



Assembly-Scale Seismic Verification of MODFRAME NSE Restraint Systems Using Quasi-Static Cyclic Testing

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ABSTRACT

Non-structural element (NSE) restraint assemblies play a significant role in controlling life-safety hazards and supporting post-earthquake building function. Current engineering practice commonly qualifies individual components and infers overall assembly behaviour, despite limited direct evidence of system-level performance under combined deformation and force demands.

This paper reports assembly-scale verification undertaken as part of the FDG Seismic Assurance Programme using quasi-static cyclic testing of complete restraint systems, supported by targeted component tests. The testing examined performance within defined geometric, detailing, and installation bounds representative of New Zealand practice. System stiffness, deformation capacity, load paths, and governing failure modes were identified to establish limits of applicability for design and installation. Frame stiffness effects were considered to inform drift compatibility, seismic gap requirements, and restraint demand assumptions.

The findings demonstrate that assembly behaviour cannot be reliably inferred from isolated component capacities alone, and that detailing and installation controls materially influence system performance. The results are intended to provide designers with evidence-based confidence in restraint system behaviour, support verification against NZS 4219 intent, and inform quality assurance approaches aligned with low-damage and service continuity objectives.

1 INTRODUCTION

Resilient infrastructure requires post-earthquake functionality of critical building services. While Non-Structural Element (NSE) restraints are vital for life safety, industry practice often qualifies isolated components, forcing designers to infer complex assembly behaviour from limited piecewise data. This research presents verification of the MODFRAME™ system, intended to shift the paradigm toward holistic system-level performance.

As part of the FDG Seismic Assurance Programme, complete restraint assemblies were subjected to quasi-static cyclic testing. By examining performance within detailing and installation bounds representative of New Zealand practice, the study identified system stiffness, load paths, and governing failure modes, such as the transition from joint deformation to T-bolt tear-out in high-stiffness braced configurations.

The programme includes additional testing beyond the scope of this paper; further results and supporting design material will be issued through subsequent programme outputs. This research provides practitioners with evidence-based confidence, ensuring modular bracing systems perform as intended to maintain service continuity and mitigate risk in both new and existing structures.

2 MOTIVATION OF THE FDG SEISMIC ASSURANCE PROGRAMME

Current practice relies on isolated component data to infer the behaviour of complex seismic restraints, ignoring critical system-level interactions revealed only through full-scale assembly testing. Technical assessments for imported systems based on EN 1993 - Eurocode 3, use partial safety factors ($\gamma_M = 1.25$) while often excluding the vital profile-to-connector interface. These international metrics do not correlate with the statistical rigor or drift-based demands of NZS 4219 or NZS 1170.5.

The FDG Seismic Assurance Programme aims to bridge the gap by interrogating full assemblies to characterize holistic, energy-dissipating hysteresis. By deriving design values through AS/NZS 1170.0 Appendix B, we establish a New Zealand-specific "tested installation and detailing bounds". This provides practitioners with verifiable resilience, ensuring modular systems maintain operational continuity during significant seismic events.

3 TEST PROGRAMME

The program evaluated the MODFRAME™ MOD100 system (100mm x 3mm) using Grade 10.9 M12 T-lock bolts torqued to 120Nm using a calibrated torque wrench. Testing transitioned from quasi-static component evaluations (shear and tension) to full-scale cyclic system tests on portal frames, cantilevers, and braced posts, using the loading protocol outlined in FEMA 461. Drift targets ranged from 0.5% to 8.3%. These system-level results establish rotational stiffness and design moment capacities at the 2.5% drift benchmark, providing the empirical evidence required for NZS 4219:2009 seismic verification.

3.1 Modframe testing

The standardized test arrangements, shown in Figure 1, replicated authentic installation conditions for portal frames and cantilevering posts. To focus seismic moment actions directly into the knee joints, all portal frame specimens utilized pinned bases with upright members spaced 1200mm apart and joint centres positioned 1200mm above the pins. Lateral demand was applied via a hydraulic actuator connected to the centre of the cross-member. The specific assemblies evaluated in this program are summarized in Table 1.

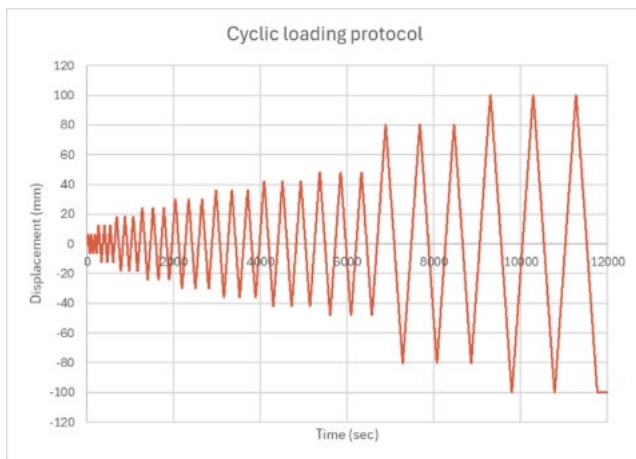


Figure 1 - Modframe cyclic test typical setup - portal frame (left) and braced cantilever (right) tests

Table 1 – Tested Modframe assemblies

Section size	Assembly type	Connectors used	No. of tests
3mm MOD100	Portal frame	MOD100CP: Corner Plate L applied to both sides of the knee joints	3
3mm MOD100	Portal frame	MOD100CP + MOD100AB: Corner Plate L (both sides) reinforced with an Angle Bracket on the underside of the knee connection	3
3mm MOD100	Portal frame	MOD100TP + MOD100AB: T-plates applied to both sides of the joint interface reinforced with Angle Brackets on both sides of the knee connection	3
3mm MOD100	Portal frame	MOD100TPL (one side only) + MOD100AB-G (Gusseted) On the bottom side only	3
5mm MOD100	Portal frame	MOD100AB-SG (Single Gusseted): Angle Brackets with additional gussets positioned above and below the joint	3
5mm MOD100	Portal frame	MOD100TP + MOD100AB-G (Gusseted): T-plates (both sides) with gusseted angles above and below the joints	3
3mm MOD100	Cantilever post	MOD100BP: Holder MOD 100 base plate secured to a rigid steel substrate.	3
3mm MOD100	Braced cantilever	Top: MOD100TP (both sides). Bottom: MOD100HHB: Joint holder horizontal used to secure the 45° brace base	3

3.2 Test protocol



An analytical model, based on component test results was created to estimate failure loads and determine suitable displacement targets to define the cyclic loading protocol for each of the assembly cyclic tests. Three cycles at each displacement target were chosen based on the generic loading protocol outlined in FEMA 461 (Applied Technology Council, 2007), to capture force-deformation properties and hysteretic behaviour. Based on this, the cyclic loading protocol shown in Figure 2 was used for all Modframe system tests, with different yield displacement targets based on the system being tested.

Figure 2 - Example cyclic loading protocol

Loading spanned ten stages, from 0.5% (6mm) to 8.3% (100mm) drift, with the 2.5% drift (30mm) level serving as the critical Ultimate Limit State (ULS) benchmark. Lateral demand was captured via a 250kN pancake loadcell, while global displacements were tracked by string potentiometers. Localized joint rotation was derived from digital linear transducers with 1µm resolution.

3.3 Test results

The experimental results demonstrated stable, ductile hysteretic behaviour across all MODFRAME™ portal frame configurations. The assemblies exhibited significant energy dissipation and a complete absence of brittle failure modes and achieved higher loads than those predicted from component level tests alone. Performance was primarily characterized by joint opening and localized deformations, including section face bending under the T-bolt heads and gusset bending, neither of which led to a sudden loss of structural capacity.

3.3.1 Portal Frame Joint Performance (MOD100)

For the standard 3mm MOD100 portal frames, joint capacity increased progressively with connection enhancement:

1. Base Configuration: Corner plates (MOD100CP) alone provided the baseline design moment capacity.
2. Reinforced Joints: The addition of angle brackets (MOD100AB) increased both strength and rotational stiffness.
3. High-Capacity Joints: Replacing corner plates with T-plates (MOD100TP) on both sides, combined with reinforced angles, provided a substantial increase in joint stiffness and moment capacity.

3.3.2 Influence of Profile Wall Thickness

Testing of the 5mm heavy-wall profile confirmed that section capacity is a primary driver of joint performance. The 5mm system with gusseted angles provided moderate capacity but exhibited relatively low stiffness at Serviceability (SLS) and Ultimate (ULS) drift limits. However, the integration of T-plates into the 5mm system more than doubled the design moment capacity compared to the gusset-only configuration, yielding the highest observed capacity of approximately 25 kNm at peak. This confirmed component level test results, which found that T-bolt stiffness in shear was much greater (approximately 5 times) than in tension (when tested with a 3mm wall thickness section) due to localised bending of the profile wall.

3.3.3 Cantilever and Braced Post Assemblies

The cantilevering MOD100 post (MOD100BP) exhibited lower moment capacity than the portal frames, as expected. Its behaviour was dominated by base plate yielding and initial slip of the T-bolt connectors.

In contrast, the braced post-tests demonstrated that system stiffness can be dramatically increased, approximately five times stiffer than the most robust portal frame configuration. Notably, the high stiffness of this arrangement shifted the governing limit state from displacement to T-bolt tear-out parallel to the brace axis, representing a critical boundary of the "tested installation and detailing bounds".

3.3.4 Derivation of Design Moment Capacities

Suggested joint design moments (summarized in Table 2) were derived following the procedure outlined in AS/NZS 1170.0 Appendix B. Capacities were evaluated at the 30mm global displacement (2.5% drift) benchmark, aligning with the standard New Zealand ULS design limit. The reported Factors of Safety (FoS), represent the ratio of average maximum test moment to suggested design capacity, generally exceed 2.0. This provides practitioners with clear reassurance of significant reserve capacity for applications where drift limits

may be secondary to absolute strength. For ultimate capacities ignoring the 2.5% drift limit, contact the author.

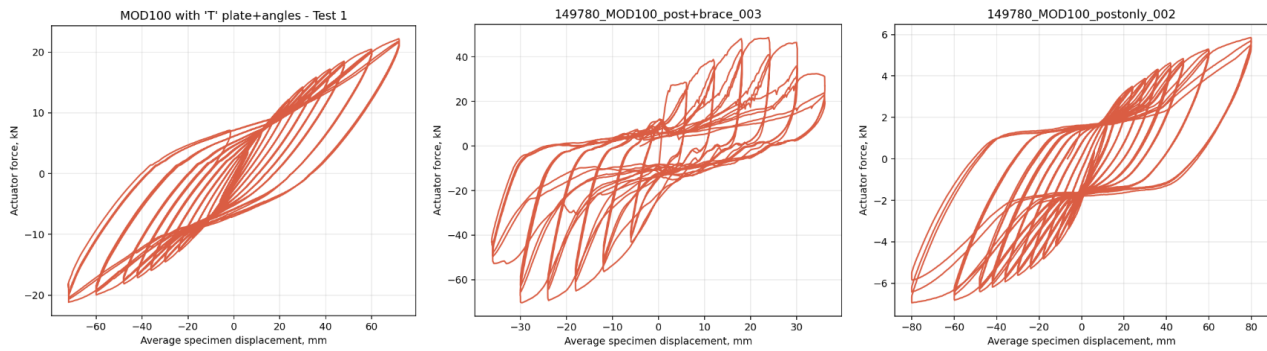


Figure 3 - Force vs displacement hysteresis plots. Portal frame with 'T' plates and angles (left), Braced cantilever post (mid) and cantilever post only (right)

Table 2 - Modframe summary of results

Config / connection type	n (tests used)	Mean moment at 30 mm disp. (kNm)	Suggested design moment (kNm) (Min/kt)	Approx. FoS*
Corner Plates (MOD100CP)	3	4.59	3.34	1.79
Corner Plates (MOD100CP) + Angle Bracket (MOD100AB)	3	5.58	3.76	2.11
T Plates (MOD100TP) + Angle Brackets (MOD100AB)	3	7.66	5.39	2.40
Large T plate (MOD100TPL) one side only + Angle Bracket Gusseted (MOD100AB-G)	2	7.36	5.87	2.28
5 mm MOD100 + Angle Brackets Gusseted (MOD100AB-SG), top and bottom	2	5.99	4.18	3.45
5 mm MOD100, T plates (MOD100TP) + Angle Bracket Gusseted (MOD100AB-G) top and bottom	2	13.76	11.62	2.18
Cantilevering post with holder to open side (MOD100BP)	2	4.37	3.31	2.53
Braced MOD100 post - T bolt parallel shear governs (system tests)	3		20.89 kN (per T bolt) -	

To ensure conservative design values and maintain statistical integrity, specific test results were excluded where specimens exhibited non-representative mechanics—such as bolts reaching the physical limit of slotted holes or anomalous bearing on base plates—ensuring the derived capacities accurately reflect the intended yielding and slip behaviour.

4 CONCLUSION

This paper reports selected findings from assembly-scale quasi-static cyclic tests of MODFRAME™ restraint configurations undertaken within the FDG Seismic Assurance Programme. Within the scope of the configurations and limits described in the paper, the results establish ‘tested installation and detailing bounds’ that can be used to support design and assessment. The findings confirm that assembly behaviour cannot be inferred reliably from isolated component capacities, because joint opening, connector slip, and member interaction control stiffness and governing limit states at the system level. The tests also show that installation controls and detailing choices materially influence performance, so these controls should be treated as design-critical inputs rather than construction preferences. Across the reported configurations, test-observed capacities generally exceeded the suggested design values derived at the 30 mm (2.5% drift) benchmark using AS/NZS 1170.0 Appendix B, typically by factors greater than 2.0. On that basis, the tested assemblies provide demonstrated reserve capacity that can be drawn upon to meet higher seismic demands anticipated under TS 1170.5:2025, provided the ‘tested installation and detailing bounds’ are met.

5 REFERENCES

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