PERFORMANCE OF RETROFIT EMBEDMENTS IN BRICK MASONRY

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ABSTRACT Test results of three types of retrofit embedments are presented. Sleeve, adhesive and toggle anchors were embedded in brick masonry and tested monotonically and cyclically in tension, shear, and combined shear and tension. Several anchors were found to be suitable for structural applications. Sleeve anchors performed well in head joint, bed joint, and brick face embedments under tension, shear, and combined loading conditions. Adhesive anchors performed well under shear and combined loadings when embedded in head joints. Toggle bolts were effective for cavity wall applications.

1. INTRODUCTION

Anchorages and embedments are frequently used in masonry as structural attachments for pipe hangers, handrails, fire escapes, and stair hangers, etc. Brown and Whitlock (1) reported on extensive testing of J-bolts subjected to monotonic and cyclic shear and axial forces. J-bolts are installed during original wall construction or require substantial destruction of the wall for retrofit installation.

Brown and Brown (2) are currently preparing a report on the performance of retrofit embedments in concrete masonry. Embedments were subjected to monotonic and cyclic axial, shear, and combined shear and axial loadings. Unlike J-bolts, retrofit embedments may be installed after construction, requiring no destruction of the existing wall. The purpose of this paper is to provide test data on retrofit embedments which are suited for installation in existing brick masonry walls.

2. SCOPE

The overall study of retrofit embedments, of which this paper is a part, included test on three types of embedments: sleeve anchor, adhesive anchor, and toggle bolts (Fig 1). Embedments were tested in both brick masonry and concrete masonry walls, however, this paper is limited to tests performed on brick masonry walls. Embedment sizes ranged from 10 mm (3/8 in) to 19 mm (3/4 in) in diameter, and embedment depths were the manufacture's minimum embedment depths. Three or more replications of each test were performed for statistical purposes. Strengths were determined for each embedment type and are reported here. A total of 520 embedments were tested.

3. TEST PROGRAM

3.1 Loading Apparatus

The loading apparatus was identical to that developed by Brown and Whitlock (1) utilizing smaller load cells. Figure 2 illustrates schematically the technique in which axial, shear, and combined axial-shear loads were applied. The embedment to be tested was installed in a 110 x 100 x 25 cm (44 x 40 x 10 in) wall specimen and then positioned in the loading channel. The anchor's axis was colinear with the horizontal actuator. The wall specimen was clamped

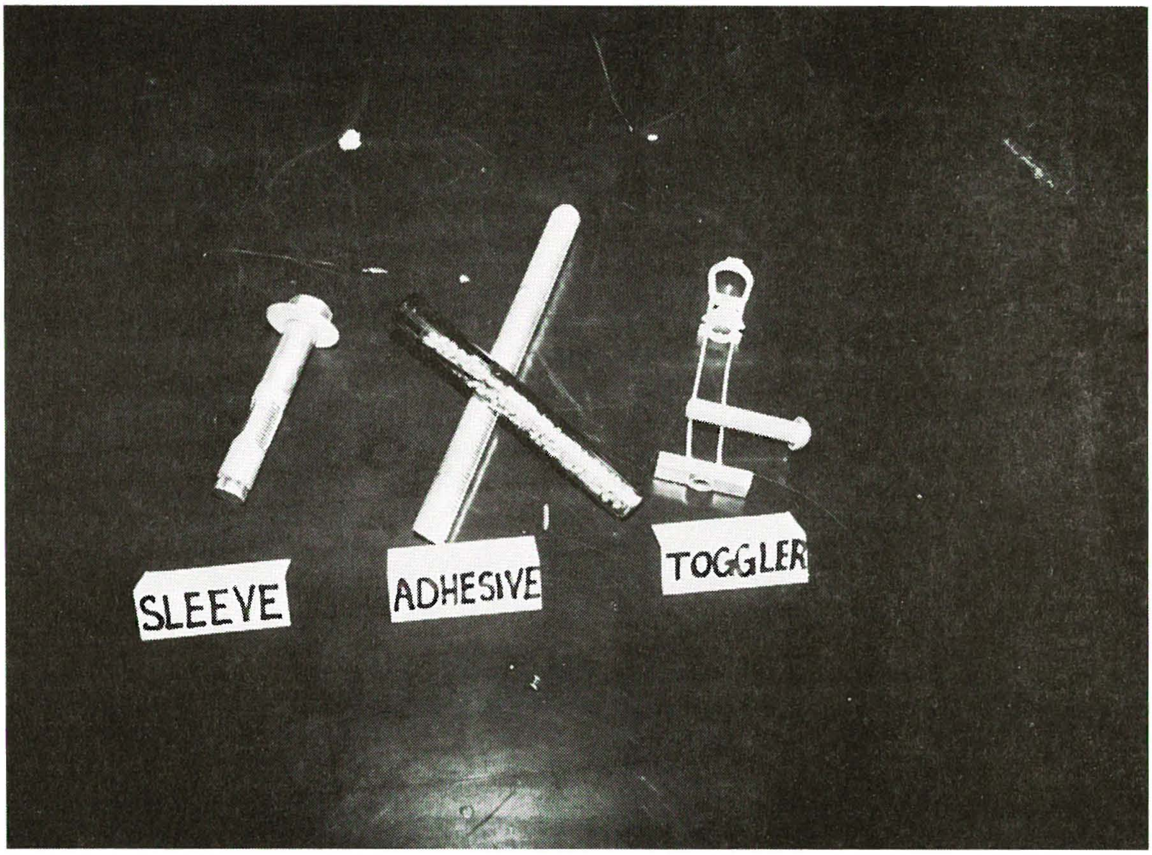

Fig 1 - Photograph of Sleeve Anchor, Adhesive Anchor and Toggle Bolt

by friction using a clamp jack (Fig 2) and clamping beam which compressed the wall specimen against the reaction frame.

3.2 Load Application

In order to apply axial tension or compression to an embedment, the horizontal actuator (Fig 2) was used. To achieve combined shear and axial load, only the inclined actuator was used. Both actuators were used simultaneously to apply direct shear loads. Direct shear was obtained by synchronizing the horizontal and inclined actuators such that the horizontal actuator component was equal and opposite the horizontal component of the inclined actuator, resulting in only a vertical load component. This technique minimized or even eliminated the eccentricity of the shear loads.

3.3 Instrumentation

3.3.1 Load Cells. Forces in both actuators were monitored using load cells mounted in series with the actuators. In most tests, the horizontal actuator was monitored by a 45 kN (10 kip) capacity load cell, and the inclined actuator was monitored by a 90 kN (20 kip) load cell.

3.3.2 Displacement Measurements. Horizontal and vertical displacements of the loading channel were monitored by displacement transducers sensitive to 0.025 mm (0.001 in), one mounted horizontally, the other vertically.

3.3.3 Data Acquisition. The data acquisition system utilized a mini-computer with disk storage which received output from the load cells and transducers.

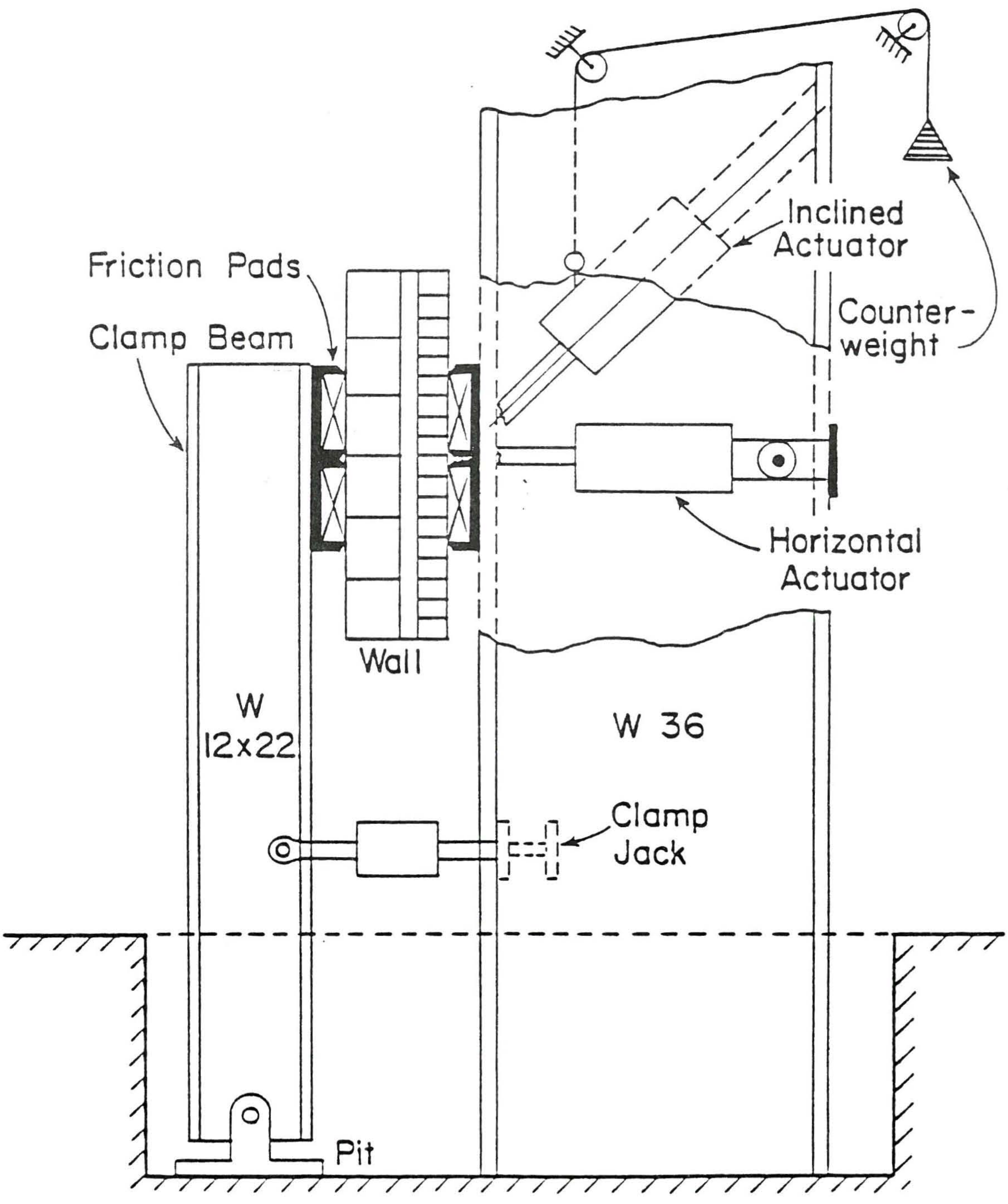

Fig 2 - Bolt Testing Machine

A sampling rate of 4.0 hz was used. An x-y plotter was also used to monitor load and displacement during the tests.

3.4 Wall Specimens

A total of 28 double wythe brick masonry walls and 10 combination "cavity-composite" walls were constructed using standard nonmodular brick with dimensions of 8.75 x 5.625 x 20 cm (3½ x 2¼ x 8 in) and light weight concrete masonry units 20 cm (8 in) in thickness. The double wythe brick walls had a 5 cm (2 in) fully grouted collar joint and the cavity-composite walls were partially grouted leaving a 40 x 100 cm (16 x 40 in) cavity between the brick and block wythes. Sleeve and adhesive anchors were tested in the double wythe brick walls, and toggle bolts were tested in the cavity-composite walls.

The wall specimens were constructed by journeymen masons, allowed to cure for one week and then filled with grout obtained from a local batch plant. Walls were allowed to cure 28 days before testing began.

Vertical reinforcing bars were placed in the collar joint and truss type joint reinforcement was used 20 cm (8 in) from the top and bottom of the walls. The steel was used to arrest cracks which may have formed during the testing procedure. The steel reinforcing was not in close proximity to any anchor test and probably had no effect on anchor strength.

3.5 Material Properties

3.5.1 Brick. The brick units used conformed to ASTM C216-81 (3), Grade SW. The units were tested for physical properties, and the results are given in Table 1.

3.5.2 Concrete Masonry Units. The blocks used were intended to conform to ASTM C90-75 (4), Grade N-I. The units were tested for physical properties and the results are given in Table 2.

3.5.3 Mortar. Type N Portland cement-lime mortar was proportioned in conformance with ASTM C270-82 (5). Mortar properties are given in Table 3.

3.5.4 Grout. Grout was obtained from a local batch plant and was intended to comply with ASTM C476-83 (6). Grout properties were determined using 15 x 30 cm (6 x 12 in) cylinders and are given in Table 4.

3.5.5 Embedments. Embedment anchors were obtained from Hilti® Manufacturing Company and were installed in accordance with manufacture's specifications for concrete applications. Embedments varied in diameter from 10 mm (3/8 in) to 19 mm (3/4 in).

4. TEST RESULTS

4.1 Load Capacities.

Failures loads, tightening torques, and embedment depths of the embedments tested are given in Tables 5, 6 and 7. Sleeve embedments gave good results for all embedment locations and loading conditions. Adhesive anchor results showed large variations in strength when subjected to axial and combined axial-shear loads. This can be attributed to the detrimental effect of voids encountered in brick masonry due to coring and workmanship. Void areas allow the chemical epoxy to flow away from the anchor stud during installation, reducing

the effective bond area between the stud and base material which is used for load transfer. Consistent results were obtained for adhesive embedments subjected to shear loading since load transfer occurred primarily through bearing between the anchor stud and masonry. Toggle bolts tested for cavity wall applications performed well under all loading conditions.

5. FAILURE MODES

There were three observed failure modes; stud failure, masonry failure, and holding mechanism failure.

5.1 Axial Loading

The 10 mm (3/8 in) and 13 mm (1/2 in) sleeve embedments experienced a failure of the holding mechanism where the stud and sleeve pulled far enough out of the hole to allow the stud to free itself from the sleeve. The 16 mm (5/8 in) and 19 mm (3/4 in) embedments experienced both holding mechanism and masonry cone failures with the holding mechanism failure being the dominant mode.

The 10 mm (3/8 in), 13 mm (/12 in), 16 mm (5/8 in) and 19 mm (3/4 in) adhesive anchors failed by epoxy bond failures. Several masonry cone failures were observed for the 16 mm (5/8 in) and 19 mm (3/4 in) embedments, but these were greatly outnumbered by bond failures.

The toggle bolts experienced a ductile holding mechanism failure of the bolt bracket which bears against the inner surface of the brick wythe in the cavity-composite walls. Only 10 mm (3/8 in) and 13 mm (1/2 in) toggle bolts were tested.

5.2 Shear Loading

The 10 mm (3/8 in), 13 mm (1/2 in), 16 mm (5/8 in) and 19 mm (3/4 in) sleeve anchors subjected to monotonic shear loadings experienced ductile failure of their studs. The 16 mm (5/8 in) and 19 mm (3/4 in) sleeve embedments experienced both stud and masonry failures when subjected to cyclic shear loads.

The 10 mm (3/8 in), 13 mm (1/2 in), and 16 mm (5/8 in), and 19 mm (3/4 in) adhesive embedments experienced ductile stud failure in all tests.

The 10 mm (3/8 in) and 13 mm (1/2 in) toggle bolts underwent stud shear failures with partial bolt bracket failures.

5.3 Combined Axial and Shear Loading.

The 10 mm (3/8 in) and 13 mm (1/2 in) diameter sleeve embedments subjected to equal magnitudes of shear and axial load exhibited holding mechanism failures similar to those experienced for these diameters tested in tension. The 16 mm (5/8 in) and 19 mm (3/4 in) diameter anchors exhibited both holding mechanism and masonry failure modes. Masonry failure became the dominant failure mode for the 19 mm (3/4 in) anchor.

The 10 mm (3/8 in), 13 mm (1/2 in), 16 mm (5/8 in), and 19 mm (3/4 in) diameter adhesive embedments exhibited ductile stud failures. The 10 mm (3/8 in) and 13 mm (1/2 in) diameter toggle bolts experienced a ductile holding mechanism failure of the bolt bracket. Large stud deformations were observed.

6. ANALYSIS OF TEST RESULTS

6.1 Effect of Embedment Diameter

It is apparent from Tables 5, 6, and 7 that load capacities increased with increasing anchor diameter for all tests except monotonic and cyclic axial tests of adhesive anchors embedded in head and bed joints and sleeve anchors embedded in bed joints. In both of these cases the 16 mm (5/8 in) diameter embedment was found to be the limiting embedment diameter for which no increase in ultimate load was observed for increased embedment diameter. Had embedment diameters larger than those used in this research been tested, it is expected that limiting embedment diameters would have been observed for the other loading conditions and embedment locations. Limiting embedment diameters are observed when the masonry strength becomes less than the strength of the embedment components (sleeve mechanism or epoxy bond).

6.2 Effect of Loading Direction

6.2.1 Comparison of Shear to Tension. With the exception of some of the adhesive embedments, average ultimate shear loads were typically 1.5 - 2.5 times the average ultimate axial loads. This was consistently true for sleeve embedments and toggle bolts. The adhesive embedments obtained ultimate average axial loads which were at times larger than the ultimate shear loads. Results of manufacturer's testing in concrete slabs (7) and results obtained by Brown and Brown (2) show that average adhesive embedment axial loads were generally 1½ - 2 times the average shear loads. This can be attributed to the large bond area over which the external embedment load is distributed when the adhesive anchor is subjected to axial load. Under shear loading, the external load is transferred primarily through the embedment stud to the base material and, as observed in this research, ultimate shear strength was governed by stud shear strength.

Divergence from the above mentioned trend can be attributed to the inherent presence of void areas in brick masonry. As stated before, the presence of voids in the base material reduces the effective bond area between anchor stud and base material and, therefore, reduces the ultimate axial load.

As can be seen in Tables 5 and 6, the coefficients of variation for axial tests were typically greater than those obtained from shear tests. This can be attributed to the holding mechanism's inability to perform correctly due to nonhomogeneity of the masonry, slightly greater hole diameter after drilling, and voids encountered in the base material.

6.2.2 Combined Shear and Axial Load. Comparing results of Tables 5, 6 and 7 shows that combined loading strengths generally fell between the values obtained for shear and axial loadings and were closer in magnitude to the axial load values. However, toggle bolts achieved higher ultimate combined load values than shear values. This is attributed to the larger shear deflections obtained in the combined tests. Shear deflections, at failure, were typically 2 times the magnitude of shear deflections observed in shear test, representing a larger yielding region over which load increase could occur.

7. SUMMARY AND CONCLUSIONS

The results of tests on 520 masonry retrofit embedments are reported. Three types of anchors of various diameters were embedded in brick masonry and subjected to shear, axial and combinations of shear and axial loads. Monotonic and cyclic tests were performed on each diameter embedded in the following

locations: head joint, bed joint, and brick face. Results of the research have led to the following conclusions:

(1) There are several commercially-manufactured retrofit embedments that are suitable as structural anchors for brick masonry.

(2) Ultimate shear loads of mechanical embedments (sleeve anchors and toggle bolts) are typically 1.5-2.5 times those found for axial loads.

(3) Combined shear and axial test loads more closely resemble axial test loads than shear test loads for mechanical embedments.

(4) Sleeve, adhesive, and toggle bolt embedments give consistent values under monotonic and cyclic shear loadings.

(5) Sleeve and adhesive embedments experience large variations in strength when subjected to axial and combined shear and axial loading.

(6) Toggle bolts have consistent shear, axial, and combined loading strengths in monotonic and cyclic loadings.

(7) Adhesive embedment axial strength is extremely sensitive to void areas encountered in brick masonry.

(8) Sleeve embedments are well-suited for brick masonry applications.

(9) Toggle bolts are well-suited for cavity wall applications.

(10) Cyclic ultimate loads were generally lower than monotonic ultimate loads.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

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TABLE 1. BRICK PROPERTIES

Sample	Comp. Strength (MPa)	Absorption,% 24 Hr. Cold	5 Hr. Boil	Sat. Coeff.	IRA gm/30in^2	Tensile Splitting (kPa)
1	69.6	8.76	11.42	0.77	52.9	482
2	71.2	6.72	9.67	0.70	49.4	620
3	73.1	8.02	10.96	0.73	49.3	1172
4	65.7	6.43	9.51	0.68	44.5	861
5	78.5	9.01	11.71	0.77	47.6	379
Mean	72.3	7.79	10.66	0.73	48.7	703
COV,%	8.2	15.0	9.5	5.6	6.3	45.3

TABLE 2. CONCRETE MASONRY UNIT PROPERTIES

Sample	Comp. Strength Gross Area (MPa)	Net Area (MPa)	Tensile Splitting (kPa)	Absorption %
1	9.9	19.7	924	14.76
2	7.1	14.2	848	15.06
3	8.8	17.7	917	14.95
Mean	8.6	17.2	896	14.92
COV,%	8.2	15.0	17.2	1.0

Note: 1 MPa = 145.0 psi

TABLE 3. MORTAR PROPERTIES

Wall Specimen	Cube Compressive Strength Mean (MPa)	Cube Compressive Strength COV %	Tensile Splitting Strength Mean (kPa)	Tensile Splitting Strength COV %
Sleeve Anchor Walls	4.1	15.6	482	19.2
Adhesive Anchor Walls	4.3	12.2	544	11.8
Composite Cavity Walls	5.9	8.9	682	18.8

TABLE 4. GROUT PROPERTIES

Wall Specimen	Cylinder Compressive Strength Mean (MPa)	Cylinder Compressive Strength COV %	Tensile Splitting Strength Mean (MPa)	Tensile Splitting Strength COV %
Sleeve Anchor Walls	19.7	9.6	-	-
Adhesive Anchor Walls	19.8	5.5	2.2	15.0
Composite Cavity Walls	29.1	0.0	2.6	18.7

Note: 1 MPa = 145 psi.

TABLE 5. AXIAL TEST RESULTS

Anchor Type	Diam. (mm)	Embed. Depth (cm)	Embed. Location	Tightening Torque (N-m)	Monotonic Results Mean Load (kN)	Monotonic Results COV %	Cyclic Results Mean Load (kN)	Cyclic Results COV %
Sleeve	10	6.35	Face	13.5	7.9	9.8	7.6	11.8
			Bed		2.9	41.7	2.2	34.6
			Head		3.9	18.2	4.8	18.9
	13	5.72	Face	40.7	11.1	11.5	9.5	7.2
			Bed		7.6	44.7	10.6	50.7
			Head		9.4	27.4	7.5	34.7
	16	9.53	Face	40.7	21.6	66.4	19.8	50.6
			Bed		29.2	9.2	22.1	57.0
			Head		27.4	57.0	25.2	15.9
	19	9.53	Face	54.2	33.3	18.0	32.9	18.2
			Bed		19.7	36.7	26.6	34.0
			Head		29.3	21.2	23.4	22.5
Adhesive	10	8.89	Face	24.4	8.6	76.9	9.3	98.4
			Bed		10.1	90.6	13.3	22.7
			Head		25.0	8.2	10.8	95.0
	13	10.80	Face	47.4	21.3	77.6	23.5	11.8
			Bed		25.9	20.6	25.2	33.4
			Head		23.1	76.7	31.2	13.9
	16	12.70	Face	108.4	54.7	11.6	39.1	52.2
			Bed		55.1	1.4	44.1	11.1
			Head		58.9	9.5	50.0	14.8
	19	16.83	Face	216.9	61.3	75.1	28.0	161.0
			Bed		39.3	127.0	25.3	164.2
			Head		93.6	10.7	83.9	4.5
Toggle	10	-	Head	13.5	7.1	32.5	6.4	14.5
	13	-	Head	20.3	11.1	21.2	10.2	11.5

Note: 1 mm = 0.04 in, 1 kN = 224.8 lb.

TABLE 6. SHEAR TEST RESULTS

Anchor Type	Diam. (mm)	Embed. Depth (cm)	Embed. Location	Tightening Torque (N-m)	Monotonic Results Mean Load (kN)	Monotonic Results COV %	Cyclic Results Mean Load (kN)	Cyclic Results COV %
Sleeve	10	6.35	Face	13.5	10.4	6.5	6.1	10.6
			Bed		11.4	5.9	8.1	6.3
			Head		9.8	19.8	8.4	5.3
	13	5.72	Face	40.7	14.2	20.5	9.5	5.4
			Bed		16.0	12.7	11.2	12.7
			Head		17.8	21.8	14.1	7.3
	16	9.53	Face	40.7	40.8	10.0	24.8	0.0
			Bed		37.9	13.0	25.4	19.2
			Head		40.0	8.0	25.4	10.1
	19	9.53	Face	54.2	45.9	9.4	32.4	14.4
			Bed		46.5	4.8	36.1	15.6
			Head		45.0	13.1	35.2	8.0
Adhesive	10	8.89	Face	24.4	16.6	18.8	14.6	5.2
			Bed		18.5	2.8	15.1	0.0
			Head		18.4	2.8	13.3	0.0
	13	10.80	Face	47.4	27.4	38.4	22.9	25.3
			Bed		34.6	1.3	28.4	0.0
			Head		34.8	2.0	28.1	1.0
	16	12.70	Face	108.4	55.2	3.8	46.2	0.0
			Bed		60.2	7.6	47.4	7.0
			Head		54.7	6.8	40.3	25.6
	19	16.83	Face	216.9	75.2	16.3	-	-
			Bed		-	-	-	-
			Head		72.9	5.0	61.6	7.0
Toggle	10	-	Head	13.5	13.7	3.4	10.1	8.3
	13	-	Head	20.3	22.7	3.7	18.6	0.0

Note: 1 mm = 0.04 in, 1 kN = 224.8 lb.

TABLE 7. COMBINED TEST RESULTS

Anchor Type	Diam. (mm)	Embed. Depth (cm)	Embed. Location	Tightening Torque (N-m)	Monotonic Results Mean Load (kN)	Monotonic Results COV %	Cyclic Results Mean Load (kN)	Cyclic Results COV %
Sleeve	10	6.35	Face	13.5	8.1	9.8	5.4	26.6
			Bed		7.5	41.7	6.3	30.0
			Head		6.5	24.4	5.9	29.3
	13	5.72	Face	40.7	7.4	4.7	8.8	10.7
			Bed		15.5	37.6	11.1	17.3
			Head		9.7	27.9	9.3	22.9
	16	9.53	Face	40.7	32.2	15.9	26.6	22.5
			Bed		23.6	10.8	26.1	21.7
			Head		21.1	19.3	18.0	17.5
	19	9.53	Face	54.2	36.6	15.6	36.3	15.2
			Bed		29.4	28.7	37.9	9.6
			Head		38.0	21.1	37.9	29.5
Adhesive	10	8.89	Face	24.4	18.0	10.6	18.0	10.6
			Bed		18.4	33.6	16.7	31.4
			Head		18.4	13.0	18.7	3.9
	13	10.80	Face	47.4	31.7	35.1	36.2	2.6
			Bed		37.0	11.9	30.4	29.6
			Head		37.0	5.1	31.4	34.6
	16	12.70	Face	108.4	38.6	74.5	56.7	5.2
			Bed		54.0	20.3	55.3	0.0
			Head		60.7	3.2	45.6	51.1
	19	16.83	Face	216.9	-	-	-	-
			Bed		-	-	-	-
			Head		77.5	11.3	59.9	50.3
Toggle	10	-	Head	15.7	11.1	18.3	15.2	15.8
	13	-	Head	23.9	16.9	3.9	22.4	16.4

Note: 1 mm = 0.04 in, 1 kN = 224.8 lb.
Mean loads are resultant loads.