

**RENOVATION STRATEGIES FOR  
BRICK VENEER STEEL STUD  
WALL CONSTRUCTION - TASK 4**

**Dinal Remedial Tie System**

Prepared for

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## **Part IX**

Canada Mortgage and Housing Corporation, the Federal Government's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban development and growth and development.

Under Part IX of the Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make available information that may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

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This study was conducted by the Building Engineering Group, University of Waterloo, for Canada Mortgage and Housing Corporation under Part IX of the National Housing Act. The analysis, interpretation, and recommendations are those of the consultants and do not necessarily reflect the views of Canada Mortgage and Housing Corporation or those divisions of the Corporation that assisted in the study and its publication.

# Executive Summary

## **Background**

Many buildings with brick-veneer, steel-stud enclosure walls have experienced or are experiencing problems. Repair is expensive and there is considerable uncertainty as to the level and extent of deterioration and damage, especially the corrosion of metal components. In many existing BV/SS wall systems, the condition and influence of the lateral ties between brickwork and steel studs are of primary concern.

Because of the importance of the long-term performance of lateral attachment between the brick veneer and the steel stud backup, a comprehensive research, development and demonstration program was developed. With funding and input from CMHC, an extensive program of work was initiated to develop various strategies for the remediation and, thus, the control or avoidance of problems in existing BV/SS wall systems. The various tasks and their related reports are:

**Task 1: Options for Remediation**

**Task 2: Four Remedial Tie Systems--Development and Conformance Testing**

**Task 3: Some Performance Considerations**

**Task 4: Dinal Remedial Tie System**

**Task 5: Summary Report**

The Dinal Tie is a proprietary product, developed in Canada, that became available after Tasks 1 and 2 of this program had already been completed. It was agreed that this tie system had retrofit potential and should be included in the overall program of work.

## **Objective**

The objective of Task 4 was to experimentally determine the structural capabilities of the Dinal tie to steel stud connection and then to develop likely design values. This report documents an experimental program to evaluate the capabilities of the Dinal retrofit tie system.

## **Test Program and Assessment**

A relatively comprehensive series of tests, for developmental as well as conformance purposes, was conducted. The Dinal tie was to be subjected to the same test program as the tie systems tested in Task 2 but, because of the experience gained in doing Task 2, it was possible to keep the number of tests down to a minimum. Note that Task 4 was not intended to replace or obviate the need for proper conformance testing of this tie.

Some 44 tests were made with a minimum of 5 identical tests in each series. Both tension (pullout) and compression (push -in) tests were conducted on two different setups; each test set-up had different degrees of stud restraint.

Service load considerations such as the effect of cyclic loading, the magnitude of the initial stiffness, and the contribution of secondary displacements (including the local deformation of the steel stud) have been quantified. Safety considerations such as ductility and structural integrity were also considered. Using the proposed and the later, issued, standard CSA A370, the structural characteristics of the Dinal tie connection have been evaluated.

### **Conclusions and Recommendations**

It needs to be acknowledged that the Dinal tie works well. It has potential for use as a retrofit tie with steel stud framing. Tentative service load design strengths are:

1.10 kN for 18 gauge and thicker stud

0.80 kN for 20 gauge stud

0.42 kN for 21 gauge stud

Minimum pullout stiffness values are also suggested. The most important recommendation is that this tie and all its metal parts should be made from stainless steel if it is to be sold as a remedial tie system for BV/SS walls.

## Résumé

### Contexte

De nombreux bâtiments comportant des murs à ossature d'acier et placage de brique ont connu ou connaissent des problèmes. Non seulement les réparations se révèlent-elles coûteuses, mais on ne peut pas établir avec certitude l'ampleur de la détérioration et des dommages, en particulier de la corrosion des composants métalliques. Dans de nombreux systèmes de murs existants à ossature d'acier et placage de brique, l'état et l'efficacité des attaches latérales raccordant la brique aux poteaux d'acier constituent vraiment un motif de préoccupation.

En raison de l'importance de la performance à long terme du raccordement latéral du placage de brique au mur de fond à ossature d'acier, un programme d'envergure de recherche, de développement et de démonstration a été lancé. Grâce au financement et à l'apport de la SCHL, un programme étendu de travaux a été entrepris dans le but d'élaborer différentes stratégies de réhabilitation et, par conséquent, de contrôler ou d'éviter la manifestation de problèmes dans de tels murs. Les cinq tâches connexes s'énoncent comme suit :

- Tâche 1 : Attaches de la brique - Options de réhabilitation
- Tâche 2 : Quatre systèmes d'attaches - Élaboration et essais de conformité
- Tâche 3 : Aspects de la performance
- Tâche 4 : Système d'attache Dinal
- Tâche 5 : Rapport sommaire

L'attache Dinal est un produit de marque déposée mis au point au Canada après l'exécution des Tâches 1 et 2 du programme de recherche. Il a été convenu que cette attache offrait des possibilités en réhabilitation et qu'elle devrait s'inscrire dans le programme général de recherche.

### Objectif

L'objectif de la Tâche 4 consistait à déterminer, par voie d'expériences, les capacités structurales du raccordement de l'attache Dinal aux poteaux d'acier, puis à établir des valeurs de calcul probables. Le présent rapport fait état du programme expérimental destiné à évaluer les capacités du système d'attache Dinal.

### Programme d'essai et évaluation

Une batterie de tests assez complets a été menée à des fins de développement et de conformité. L'attache Dinal devait être soumise au même programme d'essais que les systèmes d'attaches testés lors de la Tâche 2 mais, en raison de l'acquis obtenu en accomplissant la Tâche 2, il a été possible de réduire le nombre d'essais au minimum. À remarquer que la Tâche 4 ne devait pas se substituer ou obvier à la nécessité de soumettre cette attache à des essais de conformité appropriés.

Quelque 44 essais ont été effectués, avec au moins 5 tests identiques dans chacune des séries. Des essais en tension (arrachement) et en compression (enfouissement) ont porté sur deux assemblages différents, chacun ayant différents degrés de consolidation des poteaux.

L'effet des surcharges cycliques, l'importance de la rigidité d'origine et les déplacements secondaires (déformation locale des poteaux d'acier) devaient être quantifiés, tout comme il fallait tenir compte de considérations de sécurité telles la ductilité et de la solidité structurale. Les caractéristiques structurales du raccordement faisant appel à l'attache Dinal ont été établies à l'aide du projet de norme CSA A 370 et de la version publiée ultérieurement.

## **Conclusions et recommandations**

Il faut reconnaître que l'attache Dinal fonctionne bien. Elle offre des possibilités à titre d'attache de consolidation se prêtant à l'ossature d'acier. Les valeurs provisoires de calcul en service s'expriment comme suit :

- 1,10 kN pour le poteau d'épaisseur 18 et supérieure
- 0,80 kN pour le poteau d'épaisseur 20
- 0,42 kN pour le poteau d'épaisseur 21.

Des valeurs minimales de résistance à l'arrachement sont également proposées. La plus importante recommandation est que cette attache et tous ses composants métalliques doivent être fabriqués en acier inoxydable si elle doit être vendue à titre d'attache de consolidation des murs à ossature d'acier et placage de brique.



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This study is the fourth task in an extensive R&D project investigating strategies for the remediation of Brick Veneer/Steel Stud Systems for Canada Mortgage and Housing Corporation. We would like to thank Mr. Jacques Rousseau for initiating and managing this unique project - unique in that it required the collaboration of government, a university, a number of consultants, and numerous companies involved in the brick masonry business.

We would like to thank Ms. Ellen Hall from Dinal Inc. for supplying us with the Dinal brick ties and providing their specialized tools for retrofit tie installation.

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# 1. Introduction

## 1.1 Background

Over the years, the performance of clay-brick-veneer /steel-stud (BV/SS) enclosure systems (Figure 1.1) for multi-storey residential buildings has received a great deal of attention. Many buildings of BV/SS construction have experienced or are experiencing problems. Repair is expensive, and there is considerable uncertainty as to the level and extent of deterioration and damage, especially the corrosion of metal components (i.e., the ties, the stud system and self tapping screws). Therefore, it is difficult to decide on the form and extent of remedial action. If legal action is involved, there is considerable pressure to prescribe a conservative, and thus relatively expensive, solution. There is also the question of knowing what to do about those BV/SS walls that have yet to exhibit a visible problem but are known to be vulnerable and likely to experience problems.

In many existing BV/SS wall systems, the condition and influence of the lateral ties between brickwork and steel studs are of primary concern. In practice, one or more of the following have occurred:

- ties may have been omitted or incorrectly spaced,
- the wrong type of tie may have been used,
- the tie is corroding or likely to corrode and/or
- the tie may have been incorrectly installed.

Because of the importance of the long term performance of lateral attachment between the brick veneer and the steel stud backup, a comprehensive research, development and demonstration program was developed. With funding and input from CMHC, an extensive program was initiated to develop various strategies for the remediation and, thus, the control or avoidance of problems in existing BV/SS wall systems. A number of tasks were formulated:

**Task 1: Brick Ties - Options for Remediation**

**Task 2: Four Remedial Tie Systems--Development and Conformance Testing**

**Task 3: Some Performance Considerations**

**Task 4: Dinal Remedial Tie System**

**Task 5: Summary Report**

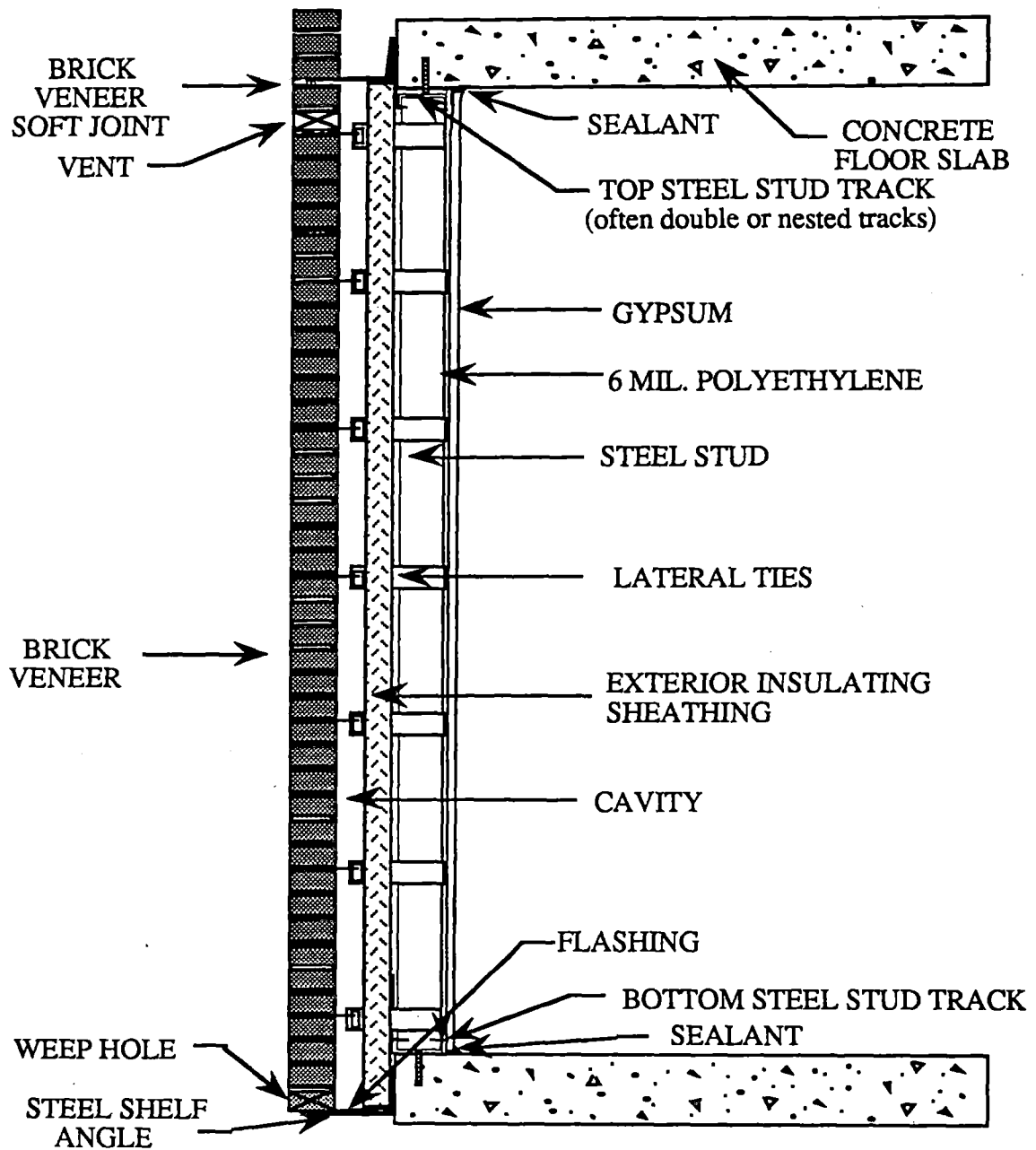


Figure 1.1: Cross-section of a Typical BV/SS Wall

Task 1 has been completed and is documented in the CMHC report entitled “Task 1 : Brick Ties - Options for Remediation.” The main objective of the first task of the research study was to identify, demonstrate, assess and document methods of providing supplemental ties on BV/SS buildings. Of the 11 remedial strategies considered, 7 tie systems were exterior installations and 4 were interior approaches.

Task 2 has also been completed. The report is entitled “Task 2 : Four Remedial Tie Systems -- Development and Conformance Testing.” This task involved a test program to establish and document the structural performance of four retrofit tie systems; two were interior fixes and two were exterior fixes.

Task 3, entitled “Task 3 : Some Performance Considerations” was completed in April 1994. This task was to test and/or assess the likely performance of BV/SS walls after remediation with particular regard to temperature, air leakage, drainage, corrosion and the stiffness of the framing.

Task 4 involved the testing of the Dinal tie system. The Dinal Tie is a proprietary product, developed in Canada, that became available after Tasks 1 and 2 of the program had already been completed. It was agreed that this tie system had retrofit potential and should be included in the program of work. Accordingly a relatively comprehensive series of tests, for developmental as well as conformance purposes, was proposed. The report that follows documents the experimental program to evaluate the capabilities of the Dinal retrofit tie system. This report is a supplement to the Task 2 report.

## **1.2 Objectives**

This project (Task 4) involves the physical testing of the Dinal tie, primarily its use as a retrofit or remedial tie. The objectives are to test and assess the capabilities of this exterior retrofit tie system and to identify and apply the relevant performance requirements.

## **1.3 Approach and Scope**

Consistent with the testing done in Task 2, a program of laboratory testing was conducted. Service load considerations such as the effect of cyclic loading, the magnitude of the initial stiffness, and the contribution of secondary displacements (the local deformation of the steel stud) were quantified. Safety considerations such as ductility and structural integrity were also taken into account.

The retrofit Dinal tie system is described in Chapter 2. The experimental test program is discussed in Chapter 3. Chapters 4 and 5 present the test results, their analysis, and a discussion of their significance. Chapter 6 documents conclusions and recommendations.

## **2. The Dinal Tie**

### **2.1 Description**

The Dinal tie, designed to laterally attach brick veneer to steel stud, was developed in response to the failure of some brick tie systems. Photo 2.1 shows the Dinal tie both assembled and disassembled. The Dinal tie uses a 3/16" galvanized, threaded steel rod with a collapsible fastener. This provides the attachment to the steel stud. An expandable rubber seal, within the exterior sheathing, provides resistance to water and air leakage. A BV/SS wall employing the Dinal tie as an externally applied remedial connector is illustrated in Figure 2.1. Photo 2.2 shows the Dinal tie attached to the steel stud during a tension test.

### **2.2 Installation**

The Dinal tie can be installed through the existing masonry veneer and attached to the steel stud backup without removing any existing veneer. Specialized tools, designed by Dinal Inc., are needed for installing the retrofit tie. The specialized drill bit, 0.5" in diameter and 9" long, has a 3/8" diameter tip that is 0.5" long. The Molly Nut Wrench and Collapser is a long, threaded extension rod that has the same diameter as the Dinal tie rod. It is used to collapse the Molly Nut.

The procedure, as provided by Dinal Inc., for installing the Dinal tie to existing BV/SS construction is as follows:

1. Drill a 0.5" diameter hole through the horizontal mortar joint of the veneer directly in line with the steel stud backup.
2. Using the specialized drill bit, insert the bit through the hole previously drilled through the mortar, and drill a 1/2" diameter hole through the exterior drywall, and a 3/8" diameter hole through the steel stud.
3. Screw the Molly Nut (stud clamping member) onto the exposed end of the threaded rod of the setting tool (Molly Nut wrench-and-collapser) until it is tight against the steel teeth.
4. Insert the setting tool into the pre-drilled holes until the clamping member stops at the face of the steel stud.
5. Collapse the Molly Nut by turning the handle of the setting tool clockwise until resistance is encountered, indicating that the Molly Nut is completely collapsed. Withdraw the tool

6. Insert tie, complete with all pieces, into the hole with fingers and begin threading it into the collapsed Molly Nut. With the specialized socket and ratchet, or socket and drill, turn the tie until it is snug.
7. Epoxy gel the portion of threaded rod within the brick depth. Allow space for re-pointed mortar at outside face.
8. Re-point mortar.

In the tests that follow, we are concerned only with the tie-stud connection and its likely contribution to performance. Numerous remedial systems utilize forms of resin bonding, and throughout Task 4, as well as Task 2, the steel stud-tie connection was considered to be the critical attachment.



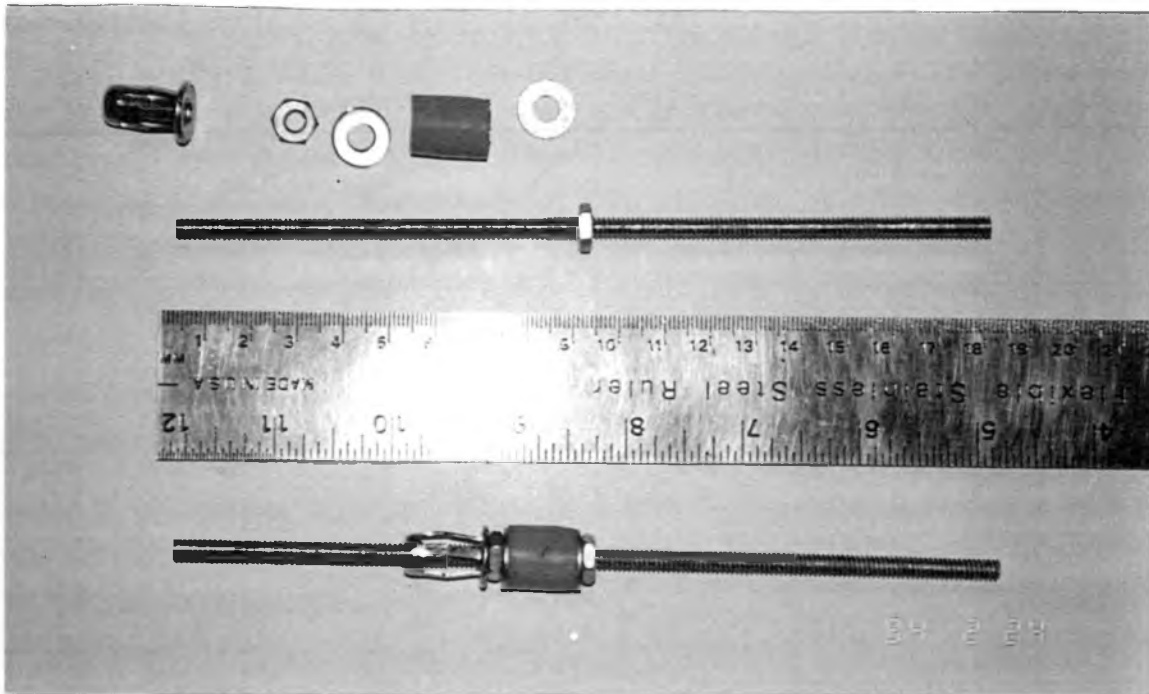


Photo 2.1 : Dinal Tie

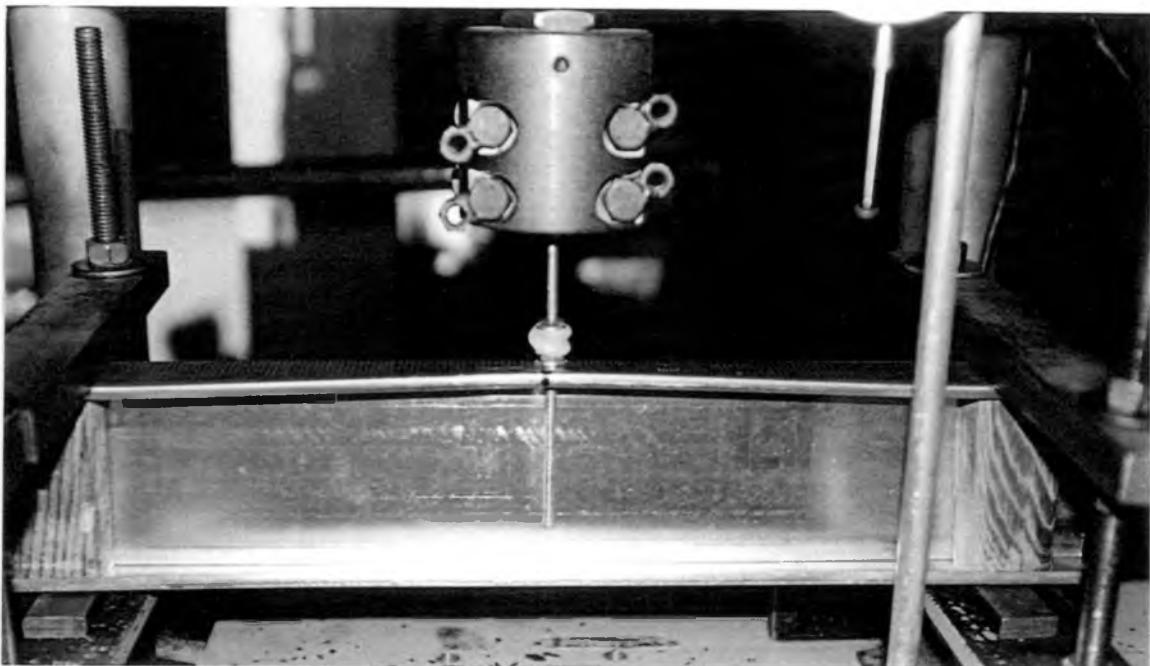


Photo 2.2 : Dinal Tie Installed in Steel Stud

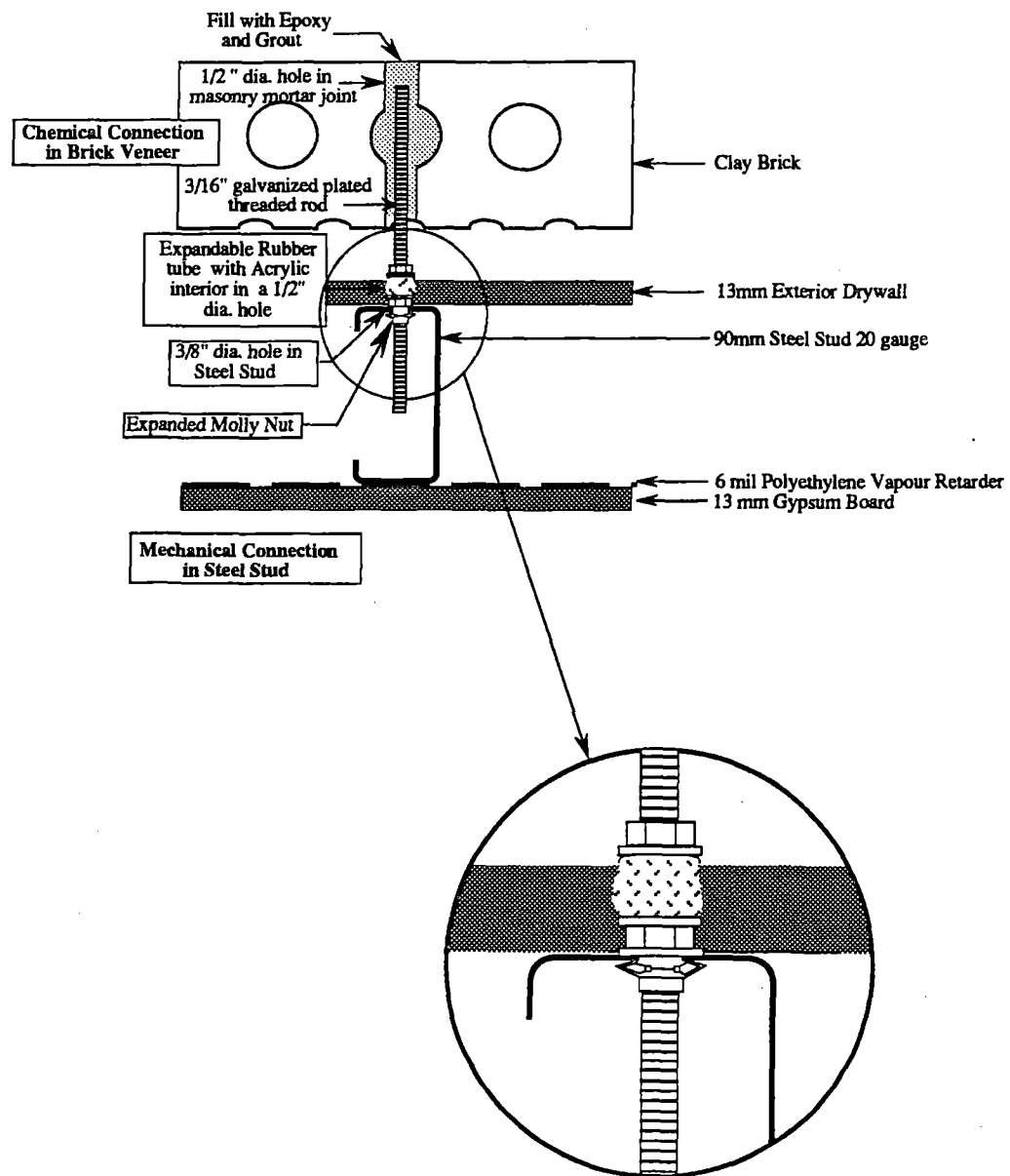


Figure 2.1 : Dinal Exterior Tie in a BV/SS System

### **3. Experimental Test Program**

#### **3.1 Introduction**

The type and number of tests to be performed on the Dinal tie system were determined by evaluating the results of Task 2. To establish the appropriate minimum number of tests, a decision tree was used incorporating the type of failure and the effects of cyclic loading (Figure 3.1).

#### **3.2 Test Setup and Procedure**

Figure 3.2 illustrates the test setup for both the beam and isolation test used in this test program. The beam test setup can also be seen in Photo 2.2. In the beam test the likely influence of the stud - both flange and web movement - is incorporated. The isolation test eliminates the beam displacement and most of the flange rotation.

Tests were conducted in a MTS electro-hydraulic test facility at the University of Waterloo. For the tension and compression tests, the ties were loaded under stroke control at a rate of approximately 6mm/min. An X-Y plotter was used to record the load and displacement values during each test.

For the tests with cyclic pre-conditioning, a sinusoidal loading with an amplitude of 0.15kN (0.33Lbf) tension and 0.15 kN compression was applied for 1,000 cycles at 1.0 Hz. The specimen was then failed under stroke-controlled monotonic loading. During the load cycling, as well as the test to failure, the displacement was recorded.

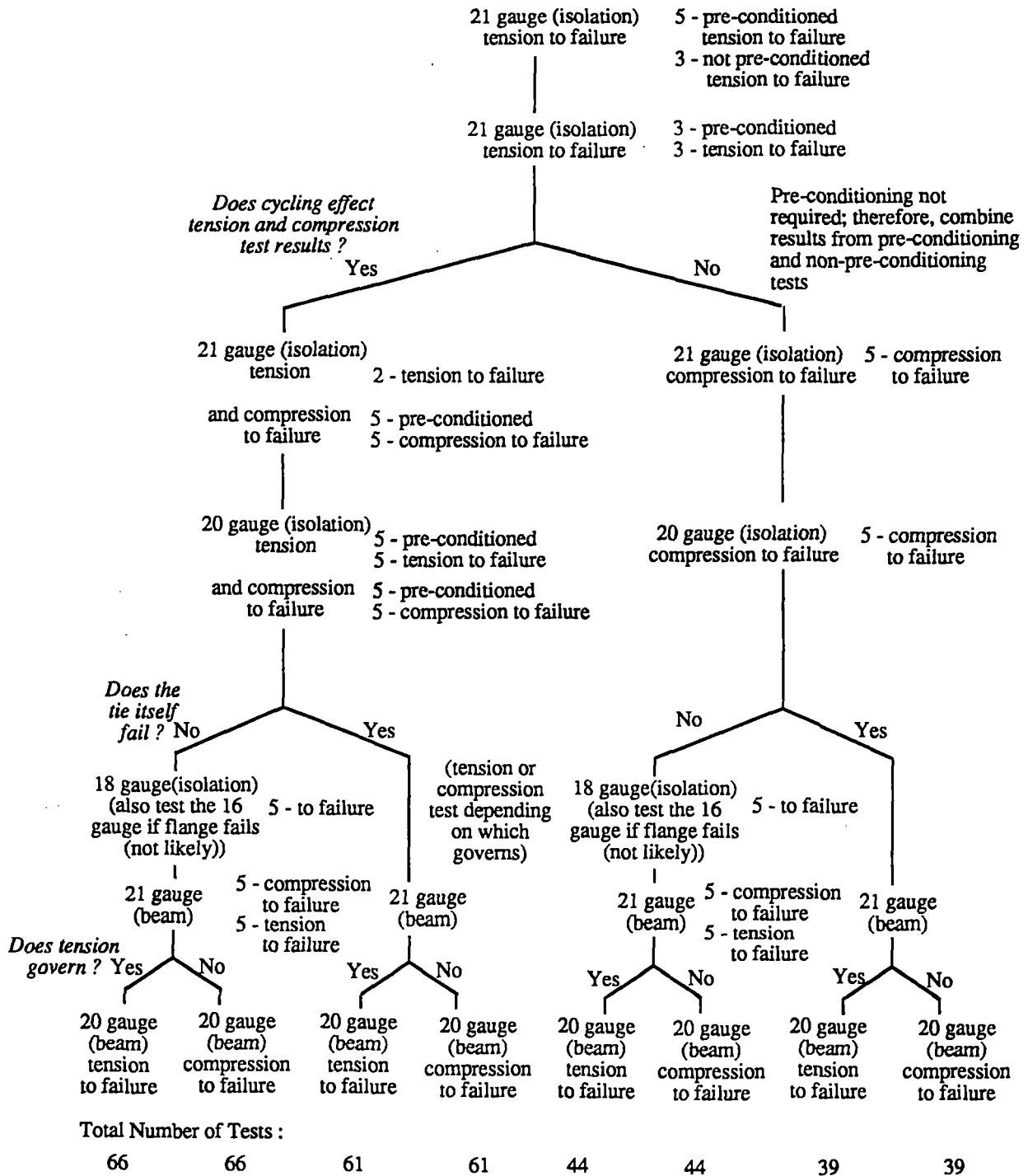
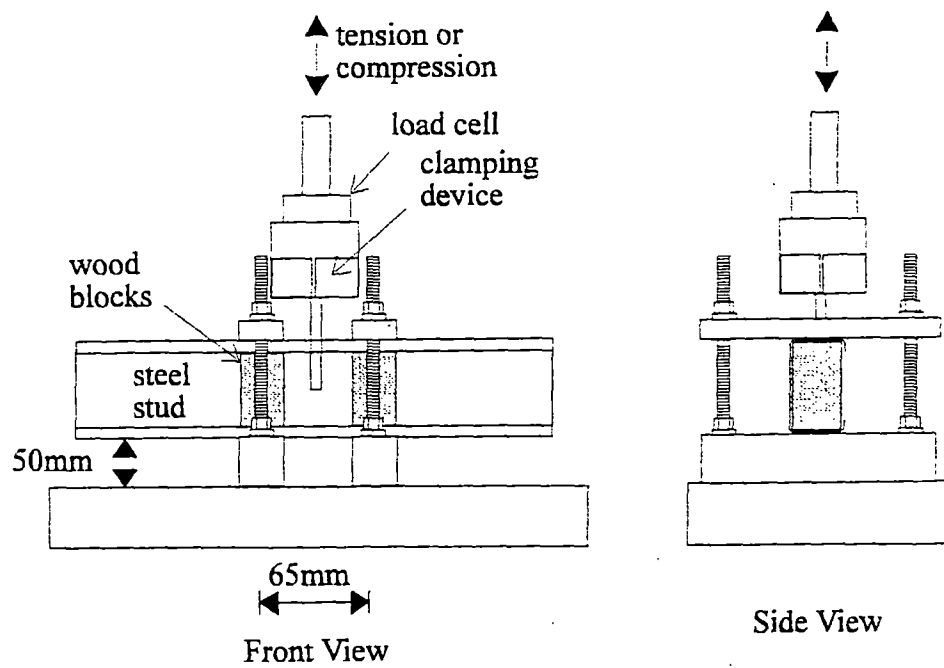
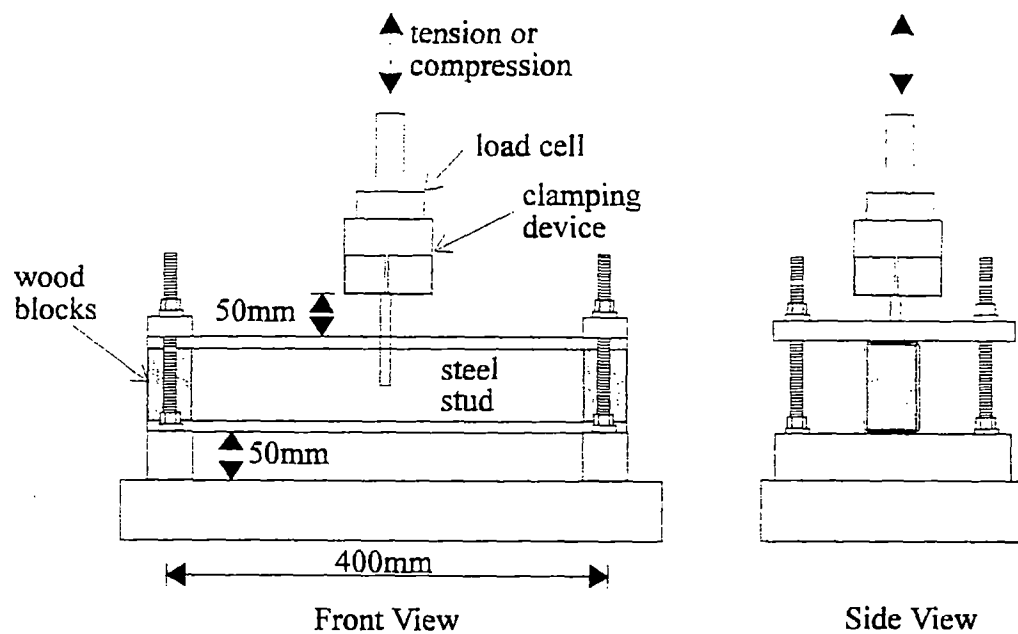


Figure 3.1: Decision Tree

**Isolation Test****Beam Test****Figure 3.2: Test Setup**

### 3.3 Test Program

To preserve consistency with Task 2, the following code was used to describe each test conducted:

**Tie Type - Test Setup - Gauge of Stud (18, 20, 21) - Test Number**  
(e.g., Test D-2-20-1).

The code letter for the Dinal tie is a 'D.' Table 3.1 identifies the code used for each test series.

Test Series	Test Setup	Test Type
1a	Isolation	Tension - Varying Gauge
1b	Isolation	Compression - Varying Gauge
1c	Isolation	Cyclic Pre-Conditioning - Tension to Failure
1d	Isolation	Cyclic Pre-Conditioning - Compression to Failure
2	Beam	Tension - Varying Gauge
3	Beam	Tension - Varying Attachment Location
4	Beam	Compression - Varying Gauge
5	Beam	Cyclic Pre-Conditioning - Tension to Failure
6	Beam	Cyclic Pre-Conditioning - Compression to Failure

**Table 3.1: Code for each Test Series**

Three different gauges of steel stud (18, 20 and 21) were used in this test program. Table 3.2 lists the key dimensions for all different sizes of steel stud in the overall project.

Gauge	Thickness (inches)	Thickness (mm)	Overall web height (mm)	Overall flange width (mm)
16	0.060	1.52	92	41
18	0.048	1.22	92	41
20	0.036	0.91	92	41
21	0.033	0.88	92	31

**Table 3.2 : Description of Steel Studs**

### 3.4 Rigid Datum Performance

The rigid datum tests that were performed in Task 2 quantified the deflection and flange rotation capabilities of the steel stud. The rigid datum connection was developed in an attempt to isolate the deformation that occurred in a beam test due to the steel stud alone. The rigid datum connection involved a 6mm diameter threaded rod that was bolted securely to one flange. The testing of this situation in compression and under tension with cyclic pre-conditioning established how the steel stud deformed under load in each beam setup, i.e., no tie deformation was involved.

In Table 3.3 relevant results from Task 2 are summarized, i.e., for beam tests conducted on the rigid datum through the exterior flange connection only. These test results quantify the stiffness and deformational characteristics of the steel stud alone in a standard beam test.

1000 cycles of  $\pm 0.15$  kN cyclic pre-conditioning were conducted on the rigid datum tension tests. It was found that cyclic preconditioning did not have a significant effect on the final performance of the rigid datum test. Therefore, no pre-conditioning was applied in the compression tests.

## a) Load and Displacement Values

Test Series	Number of Tests	Gauge	Load at 1mm (kN)	Load at 2mm (kN)	Displ. at 0.45 kN (mm)
5	2	16	1.51	2.55	0.25
5	2	18	0.80	1.39	0.55
5	3	20	0.42	0.75	1.10
5	3	21	0.34	0.52	1.60
4	1	20	0.36	0.65	1.3
4	1	21	0.37	0.54	1.4

## b) Equivalent Stiffness Values

Test Series	Number of Tests	Gauge	Stiffness based on Load at 1mm (N/mm)	Stiffness based on Load at 2mm (N/mm)	Stiffness based on Displacement at 0.45 kN (N/mm)
5	2	16	1510	1275	1800
5	2	18	800	695	818
5	3	20	420	375	409
5	3	21	340	260	281
4	1	20	360	325	346
4	1	21	370	270	321

Table 3.3: Rigid Datum Results (through one Flange) [1]

Test Series 5 - tension, cyclic pre-conditioning

Test Series 4 - compression, no cyclic pre-conditioning



With reference to the 'tie - in - tension' test results, it is clearly evident that as the stud thickness decreases (or gauge increases), there is a corresponding decrease in stiffness and thus strength at the various serviceability target levels (e.g., 1mm and 2mm deformation and at a load of 0.45 kN).

Only one test in compression was conducted for each of the 20 and 21 gauge studs. Figure 3.3 shows the characteristic curves in compression for each gauge superimposed on the tension characteristic curves. The initial stiffness is almost the same for tension and compression loading. At higher load levels, the flange of the stud tends to become more flexible in compression. This is even more pronounced for the 21 gauge.

It should be noted that, whereas the 16, 18 and 20 gauge studs have essentially the same configuration, the 21 gauge stud supplied for this project in lieu of a 22 gauge stud (not manufactured) was slightly different. The 21 gauge stud has a crimped web. Its cross-section is similar to that of an interior stud rather than an exterior stud. This may account for the fact that, unlike the 20 gauge stud, the 21 gauge stud seems to be stiffer in compression than in tension. This anomaly is not significant as the actual tie systems are generally critical in tension and not in compression. It was for this reason that compression tests were only done on the Dinal tie connected to the 20 and 21 gauge studs.

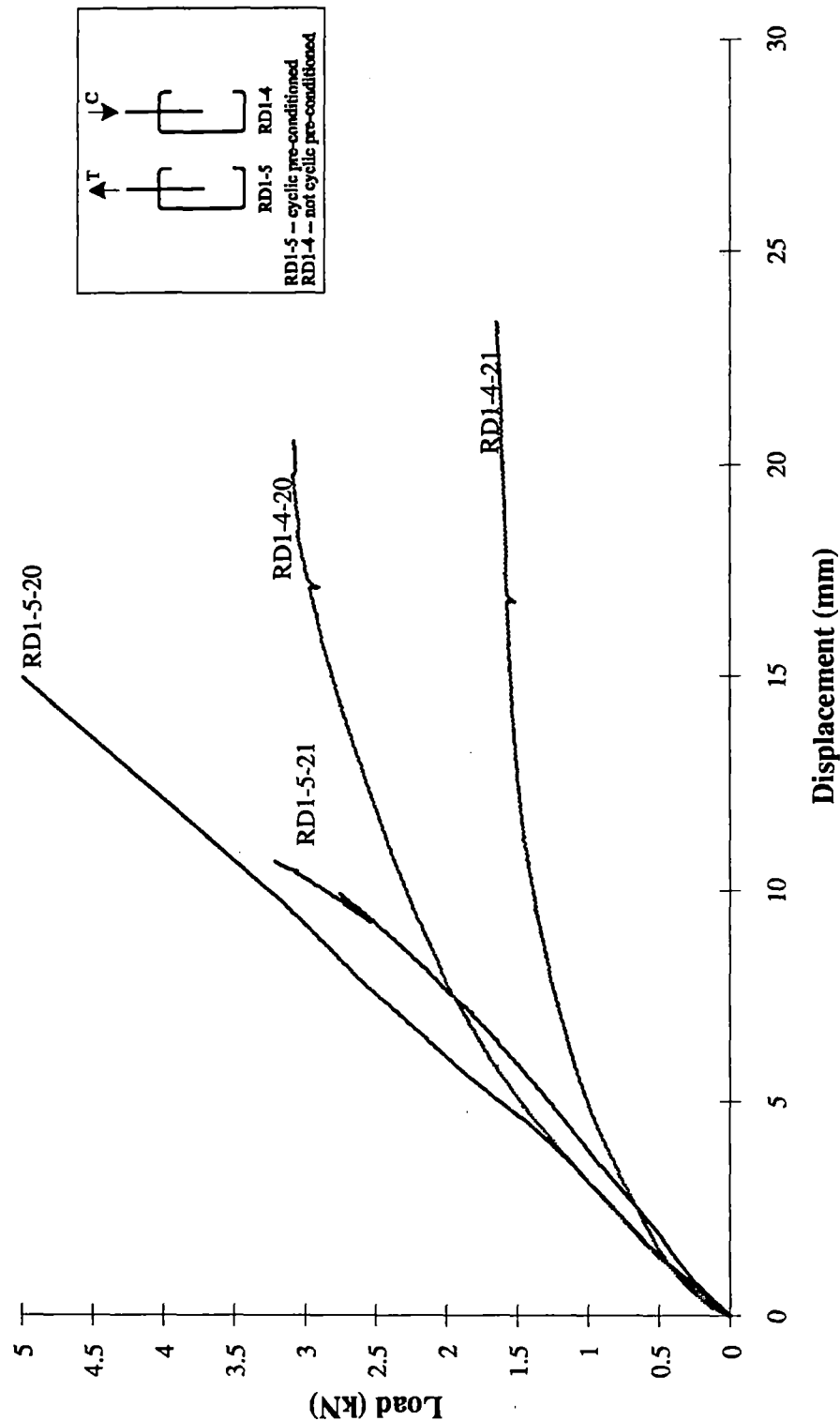


Figure 3.3 Characteristic Curves for Rigid Datum

## 4 Test Results

### 4.1 Organization of Test Results

The flow path outlined on the decision tree in Figure 4.1 illustrates the rationale for and the ordering of the tests that were performed on the Dinal tie system.

Figure 4.2 is a representative load-versus-displacement graph. The performance of the Dinal tie in tension can be characterized by an initial, relatively steep linear relationship; followed by a second linear, but less stiff phase; then non-linear response up to a maximum (M); and subsequently, under stroke control, to full unloading. The following are reported: the coordinates of the various behavioural stages, e.g., the proportional and maximum limit and the displacement at zero capacity. The point where performance initially deviates from linearity is characterized as the proportional limit (P).

The results for each Dinal test are presented in detail in Appendix A. Relevant data, such as the displacement at 0.45kN, the load at displacements of 1 and 2mm, the proportional limit load ( $P_p$ ) and corresponding displacement ( $D_p$ ), the maximum load ( $P_m$ ) and corresponding displacement ( $D_m$ ), are listed in the detailed tables and the summary tables in Appendix A and B respectively.

Table 4.1(a) is a summary of the average values from each test series, and Table 4.1(b) lists corresponding equivalent stiffness values. Separate test results for the cyclically pre-conditioned tests are not presented, because pre-conditioning did not appear to have any significant or consistent effect for the Dinal tie system, i.e., variations were well within a single standard deviation (Appendix A). Therefore, test results were combined with those from the non-pre-conditioned tests to provide one set of values for each test series.

The performance of the Dinal tie is discussed under the following headings:

- Tension versus Compression
- Isolation versus Beam Tests
- Displacement at Maximum Load and Zero Load
- In-Service Stiffness
- Influence of the Stud.

The significance of the test results and the various design considerations are discussed in Chapter 5.

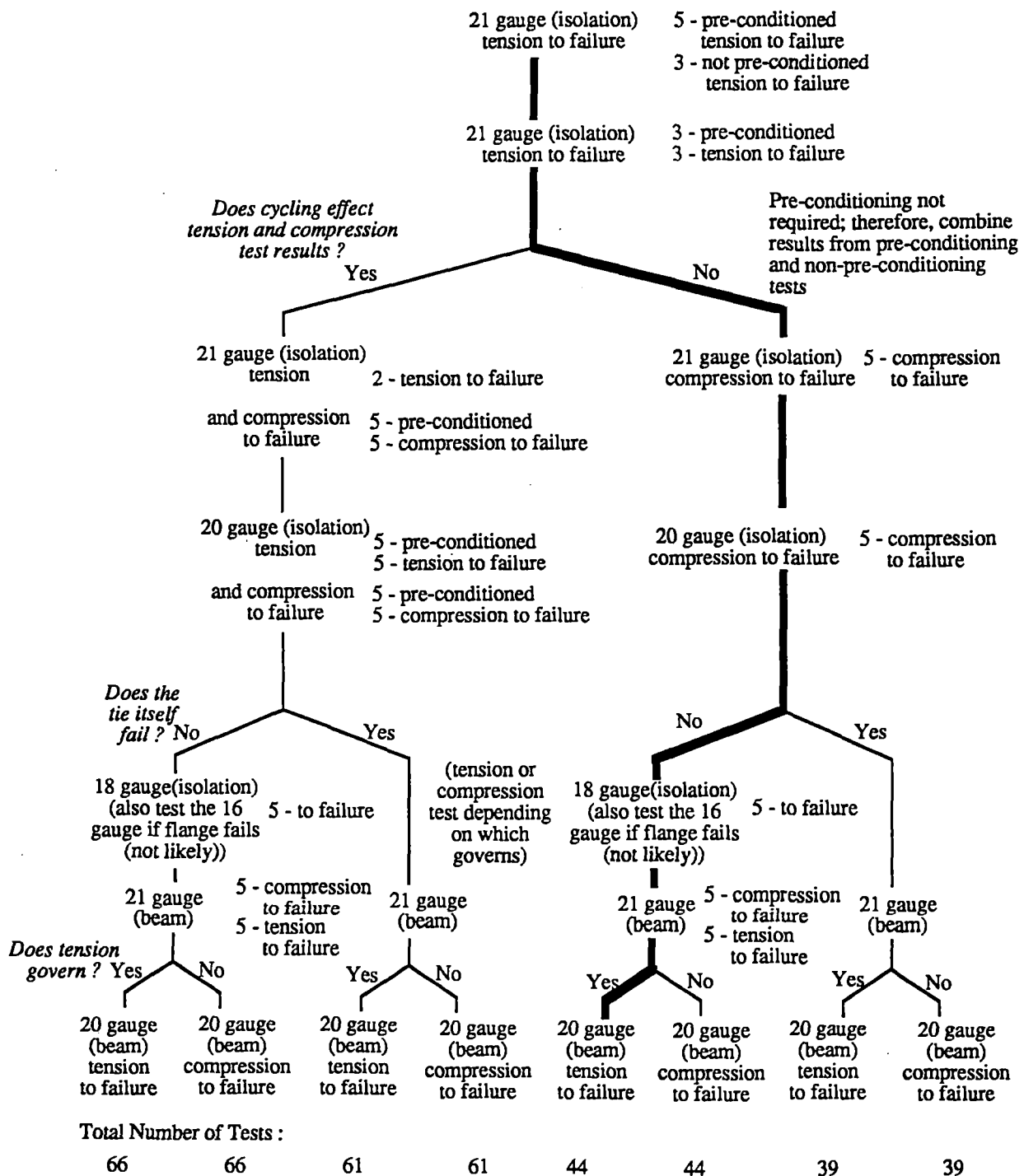


Figure 4.1: Flow Path for the Testing Program

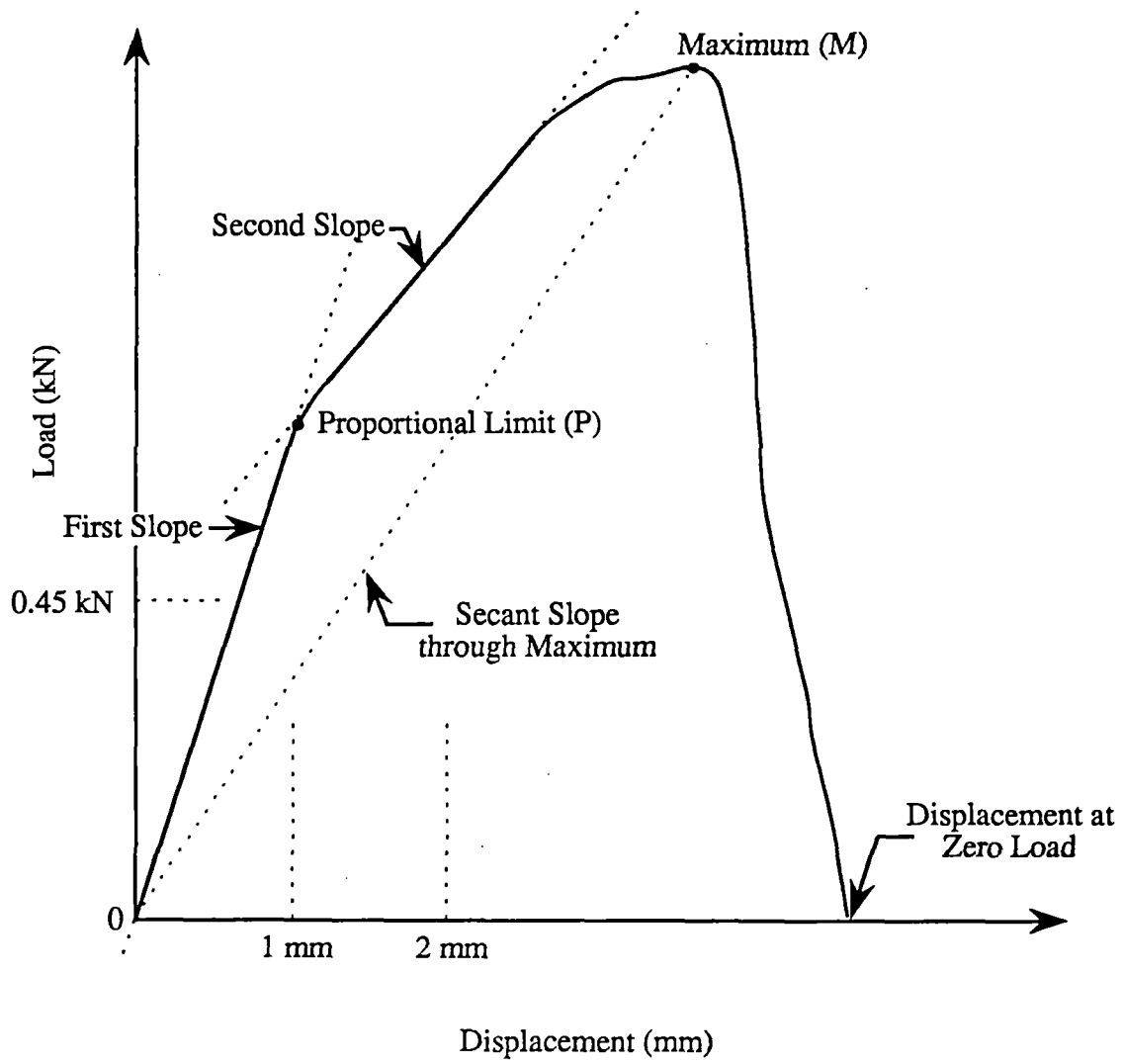


Figure 4.2: Representative Load versus Displacement Curve

Gauge	Test Type	N	Displ. at 0.45 kN (mm)	Load at 1.0mm (kN)	Load at 2.0mm (kN)	At Proportional Limit		At Maximum		Displ. at 0.0kN (mm)	Pm/Pp	Dm/Dp
						Load Pp (kN)	Displ. Dp (mm)	Load Pm (kN)	Displ. Dm (mm)			
18	Tension Isolation Test	5	0.21	1.45	2.05	1.35	0.88	3.01	4.42	5.22	2.23	5.02
20		6	0.36	0.96	1.52	0.99	1.00	2.64	5.59	11.43	2.67	5.59
21		8	0.51	0.62	0.90	0.48	0.58	2.09	6.86	12.45	4.35	11.83
20	Compression Isolation Test	5	0.38	0.94	1.65	1.08	1.22	3.67	6.34	8.90	3.40	5.20
21		5	0.49	0.75	1.25	0.58	0.72	2.69	6.50	8.78	4.64	9.03
20	Tension Test Beam Test	5	0.89	0.50	0.87	0.79	1.76	2.46	11.16	13.34	3.11	6.34
21		5	1.44	0.38	0.55	0.37	0.94	1.64	12.64	19.18	4.43	13.45
21	Compression Test Beam Test	5	1.42	0.36	0.55	0.38	1.06	>1.84	>20.60	*	N.A.	N.A.

(a)

Gauge	Test Type	Equivalent Stiffness Based on Secant Values					Initial Tangent Slope (N/mm)	Second Tangent Slope (N/mm)
		Displ. at 0.45 kN (N/mm)	Load at 1 mm (N/mm)	Load at 2 mm (N/mm)	the Proportional Limit (N/mm)	Maximum Load (N/mm)		
18	Tension Isolation Test	2143	1450	1025	1534	680	1570	520
20		1250	960	760	990	470	1020	490
21		882	620	450	828	300	870	320
20	Compression Isolation Test	1184	940	825	885	580	920	640
21		918	750	625	806	410	940	470
20	Tension Test Beam Test	506	500	435	449	220	460	190
21		313	380	275	394	130	420	120
21	Compression Test Beam Test	317	360	275	358	*	370	**

N - Number of Tests

(b)

\* Tie hit bottom flange and the test was not taken to zero load

\*\* A pronounced second slope was not achieved

Shaded values indicate co-ordinates which occur after the proportional limit (P).

Table 4.1 : Dinal Tie Results

## 4.2 Tension versus Compression

Both in tension and in compression the Dinal tie has two distinct phases of linear response followed by non-linear flattening. In compression the tie, after significant displacement, will make contact with the bottom flange, causing the tie to fail by buckling. In tension, after significant displacement, either the tie or the flange fails abruptly.

With regard to strength, it is clearly evident that the tension situation is critical at both the proportional limit and at the maximum. Tension or pullout is critical for both the isolation as well as the beam test setup. It was for this reason that more ties were tested in tension than in compression. The beam test consistently gave lower load values than the isolation test, indicating that the overall deformation of the stud does affect the capacity of the tie.

## 4.3 Isolation versus Beam Test

The tie system was inherently stiffer in the isolation tests than in the beam tests for the tie in either tension or compression. The ratios of the beam results relative to the isolation test results for the loads, displacements and various slopes are presented in Table 4.2. Clearly the response of the tie is affected by the lack of deformational restraint in the case of the weaker or thinner studs. It is evident that the thinner the stud, the greater the consequence for the tie connection. As it appeared that the maximum and proportional load values from the isolation test on the 16 and 18 gauge studs would be close to the values from the beam test, only the 20 and 21 gauge studs were tested under the beam test setup.

Test Type	Gauge	At Proportional Limit		At Maximum		First Slope	Second Slope
		Load	Displ.	Load	Displ.		
Tension	20	0.80	1.76	0.93	2.00	0.45	0.39
	21	0.77	1.62	0.78	1.84	0.48	0.38
Compression	21	0.66	1.47	>0.68	>3.17	0.39	

**Table 4.2: Ratio of Beam Test to Isolation Test Results**

#### 4.4 Displacement at Maximum Load and Zero Load

Values for the displacement at maximum load and then the subsequent zero load are listed in Table 4.1. As expected, the displacements at both maximum load and zero load in the beam tests are much larger than the values obtained in the isolation tests. A value for the zero load displacements has not been recorded for the beam tests with the tie in compression because the tie impacted the bottom flange; at which point the test was terminated. In general the displacements were larger for the beam tests with the tie in compression than for the tie in tension.

#### 4.5 In - Service Stiffness

The likely in-service performance of the Dinal tie - to - stud connection can best be described in terms of a single stiffness value and the co-ordinates of the proportional limit. Under service load, linear elastic response is desirable in order to ensure repeatable, calculable and acceptable performance. Various equivalent stiffnesses can be defined; we have considered the following different ways of defining stiffness:

Secant Values through:      0.45 kN  
                                         1 mm displacement  
                                         2 mm displacement  
                                         proportional limit  
                                         maximum load

Tangential Values:      slope of first or initial linear stage  
                                         slope of second linear stage

Note that in Table 4.1 the proportional limit load,  $P_p$ , is generally less than that at 2mm and, in many instances, less than that at 1mm displacement. It follows that these stiffness values should not be used to describe the equivalent in-service response. The stiffness values that cannot be used are shaded in Table 4.1.

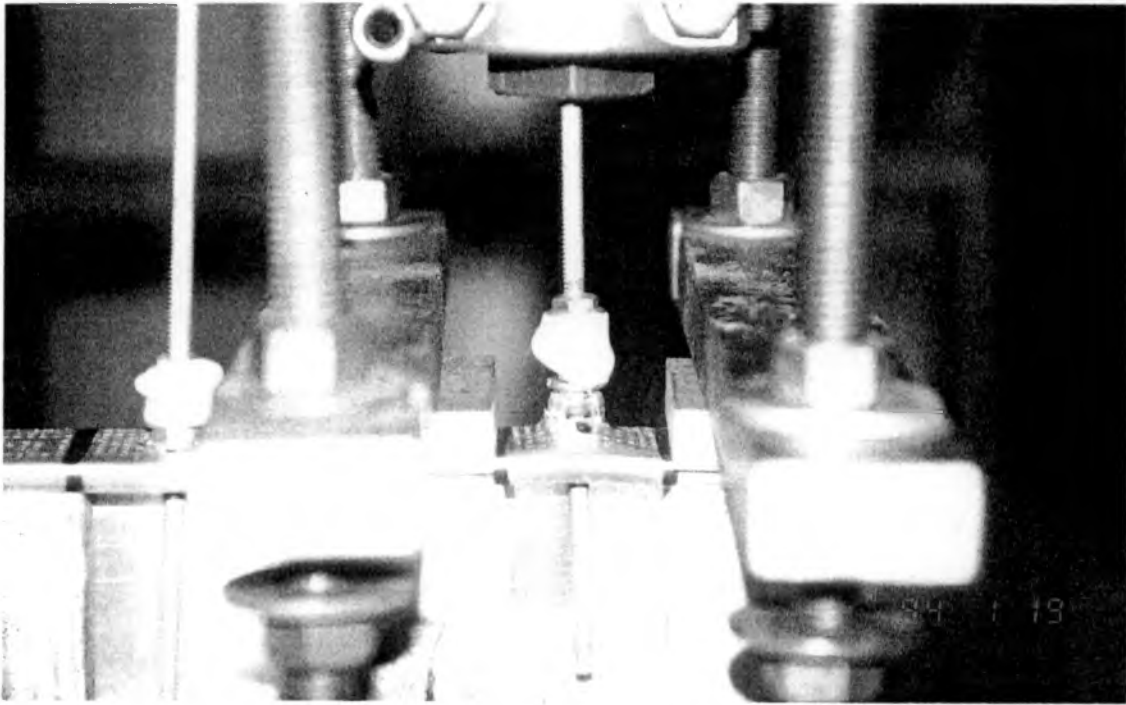
The stiffness values based on the 0.45 kN load are high for the isolation tests because 0.45 kN occurs well before the proportional limit. This is not always the case for the beam test.



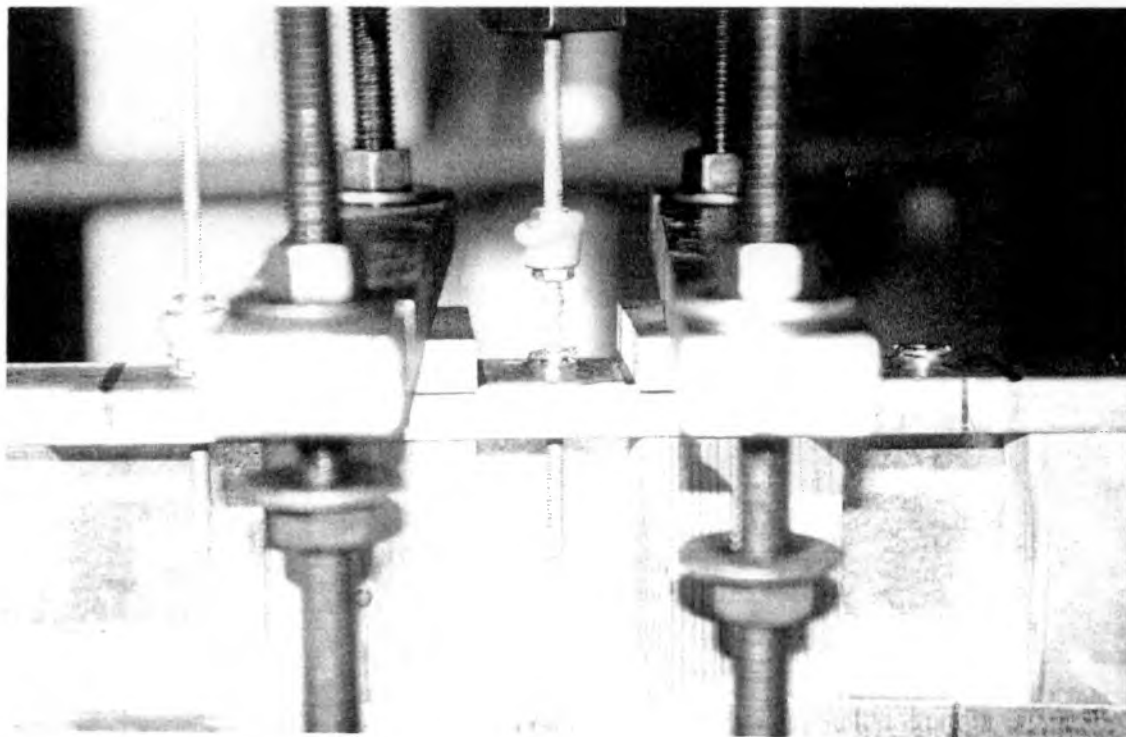
#### **4.6 Influence of the Stud**

The mode of failure in tension was different for the different stud thicknesses. For the 21 gauge application, the flange failed with considerable bending of the expandable Molly Nut (Photo 4.1). There were two failure modes for the 20 gauge application. The flange failed in most tests and only in one case did the Molly Nut fail. Therefore, the 20 gauge stud comprised the limiting thickness to ensure flange failure. This was confirmed by testing the 18 gauge stud. In all 18 gauge applications, the Molly Nut failed in shear (Photo 4.2).

The strength and equivalent initial stiffnesses of the Dinal tie increased with stud thickness both in tension and compression (Table 4.1). However for stud thicknesses greater than 18 gauge, it is likely that the maximum tension strength would be comparable to the 18 gauge value.



**Photo 4.1 : Flange Failure in Isolation Test**



**Photo 4.2 : Tie Failure in Isolation Test**

## 5. Interpretation of Test Results

### 5.1 Overall Response and the Nature of Failure

The general nature of the performance of the Dinal tie in the steel stud is discussed first, followed by a discussion of structural serviceability and structural safety.

The manner in which a tie fails is important, as it gives an indication of the likely behaviour of the interconnected wall system under a lateral load. However, the nature of the applied load is just as important. For instance, tie requirements to accommodate normal wind load are fundamentally different from the requirements to accommodate seismic or abnormal load such as explosion or airplane-induced overpressure (sonic boom).

If a connection is required to undergo large displacements due to accidental or abnormal loadings, such as an earthquake, impact or explosion, it is important for the designer to know the potential for deformability and for sustained strength at large displacements. In addition, the ability to absorb or shed energy and avoid restraint-induced loads is a very important attribute. When a masonry tie connection fails in a brittle manner, not only has irreversible damage occurred but its function has been destroyed and may induce failure or detachment of one or more units. Ductile, energy-absorbing connections are, for example, highly advantageous for the retrofit of masonry in seismic areas. The ability of the connection system to accommodate abnormal or accidental loads without causing a safety hazard or initiating a progressive form of failure is of benefit. This characteristic preserves human safety and permits later repair.

The initial stiffnesses of the Dinal tie assemblies are similar to that for the rigid datum where all the movement is due to stud displacement and rotation. The point at which the initial stiffness decreases is labeled the proportional limit, in spite of the fact that the subsequent slope in the load versus displacement graph (see Figure 4.2) is relatively linear. During testing we did not observe any obvious cause for the reduction in stiffness at the proportional limit. The reduction in stiffness may have been due to the initial deformation of the Molly Nut. After the proportional limit, the response of the Dinal tie under continuing incremental load in tension is quite ductile in that deformations are relatively large. In compression, the tie performs in a manner that is similar to the rigid datum until the tie hits the bottom flange, at which point the strength increases. Therefore, tension (pullout) rather than compression (push-in) is the critical loading.

## 5.2 Structural Serviceability

Before turning to the practical implications of the performance of the Dinal tie, it is important to consider how the steel stud deforms. For instance, neither the isolation nor the beam test correctly models all likely situations. The rigid datum tests provide the deformational characteristics for the steel stud alone in a beam test. Figure 5.1 illustrates the deformations that can occur due to the steel stud alone when a one-flange connection is tested in either tension or compression.

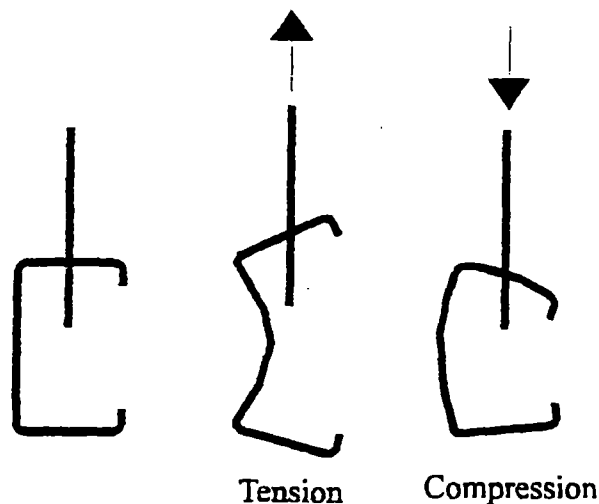


Figure 5.1: Typical Steel Stud Deformations for a One Flange Connection

Structural serviceability considerations are discussed below with reference to the requirements that were specified in the proposed revisions to the Standard CSA/CAN A370 [2]. These proposals (and, in fact, the new Standard CSA/CAN A370-94) requires for tied connections, including retrofit ties, that:-

- 1) Rigidity Requirements

A masonry connector should have a rigidity compatible to the members it connects and should be designed so that the resulting movements are acceptable.

## 2) Tie Displacement and Free Play

The total free play of multi-component ties, including any free play between a tie component and the structural backing, when assembled, shall not exceed 1.2 mm.

When tested under a compressive or tensile load of 0.45 kN, the sum of the displacement and free play of the tie shall not be more than 2.0 mm.

Displacement includes all secondary deformations of the structural backing. Secondary deformations include fastener slippage, flange rotation, bending, and compression of load bearing insulation or sheathing. Displacement does not include the primary deflection of the structural backing (i.e., bending of the steel stud wall).

In Table 3.3, it is shown that for the rigid datum test and one flange connection the displacement at a load 0.45kN is 0.25, 0.55, 1.10 and 1.60mm for 16, 18, 20 and 21 gauge studs respectively. The compression values are similar to the tension values. Thus for 20 and 21 gauge studs the contribution of the stud to displacement alone accounts for 55% and 80% of the 2mm limit for serviceability. Although sheathing (s) may reduce this displacement, it is evident that with 20 and 21 gauge studs, the deformation of the stud, not the Dinal tie, may be critical.

To account for statistical variability within each test series, characteristic values are obtained as follows:

$$\text{Displacement}_{@0.45\text{kN char}} = \bar{x} + 1.5 \cdot (\text{Standard Deviation})$$

Table 5.1 lists the displacement values at the 0.45 kN load and their characteristic values for all the test series conducted on the Dinal tie. These displacement values are representative of a confidence level of 93.32%. As would be expected, the values for the beam tests are greater than those for the isolation tests.

Gauge	Test Type	Average Displ. at 0.45 kN $\Delta_{0.45kN}$ mm	Standard Deviation  S.D. mm	Charact. Displ. at 0.45 kN $\Delta_{char}$ mm	Rigid Datum Displacement at 0.45 kN $\Delta_{datum}$ mm	Net Charact. Displ. at 0.45 kN $\Delta_{tie} = \Delta_{char} - \Delta_{datum}$ mm
18	<b>Tension</b> Isolation Test	0.21	0.02	0.24	N.A.	N.A.
20		0.36	0.05	0.44	N.A.	N.A.
21		0.51	0.07	0.62	N.A.	N.A.
20	<b>Compression</b> Isolation Test	0.38	0.03	0.43	N.A.	N.A.
21		0.49	0.10	0.64	N.A.	N.A.
20	<b>Tension</b> Beam Test	0.89	0.04	0.95	1.10	(-0.15)
21		1.44	0.15	1.67	1.60	0.07
21	<b>Compression</b> Beam Test	1.42	0.08	1.54	1.40	0.14

N.A.: Not applicable, because no isolation datum tests were performed.

**Table 5.1 : Characteristic Displacements at 0.45 kN**

Also shown in Table 5.1 is the net tie displacement at a load of 0.45 kN. This value is found by subtracting the rigid datum displacement at 0.45 kN (Table 3.3) from the characteristic displacement. The resulting displacement is due to the deformation and pullout of the tie only and is independent of the steel stud deformation; the value is very small. Clearly for loads at least up to 45 kN the tie deformation is small. It follows that in the isolation tests the majority of the measured displacement is due to the rotation of the flange of the stud. It also follows that the Dinal tie satisfies 2 mm limit on displacement for 21, 20 and thus all thicker steel stud framing.

Given that the isolation test results are relevant, it is evident from Table 5.1 that the Dinal tie satisfies both the Tie Displacement and Free Play requirement. Even including some provision for primary deflection of the steel stud wall (i.e., beam test results), the characteristic displacement values at 0.45 kN are less than 2 mm. As there is little free play of the tie, it follows that the free play provision of 1.2 mm is also satisfied.

The characteristic values for the proportional load may be calculated, i.e.  $\bar{x} + 1.5 \cdot \text{S.D.}$  and these values are presented in Table 5.2. Only the tension test values are given because, as discussed in section 4.2, tension is critical. The recommended stiffness values (taken from Table 4.1) are also presented in Table 5.2.

Gauge	Test Type	Average Proportional Load $\bar{x}$ kN	Standard Deviation  S.D. kN	Characteristic Proportional Load $P_{char}$ kN
18	Tension Isolation Test	1.35	0.08	1.230
20		0.99	0.13	0.795
21		0.48	0.04	0.420
20	Tension Beam Test	0.79	0.10	0.640
21		0.37	0.03	0.325

### Table 5.2: Characteristic Proportional Loads

On the basis of the isolation tests it may also be concluded that characteristic values for  $P_p$  and the equivalent initial stiffness values are, for the purpose of design, as follows:

for the 18 gauge (and thicker) studs	1.23 kN and	1500 N/mm
20 gauge studs	0.80 kN and	900 N/mm

No recommendation is made for the 21 gauge stud connection because the limit of proportionality is less than 0.45 kN.

### 5.3 Structural Safety

Structural safety for the Dinal tie to steel stud connection may be discussed with respect to the requirements specified in the proposed (and since published) Standard CSA/CAN A370. There is a general provision that the strength or capacity be greater than 1kN for the purpose of design. The characteristic value for this maximum strength is obtained from maximum test values as follows:

$$R_{char} = \bar{x} - 1.5 \cdot (\text{Standard Deviation})$$

This value is representative of a confidence level of 93.32%. Based on the current live load factor of 1.5 and the proposed resistance factors [2] the maximum permissible design value at the service load level may be calculated as:

$$R_w = \frac{R_{char}}{1.67} \quad \text{for material failure of the metal components of the connector (i.e., } \phi \text{ factor of 0.9 and a load factor of 1.5)}$$

$$R_w = \frac{R_{char}}{2.50} \quad \text{for embedment failure or failure of the fasteners, or elastic buckling failure of the connector (i.e., } \phi \text{ factor of 0.6 and a load factor of 1.5).}$$

Given that the failure of either the steel stud flange or of the Molly Nut is involved, it is appropriate to use the latter, more conservative criterion. Table 5.3 lists the various characteristic strength values. Only the tension test values are presented because, as discussed in section 4.2, they are critical. The governing values of the characteristic strengths,  $R_{char}$ , and equivalent design service load resistances,  $R_w$ , are listed in Table 5.4. The 18 gauge isolation test value was used for characteristic strength because, as discussed in section 4, the tie rather than the stud fails. With the 20 and 21 gauge studs, the thinner flange is the cause of failure. Because stud movement does affect the failure mechanism, it is appropriate to use the lower beam test values for the thinner studs. Also shown in Table 5.4 are the recommended values for the proportional limit load ( $P_p$ ).

Table 5.3 indicates that the characteristic values for maximum capacity are always greater than 1.0 kN. In Table 5.4 it is evident that for the 21 and 20 gauge studs the proportional limit value should constitute the recommended service load design value. For the 18 gauge and thicker studs it is appropriate to use a value based on maximum strength. Recommended values for the service load design capacity are listed in Table 5.4.



Gauge	Test Type Tension	Average Maximum Load x kN	Standard Deviation S.D. kN	Characteristic Strength $R_{char}$ kN	Service Load Resistance for F.S.=2.5 $R_w$ kN
18	Isolation Test	3.01	0.18	2.740	1.096
20		2.64	0.07	2.535	1.014
21		2.09	0.07	1.985	0.794
20	Beam Test	2.46	0.05	2.385	0.954
21		1.64	0.07	1.535	0.614

Table 5.3: Characteristic Strength and Resistance Values

Gauge	Limiting Characteristic Strength $R_{char}$ kN	Service Load Resistance for F.S.=2.5 $R_w$ kN	Characteristic Proportional Load $P_{char}$ kN	Recommended Design Service Load kN
18	2.740	1.096	1.23	1.10
20	2.385	0.954	0.80	0.80
21	1.535	0.614	0.42	0.42

Table 5.4: Governing Characteristic Strength, Resistance and Recommended Design Values

## 6. Conclusions and Recommendations

The interconnection between the Dinal retrofit tie and structural steel studs of various gauges has been tested. The performance of this external fix has been assessed with regard to various performance requirements, in particular the structural safety and structural serviceability requirements of the proposed (and later adopted) version of the Standard CSA/CAN A370.

Recommended design values for tie capacity are listed in Table 6.1. These values apply to service load levels and incorporate both safety and serviceability considerations. It should be noted that the characteristic value for the actual capacity of the connection were always greater than 1 kN and the maximum capacity occurred with considerable deformation. Thus the ties were relatively ductile beyond their proportional limit which is beneficial in dealing with abnormal or dynamic loadings.

In the 18 gauge application, the Molly Nut of the tie fails, therefore, it is likely that the capacity of the Dinal tie in a thicker stud will be of comparable value. Therefore, it is recommended that the design capacity at maximum service load for studs stronger than the 18 gauge be no greater than 1.10 kN, which is the design capacity at maximum service load for the 18 gauge stud. For the 21 gauge application, the code specified 0.45 kN serviceability target is, in fact, beyond the design recommended capacity at service load, therefore the design capacity at service load for the Dinal connection to studs thinner than the 21 gauge stud will be much lower than 0.45 kN. Therefore, with these thinner studs it is structural serviceability rather than connection capacity that limits the design capacity.

Serviceability limits in the proposed CSA Standard require that the tie deflect no more than 2mm when loaded to 0.45 kN in tension or compression. It is stipulated that these serviceability limit deflections include tie pullout, flange rotation and insulation deformation (if applicable) but exclude primary beam displacements. In the tests neither the contribution of the interior sheathing nor any exterior sheathing has been included; it would be difficult to quantify their contribution. It is likely that for deformation and stiffness values, the beam test setup is overly flexible and not truly representative of reality. The isolation test setup does incorporate some degree of flange rotation but not overall stud deformation, i.e., primary displacement. Given that the isolation test results for the 18, 20 and 21 gauge studs are relevant, the Dinal tie clearly satisfies the deformation limit for serviceability by a large margin. It follows that for stud thicknesses greater than the 18 gauge, serviceability will also be satisfied. The serviceability limits for the Dinal tie in thinner or more flexible studs, such as the 24 and 26 gauge versions, may also satisfy the serviceability limit. Note that with the 21 gauge stud, the measured

displacement at 0.45 kN was only 0.62 mm. However, we do have some reservations about the use of this tie with 24 or 26 gauge studs; bending and tearing of the flange and thus tie capacity are the important concerns.

Gauge	Design Capacity at Maximum Service Load $R_w$ kN	Equivalent Stiffness Values under Service Load N/mm
18	1.10	1500
20	0.80	900
21	0.42	800

**Table 6.1: Recommended Design Values for the Dinal Tie**

In conclusion it is evident that the Dinal tie has potential for use as a retrofit tie into steel stud framing. It is however recommended that stainless steel be used for all the metal parts of any tie used as the retrofit tie in a BV/SS wall, especially if corrosion of the tie is the reason for the retrofit.

## 7. References

- 1 Postma, M.A. and Burnett, E.F.P., *Renovation Strategies for Brick Veneer/Steel Stud Wall Construction - Task 2 : Four Remedial Tie Systems for BV/SS Walls- Development and Conformance Testing*, Canada Mortgage and Housing Corporation, Ottawa, Ontario, August, 1993.
- 2 CSA-CAN3-A370 draft, *Connectors for Masonry*, Canadian Standards Association, revised March 1993. and the issued Standard A370-94

**Appendix A**

**Detailed Test Results**

**Table D-1a-21: Dinal Tie - Exterior Repair/Tension Test Results**  
**Isolated Connection Test**  
**Tension to Failure**  
**0.88 mm Stud (0.033" - 21 gauge)**

Series Number	Cyclic Displ. (mm)	Displ. at 0.45 kN (mm)	Load at 1.0mm (kN)	Load at 2.0mm (kN)	At Proportional Limit		At Maximum		First Slope (kN/mm)	Second Slope (kN/mm)	Displ. at 0.0kN (mm)	Secant Slope through Max. Load (kN/mm)
					Load (kN)	Tie Dipl. (mm)	Load (kN)	Tie Dipl. (mm)				
D-1a-21-1	N.A.	0.55	0.61	0.89	0.46	0.60	1.94	7.00	0.82	0.29	12.30	0.28
D-1a-21-2	N.A.	0.50	0.64	0.95	0.50	0.60	2.18	6.60	0.80	0.33	12.20	0.33
D-1a-21-3	N.A.	0.60	0.62	0.99	0.54	0.80	2.14	6.30	0.70	0.34	12.20	0.34
D-1a-21-4	N.A.	0.50	0.60	0.82	0.45	0.50	2.09	7.00	1.03	0.32	12.40	0.30
D-1a-21-5	N.A.	0.50	0.60	0.89	0.45	0.50	2.09	7.20	0.92	0.31	13.00	0.29
Average		0.53	0.61	0.91	0.48	0.60	2.09	6.82	0.85	0.32	12.42	0.31
Standard Deviation	N.A.	0.04	0.02	0.06	0.04	0.12	0.09	0.36	0.13	0.02	0.33	0.03
C. of Variation (%)		8.4	2.7	7.2	8.2	20.4	4.4	5.3	14.7	6.0	2.7	8.4

**Table D-1c-21: Dinal Tie - Exterior Repair/Tension Test with Pre-Conditioning**  
**Isolated Connection Test**  
**Compression/Tension Cycling - Tension to Failure**  
**0.88 mm Stud (0.033" - 21 gauge)**

Series Number	Cyclic Displ. (mm)	Displ. at 0.45 kN (mm)	Load at 1.0mm (kN)	Load at 2.0mm (kN)	At Proportional Limit		At Maximum		First Slope (kN/mm)	Second Slope (kN/mm)	Displ. at 0.0kN (mm)	Secant Slope through Max. Load (kN/mm)
					Load (kN)	Tie Dipl. (mm)	Load (kN)	Tie Dipl. (mm)				
D-1c-21-6	0.15	0.45	0.62	0.88	0.48	0.50	2.11	7.50	0.92	0.27	12.80	0.28
D-1c-21-7	0.11	0.40	0.66	0.86	0.54	0.50	2.07	7.00	0.94	0.30	12.30	0.30
D-1c-21-8	0.14	0.60	0.59	0.93	0.45	0.60	2.06	6.30	0.83	0.37	12.40	0.33
Average	0.13	0.48	0.62	0.89	0.49	0.53	2.08	6.93	0.90	0.31	12.50	0.30
Standard Deviation	0.02	0.10	0.04	0.04	0.05	0.06	0.03	0.60	0.06	0.05	0.26	0.03
C. of Variation (%)	15.6	21.5	5.6	4.1	9.4	10.8	1.3	8.7	6.5	16.4	2.1	8.3

**Table D-1ac-21: Dinal Tie - Exterior Repair/Combined Tension and Tension with Pre-Conditioning Test Results**  
**Isolated Connection Test**  
**Combined Tension to Failure and Compression/Tension Cycling-Tension to Failure**  
**0.88 mm Stud (0.033" - 21 gauge)**

Average		0.51	0.62	0.90	0.48	0.58	2.09	6.86	0.87	0.32	12.45	0.31
Standard Deviation		0.07	0.02	0.05	0.04	0.10	0.07	0.43	0.10	0.03	0.29	0.02
C. of Variation (%)		13.5	3.7	5.9	8.0	18.0	3.4	6.2	11.8	9.8	2.4	7.8

**Table D-1b-21: Dinal Tie - Exterior Repair/Compression Test Results**  
**Isolated Connection Test**  
**Compression to Failure**  
**0.88 mm Stud (0.033" - 21 gauge)**

Series Number	Cyclic Displ. (mm)	Displ. at 0.45 kN (mm)	Load at 1.0mm (kN)	Load at 2.0mm (kN)	At Proportional Limit		At Maximum		First Slope (kN/mm)	Second Slope (kN/mm)	Displ. at 0.0kN (mm)	Secant Slope through Max. Load (kN/mm)
					Load (kN)	Tie Dipl. (mm)	Load (kN)	Tie Dipl. (mm)				
D-1b-21-1	N.A.	0.50	0.72	1.22	0.54	0.70	2.66	6.10	0.91	0.44	9.30	0.44
D-1b-21-2	N.A.	0.40	0.82	1.37	0.66	0.70	2.74	6.20	0.98	0.49	8.50	0.44
D-1b-21-3	N.A.	0.65	0.64	1.12	0.42	0.70	2.71	7.00	0.83		8.80	0.39
D-1b-21-4	N.A.	0.45	0.78	1.27	0.72	0.90	2.66	6.50	0.89			0.41
D-1b-21-5	N.A.	0.45	0.77	1.27	0.54	0.60	2.66	6.70	1.07		8.50	0.40
<b>Average</b>		<b>0.49</b>	<b>0.75</b>	<b>1.25</b>	<b>0.58</b>	<b>0.72</b>	<b>2.69</b>	<b>6.50</b>	<b>0.94</b>	<b>0.47</b>	<b>8.78</b>	<b>0.42</b>
Standard Deviation	N.A.	0.10	0.07	0.09	0.12	0.11	0.04	0.37	0.09	0.04	0.38	0.02
C. of Variation (%)		19.6	9.3	7.3	20.3	15.2	1.4	5.7	9.8	7.6	4.3	5.5

**Table D-1a-20: Dinal Tie - Exterior Repair/Tension Test Results**  
 Isolated Connection Test  
 Tension to Failure  
 0.91 mm Stud (0.036" - 20 gauge)

Series Number	Cyclic Displ. (mm)	Displ. at 0.45 kN (mm)	Load at 1.0mm (kN)	Load at 2.0mm (kN)	At Proportional Limit		At Maximum		First Slope (kN/mm)	Second Slope (kN/mm)	Displ. at 0.0kN (mm)	Secant Slope through Max. Load (kN/mm)
					Load (kN)	Tie Dipl. (mm)	Load (kN)	Tie Dipl. (mm)				
D-1a-20-1	N.A.	0.45	0.84	1.40	0.84	1.00	2.69	5.90	0.92	0.46	11.80	0.46
D-1a-20-2	N.A.	0.30	0.97	1.48	0.86	0.80	2.68	5.90	1.09	0.48	11.30	0.45
D-1a-20-3*	N.A.	0.35	0.98	1.61	1.12	1.20	2.49	4.50	0.96		10.40	0.55
<b>Average</b>		<b>0.37</b>	<b>0.93</b>	<b>1.50</b>	<b>0.94</b>	<b>1.00</b>	<b>2.62</b>	<b>5.43</b>	<b>0.99</b>	<b>0.47</b>	<b>11.17</b>	<b>0.49</b>
Standard Deviation	N.A.	0.08	0.08	0.11	0.16	0.20	0.11	0.81	0.09	0.01	0.71	0.06
C. of Variation (%)		20.8	8.4	7.1	16.6	20.0	4.3	14.9	9.0	3.0	6.4	11.3

Note \*: Second Failure Mechanism

**Table D-1c-20: Dinal Tie - Exterior Repair/Tension Test with Pre-Conditioning**  
 Isolated Connection Test  
 Compression/Tension Cycling - Tension to Failure  
 0.91 mm Stud (0.036" - 20 gauge)

Series Number	Cyclic Displ. (mm)	Displ. at 0.45 kN (mm)	Load at 1.0mm (kN)	Load at 2.0mm (kN)	At Proportional Limit		At Maximum		First Slope (kN/mm)	Second Slope (kN/mm)	Displ. at 0.0kN (mm)	Secant Slope through Max. Load (kN/mm)
					Load (kN)	Tie Dipl. (mm)	Load (kN)	Tie Dipl. (mm)				
D-1c-20-4	0.14	0.35	0.93	1.51	0.93	1.00	2.66	5.75	1.08	0.53	11.70	0.46
D-1c-20-5	0.15	0.35	1.09	1.65	1.09	1.00	2.67	5.65	0.99	0.51	11.50	0.47
D-1c-20-6	0.15	0.35	0.96	1.48	1.09	1.00	2.63	5.85	1.09	0.46	11.90	0.45
<b>Average</b>	<b>0.15</b>	<b>0.35</b>	<b>0.99</b>	<b>1.55</b>	<b>1.04</b>	<b>1.00</b>	<b>2.65</b>	<b>5.75</b>	<b>1.05</b>	<b>0.50</b>	<b>11.70</b>	<b>0.46</b>
Standard Deviation	0.01	0.00	0.09	0.09	0.09	0.00	0.02	0.10	0.06	0.04	0.20	0.01
C. of Variation (%)	3.9	0.0	8.6	5.9	8.9	0.0	0.8	1.7	5.2	7.2	1.7	2.2

**Table D-1ac-21: Dinal Tie - Exterior Repair/Combined Tension and Tension with Pre-Conditioning Test Results**  
 Isolated Connection Test  
 Combined Tension to Failure and Compression/Tension Cycling-Tension to Failure  
 0.91 mm Stud (0.036" - 20 gauge)

<b>Average</b>		<b>0.36</b>	<b>0.96</b>	<b>1.53</b>	<b>0.97</b>	<b>1.00</b>	<b>2.64</b>	<b>5.54</b>	<b>1.01</b>	<b>0.50</b>	<b>11.34</b>	<b>0.48</b>
Standard Deviation		0.05	0.09	0.10	0.13	0.14	0.08	0.59	0.07	0.03	0.56	0.04
C. of Variation (%)		15.2	9.4	6.6	13.4	14.1	3.2	10.7	7.4	6.3	4.9	8.5



**Table D-1b-20: Dinal Tie - Exterior Repair/Compression Test Results**  
**Isolated Connection Test**  
**Compression to Failure**  
**0.91 mm Stud (0.036" - 20 gauge)**

Series Number	Cyclic Displ. (mm)	Displ. at 0.45 kN (mm)	Load at 1.0mm (kN)	Load at 2.0mm (kN)	At Proportional Limit		At Maximum		First Slope (kN/mm)	Second Slope (kN/mm)	Displ. at 0.0kN (mm)	Secant Slope through Max. Load (kN/mm)
					Load (kN)	Tie Dipl. (mm)	Load (kN)	Tie Dipl. (mm)				
D-1b-20-1	N.A.	0.40	0.88	1.60	1.00	1.20	3.88	6.80	0.85	0.64	8.90	0.57
D-1b-20-2	N.A.	0.35	1.00	1.75	1.14	1.20	3.79	6.20	0.96	0.68		0.61
D-1b-20-3	N.A.	0.40	0.90	1.60	1.18	1.40	3.50	6.10	0.86	0.60		0.57
D-1b-20-4	N.A.	0.40	0.94	1.60	1.00	1.10	3.61	6.50	0.99	0.63		0.56
D-1b-20-5	N.A.	0.35	0.96	1.68	1.10	1.20	3.57	6.10	0.93	0.66		0.59
<b>Average</b>		<b>0.38</b>	<b>0.94</b>	<b>1.65</b>	<b>1.08</b>	<b>1.22</b>	<b>3.67</b>	<b>6.34</b>	<b>0.92</b>	<b>0.64</b>		<b>0.58</b>
Standard Deviation	N.A.	0.03	0.05	0.07	0.08	0.11	0.16	0.30	0.06	0.03		0.02
C. of Variation (%)		7.2	5.1	4.1	7.5	9.0	4.3	4.8	6.7	4.7		3.4

**Table D-1a-18: Dinal Tie - Exterior Repair/Tension Test Results**  
**Isolated Connection Test**  
**Tension to Failure**  
**1.22 mm Stud (0.048" - 18 gauge)**

Series Number	Cyclic Displ. (mm)	Displ. at 0.45 kN (mm)	Load at 1.0mm (kN)	Load at 2.0mm (kN)	At Proportional Limit		At Maximum		First Slope (kN/mm)	Second Slope (kN/mm)	Displ. at 0.0kN (mm)	Secant Slope through Max. Load (kN/mm)
					Load (kN)	Tie Dipl. (mm)	Load (kN)	Tie Dipl. (mm)				
D-1a-18-1	N.A.	0.20	1.43	2.12	1.43	1.00	3.00	3.90	1.50	0.64	4.40	0.77
D-1a-18-2	N.A.	0.25	1.33	2.00	1.26	0.90	3.12	4.70	1.40	0.52	5.20	0.66
D-1a-18-3	N.A.	0.20	1.46	2.05	1.30	0.80	3.19	5.00	1.65	0.48	5.50	0.64
D-1a-18-4	N.A.	0.20	1.51	2.04	1.44	0.90	2.72	4.10	1.64	0.46	5.80	0.66
D-1a-18-5	N.A.	0.20	1.50	2.02	1.34	0.80	3.02	4.40	1.68	0.48	5.20	0.69
<b>Average</b>		<b>0.21</b>	<b>1.45</b>	<b>2.05</b>	<b>1.35</b>	<b>0.88</b>	<b>3.01</b>	<b>4.42</b>	<b>1.57</b>	<b>0.52</b>	<b>5.22</b>	<b>0.68</b>
Standard Deviation	N.A.	0.02	0.07	0.05	0.08	0.08	0.18	0.44	0.12	0.07	0.52	0.05
C. of Variation (%)		10.6	5.0	2.2	5.9	9.5	6.0	10.0	7.6	14.1	10.0	7.5

**Table D-2-21: Dinal Tie - Exterior Repair/Tension Test Results**  
 Beam Test  
 Tension to Failure  
 0.88 mm Stud (0.033" - 21 gauge)

Series Number	Cyclic Displ. (mm)	Displ. at 0.45 kN (mm)	Load at 1.0mm (kN)	Load at 2.0mm (kN)	At Proportional Limit		At Maximum		First Slope (kN/mm)	Second Slope (kN/mm)	Displ. at 0.0kN (mm)	Secant Slope through Max. Load (kN/mm)
					Load (kN)	Tie Dipl. (mm)	Load (kN)	Tie Dipl. (mm)				
D-2-21-1	N.A.	1.50	0.37	0.51	0.37	1.00	1.59	13.90	0.40	0.12	18.80	0.11
D-2-21-2	N.A.	1.50	0.38	0.53	0.32	0.70	1.74	12.50	0.46	0.13	20.30	0.14
D-2-21-3	N.A.	1.60	0.36	0.60	0.36	1.00	1.67	14.70	0.37	0.10	18.90	0.11
D-2-21-4	N.A.	1.20	0.41	0.56	0.41	1.00	1.59	11.80	0.45	0.12	19.00	0.12
D-2-21-5	N.A.	1.40	0.38	0.54	0.38	1.00	1.59	10.30	0.42	0.15	18.90	0.15
Average		1.44	0.38	0.55	0.37	0.94	1.64	12.64	0.42	0.12	19.18	0.13
Standard Deviation	N.A.	0.15	0.02	0.03	0.03	0.13	0.07	1.73	0.04	0.02	0.63	0.02
C. of Variation (%)		10.5	4.9	6.2	8.9	14.3	4.1	13.7	8.7	14.6	3.3	14.2

**Table D-4-21: Dinal Tie - Exterior Repair/Compression Test Results**  
 Beam Test  
 Compression to Failure  
 0.88 mm Stud (0.033" - 21 gauge)

Series Number	Cyclic Displ. (mm)	Displ. at 0.45 kN (mm)	Load at 1.0mm (kN)	Load at 2.0mm (kN)	At Proportional Limit		At Maximum		First Slope (kN/mm)	Second Slope (kN/mm)	Displ. at 0.0kN (mm)
					Load (kN)	Tie Dipl. (mm)	Load (kN)	Tie Dipl. (mm)			
D-4-21-1	N.A.	1.35	0.37	0.58	0.42	1.20	>1.73	>18.2	0.38		
D-4-21-2	N.A.	1.40	0.36	0.55	0.34	0.90	>1.73	>20.0	0.38		
D-4-21-3	N.A.	1.35	0.38	0.57	0.38	1.00	>1.86	>20.9	0.39		
D-4-21-4	N.A.	1.50	0.34	0.54	0.34	1.00	>1.96	>22.0	0.36		
D-4-21-5	N.A.	1.50	0.34	0.53	0.40	1.20	>1.92	>21.9	0.32		
Average		1.42	0.36	0.55	0.38	1.06	>1.84	>20.60	0.37		
Standard Deviation	N.A.	0.08	0.02	0.02	0.04	0.13	0.11	1.57	0.03		
C. of Variation (%)		5.3	5.0	3.7	9.5	12.7	5.8	7.6	7.6		

**Table D-2-20: Dinal Tie - Exterior Repair/Tension Test Results**  
**Beam Test**  
**Tension to Failure**  
**0.91 mm Stud (0.036" - 20 gauge)**

Series Number	Cyclic Displ. (mm)	Displ. at 0.45 kN (mm)	Load at 1.0mm (kN)	Load at 2.0mm (kN)	At Proportional Limit		At Maximum		First Slope (kN/mm)	Second Slope (kN/mm)	Displ. at 0.0kN (mm)	Secant Slope through Max. Load (kN/mm)
					Load (kN)	Tie Dipl. (mm)	Load (kN)	Tie Dipl. (mm)				
D-2-20-1	N.A.	0.90	0.50	0.90	0.92	2.10	2.48	11.20	0.45	0.18	14.90	0.22
D-2-20-2	N.A.	0.90	0.48	0.84	0.74	1.70	2.43	11.70	0.45	0.19	12.70	0.21
D-2-20-3	N.A.	0.85	0.54	0.94	0.88	1.80	2.54	11.60	0.51	0.18	15.00	0.22
D-2-20-4	N.A.	0.95	0.47	0.80	0.68	1.60	2.40	10.70	0.44	0.21	12.00	0.22
D-2-20-5	N.A.	0.85	0.51	0.87	0.74	1.60	2.47	10.60	0.47	0.20	12.10	0.23
<b>Average</b>		<b>0.89</b>	<b>0.50</b>	<b>0.87</b>	<b>0.79</b>	<b>1.76</b>	<b>2.46</b>	<b>11.16</b>	<b>0.46</b>	<b>0.19</b>	<b>13.34</b>	<b>0.22</b>
<b>Standard Deviation</b>	N.A.	0.04	0.03	0.05	0.10	0.21	0.05	0.50	0.03	0.01	1.49	0.01
<b>C. of Variation (%)</b>		4.7	5.5	6.2	13.0	11.8	2.2	4.5	6.0	6.8	11.2	3.2

**Appendix B**

**Summary of Test Results**

Isolated Connection Test Summary Table

Steel Stud Gauge	Test Type and Statistics	N	Displ. at 0.45 kN (mm)	Load at 1.0mm (kN)	Load at 2.0mm (kN)	At Proportional Limit		At Maximum		First Slope (kN/mm)	Second Slope (kN/mm)	Displ. at 0.0kN (mm)	Secant Slope through Max. Displ. (kN/mm)
						Load (kN)	Tie Displ. (mm)	Load (kN)	Tie Displ. (mm)				
18	<b>Tension Test</b>	5											
	Average		0.21	1.45	2.05	1.35	0.88	3.01	4.42	1.57	0.52	5.22	0.68
	Standard Deviation		0.02	0.07	0.05	0.08	0.08	0.18	0.44	0.12	0.07	0.52	0.05
	C. of Variation (%)		10.6	5.0	2.2	5.9	9.5	6.0	10.0	7.6	14.1	10.0	7.4
20	<b>Tension Test</b>	6											
	Average		0.36	0.96	1.52	0.99	1.00	2.64	5.59	1.02	0.49	11.43	0.47
	Standard Deviation		0.05	0.08	0.09	0.13	0.13	0.07	0.54	0.07	0.03	0.55	0.04
	C. of Variation (%)		13.7	8.4	6.1	12.8	12.6	2.8	9.7	7.3	6.4	4.8	7.1
	<b>Compression Test</b>	5											
	Average		0.38	0.94	1.65	1.08	1.22	3.67	6.34	0.92	0.64	8.90	0.58
	Standard Deviation		0.03	0.05	0.07	0.08	0.11	0.16	0.30	0.06	0.03	-	0.02
	C. of Variation (%)		7.2	5.1	4.1	7.5	9.0	4.3	4.8	6.7	4.7	-	3.6
21	<b>Tension Test</b>	8											
	Average		0.51	0.62	0.90	0.48	0.58	2.09	6.86	0.87	0.32	12.45	0.30
	Standard Deviation		0.07	0.02	0.05	0.04	0.10	0.07	0.43	0.10	0.03	0.29	0.02
	C. of Variation (%)		13.5	3.7	5.9	8.0	18.0	3.4	6.2	11.8	9.8	2.4	8.2
	<b>Compression Test</b>	5											
	Average		0.49	0.75	1.25	0.58	0.72	2.69	6.50	0.94	0.47	8.78	0.41
	Standard Deviation		0.10	0.07	0.09	0.12	0.11	0.04	0.37	0.09	0.04	0.38	0.02
	C. of Variation (%)		19.6	9.3	7.3	20.4	15.2	1.4	5.7	9.8	7.6	4.3	5.8

N - Number of Tests

Beam Test Summary Table

Steel Stud Gauge	Test Type and Statistics	N	Displ. at 0.45 kN (mm)	Load at 1.0mm (kN)	Load at 2.0mm (kN)	At Proportional Limit		At Maximum		First Slope (kN/mm)	Second Slope (kN/mm)	Displ. at 0.0kN (mm)	Secant Slope through Max. Displ. (kN/mm)
						Load (kN)	Tie Displ. (mm)	Load (kN)	Tie Displ. (mm)				
20	<b>Tension Test</b>	5											
	Average		0.89	0.50	0.87	0.79	1.76	2.46	11.16	0.46	0.19	13.34	0.22
	Standard Deviation		0.04	0.03	0.05	0.10	0.21	0.05	0.50	0.03	0.01	1.49	0.01
	C. of Variation (%)		4.7	5.5	6.2	13.0	11.8	2.2	4.5	6.0	6.8	11.2	4.2
21	<b>Tension Test</b>	5											
	Average		1.44	0.38	0.55	0.37	0.94	1.64	12.64	0.42	0.12	19.18	0.13
	Standard Deviation		0.15	0.02	0.03	0.03	0.13	0.07	1.73	0.04	0.02	0.63	0.02
	C. of Variation (%)		10.5	4.9	6.2	8.9	14.3	4.1	13.7	8.7	14.6	3.3	13.2
20	<b>Compression Test</b>	5											
	Average		1.42	0.36	0.55	0.38	1.06	>1.84	>20.60	0.37			
	Standard Deviation		0.08	0.02	0.02	0.04	0.13	0.11	1.57	0.03			
	C. of Variation (%)		5.3	5.0	3.7	9.5	12.7	5.8	7.6	7.6			

N - Number of Tests