# *THE EFFECT OF TIE TYPE ON BRICK VENEER WALLS*

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# THE EFFECT OF TIE TYPE ON BRICK VENEER WALLS

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## 1. INTRODUCTION

The use of masonry veneer and steel stud curtain walls has grown in popularity in the past few years. In this type of wall system clay brick veneer is connected to steel studs by means of metal ties which act to transfer the wind load from the brick veneer to the stud backing. The poor performance of some recently constructed walls prompted the present investigation. The primary goal of this experimental investigation conducted at the University of Alberta was to evaluate the interaction of the brick veneer, the metal ties and the steel studs in a curtain wall system. Because the ties are a critical link in the wall system, their load-deflection behaviour was of special concern.

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## 2. TESTING PROGRAM

To better understand the interaction of the tie and steel stud, two series of tests were conducted on specimens consisting of only these two components. In the first series, five different types of ties were tested individually in combination with single 450 mm lengths of steel stud. These ties were 24, 22, and 16 gauge corrugated strip ties, a 6 gauge adjustable rod "V" tie and a 9 gauge wire ladder tie (see Figure 1). A pad of gyproc was placed between the tie and stud to simulate a typical connection detail. Each specimen was subjected to a compressive axial load applied through a clamping mechanism attached to the free end of the tie. During each test a plot of the load-deflection behaviour of the stud and tie system was recorded.

In the second series of tests, a 1210 mm by 1210 mm three-stud wall section was used as the support backing for the ties (see Figure 2). The studs were fastened to top and bottom supports by means of a standard track and both sides of the backing wall were sheathed with gyproc. 22 gauge corrugated ties and Block-Loc No.319 adjustable wire veneer ties ("T" ties) were tested in this series. The ties were subjected to a compressive axial load through a clamping mechanism and the load-deflection behaviour of the specimen was recorded.

Tests were performed on two full-sized sections of curtain wall shown in Figure 3. Each specimen was constructed with a tie spacing of 400 mm by 533 mm and a wall cavity width of 50 mm. One specimen utilized 22 gauge corrugated ties and the other utilized "T" ties. Each specimen was subjected to a positive uniformly distributed lateral loading applied by means of an air bag.

## 3. SUMMARY OF TEST RESULTS

The load-deflection plots generated in the tie and stud tests exhibited two distinct types of behaviour. Curve No.1, in Figure 4, shows the typical load-delection behaviour of the 24 and 22 gauge corrugated tie and stud specimens while curve No.2 shows the typical load-deflection behaviour of the remaining tie and stud specimens. Both load-deflection curves consist of two regions, an elastic region and an inelastic region. The primary difference between the load-deflection behaviour of the two groups of specimens was in the inelastic region. The 22 and 24 gauge corrugated ties buckled at much lower loads than the other ties. All but the 22 and 24 gauge corrugated tie specimens exhibited a significant increase in strength and sustained significant deflections in the inelastic region.

The load-deflection behaviour for all the tie and stud specimens can be described by linear approximations in the elastic region. The slopes of these approximations are summarized in Table 1. Also included in Table 1 are the maximum elastic tie load and the ultimate tie load for each test specimen.

In the tests on the ladder tie, "T" tie and 16 gauge corrugated tie specimens, severe crushing of the gyproc backing occurred. In the test on the "V" ties, both the stud and backing clip provided with this tie underwent permanent deformation.

The load-deflection plots for the full sized wall sections are shown in Figures 5 and 6. Specimen No.1 was constructed using 22 gauge corrugated ties and Specimen No.2 was constructed using "T" ties.

In the test of Specimen No.1, the brick veneer cracked in a mortar joint near mid-height at a load of 1.75 KPa (36.5 psf). The ties at mid-height began to buckle at a load of 2.96 Kpa (60 psf). At the maximum load of 3.46 KPa (72.2 psf) the top ties buckled and the upper section of brick veneer rotated into the backing wall.

Specimen No.2 behaved similarily to Specimen No.1. The brick veneer cracked in a mortar joint near mid-height at a load of 2.07 KPa (43.2 psf). This specimen was loaded to a maximum of 4.83 KPa (100.8 psf) without any tie failure.

## 4. DISCUSSION

To fully understand the effect of tie type on the load-deflection behaviour of the full-sized walls it is necessary to first analyze the action of the tie and stud at their junction.

Figure 7 shows the action of the tie and stud system. The far end of the web is assumed as fixed and the web and the near flange are considered as a cantilevered frame. If the gyproc sheathing is ignored, the tie is fastened directly to this frame by a screw. This screw connection allows significant rotation and is, therefore, assumed to behave as a pin. The brick end of the tie is assumed to be fixed with respect to rotation but free to translate axially (along the X-axis). When the tie is loaded, the tie force is transferred to the frame at the junction of stud and tie causing the cantilevered frame to deflect in the manner shown in Figure 7.

The total movement of the brick end of the tie, along the X-axis, governs the effect of the tie and stud system on the behaviour of the brick veneer. Apart from the flexural deflection of the stud, the significant stud and tie system deflections are those resulting from frame sway (d1) and those resulting from the flange movement (d2). The system stiffness is defined as the resistance of the tie and stud frame to movements of the brick end of the tie along the X-axis. The slope of the linear approximation of the elastic load-deflection behaviour of the tie and stud system is considered to be a measure of the system stiffness.

The stiffness of the tie in the Y-direction (lateral stiffness) acts to restrain the sway (S) of the web and flange frame. Both the sway (S) and the deflection (d1) decrease as the lateral stiffness of the tie increases. However, the lateral stiffness of the tie has no significant effect on the deflection of the stud flange (d2). It only significantly affects the smaller deflection (d1) and thus only slightly affects the tie and stud system stiffness. Therefore, for ties of the same type, a laterally stiff tie produces a greater system stiffness than a laterally weak tie.

A two dimensional analysis was conducted on the frame formed by the tie and stud. This analysis revealed little difference in the pre-buckling load-deflection behaviour of the various corrugated ties. Although there was a large variation in lateral stiffness, all the corrugated ties were sufficiently stiff to reduce the sway to an insignificant value. The analysis also indicated that the axial compression of the tie accounted for less than one percent of the total movement of the brick end of the tie along the X-axis.

In the short stud tests, both the 22 and 24 gauge corrugated tie and stud specimens exhibited elastic behaviour until the ties buckled. As predicted by the analysis, these two tie and stud systems demonstrated approximately the same stiffness. The average slopes of the load-deflection plots were 619 N/mm and 587 N/mm for the 22 gauge and the 24 gauge ties respectively; a difference of only five percent.

The 16 gauge corrugated ties, when tested in conjuction with short studs and gyproc, exhibited both elastic and significant inelastic behaviour. The average slope for the system (stud, drywall, screw and tie), in the elastic region, was 278 N/mm which was approximately 50 percent less than that predicted by analysis. Examination of the test specimens after failure appears to support the following explanation for this difference. The 90 degree bend for the 16 gauge ties had a larger radius than for the 22 gauge ties. This larger radius combined with larger amplitude corrugations moved the tie and gyproc contact further away from the line of action of the tie load. This eccentricity of load resulted in a prying action which increased the load on the area of contact between gyproc and tie. The corrugations and bend also reduced the effective contact area. Thus the stress on the gyproc behind the 16 gauge ties was larger than that behind the 22 gauge ties. Because of the high stress on the contact area, the gyproc behind the 16 gauge tie crushed at a relatively low load causing permanent deformation of the tie and stud system over the entire load range. As the gyproc crushed, the eccentricity of the load increased and the prying effect also increased. These deformations reduced thus the effective stiffness of the tie and stud system.

The deformation of the gyproc was also affected by the lateral stiffness of the 16 gauge ties. As the flange of the stud deflected, the very stiff 16 gauge tie remained rigid. Thus the angle formed between the tie and stud flange increased and the tie load acted on a decreasing area. The resulting increased stress produced increased gyproc deformations.

The "T" ties also exhibited reduced system stiffness due to the permanent deformation of the gyproc backing. This tie was predicted to produce a greater system stiffness than a 22 gauge corrugated tie. However, the slopes for the specimens containing "T" ties were substantially lower than the slopes for identical specimens containing 22 gauge ties and tested in the same manner. Because the circular cross-section of the "T" tie resulted in a small contact area and high stress levels in the gyproc, the deformation of the gyproc became a significant part of the deflection of the "T" tie and stud system.

Crushing of the gyproc was not significant for the 22 and 24 gauge corrugated tie and stud systems or in the elastic region of the ladder tie and stud system. The deformation of the gyproc was also not significant for the "V" tie and stud system as a backing platform, developed for use in conjuction with metal studs, was used to connect the "V" ties directly to the stud flange.

Ladder ties are much weaker laterally than corrugated ties. This decreased lateral stiffness caused an increase in the stud web sway resulting in greater deflection along the X-axis. Therefore, the system stiffness of a ladder tie and stud combination should be less than the stiffness of a corrugated tie and stud combination. As shown in Table 1, test results verified that the ladder tie systems were less stiff than the 22 and 24 gauge corrugated tie systems.

The analysis predicted that the "V" tie and stud system should have had the greatest system stiffness of all the specimens tested. However, test results indicated that the "V" tie system was not as stiff as the 22 and 24 gauge corrugated tie and ladder tie systems (see Table 1). Examination of the clip for the "V" tie connection showed that the connection allowed a significant amount of slip between the rod and backing platform. This slip significantly reduced the lateral restraint that the "V" tie provided to the stud and therefore reduced the system stiffness.

In the absence of a compressible sheathing such as gyproc, lateral stiffness of the ties has the greatest effect on the tie and stud system stiffness with the stiffness increasing with increasing lateral stiffness of the tie. The data in Table 1, however, indicates that other factors, such as the restraint provided by the continuous sheathing, also affected the system stiffness.

The magnitude of bearing stress on the gyproc sheathing is an important factor affecting the system stiffness. The backing of the ties should ensure that the stress applied to the gyproc is low enough to preclude significant deformation of the gyproc at service load levels. It is recommended that a type of metal backing be used to transfer the tie load directly to the stud flange.

The ultimate and maximum elastic loads on the tie and stud system were significantly affected by the type of tie. For 22 and 24 gauge corrugated tie specimens, the maximum elastic and ultimate loads corresponded to the buckling load of the tie. The ultimate loads for the other tie and stud systems were also governed by the tie type in cases where the system failed by tie buckling. For a constant effective tie length, systems having ties with greater radii of gyration sustained higher ultimate loads.

When the tie had a radius of gyration sufficiently large to prevent tie buckling, as did the "V" ties, the ultimate system load was governed by the maximum load that the stud flange and web could sustain. Thus, the use of very stiff ties is of no advantage because the ultimate tie and stud system load can not exceed the stud failure load.

The ladder, "V", "T" and 16 gauge corrugated tie and stud specimens exhibited higher maximum elastic loads than those of the 22 and 24 gauge corrugated tie and stud specimens. However, as previously mentioned, the gyproc behind the ladder, "T", and 16 gauge corrugated ties underwent significant permanent deformation. Thus, where these three types of ties were fastened to the gyproc, the maximum elastic system load was governed by the contact stress on the gyproc and not the strength of either the tie or the stud.

By applying the results of the tie and stud tests to the full-sized wall tests it would appear that the brick veneer of Specimen No.2 should have deflected more than the brick veneer of Specimen No.1. However, Figures 5 and 6 show that for loads up to the veneer cracking load there was no significant difference in the deflections. Because the distance between the stud web and the point of tie connection has a significant effect on the stiffness of the tie and stud system, variation in this distance could have affected the differences in the stiffness of the two systems.

Although both wall specimens failed by cracking of the brick veneer, Specimen No. 2 had a higher post-cracking strength. However, each wall exceeded the design load of 1.21 KPa (25.2 psf) and reached an ultimate load that was greater than twice the design load. Therefore, both types of tie would function equally well for most curtain wall applications.

## 5. CONCLUSIONS

The results of an experimental investigation into the effects of tie type on the load-deflection behaviour of brick veneer and steel stud curtain walls lead to the following conclusions:

1. The tie characteristic that has the greatest effect on the stiffness of the tie and stud system is the lateral stiffness of the tie. As a result of the frame action of the open cross-section of the stud, the system stiffness increases as the lateral stiffness of the tie is increased.
2. The deformation of the compressible exterior sheathing is a significant portion of the tie and stud system deflection if the sheathing is subjected to high contact stress. To prevent this deformation the use of a backing platform to transfer the tie load directly to the stud is recommended.
3. Although tie type has no significant effect on the load-deflection behaviour of full-sized curtain walls at service load levels, it does affect the ultimate failure mode of the wall. Depending on the tie type and arrangement, ties may buckle causing the collapse of the brick veneer into the backing wall. If tie buckling does not occur then the load-deflection behaviour of the veneer wall is not greatly affected by the type of tie used to connect the wall to the back-up system.

# ABSTRACT

This paper describes an experimental investigation conducted at the University of Alberta which evaluated the effect of tie type on the load-deflection behaviour of brick veneer and steel stud curtain walls. In this investigation, various ties were tested both for their own load-deflection response and for their effect on the load-deflection behaviour of full-sized walls. Results of tests conducted on isolated tie and stud systems indicated that the type of tie did affect the load-deflection behaviour of these systems. Significant deflections are produced by the frame action of the open cross-section of the steel studs. The in-plane stiffness of the tie restrains the movement of this frame and thus affects the stiffness of the stud and tie system. The axial deflection of the ties was insignificant when compared to the deflection of the frame formed by the steel stud.

Also determined from these tests was the importance of the stress applied to the exterior sheathing by the tie contact. In some cases, permanent deformation of this sheathing accounted for more than 30 percent of the total system deflection.

A number of full sized curtain wall sections were tested under positive pressure wind loading. Test results indicated that the type of tie had little effect on the load-deflection behaviour of the walls at service load

levels.

The investigation showed that if tie buckling does not occur then the load-deflection behaviour of the veneer wall is not greatly affected by the type of tie used to connect the wall to the back-up system.

TABLE 1

| STUD AND TIE TEST RESULTS | | | |
|---|---|---|---|
| Tie Type | Maximum Load (N) | Ultimate Load (N) | Slope (N/mm) |
| 24ga. Corr. | 400. | 400. | 493. |
| 24ga. Corr. | 578. | 578. | 585. |
| 24ga. Corr. | 435. | 435. | 438. |
| 24ga. Corr. | 519. | 519. | 737. |
| 24ga. Corr. | 623. | 623. | 648. |
| 24ga. Corr. | 519. | 519. | 619. |
| 22ga. Corr. | 593. | 593. | 611. |
| 22ga. Corr. | 608. | 608. | 648. |
| 22ga. Corr. | 499. | 499. | 669. |
| 22ga. Corr. | 692. | 692. | 514. |
| 22ga. Corr. | 643. | 643. | 598. |
| 22ga. Corr. | 722. | 722. | 675. |
| 16ga. Corr. | 816. | 1631. | 317. |
| 16ga. Corr. | 1110. | 1705. | 258. |
| 16ga. Corr. | 1170. | 1720. | 261. |
| V. | 1850. | 3351. | 397. |
| V. | 1990. | 3559. | 438. |
| V. | 1900. | 2867. | 404. |
| ladder | 1490. | 2155. | 497. |
| ladder | 1577. | 2199. | 434. |
| ladder | 1383. | 1829. | 564. |
| 22ga. Corr. | 689.* | 689. | 1186. |
| 22ga. Corr. | 678.* | 678. | 1221. |
| 22ga. Corr. | 765.* | 765. | 2299. |
| T. | 1412.* | 1973. | 774. |
| T. | 861.* | 1847. | 1012. |
| T. | 889.* | 1790. | 555. |

Note: (1) "Slope" is the slope of the linear-elastic approximations
(2) * denotes wall section tests

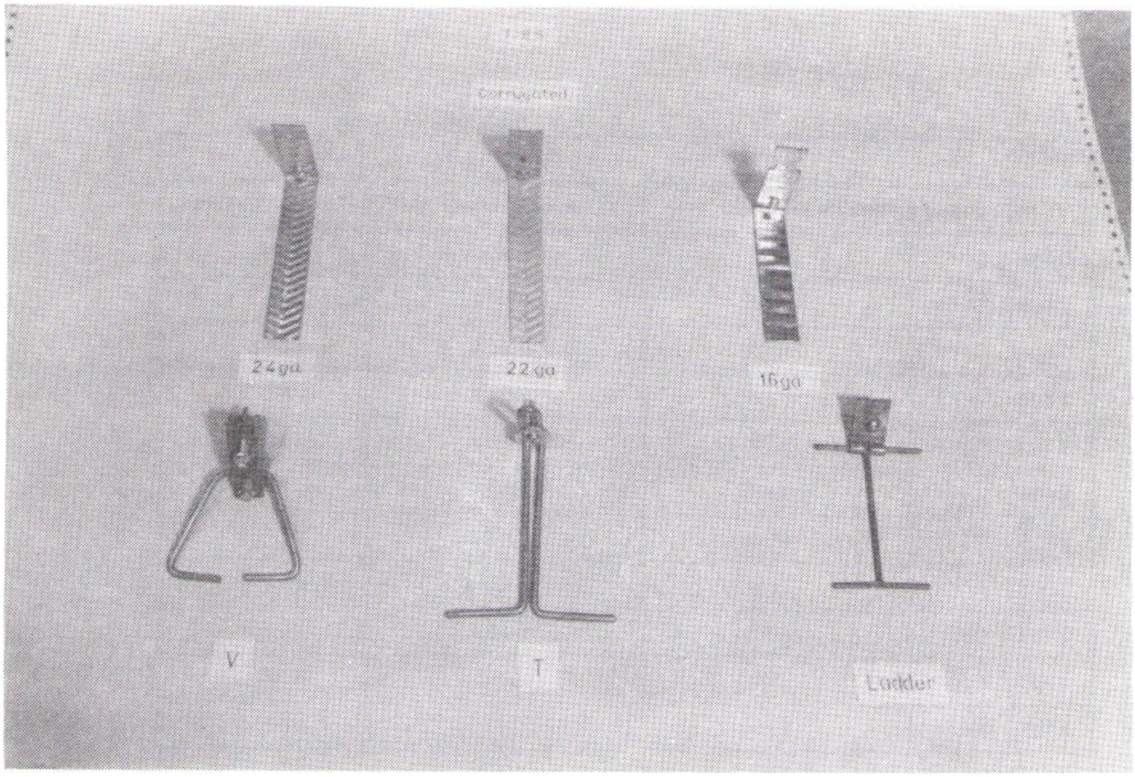


Figure 1 Ties Tested

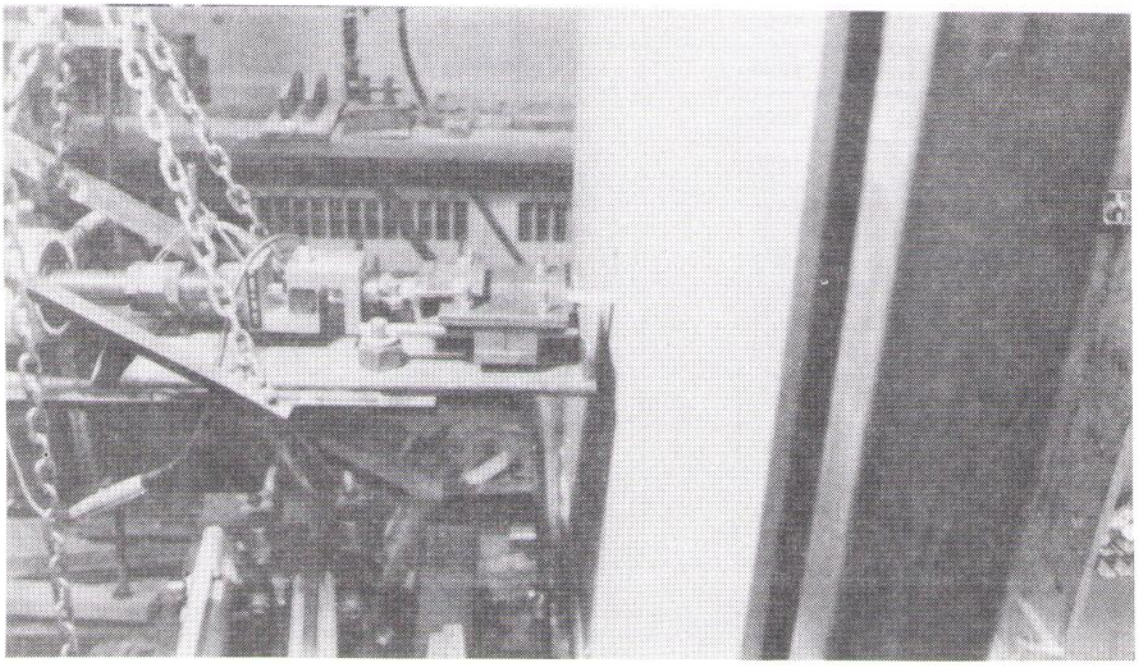
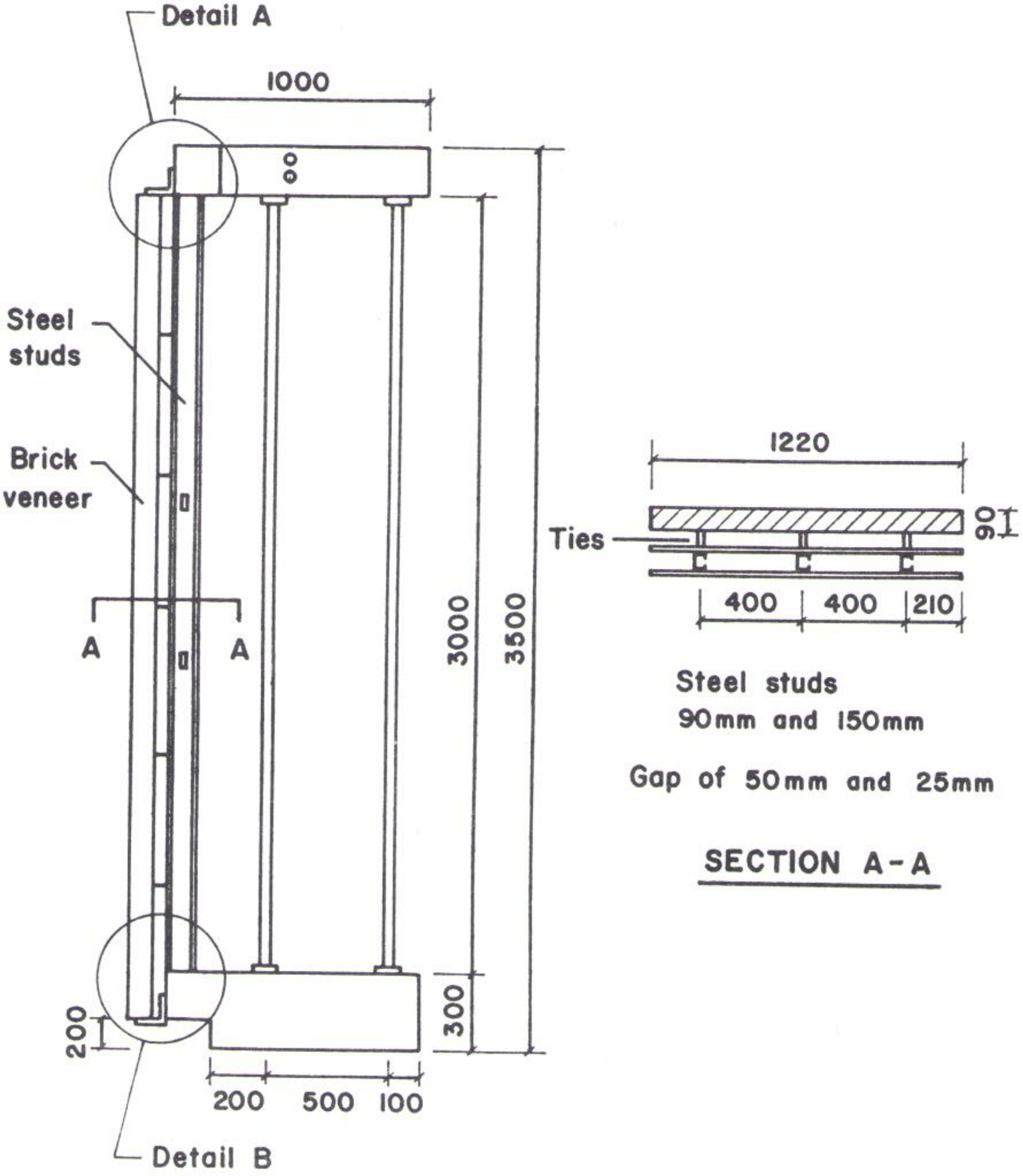
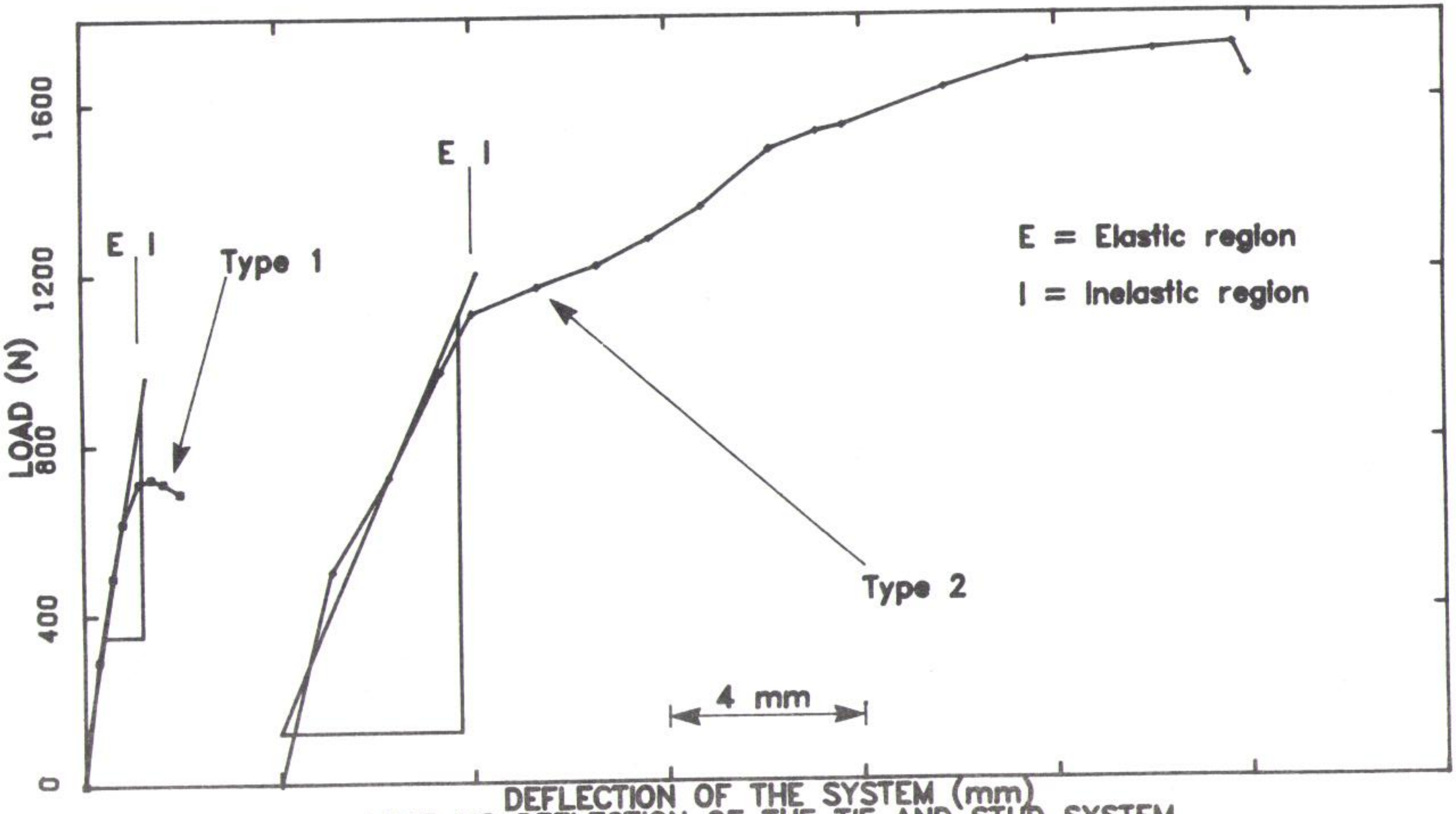


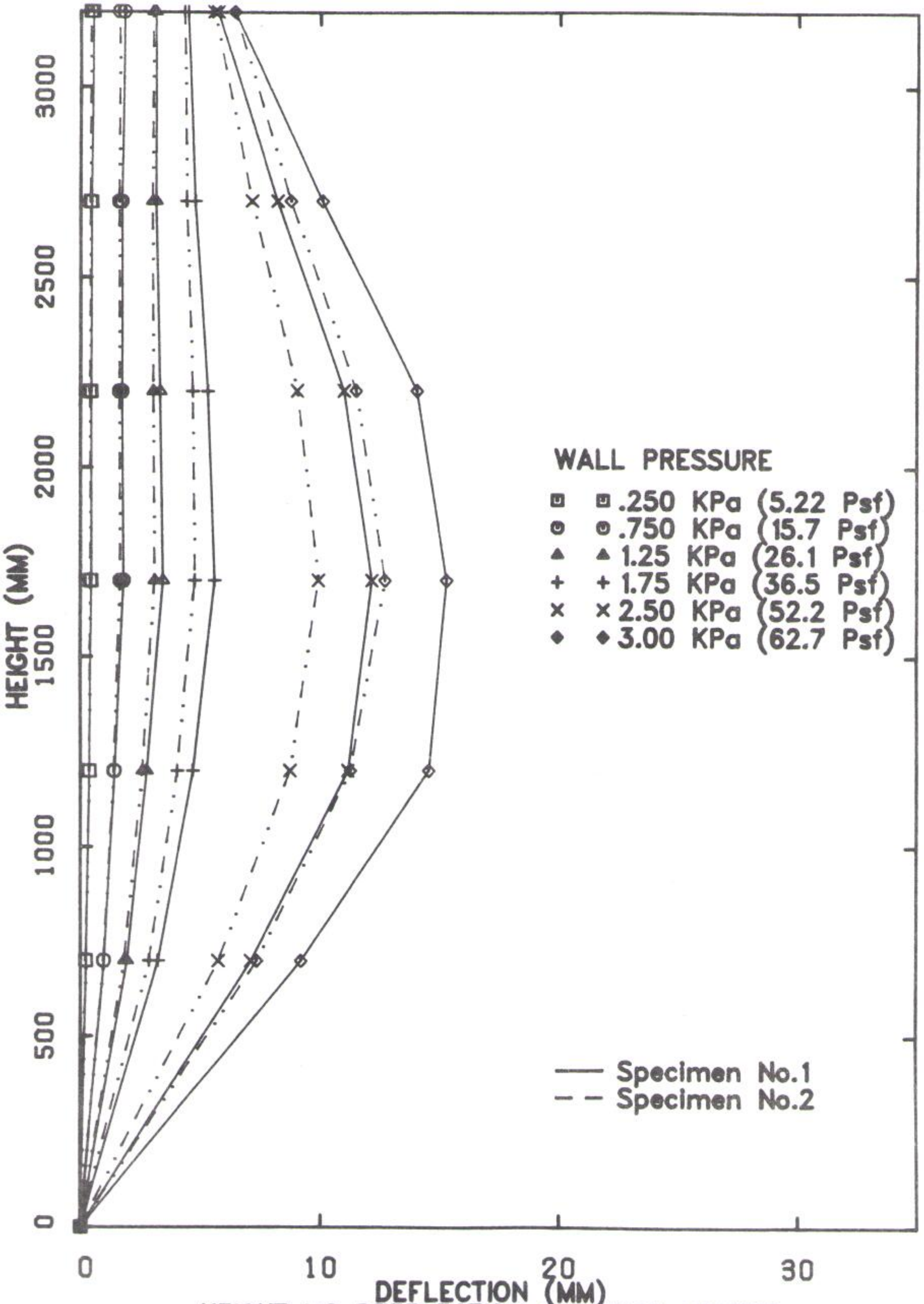
Figure 2 Wall Section Testing Apparatus and Specimen



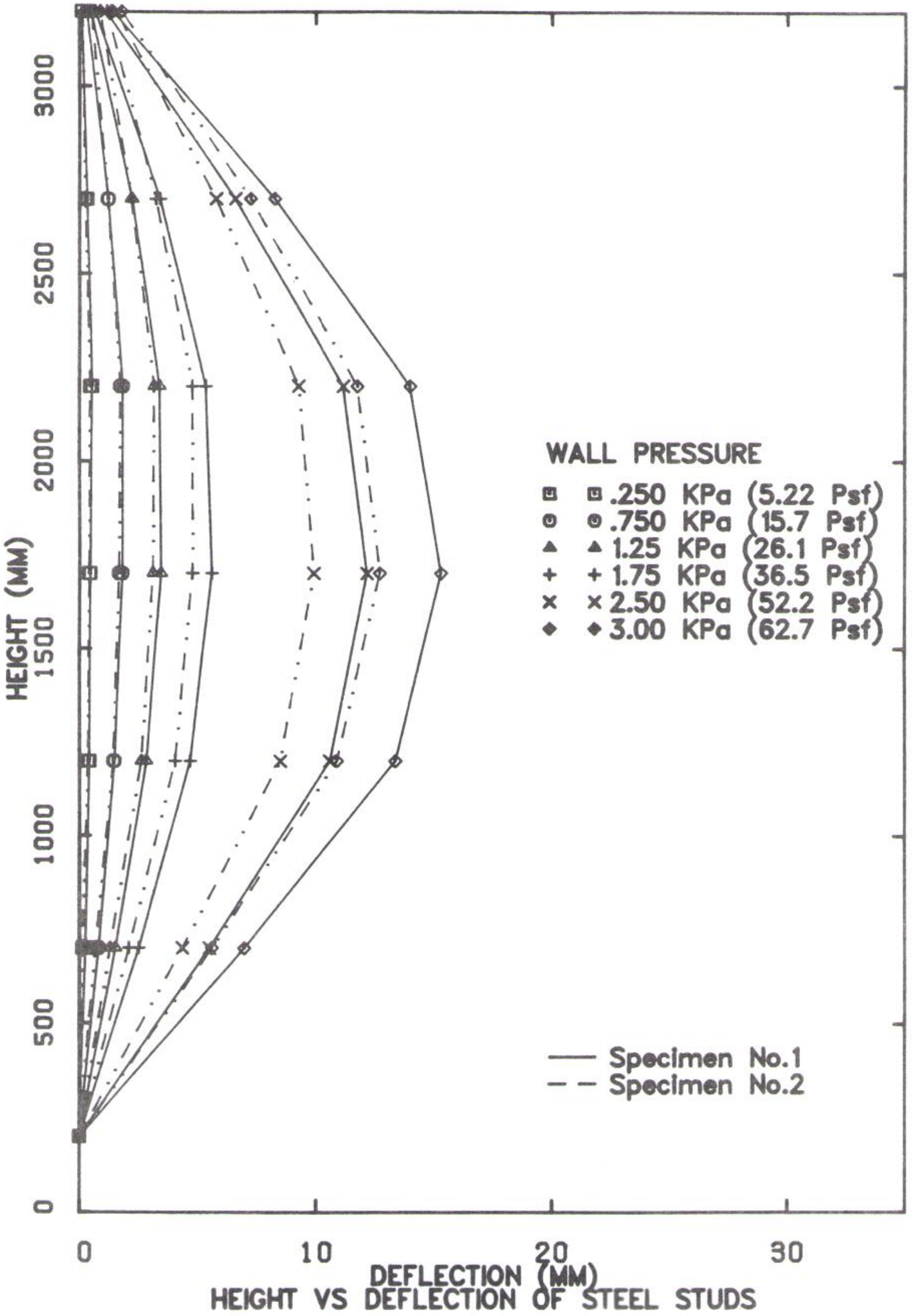
Full-sized Specimen



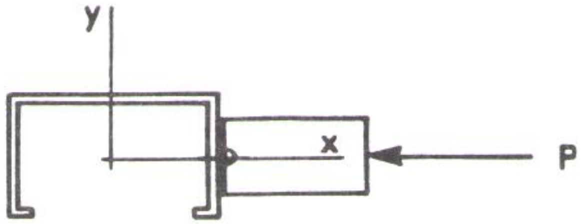
LOAD VS DEFLECTION OF THE TIE AND STUD SYSTEM



HEIGHT VS DEFELECTION OF BRICK VENEER

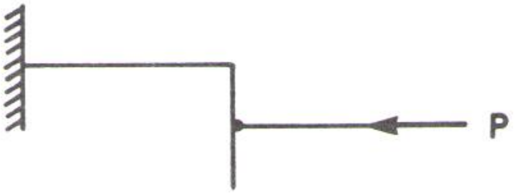


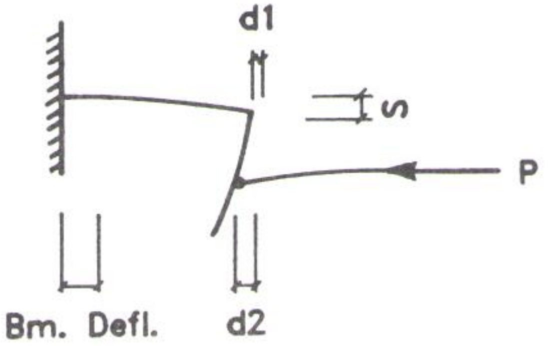
HEIGHT VS DEFLECTION OF STEEL STUDS



TYPICAL TIE AND STUD SYSTEM

SYSTEM MODEL





ACTION OF SYSTEM UNDER LOAD