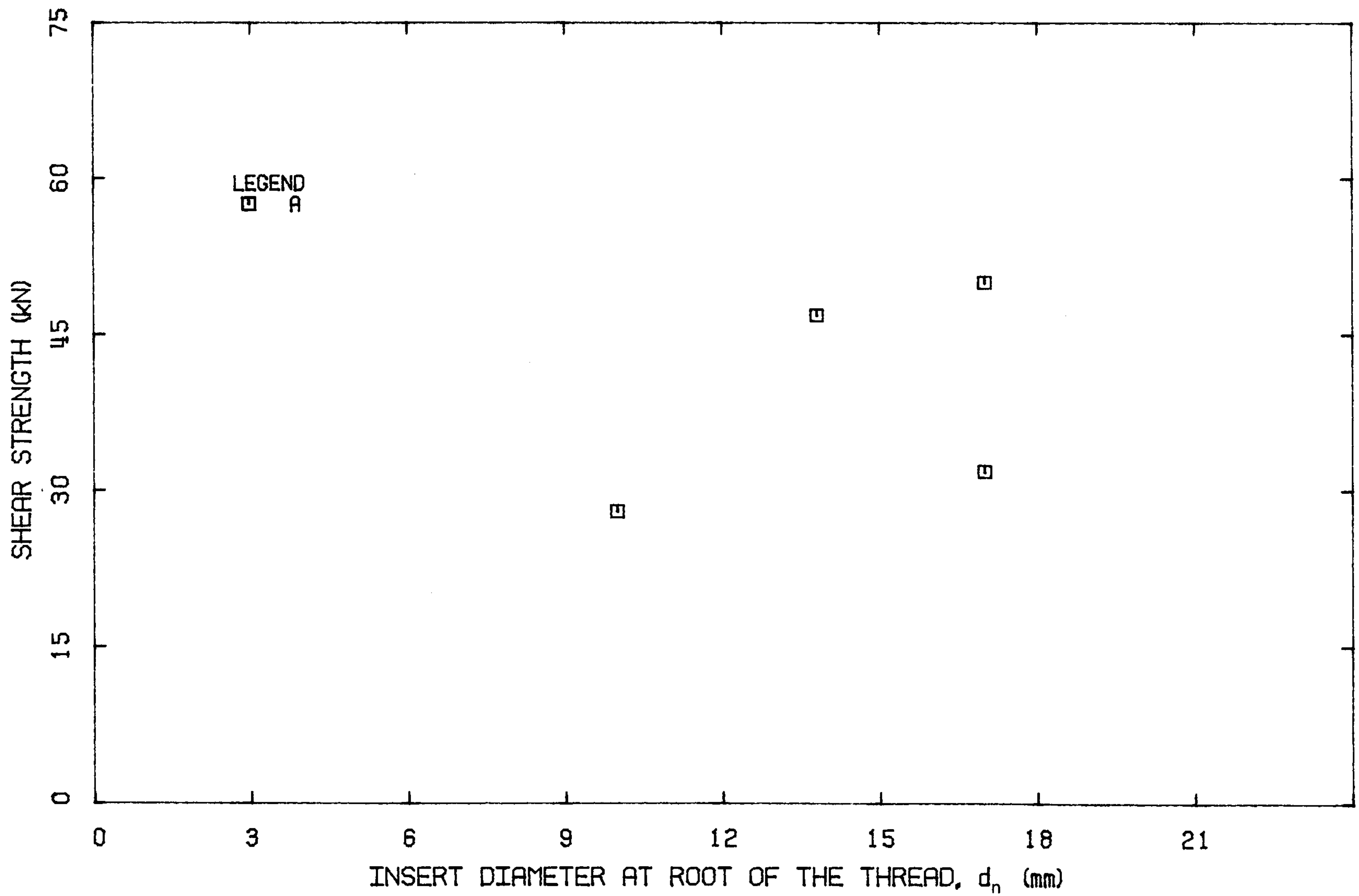

Figure 4.10 Shear Strength of Adhesive Inserts at an Edge Distance of 495 mm in Grouted Concrete Block Masonry

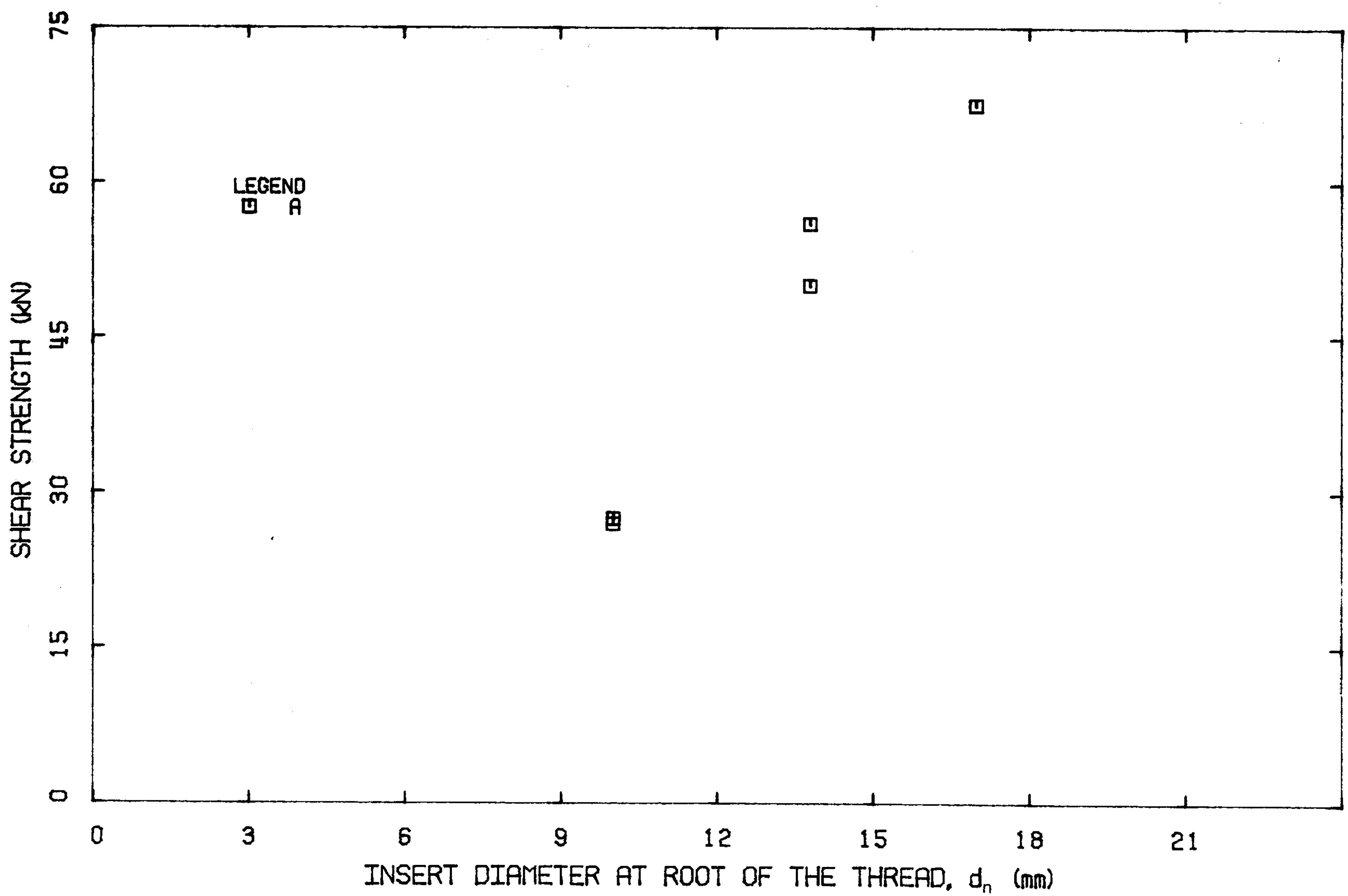

Figure 4.11 Shear Strength of Adhesive Inserts at an Edge Distance of 695 mm in Grouted Concrete Block Masonry

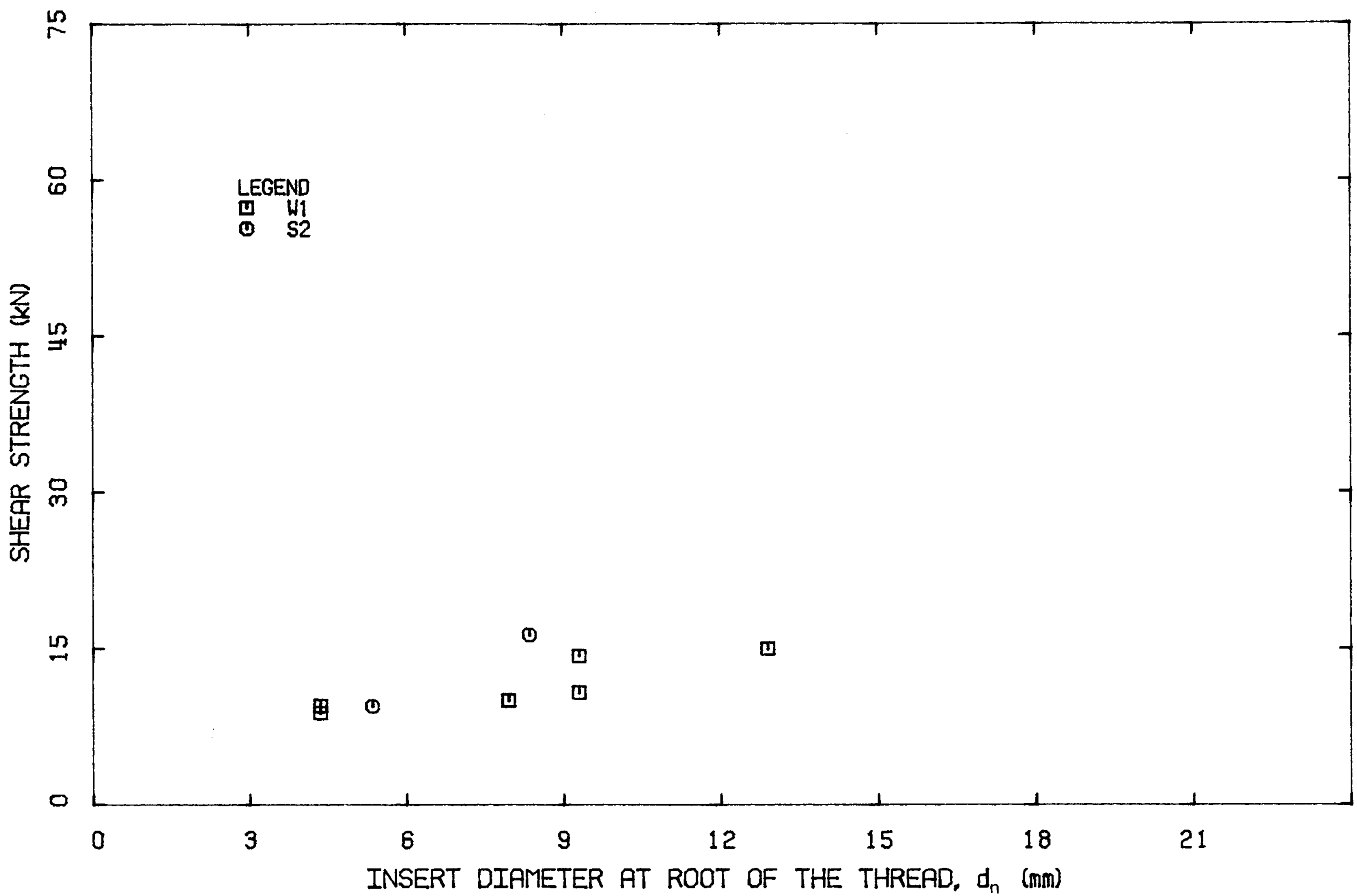

Figure 4.12 Shear Strength of Expansion Inserts at an Edge Distance of 95 mm in Grouted Concrete Block Masonry

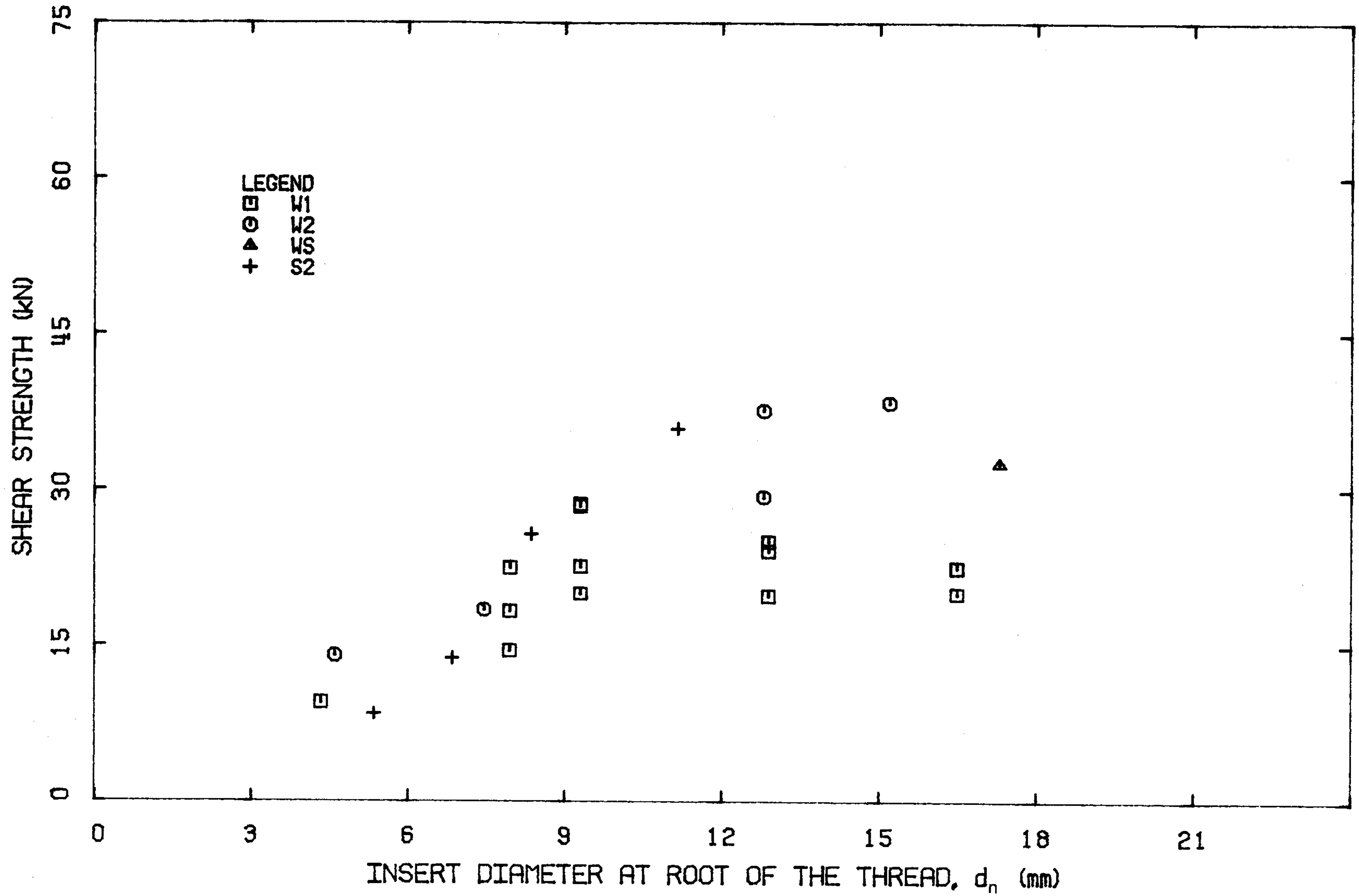

Figure 4.13 Shear Strength of Expansion Inserts at an Edge Distance of 295 mm in Grouted Concrete Block Masonry

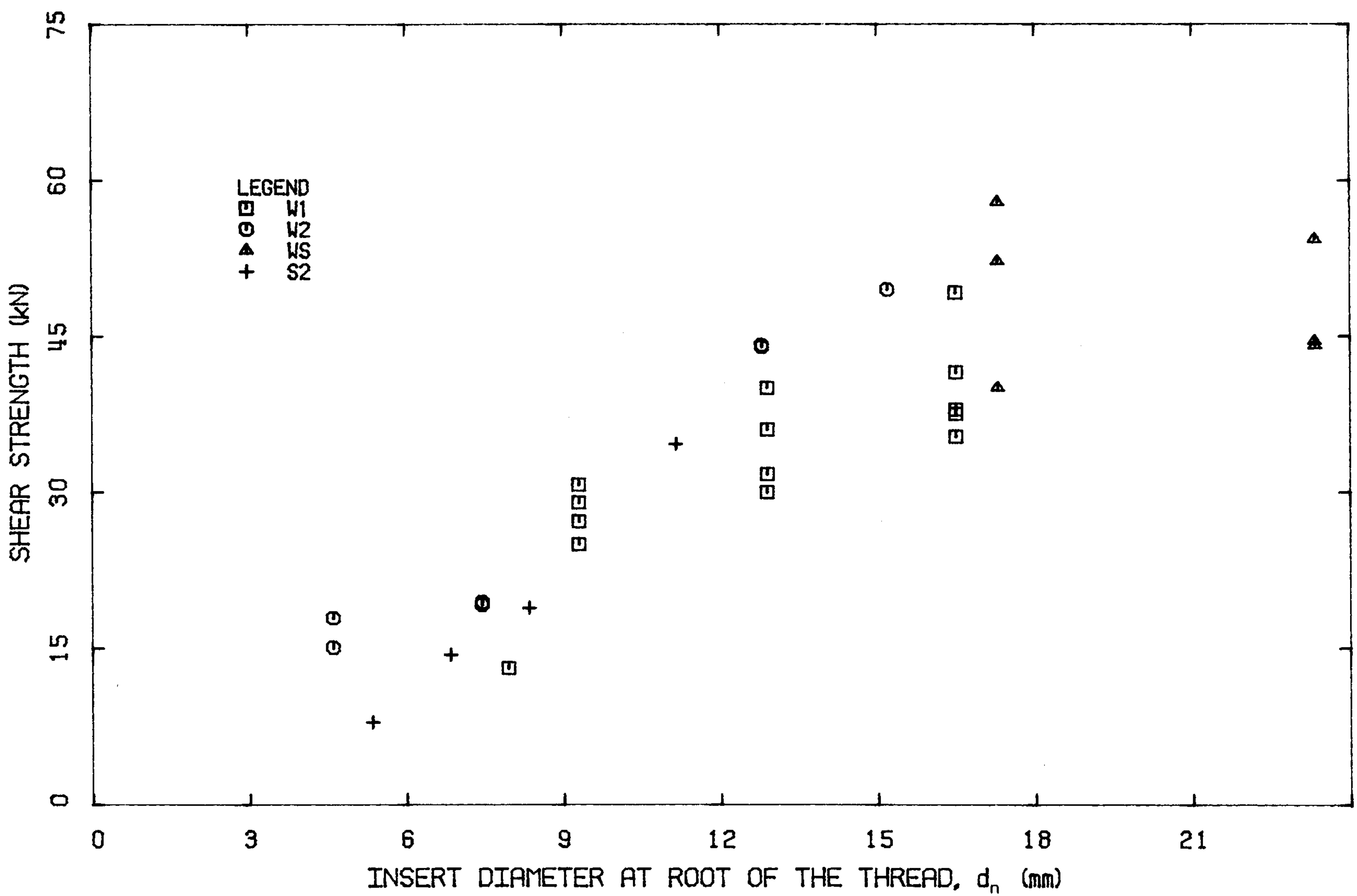

Figure 4.14 Shear Strength of Expansion Inserts at an Edge Distance of 495 mm in Grouted Concrete Block Masonry

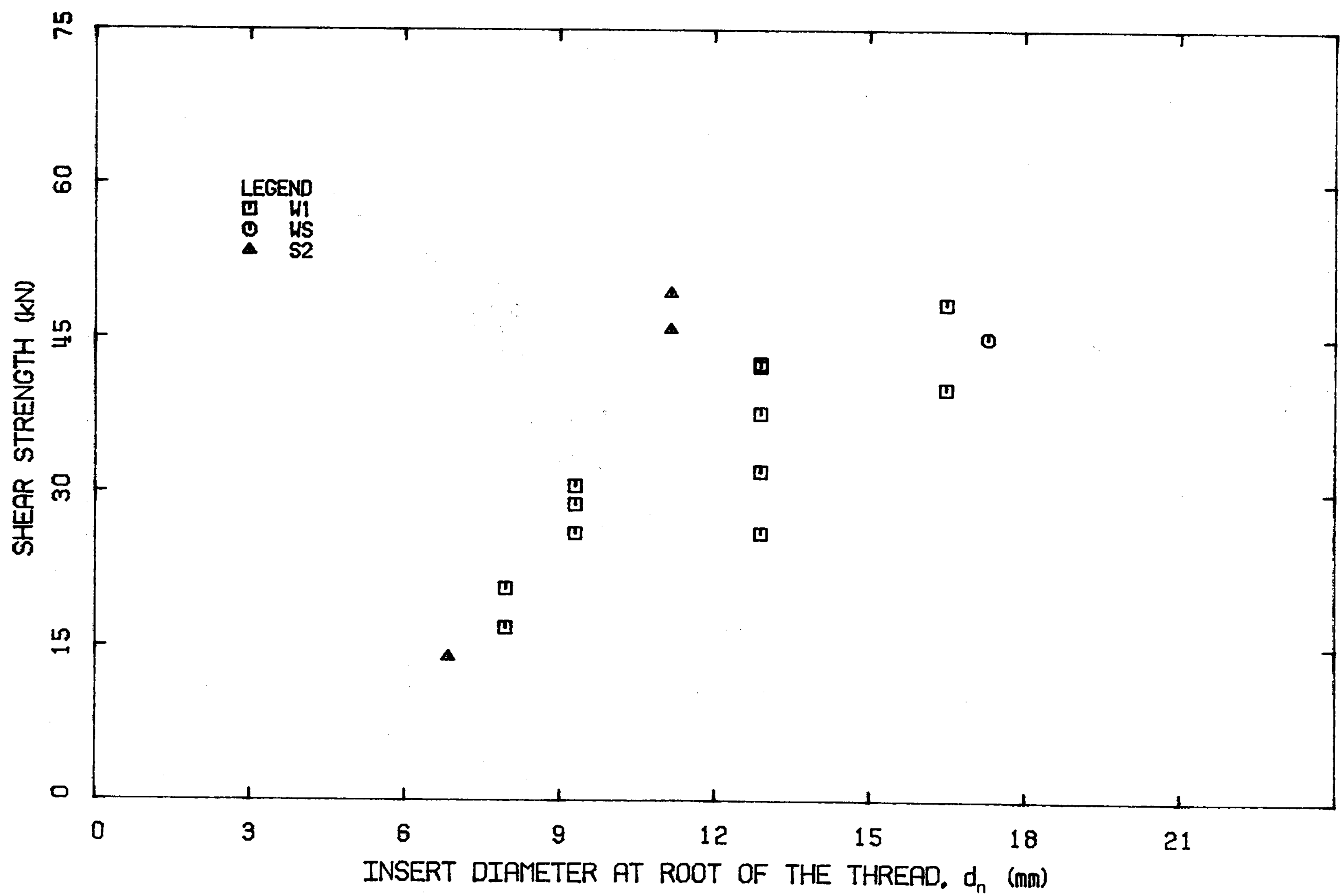

Figure 4.15 Shear Strength of Expansion Inserts at an Edge Distance of 695 mm in Grouted Concrete Block Masonry

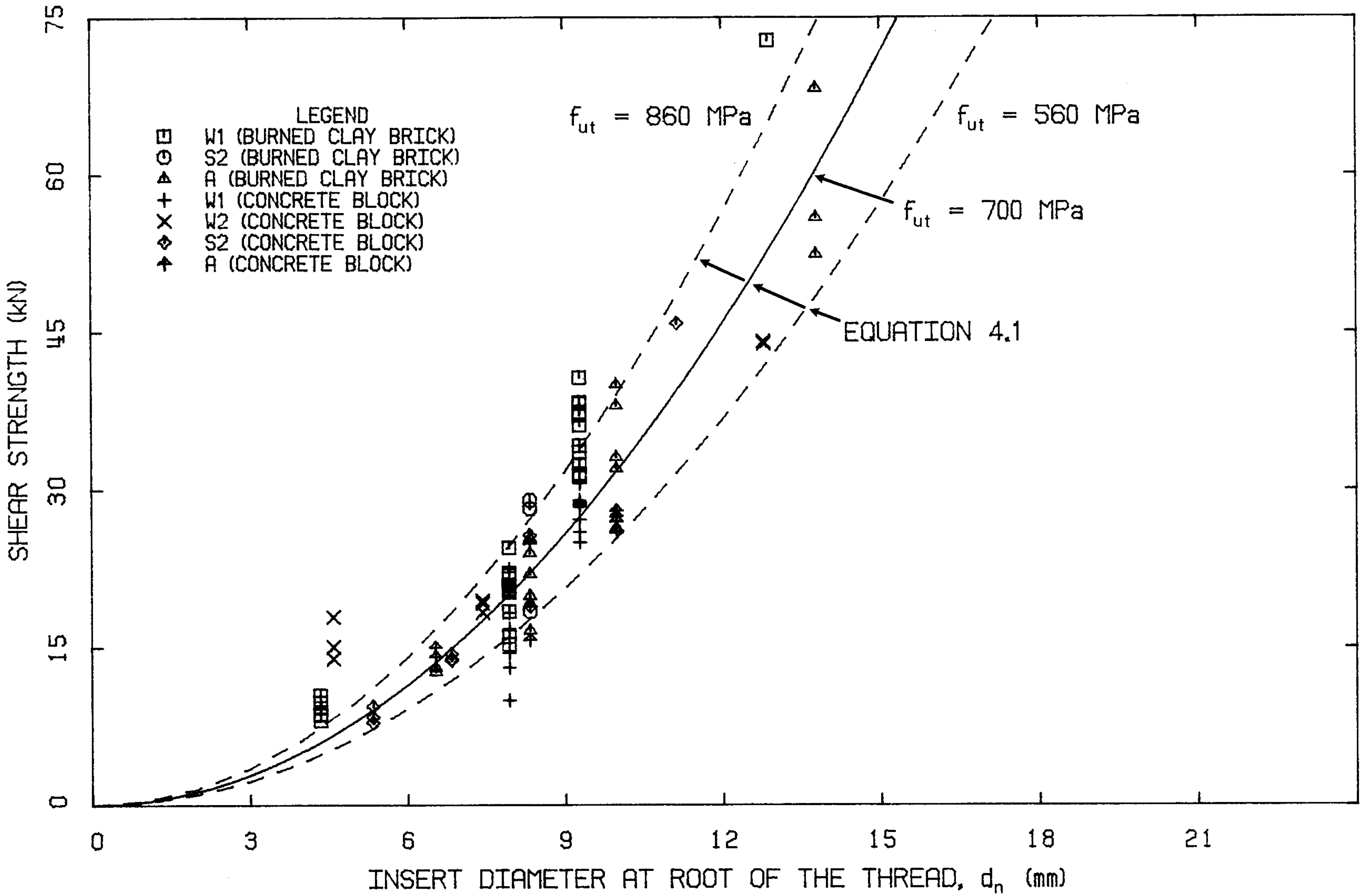

Figure 4.16 Shear Strength of Inserts in Grouted Masonry

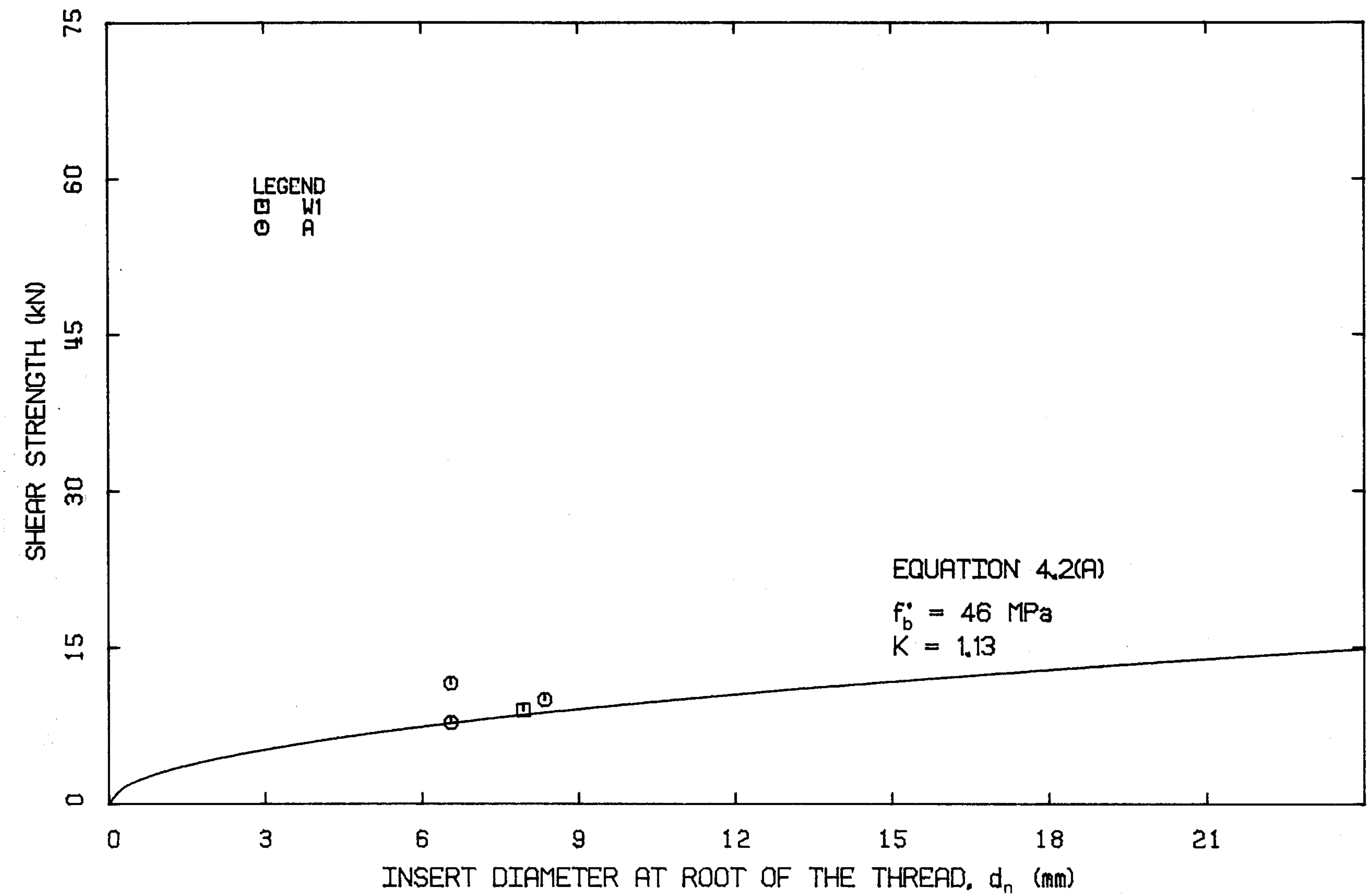

Figure 4.17 Shear Strength of Inserts at an Edge Distance of 50 mm in Grouted Brick Masonry

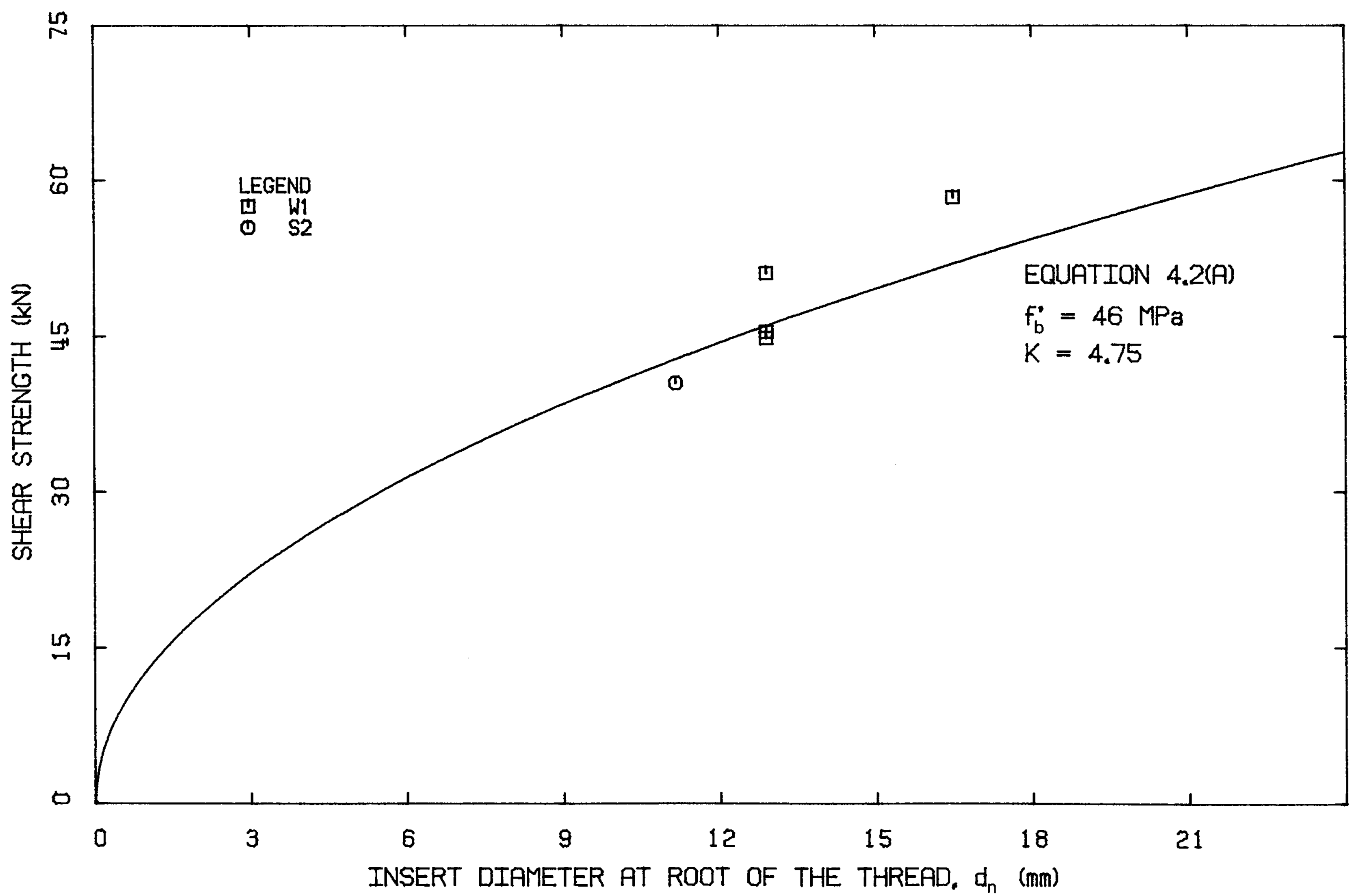

Figure 4.18 Shear Strength of Inserts at an Edge Distance of 450 mm in Grouted Brick Masonry

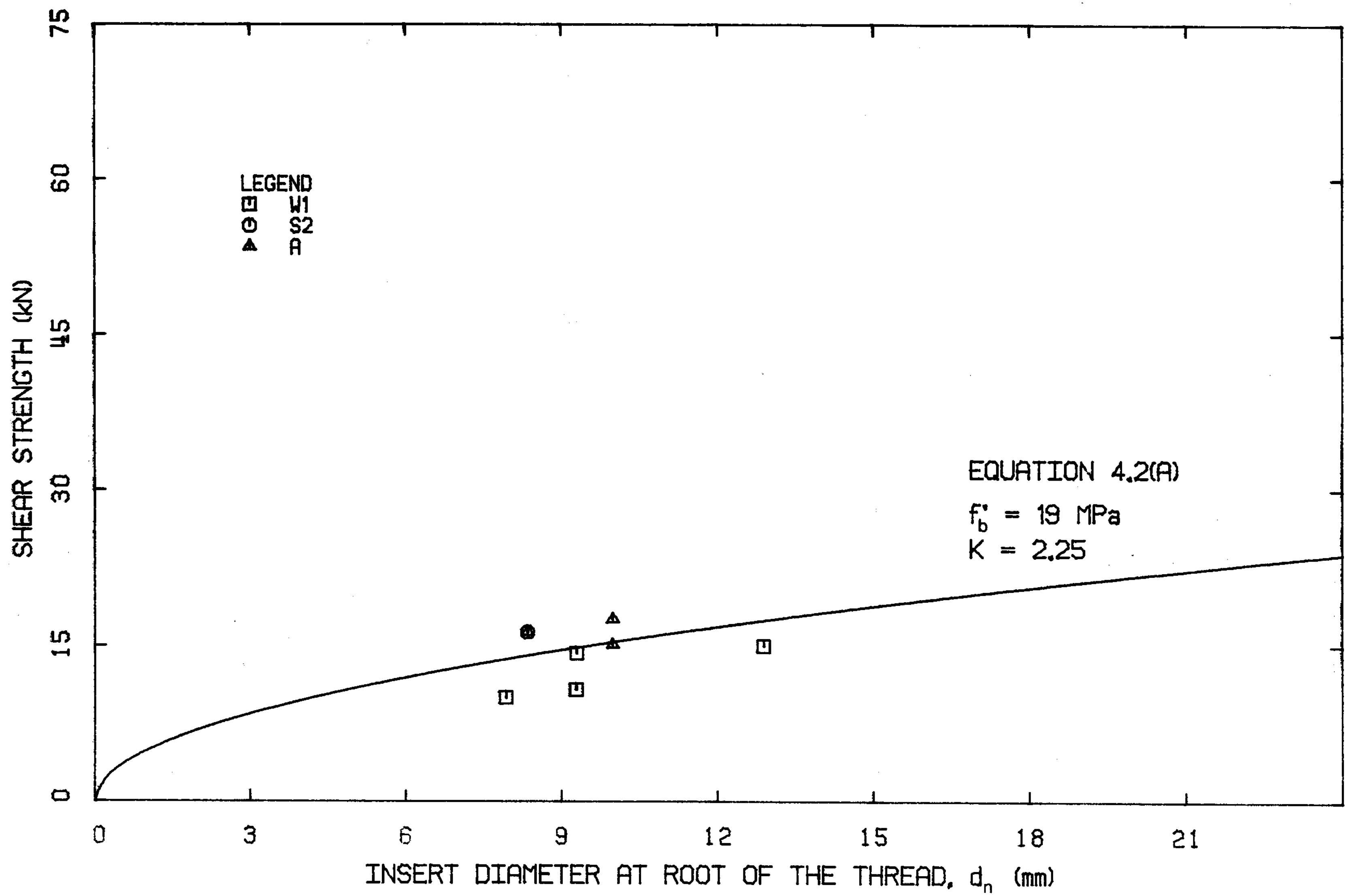

Figure 4.19 Shear Strength of Inserts at an Edge Distance of 95 mm in Grouted Concrete Block Masonry

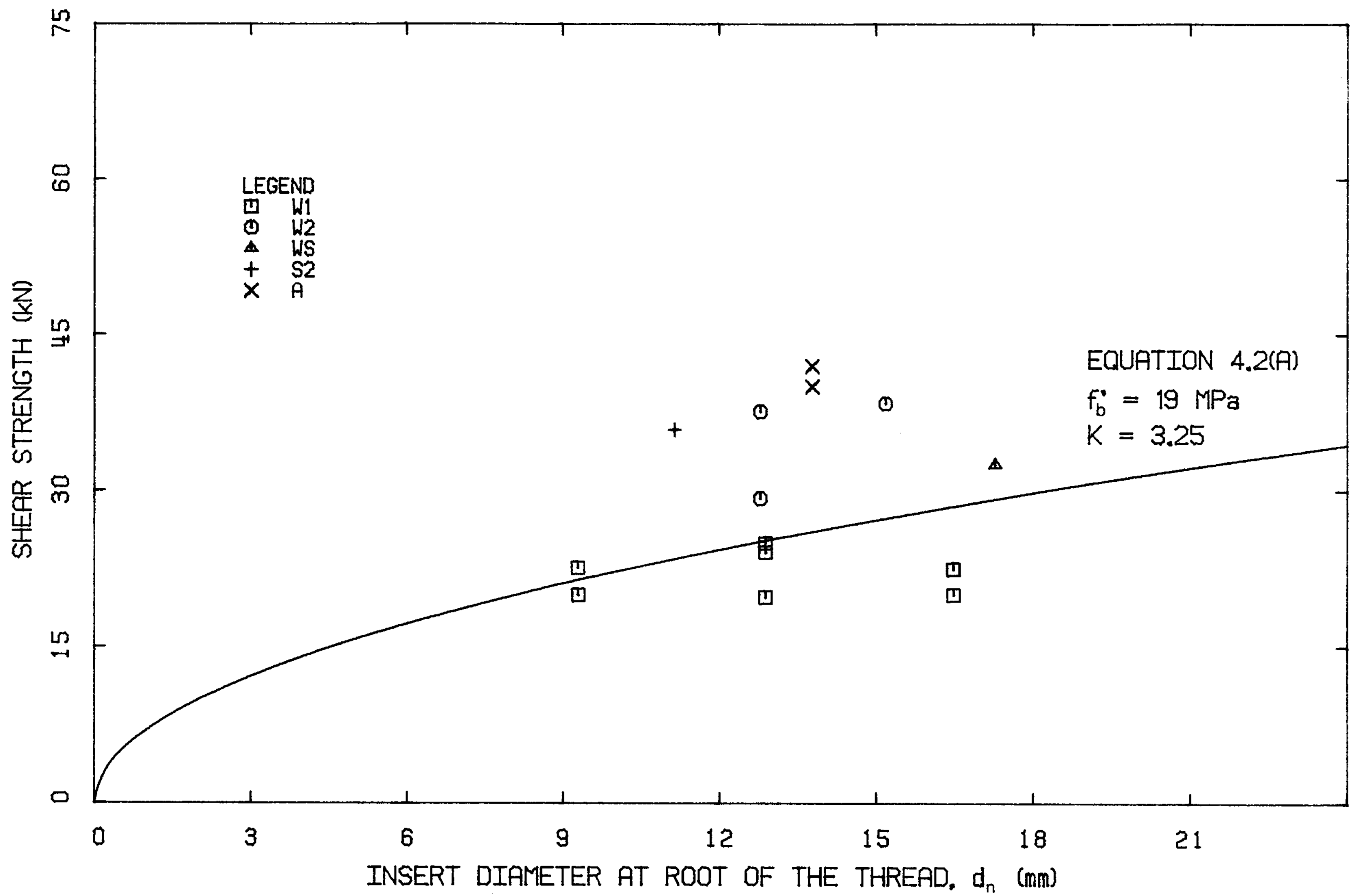

Figure 4.20 Shear Strength of Inserts at an Edge Distance of 295 mm in Grouted Concrete Block Masonry

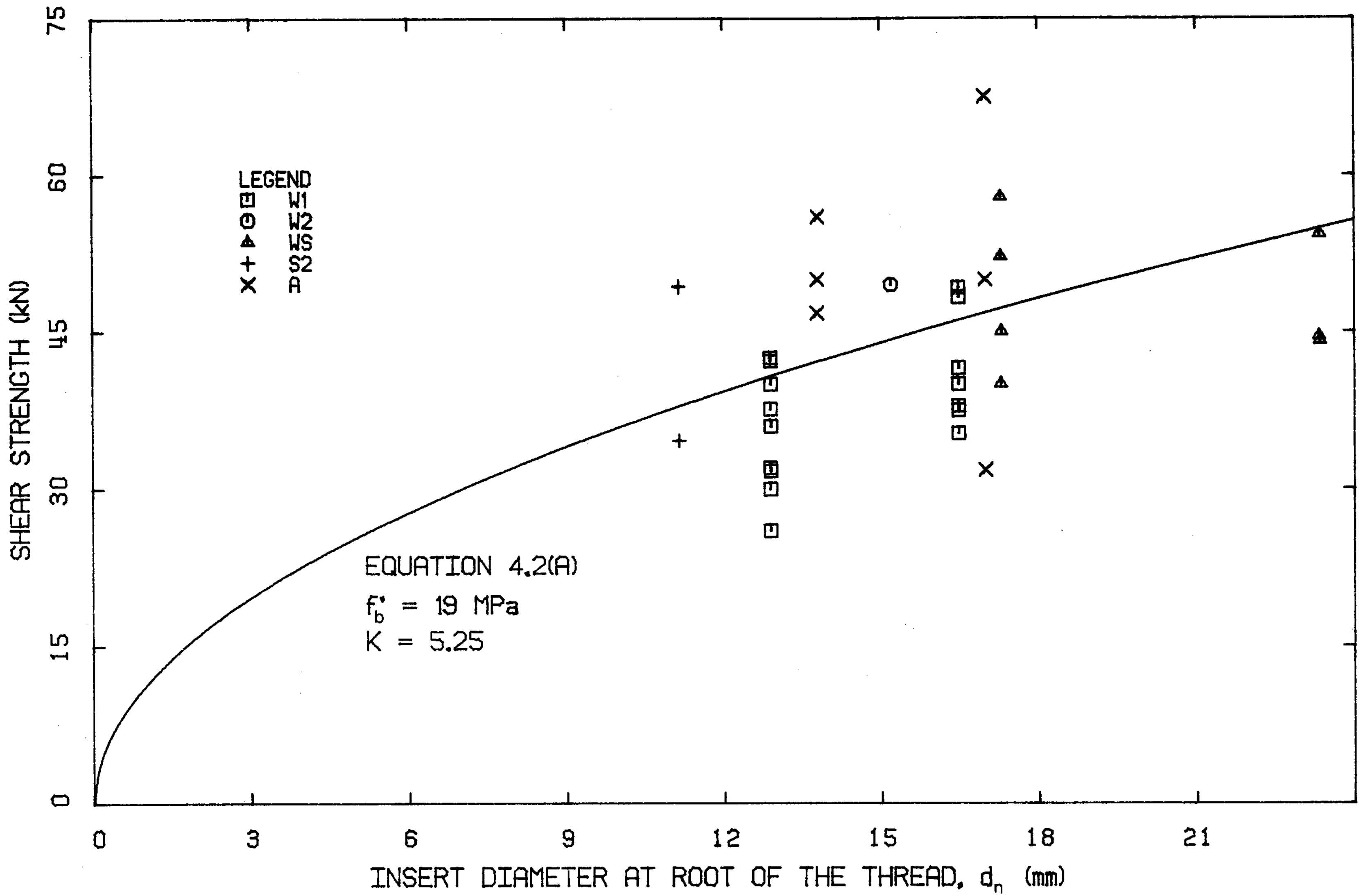

Figure 4.21 Shear Strength of Inserts at an Edge Distance of 495 mm and over in Grouted Concrete Block Masonry

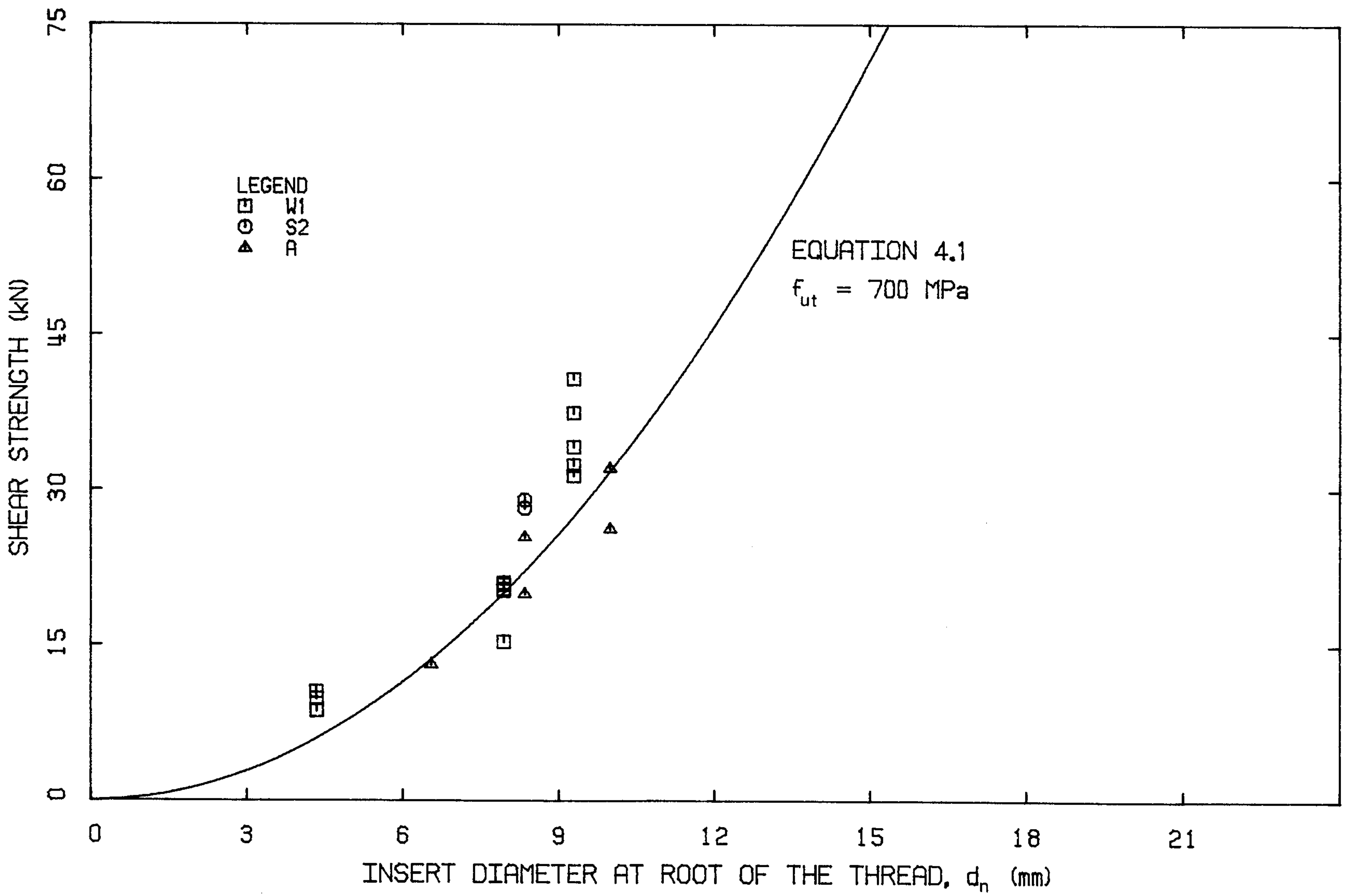

Figure 4.22 Shear Strength of Inserts at an Edge Distance of 250 mm in Grouted Brick Masonry

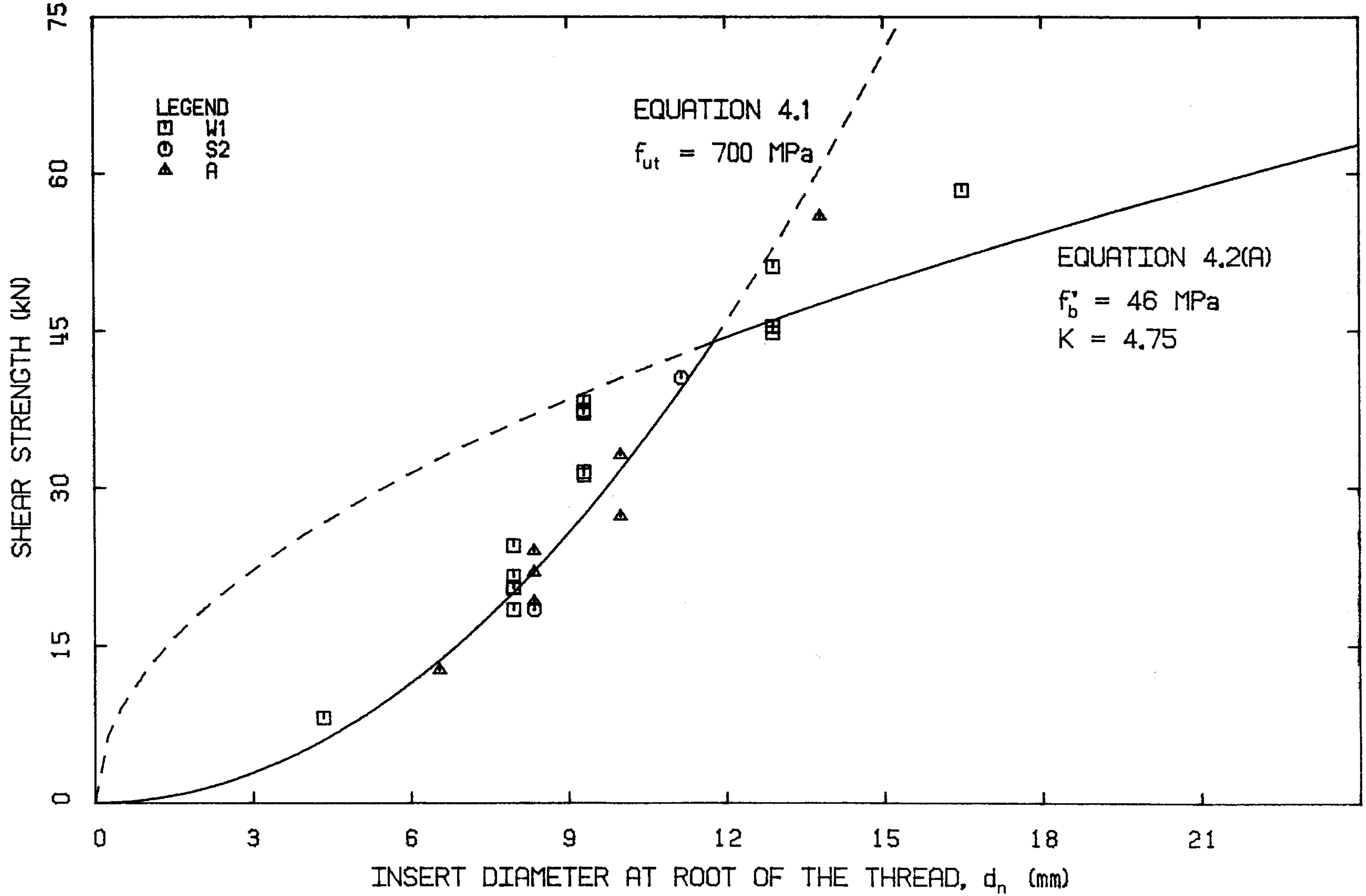

Figure 4.23 Shear Strength of Inserts at an Edge Distance of 450 mm in Grouted Brick Masonry

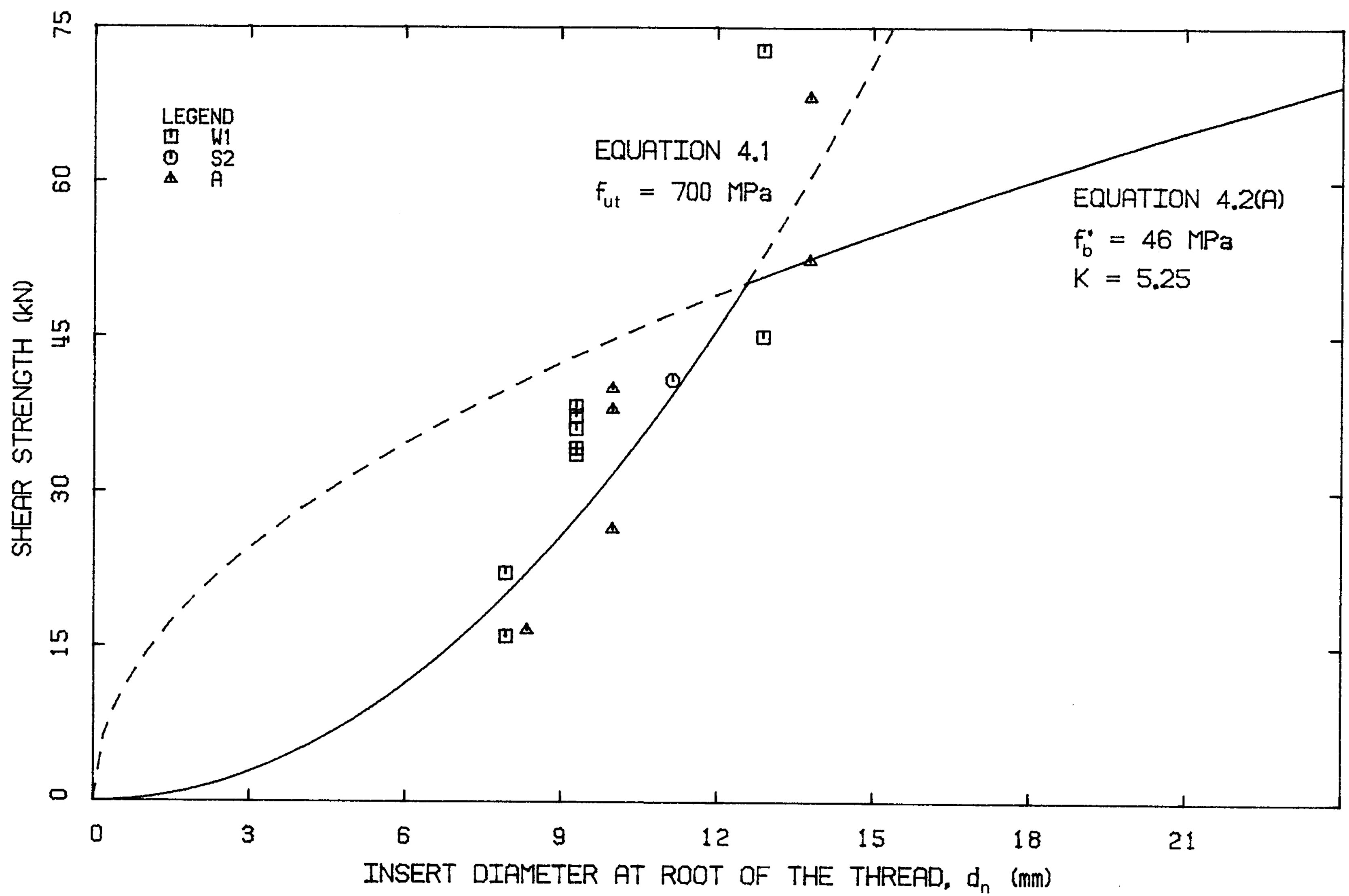

Figure 4.24 Shear Strength of Inserts at an Edge Distance of 650 mm in Grouted Brick Masonry

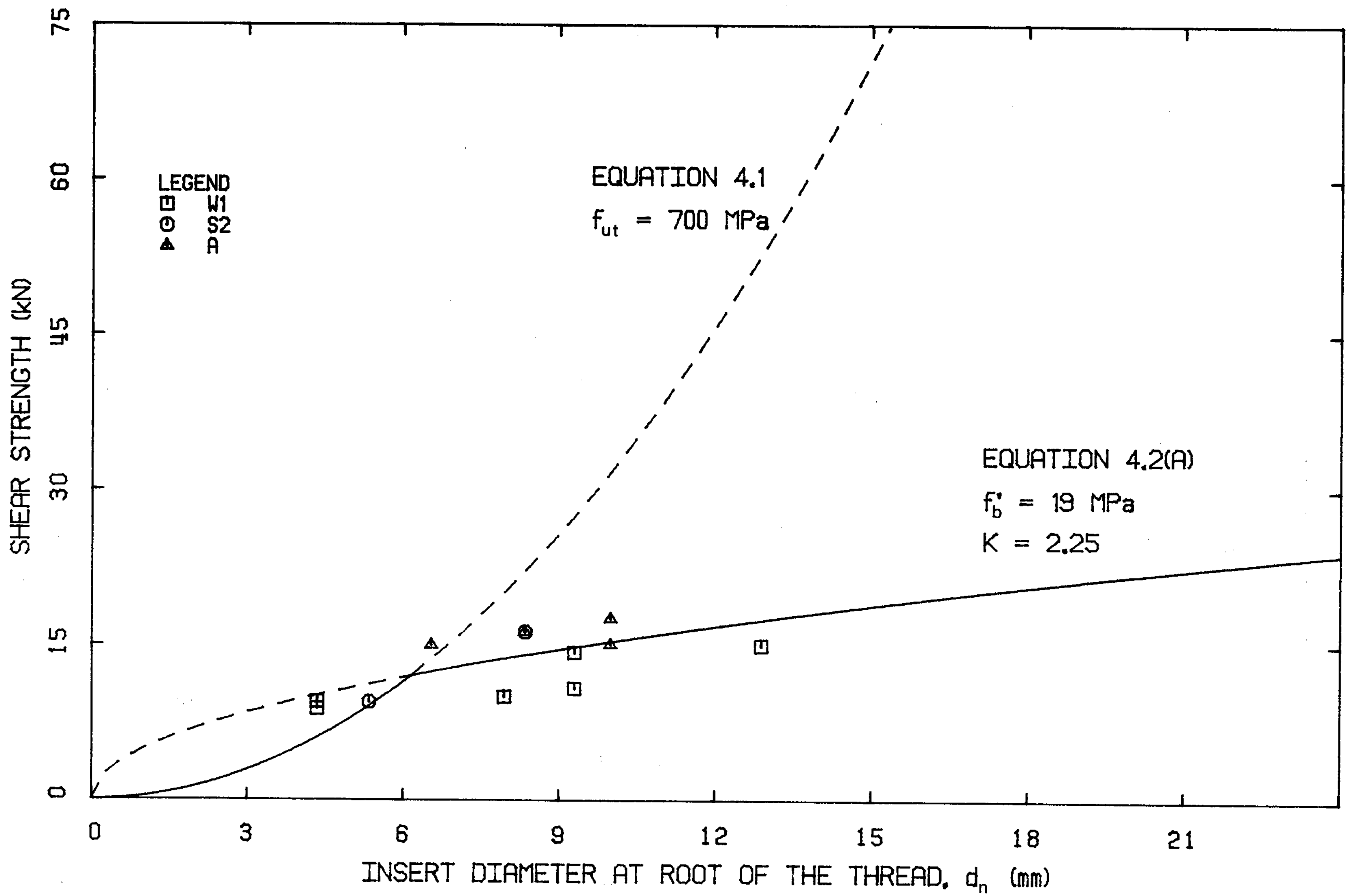

Figure 4.25 Shear Strength of Inserts at an Edge Distance of 95 mm in Grouted Concrete Block Masonry

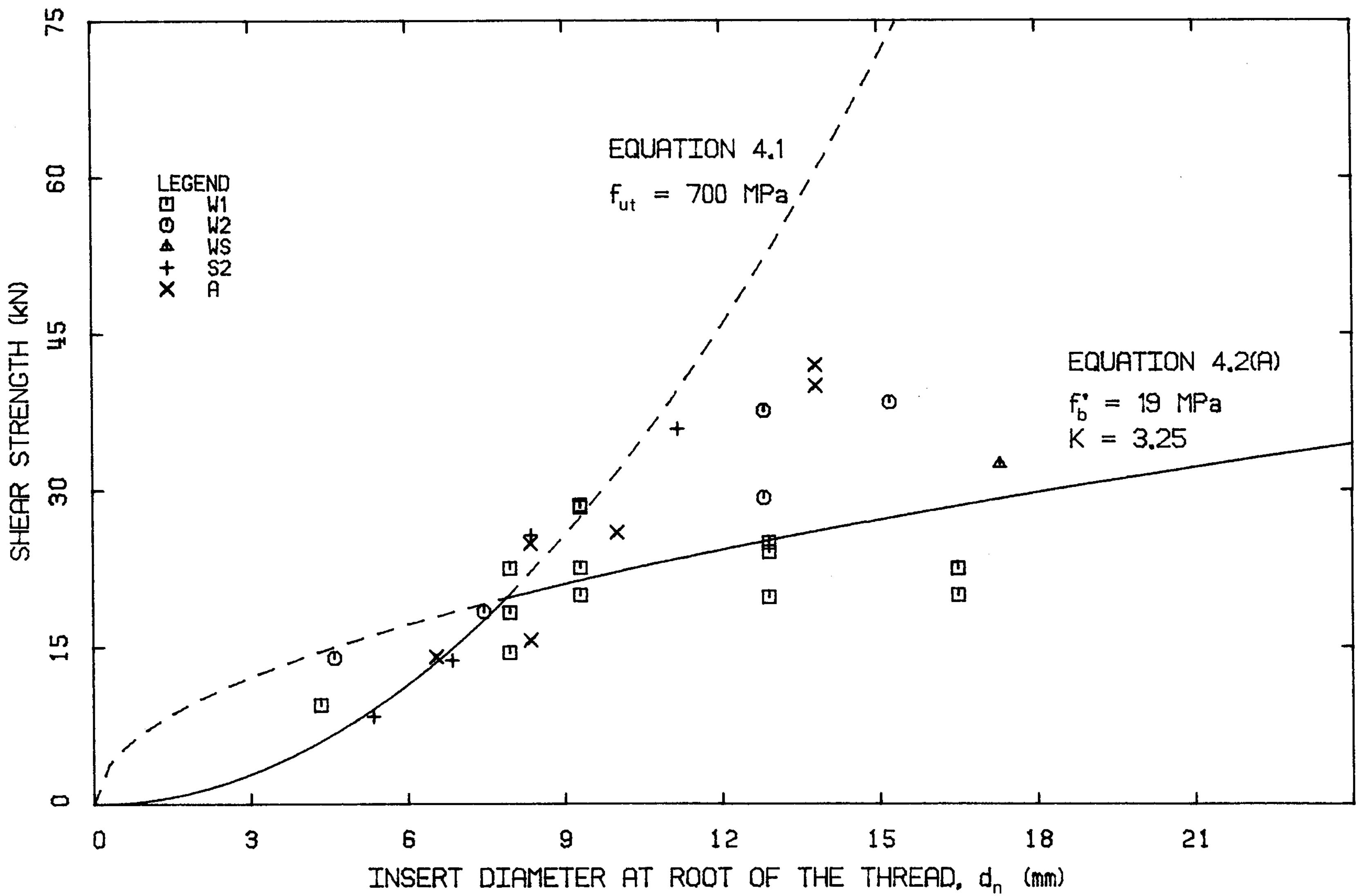

Figure 4.26 Shear Strength of Inserts at an Edge Distance of 295 mm in Grouted Concrete Block Masonry

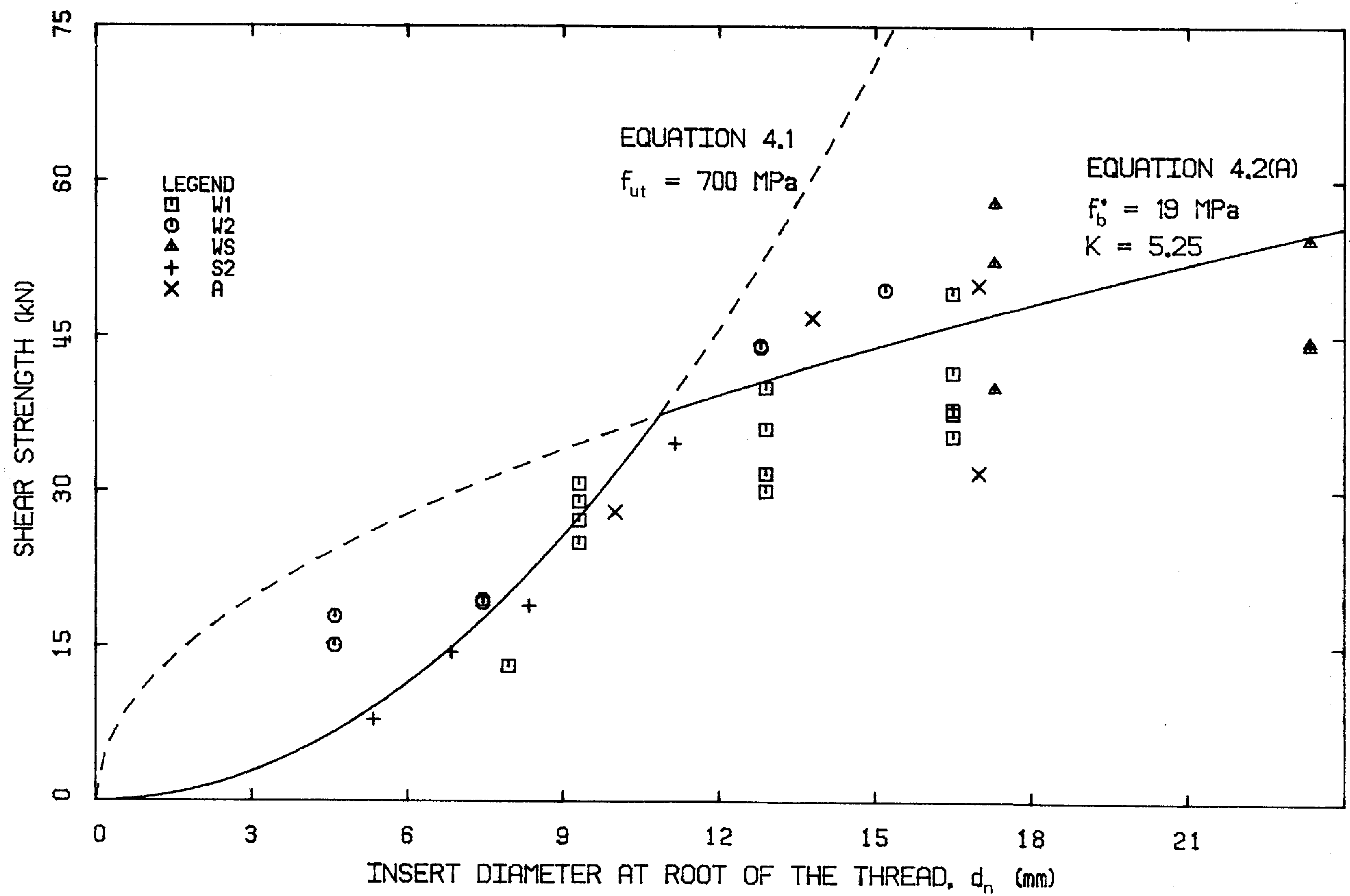

Figure 4.27 Shear Strength of Inserts at an Edge Distance of 495 mm in Grouted Concrete Block Masonry

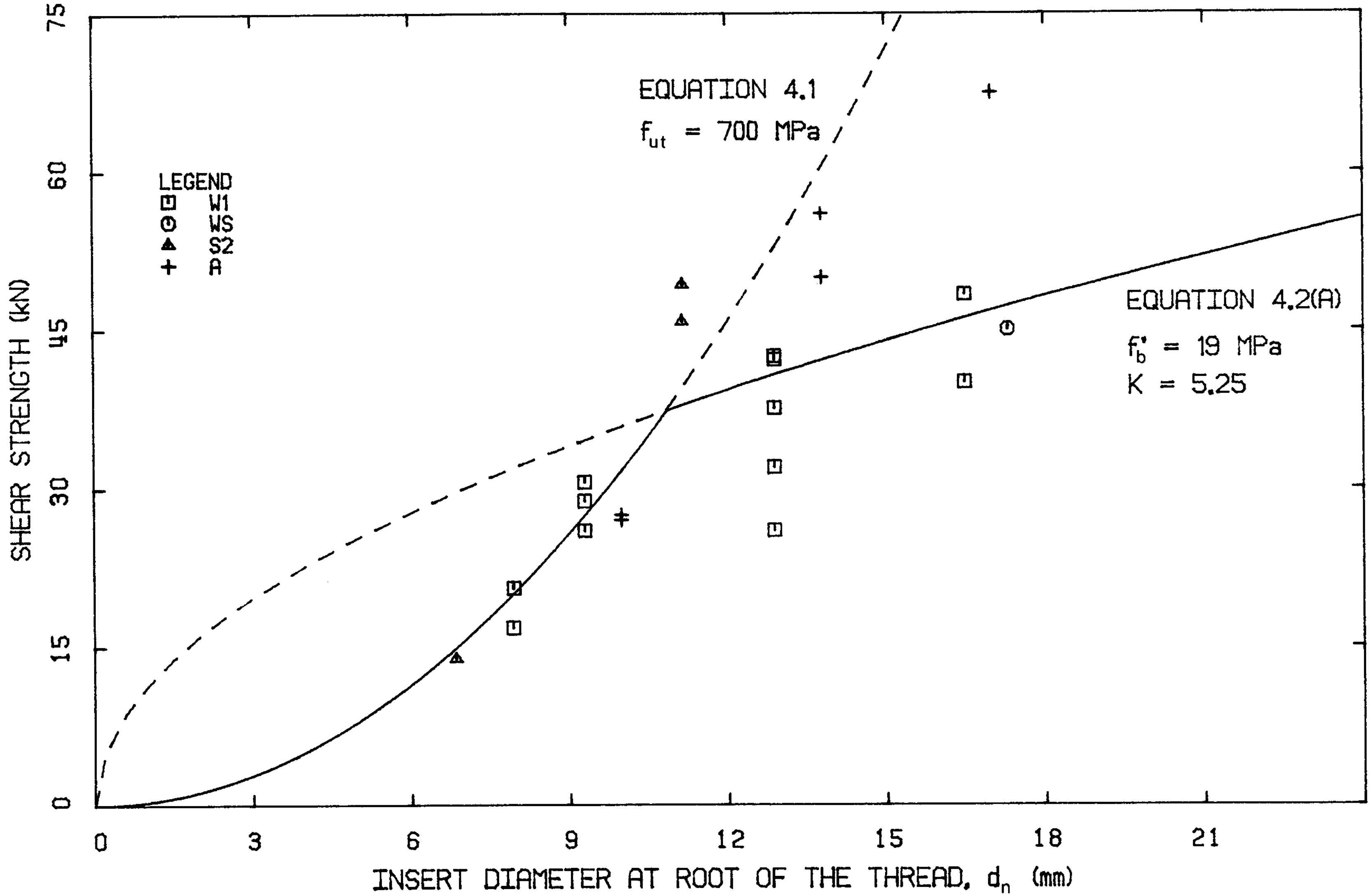

Figure 4.28 Shear Strength of Inserts at an Edge Distance of 695 mm in Grouted Concrete Block Masonry

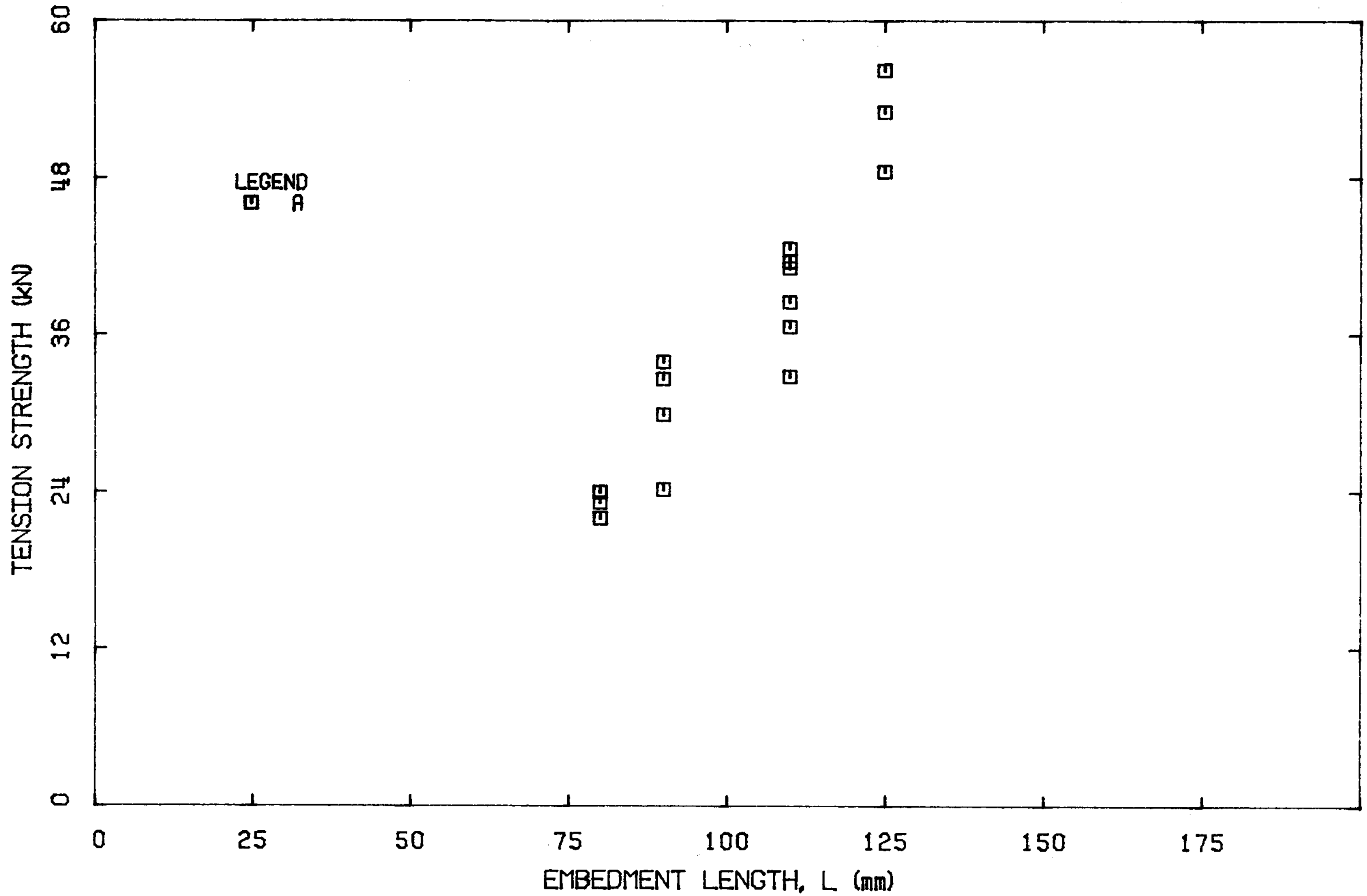

Figure 4.29 Tension Strength vs Embedment Length for Adhesive Inserts in Grouted Brick Masonry

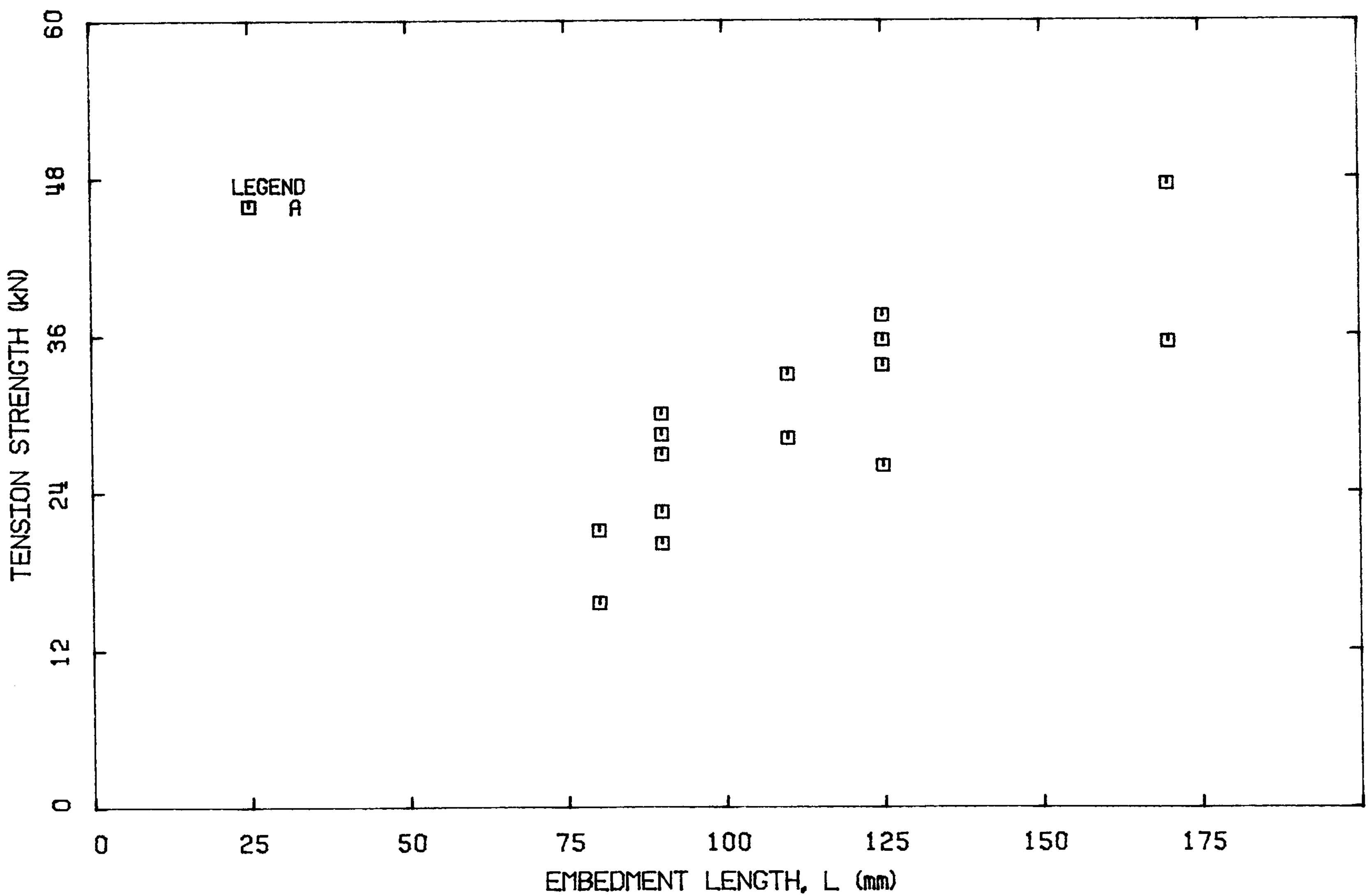

Figure 4.30 Tension Strength vs Embedment Length for Adhesive Inserts in Grouted Concrete Block Masonry

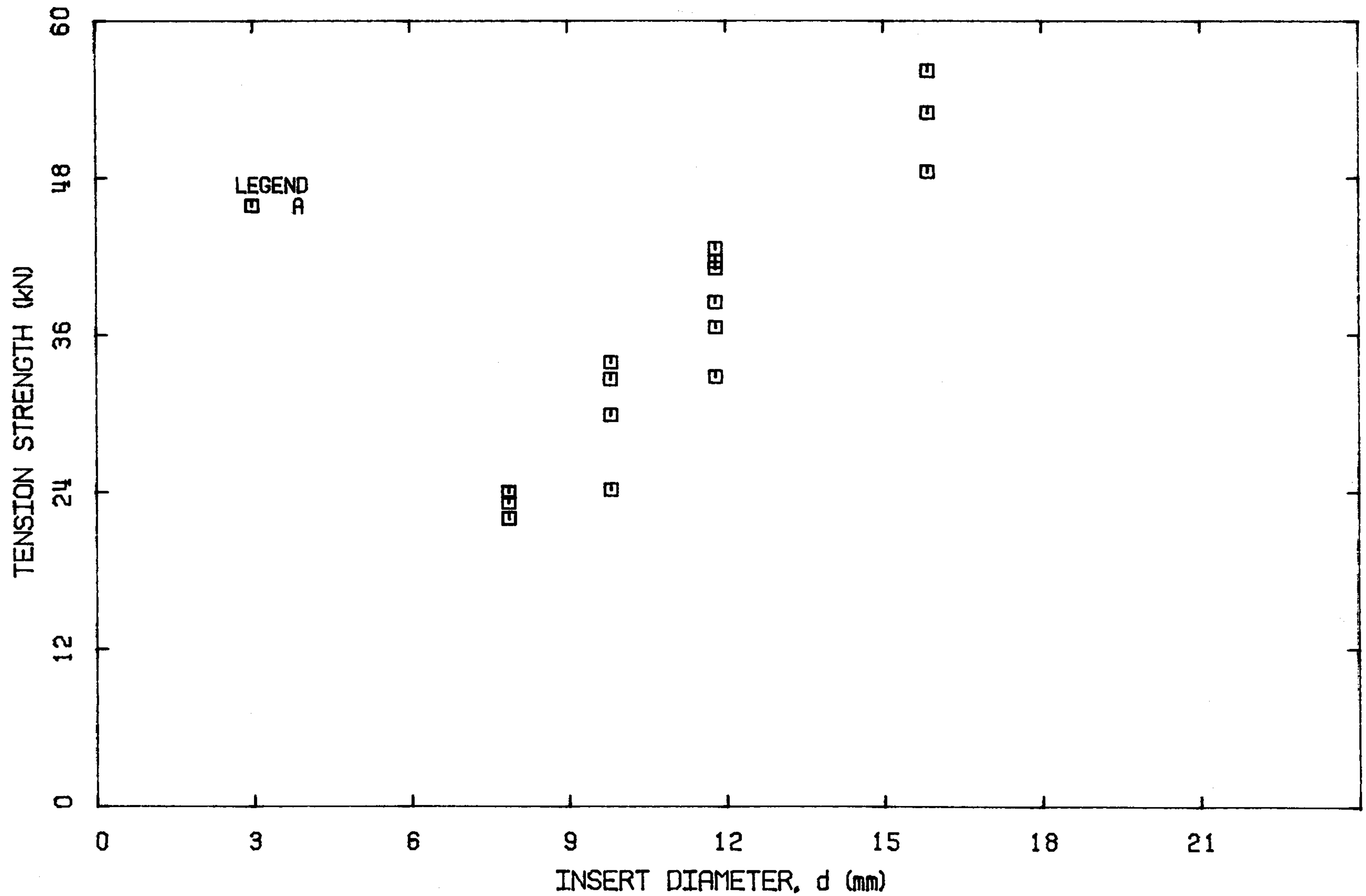

Figure 4.31 Tension Strength vs Insert Diameter for Adhesive Inserts in Grouted Brick Masonry

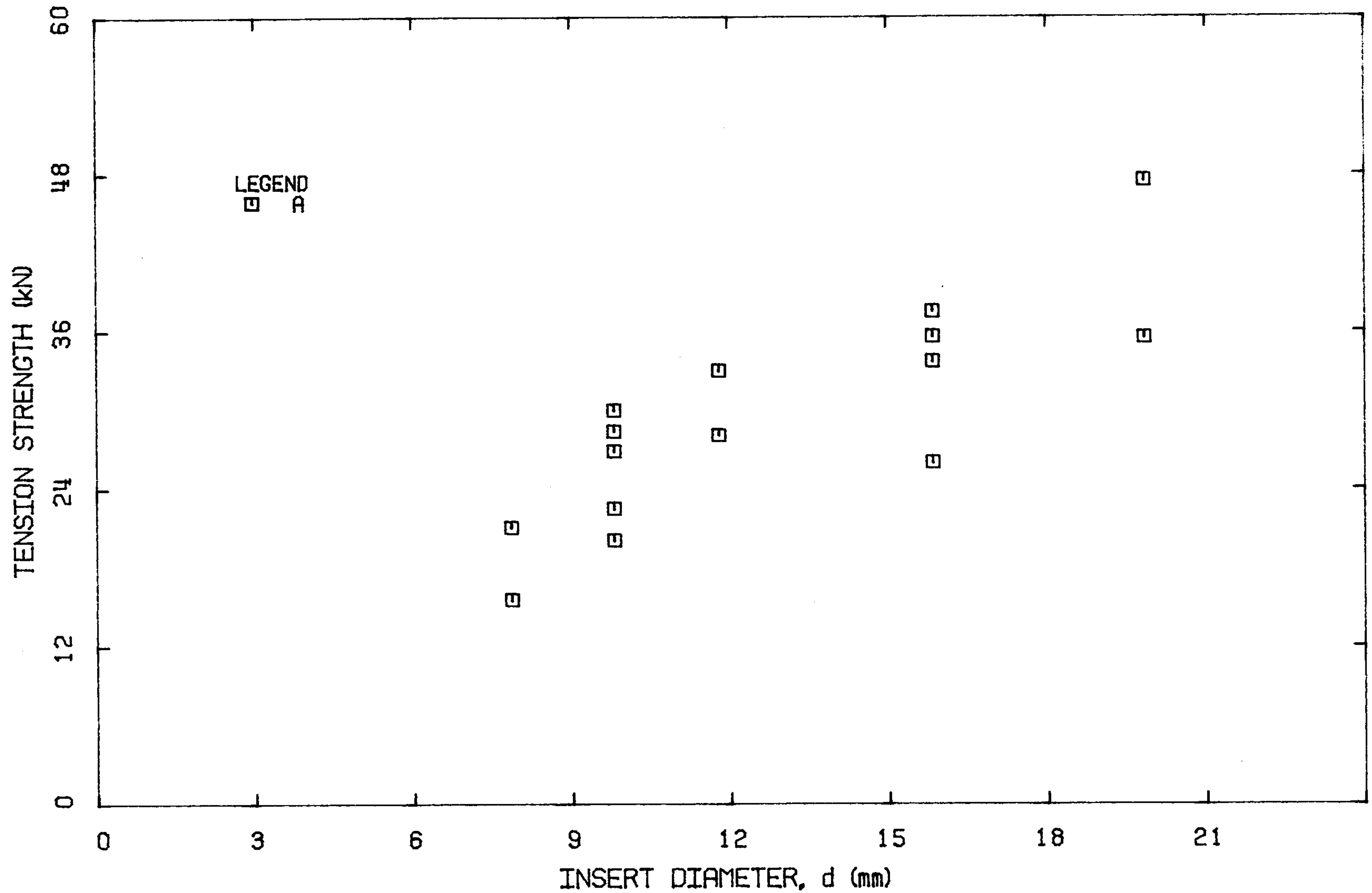

Figure 4.32 Tension Strength vs Insert Diameter for Adhesive Inserts in Grouted Concrete Block Masonry

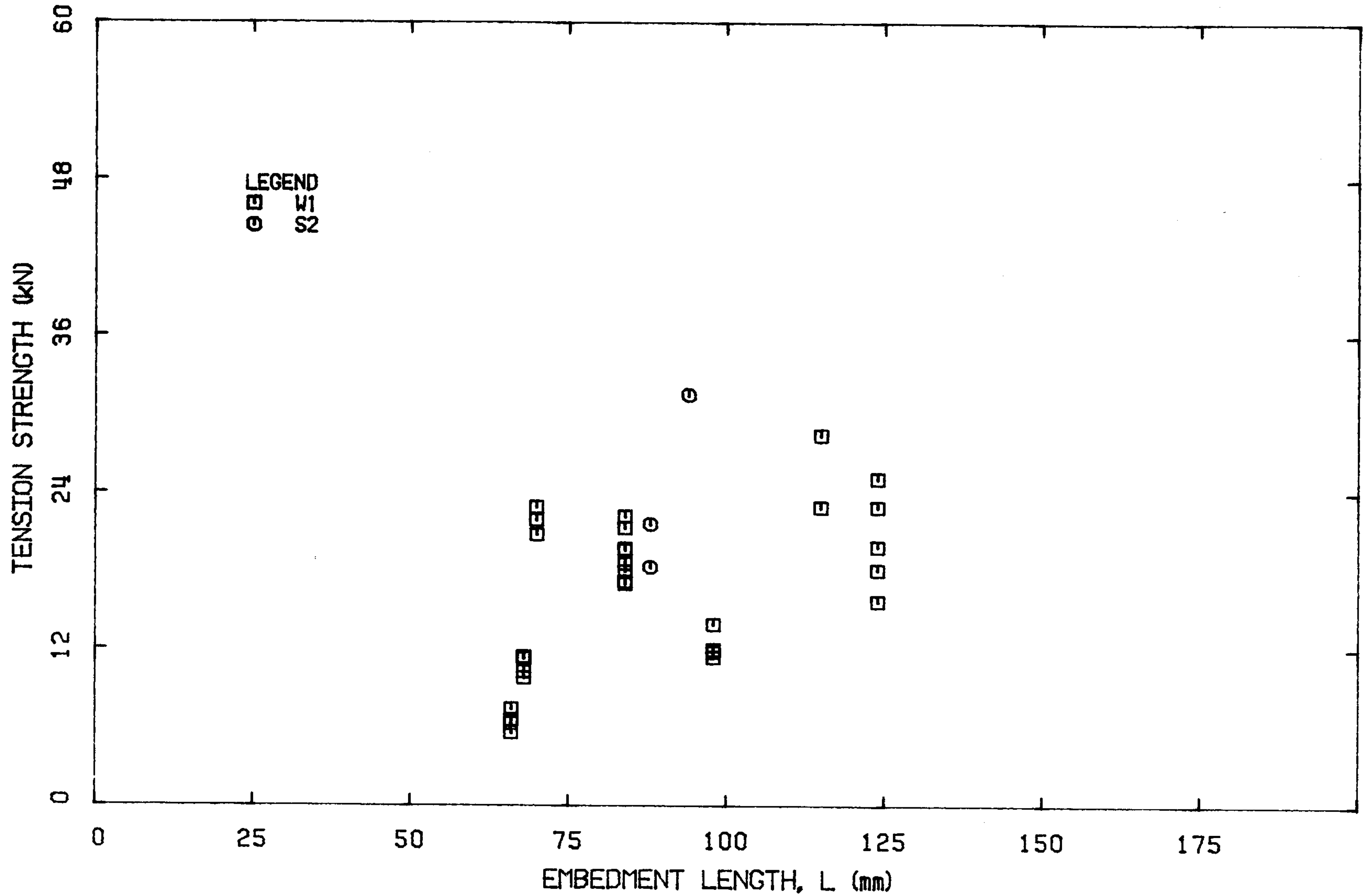

Figure 4.33 Tension Strength vs Embedment Length for Expansion Inserts in Grouted Brick Masonry

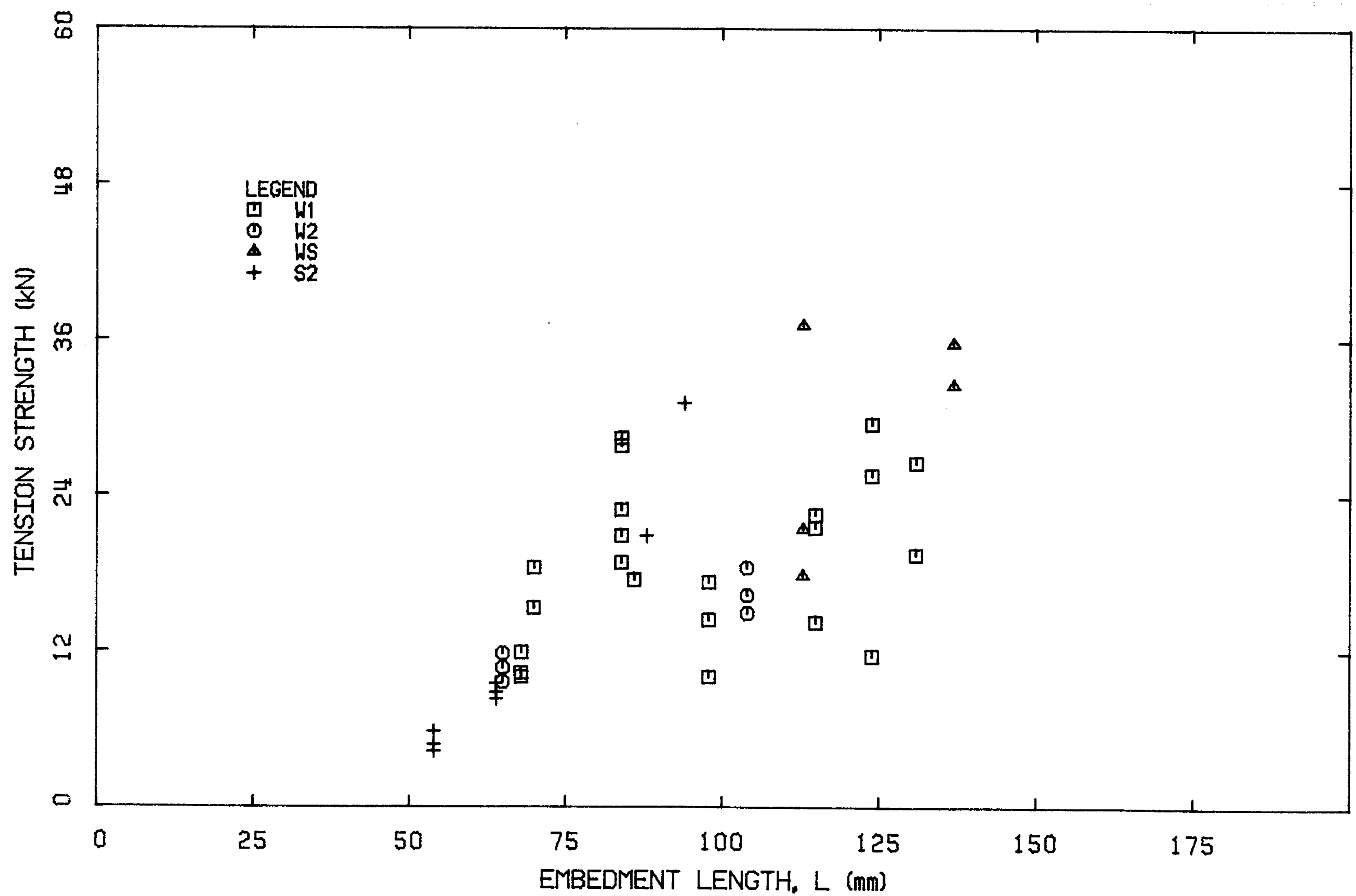

Figure 4.34 Tension Strength vs Embedment Length for Expansion Inserts in Grouted Concrete Block Masonry

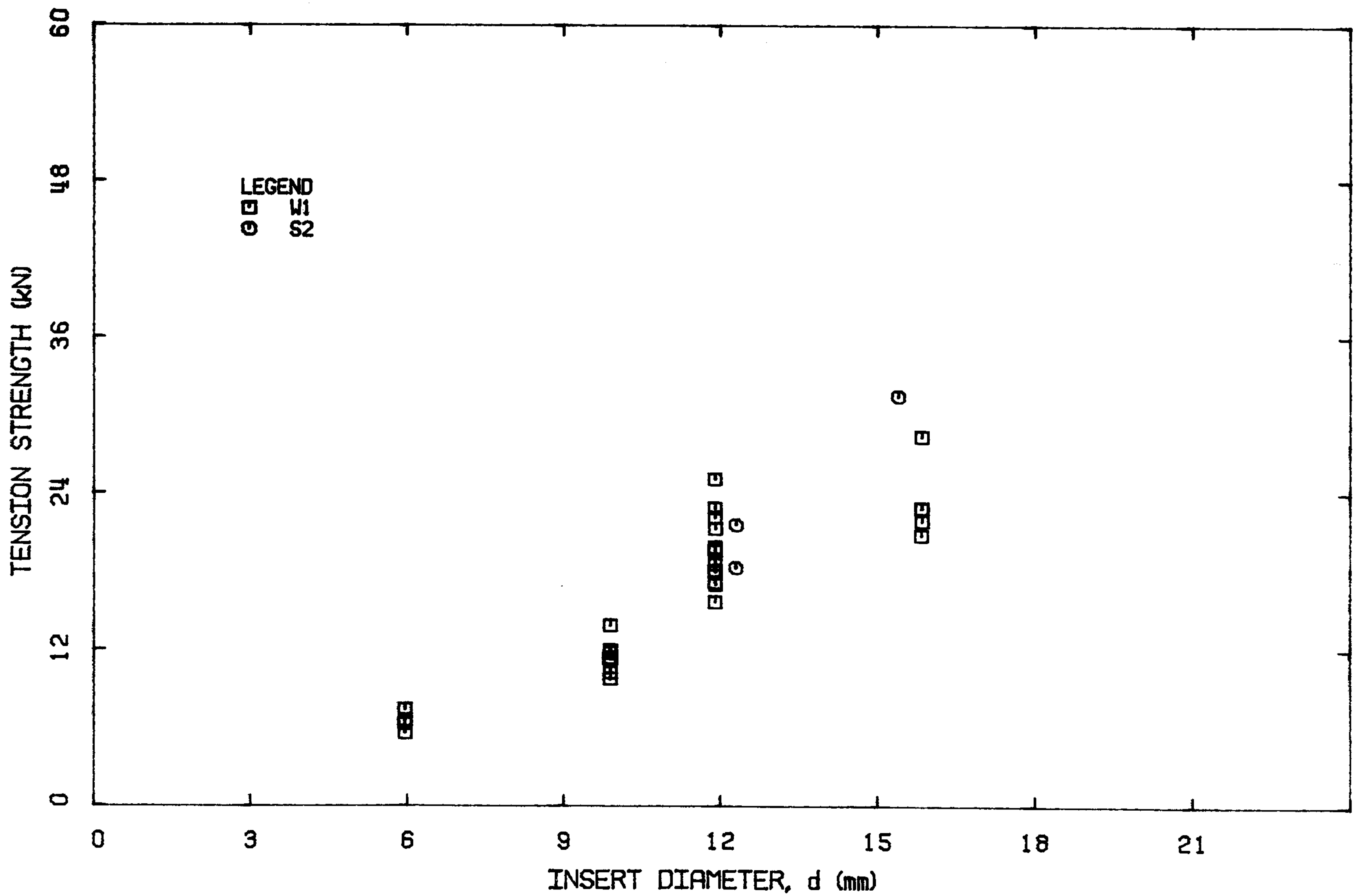

Figure 4.35 Tension Strength vs Insert Diameter for Expansion Inserts in Grouted Brick Masonry

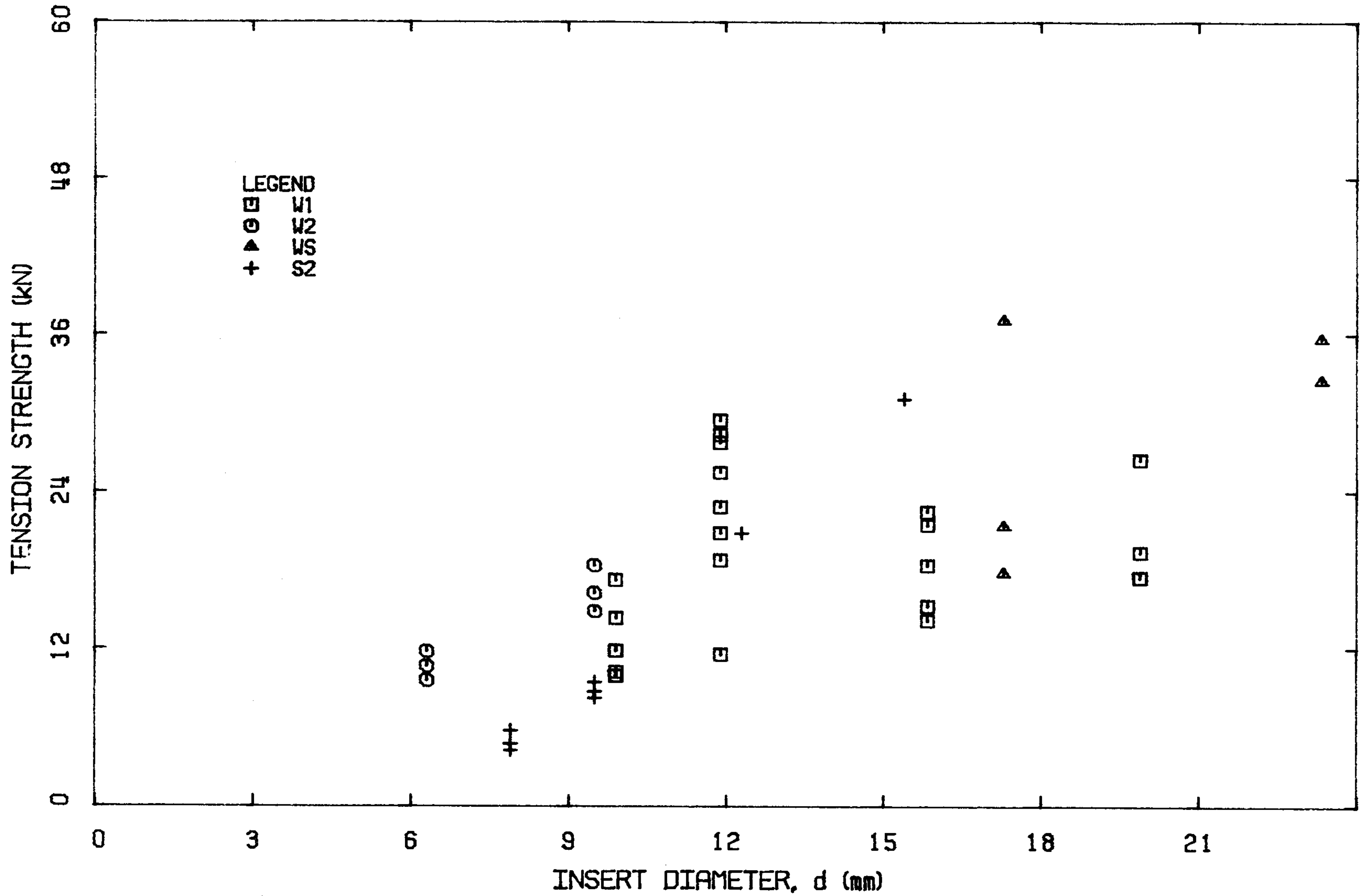

Figure 4.36 Tension Strength vs Insert Diameter for Expansion Inserts in Grouted Concrete Block Masonry

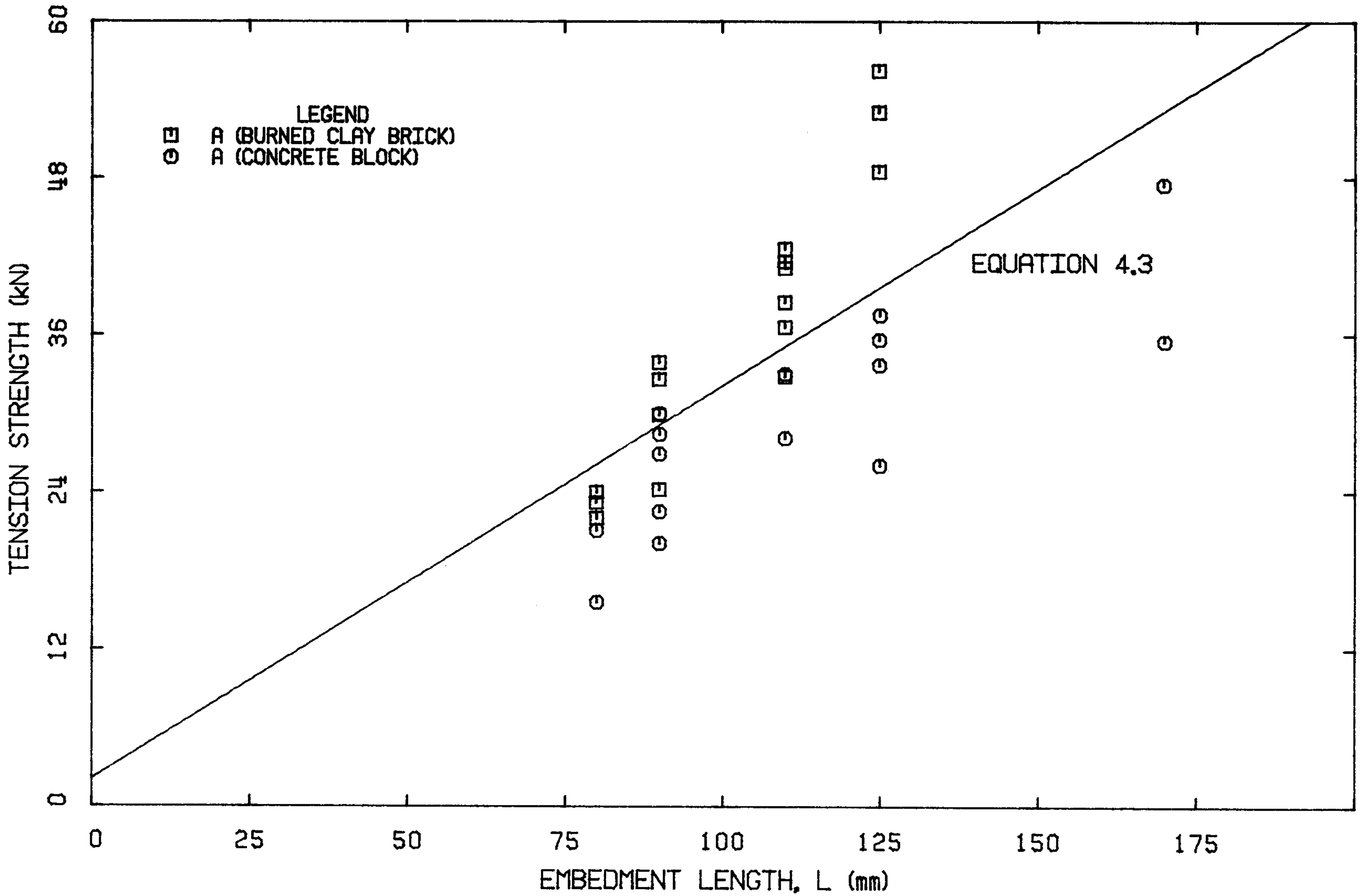

Figure 4.37 Tension Strength vs Embedment Length for Adhesive Inserts in Grouted Masonry

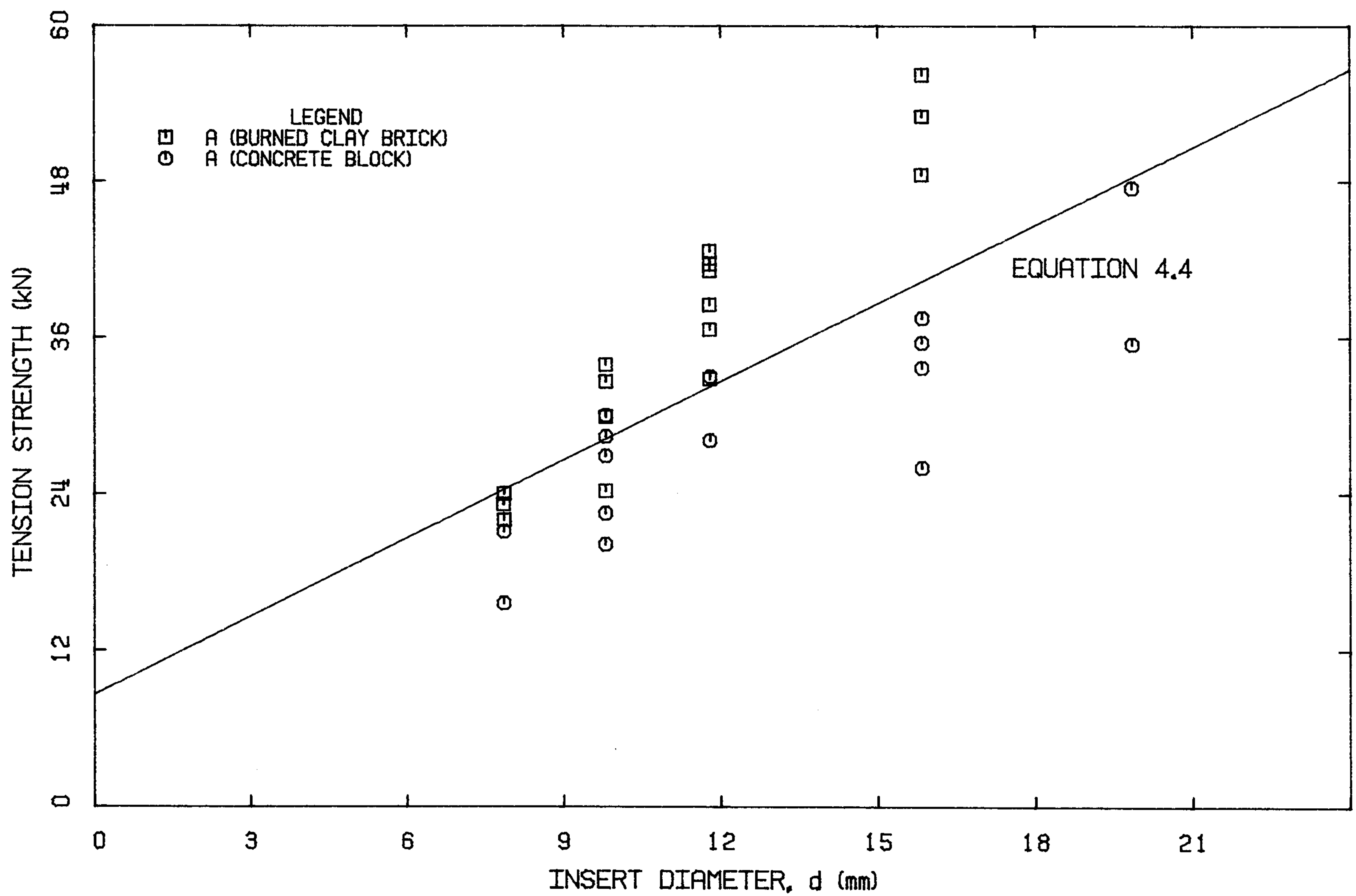

Figure 4.38 Tension Strength vs Insert Diameter for Adhesive Inserts in Grouted Masonry

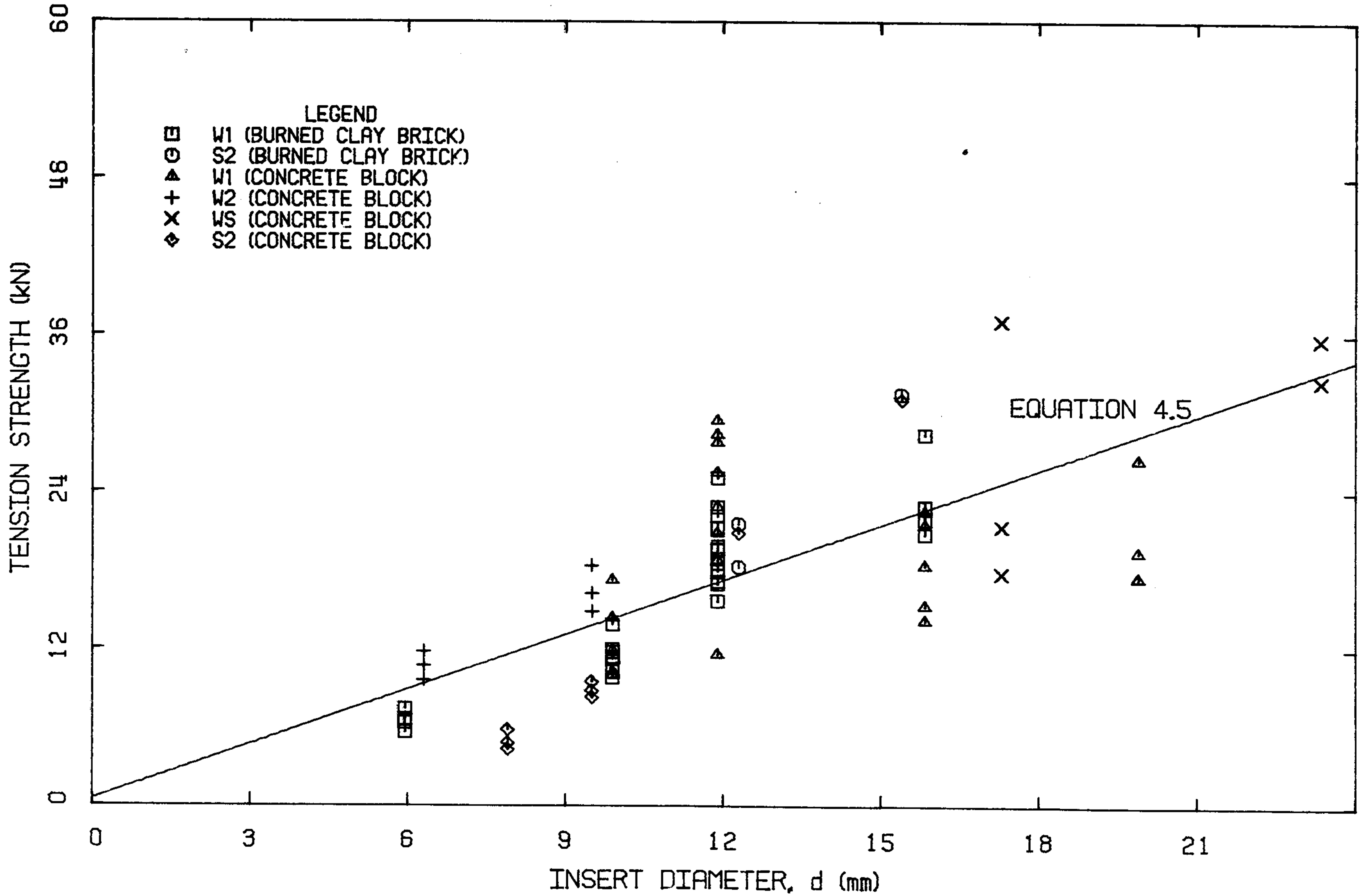

Figure 4.39 Tension Strength vs Insert Diameter for Expansion Inserts in Grouted Masonry

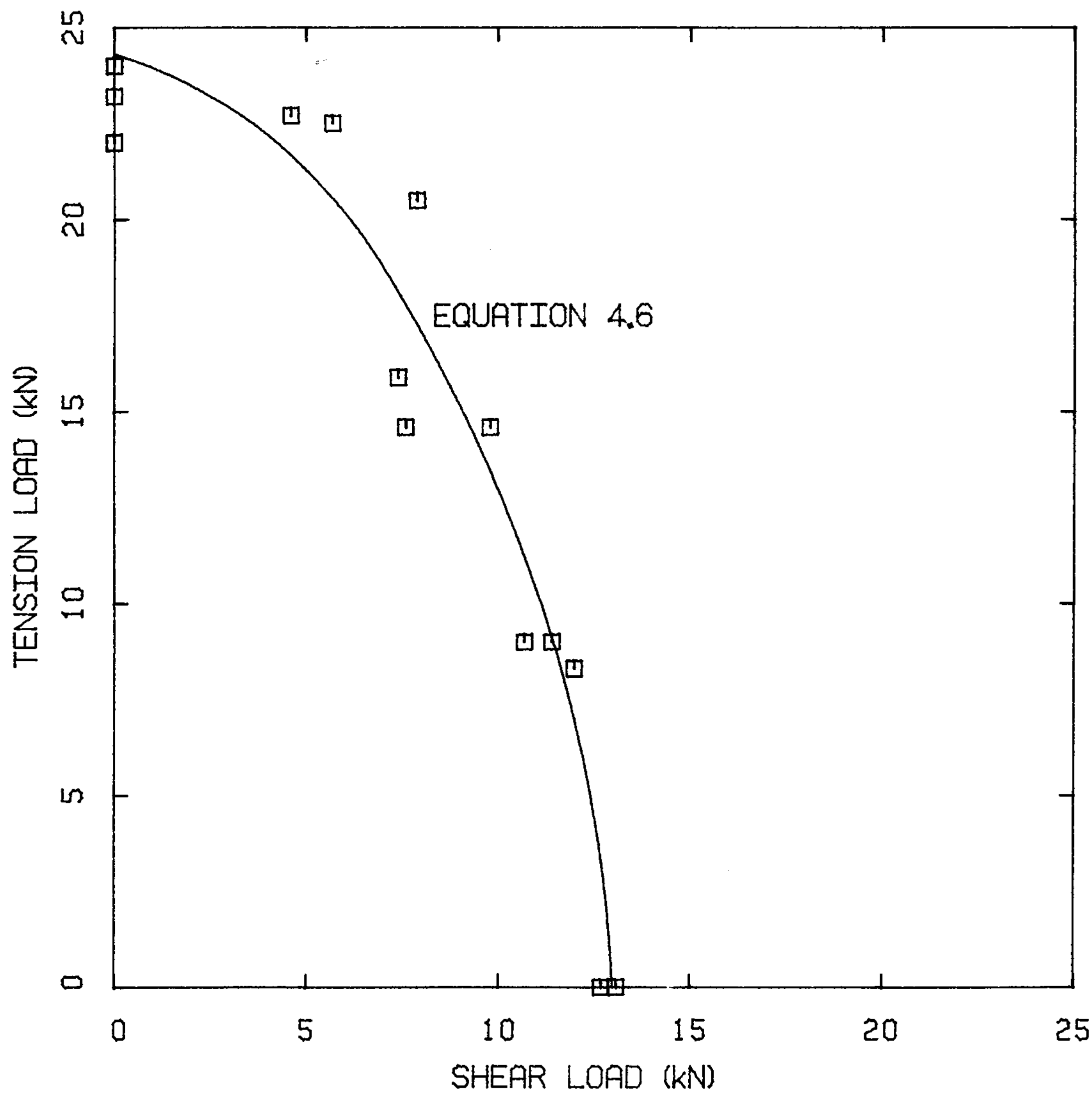

Figure 4.40 Load Interaction Diagram for HVA M8

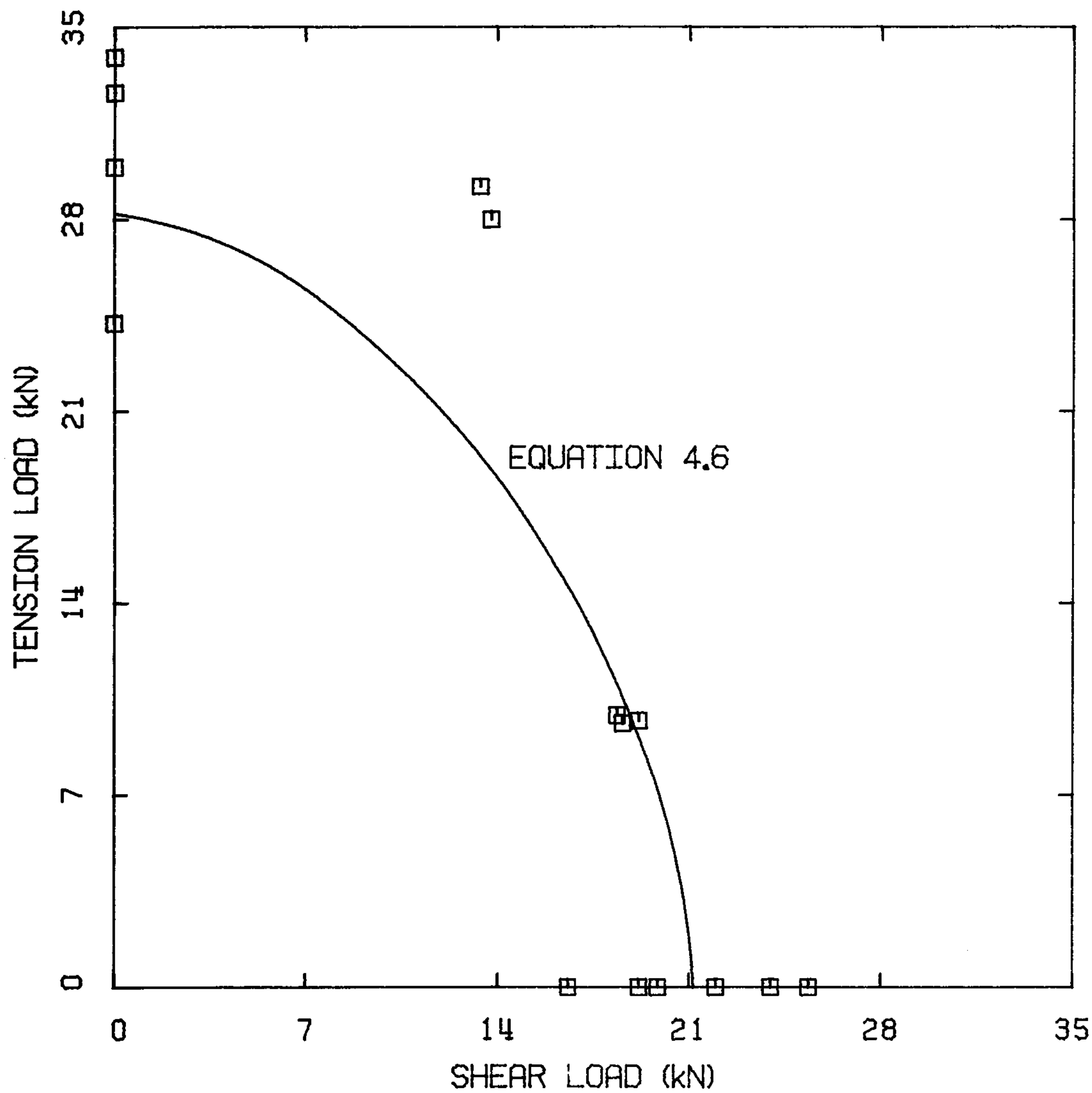

Figure 4.41 Load Interaction Diagram for HVA M10

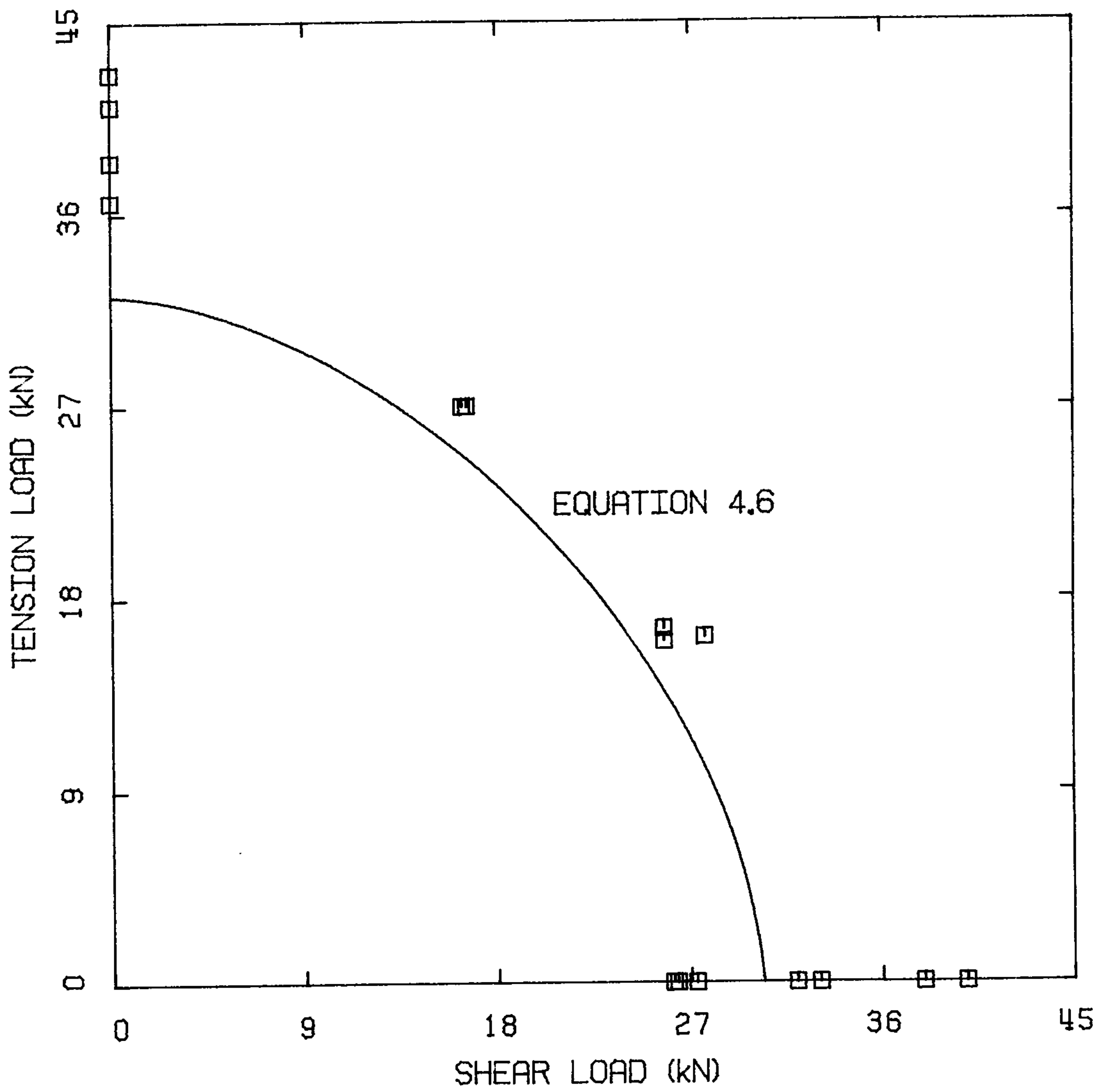

Figure 4.42 Load Interaction Diagram for HVA M12

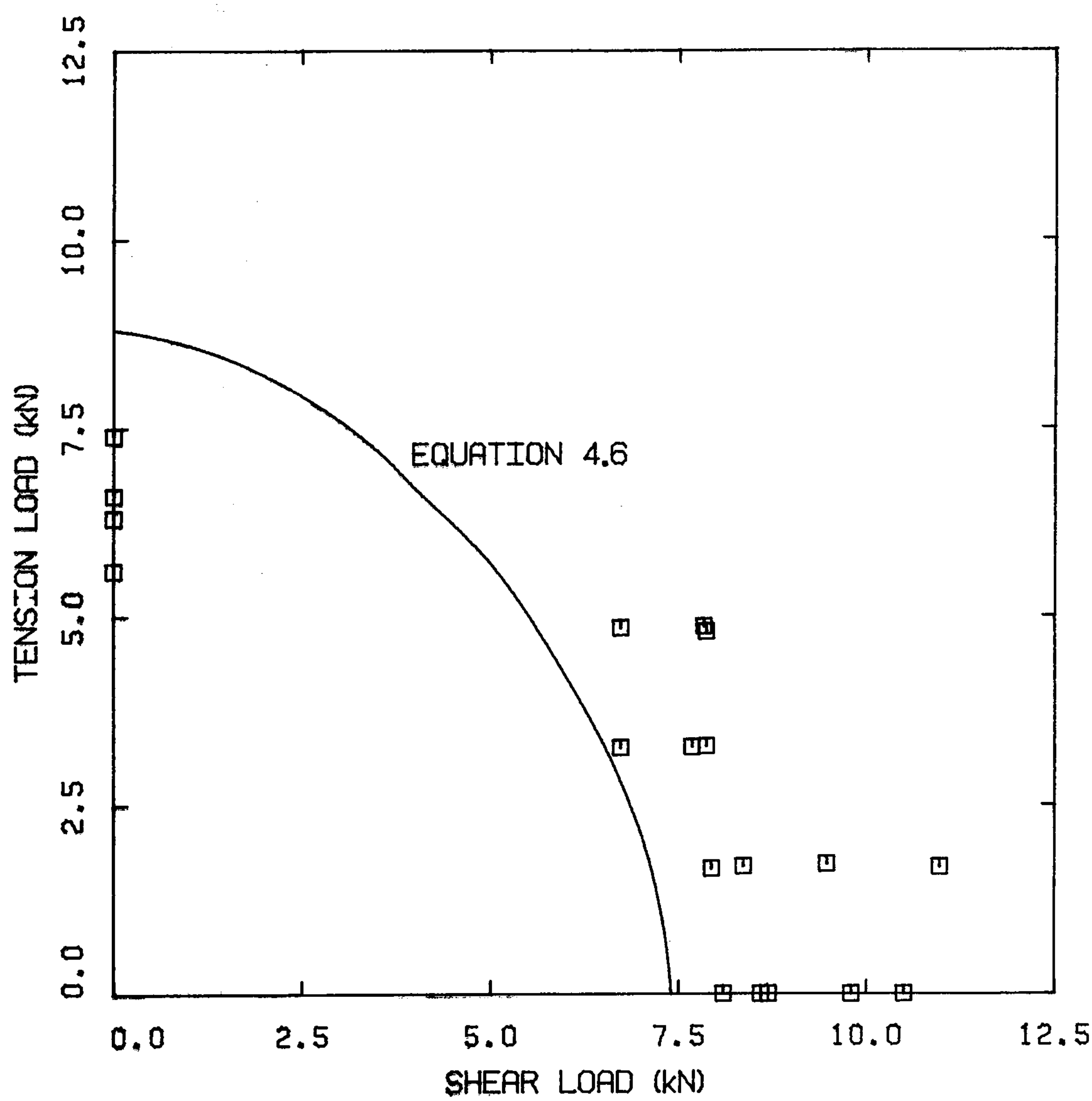

Figure 4.43 Load Interaction Diagram for HSA M6x80

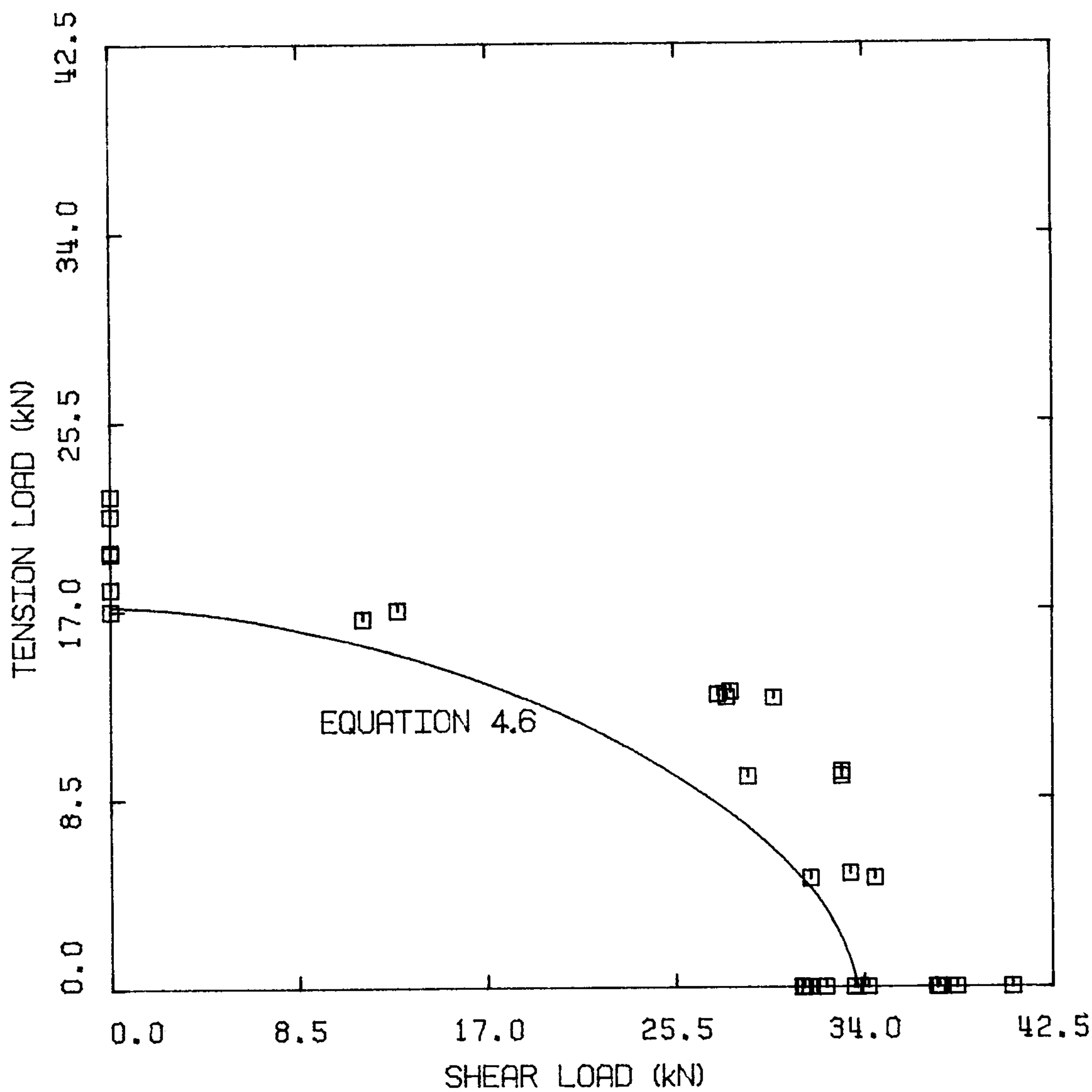

Figure 4.44 Load Interaction Diagram for HSA M12x110

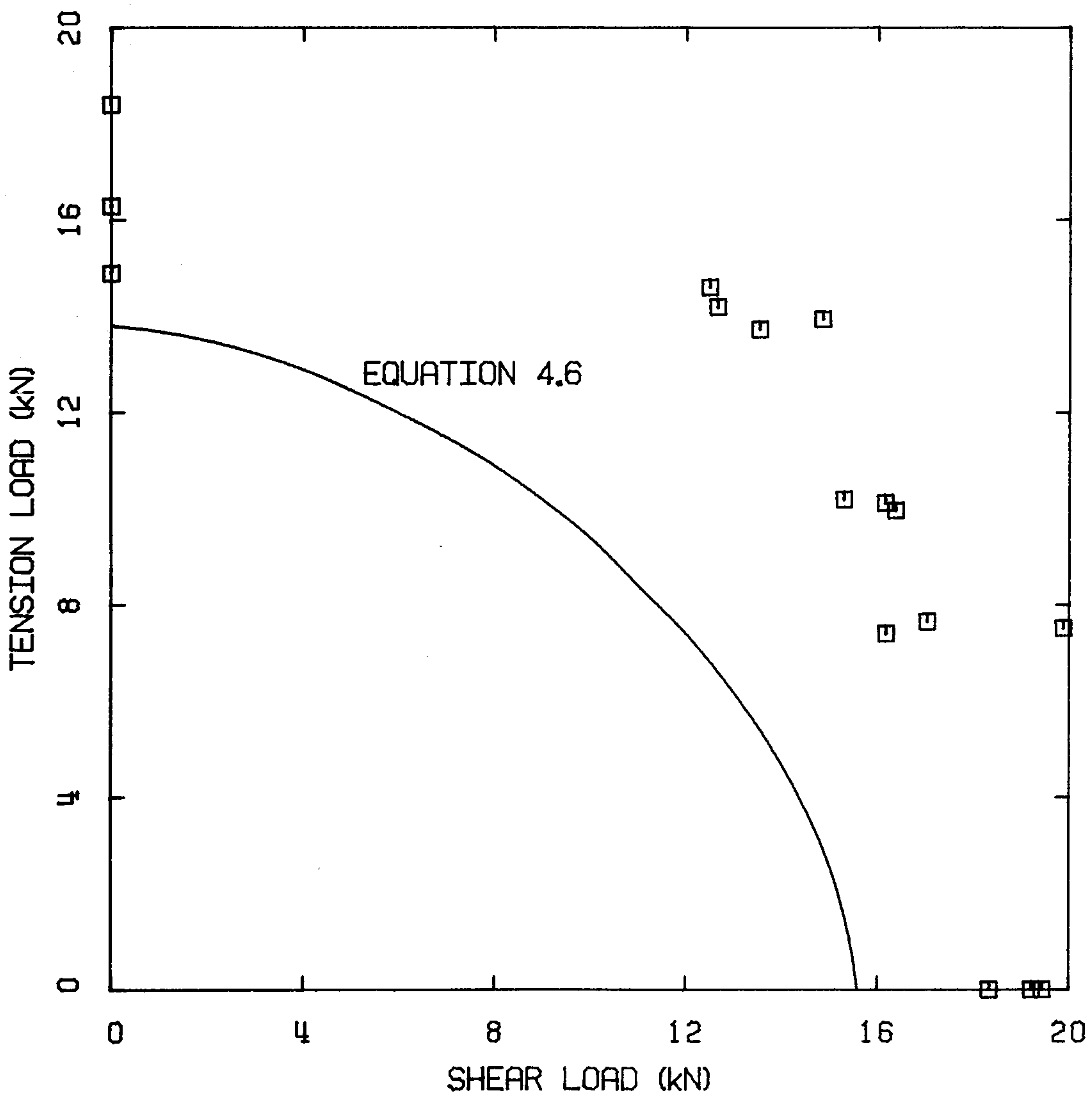

Figure 4.45 Load Interaction Diagram for WS 3850

5. Summary, Conclusions and Recommendations

5.1 Summary

In this investigation related to drilled-in inserts embedded in burned clay brick and concrete block masonry, the objectives were to establish the behavior, modes of failure and strength of inserts under shear, tension, and combined shear and tension loadings. The experimental phase of the study consisted of direct shear, direct tension and combined shear and tension tests of one type of adhesive insert and six types of expansion inserts. A total of 440 specimens were tested. Test results included failure loads, longitudinal and lateral displacements. Based on the test results, empirical relationships were established to predict insert capacities. Using appropriate factors of safety, working load design relationships are recommended.

5.2 Conclusions

The following conclusions are based on test results obtained in this investigation.

1. Failure of drilled-in inserts installed in masonry may occur as a result of failure of the insert or failure of the masonry. Insert failure results from shearing of the insert in direct shear and insert slip or bond failure in direct tension. Failure of the masonry consists of crushing and cracking.
2. Capacity of drilled-in inserts increases with insert

diameter.

3. Shear deflection or tensile displacement of an insert decreases as the size of an insert increases.
4. Shear capacity of an insert is limited by the strength of masonry unit and the strength of the insert material, and also depends on edge distance when masonry failure governs.
5. Tension capacity of adhesive inserts depends on insert diameter and embedment length, whereas tension capacity of expansion inserts depends on the insert diameter and not on the embedment depth provided that the embedment length is longer than the minimum embedment depth as specified by the manufacturer.
6. Combined shear and tension capacity appears to follow an elliptical interaction relationship.
7. Empirical equations can be used to reasonably predict the capacity of drilled-in inserts.

5.3 Recommendations

Based on the test results in this investigation, the following recommendations are presented for the design of drilled-in inserts in masonry.

1. In the case of direct shear, the recommended maximum allowable shear load (V_a) shall be the smaller of:

$$V_a = \frac{1}{FS} \frac{f_{ut} A_s}{10^3 \cdot \sqrt{3}} \qquad (5.1)$$

$$V_a = \frac{5.25}{FS} \sqrt[4]{f_b' A_s} \tag{5.2}$$

where in Equation 5.1, $A_s = A_{sg}$ or $A_s = A_{sn}$, depending on whether the gross area or the area at the root of the thread is subjected to the applied shear load; and in Equation 5.2, $A_s = A_{sg}$.

It is recommended that a factor of safety (FS) of 2 be used in Equation 5.1. For Equation 5.2, a factor of safety of 10 is recommended for a minimum edge distance of 100 mm and a factor of safety of 4 is recommended for an edge distance 500 mm or more. For edge distances between 100 and 500 mm, factors of safety for Equation 5.2 may be obtained by linear interpolation.

2. In the case of direct tension, the recommended maximum allowable tension load (T_a) shall be:

For adhesive inserts, the smaller of

$$T_a = \frac{1}{FS} (2.1 + 0.3L) \tag{5.3}$$

or

$$T_a = \frac{1}{FS} (8.6 + 2.0d) \tag{5.4}$$

For expansion inserts

$$T_a = \frac{1}{FS} (0.5 + 1.4d) \tag{5.5}$$

It is recommended that a factor of safety of 3.75 be used in Equations 5.3, 5.4 and 5.5.

3. In the case of combined shear and tension, an elliptical interaction relationship provides the best fit for ultimate conditions. However, on the basis of the limited number of tests performed, it is recommended that a linear interaction relationship between shear and tension be used where

$$\frac{T}{T_u} + \frac{V}{V_u} = 1 \tag{5.6}$$

Design for this combined loading shall be based on

$$\frac{T}{T_a} + \frac{V}{V_a} = 1 \tag{5.7}$$

in which T_a is defined by Equations 5.3, 5.4 or 5.5, and V_a is defined by Equations 5.1 or 5.2.

4. It is recommended that the minimum distance from the loaded edge to the insert be 100 mm, and only one insert be placed per core in any masonry unit, i.e., no more than two inserts in a two core unit. Moreover, inserts should not be installed at mortar joints.

5. For grouted masonry, the shell of the masonry units shall be considered as part of the embedment of an insert. For adhesive inserts, the embedment depth shall be equal to the length of the adhesive cartridge as specified by the manufacturer. For expansion inserts, the insert shall be installed so that the wedge or the sleeve portion of the insert is completely inside the

face shell. In other words, the minimum embedment depth shall be that specified by the manufacturer, and in no case shall the embedment length be less than the thickness of the face shell plus the length of the wedge or sleeve portion of the insert.

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3. Hatzinikolas, M., Longworth, J., and Warwaruk, J. "Strength and Behaviour of Anchor Bolts Embedded in Concrete Masonry." Proceedings of the Second Canadian Masonry Symposium, Carleton University, Ottawa, Ontario, June, 1980.

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