

ANGLELOCK® JOINT TECHNOLOGY WHITE PAPER

High Performance & Dynamic Aluminum Structure

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Original: July 13, 2022 · Revised: September 15, 2026 — Carl Richter, P.E.

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Abstract

Engineers favor the most abundant aluminum material in the Earth's crust. It is durable, lightweight, relatively soft, ductile, and malleable metal. One of the disadvantages of aluminum is that it is not strong and is always alloyed to improve its properties. Controlled Dynamics' marvelous innovation of the Anglock® patented connectors enables a high-quality T-slot aluminum framing system to sustain high loads in different modes: static vertical proof load of ~5100 N, static horizontal load of ~1615 N, tension load of ~8630 N, moment proof load of ~1800 N·m, and torsion load of ~319 N·m. This paper highlights the unique features of the Anglock® technology design, performance testing methodology, and analysis. While the aluminum structure profiles look similar to the traditional T-Slot design at first glance, their unique design features make them superior in structural integrity, reliability, and tight tolerances. Utilizing the Anglock® technology in various component configurations coupled with multiple aluminum profiles, Controlled Dynamics offers various engineering design solutions to the most common problems in structure framing, the aerospace industry, manufacturing, assembly, material handling, packaging, workstation design, and enclosures.

Problem Statement

The T-slot design has been in the market since 1975, using the most affordable and manufacturable aluminum material. The modular material offers a wide variety of extrusion profiles that could be used to build practically anything. However, due to its lack of strength and relatively soft properties, its application in various industries was limited. The dynamic load is compromised by the nature of the design of the connectors, where only frictional force is applied between planes (Figure 1). The pivot point allows for movement and slippage between components, causing misalignment and loosening of the fastener. An innovative design solution was needed to eliminate the planar contact and pivot point and offer a mechanical lock connector feature to achieve structural integrity, reliability, and tight tolerance.

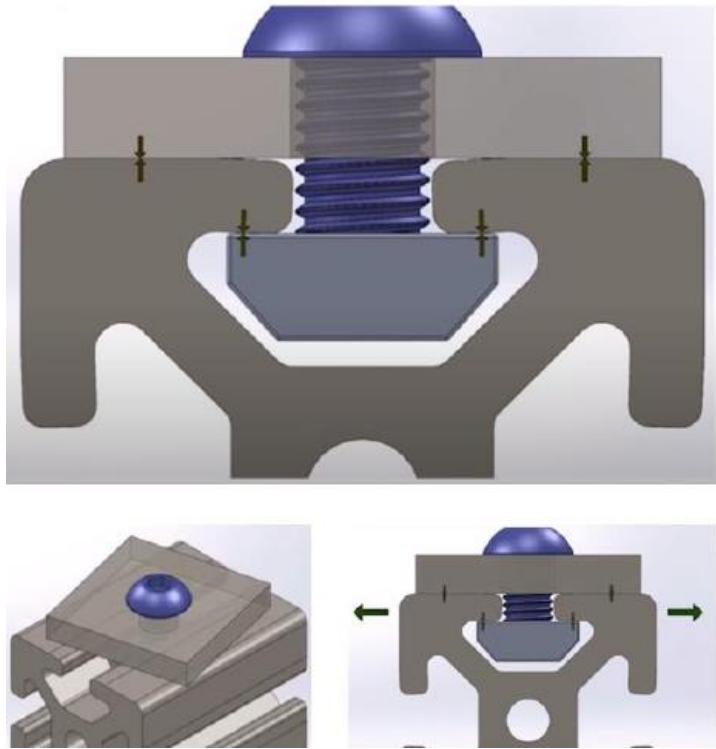


Figure 1: Traditional T-Slot Design (1975 Technology)

Background

The T-slot aluminum structure offers modular versatility with numerous extrusion profiles that have been used to build a variety of structures with simple designs while maintaining its aesthetic appeal. The bolted T-slot design is highly desired over welded, nailed, or permanently fixed connections. Therefore, it inherently provides fast assembly, easy reconfiguration, and the ability to reuse the materials for other projects in the future. The aluminum structure is used for complex builds like automated manufacturing lines, safety enclosures, robot frames, displays, carts, and architectural applications that can be built in small assemblies and shipped as needed. It is also rated for clean rooms and medical applications.

The traditional T-nut design is based on a frictional force between the contact planes that are subjected to pivoting, resulting in slippage between components, causing misalignment and loosening of the fasteners. This design feature limits the usage of the T-slot aluminum structure in various dynamic applications. Furthermore, the aluminum structure's strength was not fully utilized due to the weak connectors and the application of a much lesser load than the material strength can handle to prevent failures. Some designers provided various gussets and T-nut designs to solve this issue. However, the weakest link remained in the design concept of the T-nut coupled with the T-slot in the aluminum extrusion. A solution was very much needed that eliminates the frictional force approach in the contact planes to prevent slippage and fastener loosening.

Solution

Controlled Dynamics answered the industry call for a solution to the T-slot design limitation by providing the marvelous innovation design of the Anglelock® technology. It eliminates all pivot points, providing a complete mechanical lock as a dynamic load is applied.

How It Works:

The Anglelock® design is constructed of a nut that has three angled surfaces to meet matching angled surfaces on the aluminum extrusion profile. An angled screw is inserted in a threaded hole in the nut after passing first through the component fastening it to the aluminum extrusion slot (Figure 2). The steps taken to fasten components with the Anglelock® design, showing the five different contact planes, are illustrated in Figure 3:

1) & 2) Anchor the nut in two planes into the v-shaped area of the extruded profile.



Figure 2: Anglelock® Design

3) As the fastener is tightened, the nut rotates up and locks into the opposite side, anchoring itself into a third plane.

4) The upper bracket slides into position and is precision-aligned to the extruded profile, creating a fourth locking plane.

5) The fastener is brought up to its required torque; the appropriately sized bolt stretches slightly and friction is created in a fifth plane between the bracket and profile.

Unlike the traditional T-slot, where frictional contact force and pivoting planes result in fastener loosening, the Anglelock® design pulls the entire assembly together as it tightens, forming a mechanical lock.

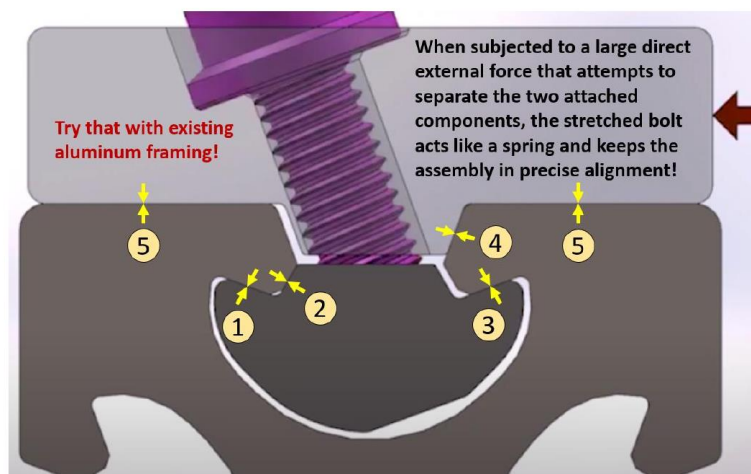


Figure 3: ANGLE-LOCK™ Patented Technology (2021)

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Test Methodology

Controlled Dynamics offers a wide variety of bracket designs utilizing the Anglelock® technology. The 40mm Heavy Duty Corner Bracket is used in this paper to demonstrate the bracket performance (Figure 4).

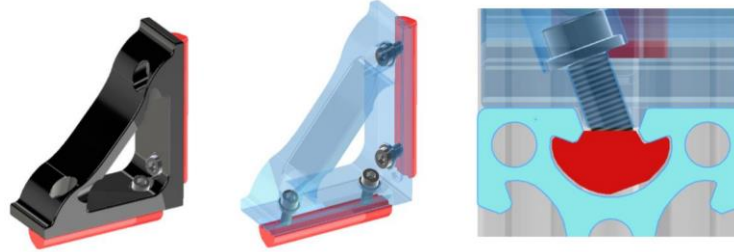


Figure 4: 40MM Heavy Duty Corner Bracket using ANGLE-LOCK Technology

Figure 4: 40mm Heavy Duty Corner Bracket using Anglelock® Technology

The Anglelock® support structure was tested and proved high performance in the following characteristics, and only the first three are presented in this paper:

- Supporting cantilever structure
- Moment and torque resistance
- Can be assembled and reassembled with precision
- Resisting cyclic load application
- Vibration applications

Testing the HD corner bracket provides very important data: the proof load at which the bracket could be used. The bolted joint is a stiff metal spring, and by tightening the nut, a tension load is created to pull on both ends of the bolt. As the tension load increases by tightening the bolt further, the bolt stretches like a spring pulled on both ends. By loosening the nut, the bolt returns to its original length the same way the spring would when the load is removed. This characteristic of a bolt is called elasticity. The elasticity is what causes the bolt and a nut to clamp down on both sides of a joint as the nut is tightened. Therefore, the proof load is the limit of the elastic range of the bolt, where the curve shown in Figure 5 is linear. The proof load by industry practice is typically 85–95% of the yield strength, and in this paper the conservative value of 85% of the yield load was applied to the test results.

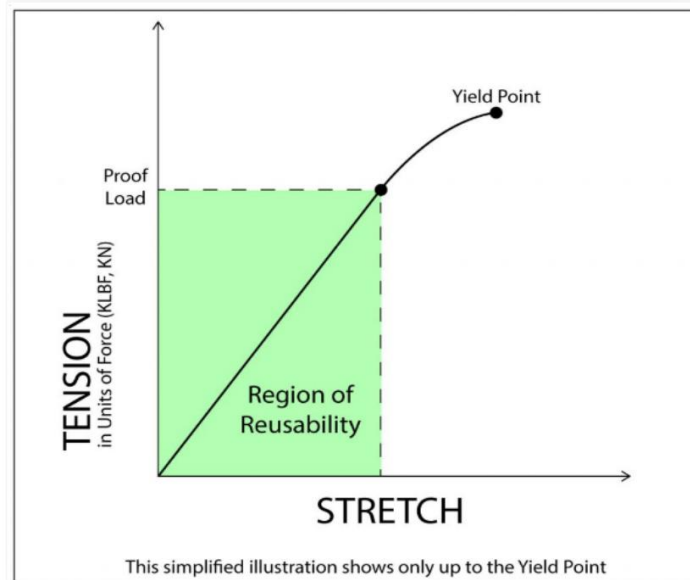


Figure 5: Bolt Proof Load Curve

A 40mm Heavy Duty corner bracket is mounted on Controlled Dynamics (CDI) 40x40 4-Slot High-Definition Extrusion, forming the assembly shown in each test configuration. The assembly is fastened to a hole-patterned plate and mounted on an Instron in four different test configurations for three test modes: vertical load test, horizontal load test, torsional, and moment load tests.

Suitable test fixtures were especially designed for each test configuration to secure the bracket in the desired test position and orientation. A cylindrical fixture was designed and fastened to the Instron head to apply the vertical and horizontal loads at a 250mm distance from the base of the assembly, ensuring even load distribution across the 40 x 40 4-Slot HD Extrusion.

Vertical Load Test

In the vertical test configurations, a 25 N preload was applied to the bracket assembly shown in Figure 6 at 250mm from the base. The vertical proof load (85% of the Instron yield strength) and fracture load were recorded and are shown in Figure 10.

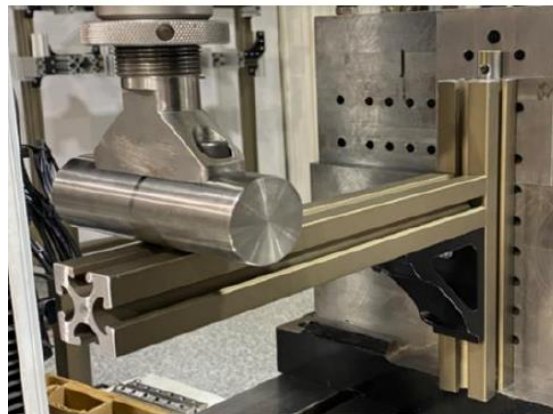


Figure 6: 40mm HD Corner Bracket mounted on 40x40 4-Slot HD Extrusion vertically

Tension Test

The test assembly's L-shaped vertical profile was fastened to the Instron head, and the vertical profile was constrained between two parallel, fixed test fixtures to apply tension load, as shown in Figure 7. A 25 N preload was applied to the bracket assembly, and the test results are shown in Figure 10.



Figure 7: 40mm HD Corner Bracket mounted on 40x40 4-Slot HD Extrusion in Tension

Horizontal Load Test

While the bracket orientation did not affect the vertical test, it certainly impacted the horizontal test results. Therefore, two different bracket orientations were considered, and they are referred to as Orientation 1 and Orientation 2, labeled in the test configuration images. A bracket is in "Orientation 1" when it is sitting on its side and the bolt heads are positioned to point downwards at the bottom of the bracket; in other words, the bolt is at an angle below horizontal. A bracket is in "Orientation 2" when it is sitting on its side and the bolt heads are positioned to point upwards at the top of the bracket; in other words, the bolt is at an angle above horizontal.

In the horizontal test configurations, Orientation 1 and Orientation 2, a 25 N preload is applied to the bracket assembly shown in Figure 8 at 250mm from the base. The horizontal proof load was determined as 85% of the Instron yield strength, and the fracture load data were collected and are shown in Figure 10.

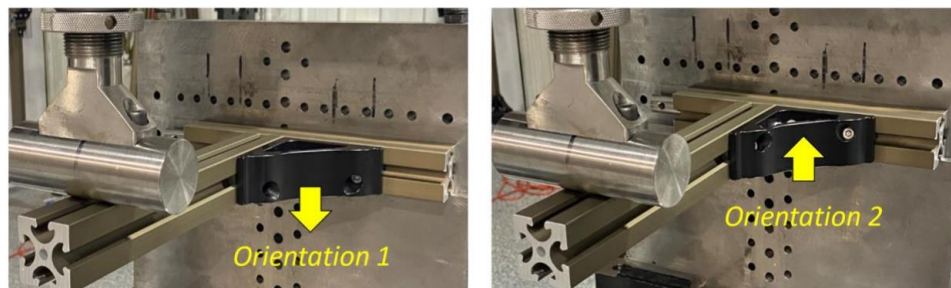


Figure 8: 40mm HD Corner Bracket Horizontal Test Configurations, Orientation 1 (left), and Orientation 2 (right)

Torsional Test

Like the horizontal test, the bracket orientation is shown to affect the torsional test results. In the torsional test configurations, Orientation 1 and Orientation 2, a 20 N preload was applied to the bracket assembly shown in Figure 9 at 250mm from the base. A 40x40 4-Slot HD extrusion profile is mounted on both sides of the bracket, forming a T-shaped assembly. The horizontal profile is constrained from rotational movement by two parallel cylindrical rods fixed to the test device, as shown in Figure 9. The vertical profile, which is fastened on the other side of the bracket, is fixed

on its free end to a rotating spindle applying the torsional load. The torsional proof load (85% of the Instron yield strength) and fracture load data were collected and are shown in Figure 10.

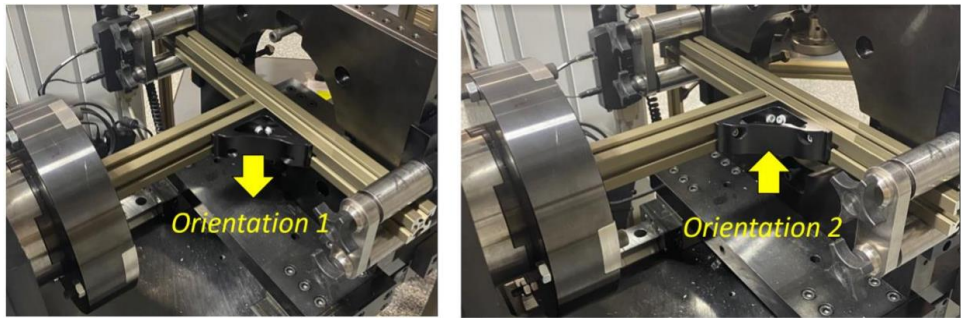


Figure 9: 40mm HD Corner Bracket Torsional Test Configurations, Orientation 1 (left) and Orientation 2 (right)

Test Results

The Instron data were collected from the five different test configurations (vertical, horizontal, and torsional), where the horizontal and torsional tests had two orientations (Orientation 1 and Orientation 2). The proof load and the fracture load are plotted in Figure 10, shown below.

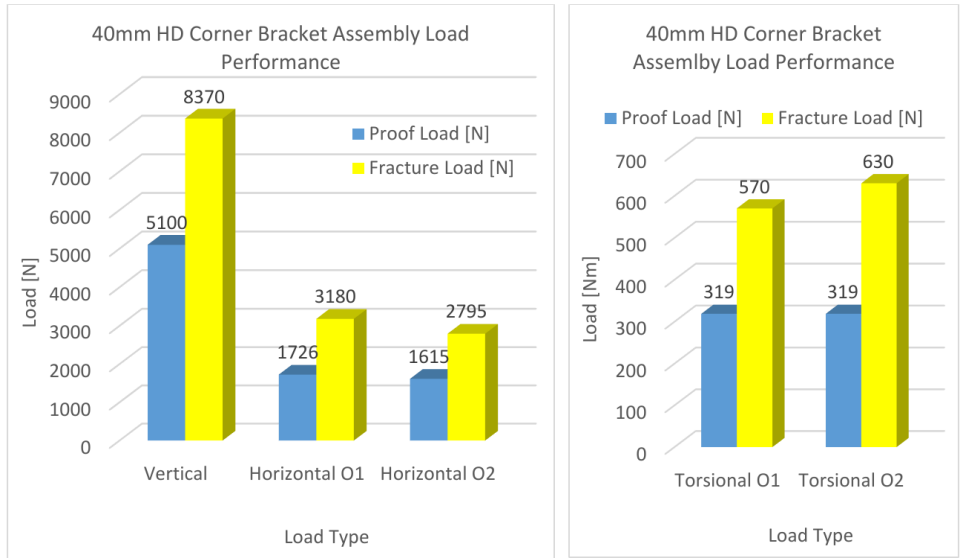


Figure 10: 40mm HD Corner Bracket Cantilever Load and Torsional Performance

Heavy Duty Extrusion Profile Analysis

The 40x40 4-Slot HD Extrusion profile’s performance (Figure 11) was analytically evaluated for tensile and shear loading in both directions, X-axis and Y-axis, and for torque loading. The analytical equations used to determine the proof loads, and the fracture loads are presented in the Discussion section, and the analysis results are shown in Figure 12 and Figure 13.

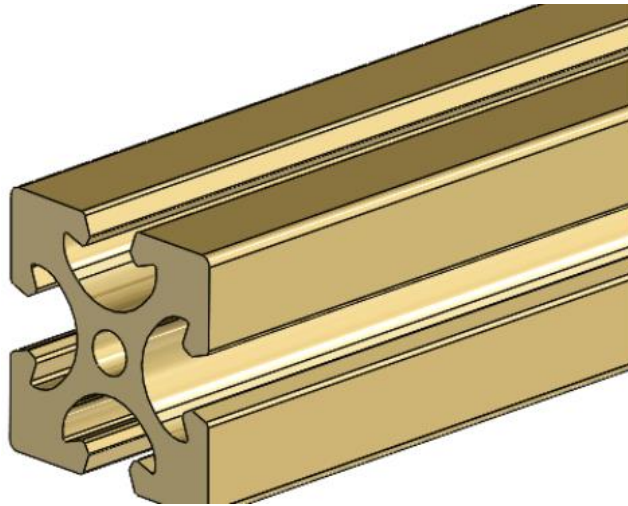


Figure 11: 40 x 40 4-Slot HD Extrusion Profile

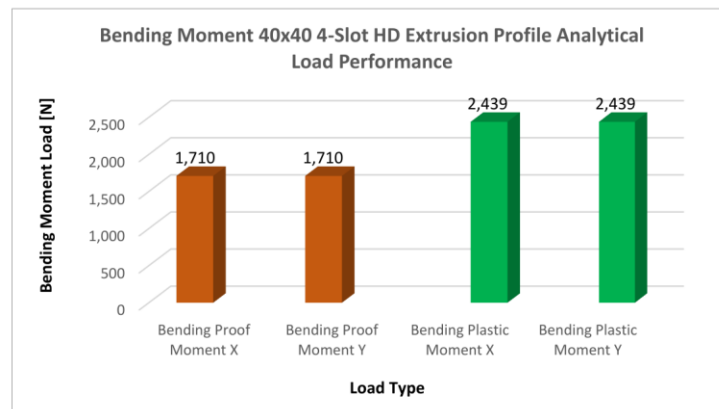


Figure 12: 40x40 4-Slot HD Extrusion Profile Bending Moment Load Performance

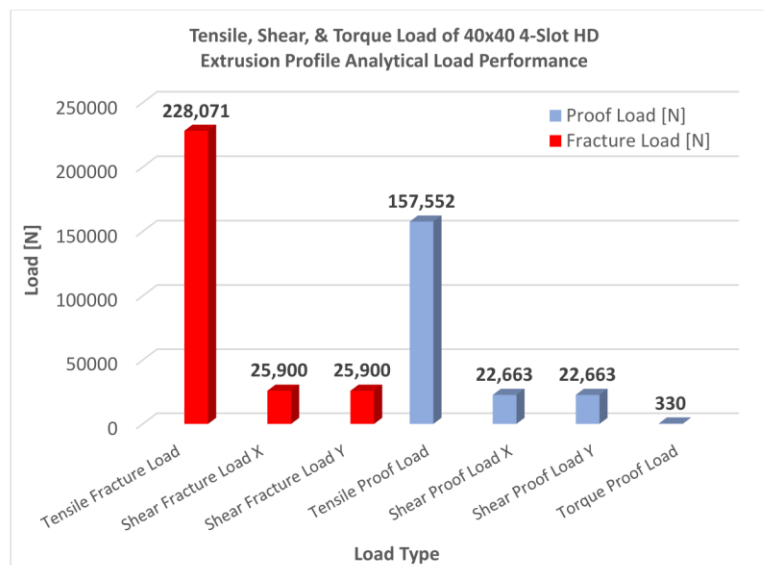


Figure 13: 40x40 4-Slot HD Extrusion Profile Tensile, Shear, and Torque Load Performance

Moment Tests

The moment tests were conducted with the bracket position and orientation taken into consideration, like the horizontal and torsional tests. In this test, two types of loads were tested: vertical load and horizontal load. The test configuration consists of an I-shaped 40 x 40 4-Slot HD Extrusion with two 40mm HD corner brackets mounted on one side of the I-shaped extrusion profile, as shown in Figure 14.

The vertical load is applied to the two-bracket assembly in two different orientations. When the brackets in the test setup are mounted above an I-shaped 40 x 40 4-Slot HD Extrusion, it is referred to as “Vertical – Closing,” and when the brackets in the test setup are mounted below the I-shaped extrusion, it is referred to as “Vertical – Opening.”

The horizontal load is applied to the same test assembly used for the vertical load, only rotated 90 degrees to be positioned horizontally in the test setup. In this test, Orientation 1 and Orientation 2, described previously, were considered and are labeled clearly in the test setup images associated with each test.

Moment Tests: Vertical – Closing

The test assembly is set up as described previously and is shown in Figure 14. The two vertical HD extrusions are fastened to two T-shaped test fixtures that rest on two cylindrical rods fastened to the Instron plate in the “Vertical – Closing” orientation. A preload of 25 N is applied at a rate of 5.08 mm/min. The Instron data were collected, and the proof load and the fracture load are shown in the moment test result chart in Figure 17.

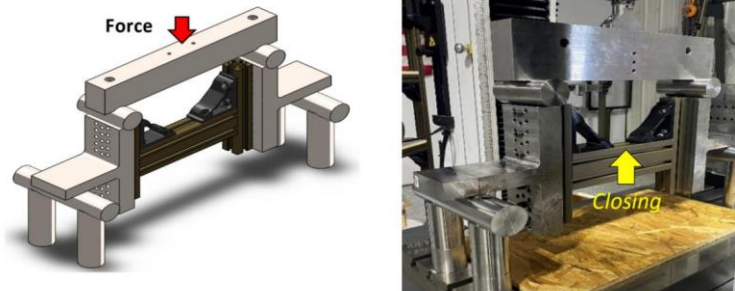


Figure 14: 40MM HD Corner Bracket Moment about X-axis-Closing test setup

Moment Tests: Vertical – Opening

The same moment test of the X-axis-Closing orientation was repeated after positioning the brackets to point downwards, as previously described, in the “Vertical – Opening” configuration shown in Figure 15. A preload of 25 N is applied at a rate of 5.08 mm/min. The Instron data were collected, and the proof load and the fracture load are shown in the moment test result chart in Figure 17.

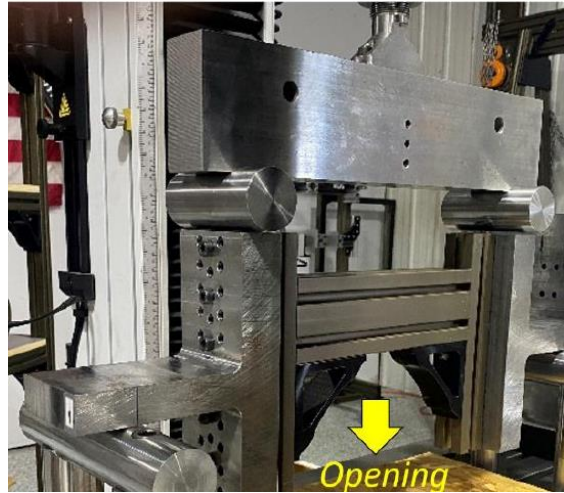


Figure 15: 40MM HD Corner Bracket Moment about X-axis-Opening test setup

Moment Tests: Horizontal – Orientation 1

The test assembly was positioned horizontally in “Horizontal – Orientation 1,” previously described and shown in Figure 16. A preload of 25 N is applied at a rate of 5.08 mm/min. The Instron data were collected, and the proof load and the fracture load are shown in the moment test result chart in Figure 17.

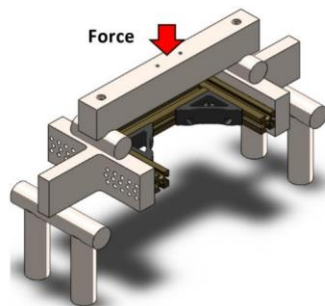


Figure 16: 40mm HD Corner Bracket Moment about Y-axis Orientation 1 (right) test setup

Moment Tests: Horizontal – Orientation 2

The test assembly is oriented in the “Horizontal – Orientation 2” configuration described previously, with the load applied the same way, as shown in Figure 16. A preload of 25 N is applied at a rate of 5.08 mm/min. The Instron data were collected, and the proof load and the fracture load are shown in the moment test result chart in Figure 17.

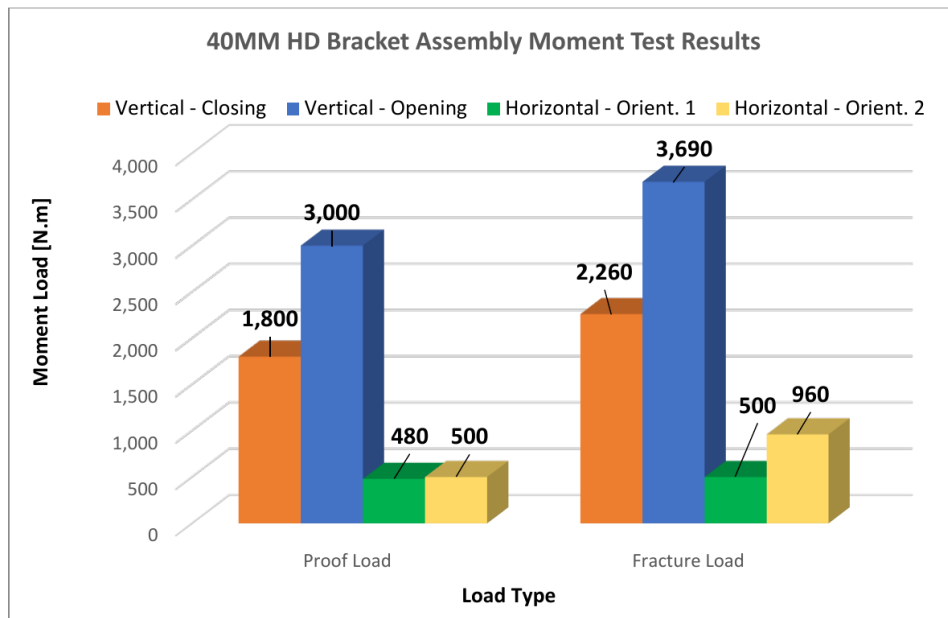


Figure 17: 40MM HD Bracket Moment Test Results

Self-aligning Assembly and Reassembly

A 40mm Heavy Duty Corner Bracket was used to connect two pieces of profile, as shown in Figure 18. This connection was then set upright, and two data points were collected at the bottom of the assembly and 254 mm away from the bottom along the vertical profile. First, a dial indicator was zeroed at the bottom of the vertical profile; then the gauge was moved 254 mm vertically and a second measurement was taken. The measurements show the deviation of the profile from the vertical axis.

After the measurements were recorded, the assembly was completely disassembled and reassembled in the same orientation, with the profiles in the same locations. The measurements were recorded again. These steps were repeated a total of 10 times, and the results are shown in Figure 19.



Figure 18: 40MM HD Corner Bracket - 40 x 40 2-Slots Profile Test Assembly

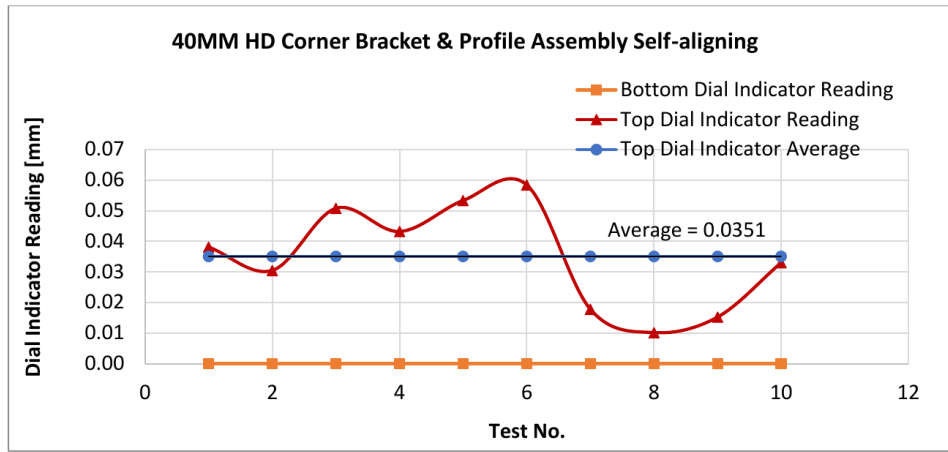


Figure 19: 40MM HD Corner Bracket Assembly Self-aligning Test Results

It is worth noting that some of the variance in the data is contributed to by the profile's "straightness" produced from the extrusion manufacturing process. Also, no squares or other alignment tools were used to aid in the assembly of the components, to perfectly emulate actual scenarios.

Discussion

Controlled Dynamics tested unique design solutions across various modes: axial load in the vertical and horizontal directions, torsional load, and moment load, using Anglelock® technology that other competitors don't have. To ensure repeatable performance, three specimens were used in each test, and the proof loads were calculated using the test result graphs from Figure 20 to Figure 24, shown below. Fracture loads were interpreted directly from the graphs. Also, all bolts on the brackets were torqued to 20.33 N·m for every test to maintain high-strength performance and consistency.

All test specimens were tested using the exact same setup procedure, materials, and fixtures to ensure repeatability. The precision of the brackets and connections was proven by the close values of the test data for each test specimen. The slight variation in the results could be due to the presence of oil or cutting fluid on the connection surfaces, which may have decreased the friction between the bracket and profiles. Another contributor to the slight variation in the test results is the use of components from different production runs, where the bracket anodization or the extrusion profiles may vary slightly from batch to batch. The extrusion profile performance was evaluated using the following equations.

Tensile Loading, 6005-T5 Aluminum

A) Tensile Proof Load: $P_{np} = F_{ty}A_g\phi_t$ (D.2.1)

B) Tensile Fracture Load: $P_{nf} = F_{tu}A_g$ (D.2.3)

Where F_{ty} = tensile yield, F_{tu} = tensile ultimate, A_g = cross-sectional area, and ϕ_t = building type limit factor.

Shear Loading, 6005-T5 Aluminum

A) Ultimate Shear Force: $V_{ux} = F_{su}I_xb_x / Q_x$, $V_{uy} = F_{su}I_yb_y / Q_y$

B) Yield Shear Force: $V_{yx} = F_{sy}I_xb_x / Q_x$, $V_{yy} = F_{sy}I_yb_y / Q_y$

C) First Moment of the Area: $Q_x = A'_x \bar{y}$, $Q_y = A'_y \bar{x}$

Where F_{su} = shear ultimate, F_{sy} = shear yield, I = moment of inertia, b = total thickness of material at centroid, and $\bar{x}$, $\bar{y}$ = distance from the centroid of the cross-section.

Bending Moment, 6005-T5 Aluminum

A) Proof Moment: $M_x = F_{ty}I_x / c_y$, $M_y = F_{ty}I_y / c_x$

B) Plastic Moment: $M_{px} = (F_{ty}A / 2)(d_a + d_b)$, $M_{py} = (F_{ty}A / 2)(d_a + d_b)$

C) Lateral-Torsional Buckling: $M_n = F_b S_c$

Where F_{ty} = tensile yield; I_x , I_y = moment of inertia; c_x , c_y = distance from the centroidal axis to the furthest edge of the profile; A = cross-sectional area; d_a = distance from the axis of equal area to the centroid of the half-area above the axis; d_b = distance from the axis of equal area to the centroid of the half-area below the axis; L_b = length of beam between supports; r_{ye} = effective radius of gyration; J = torsion constant; d = depth of beam; E = shear modulus; and S_c = section modulus of the compression side.

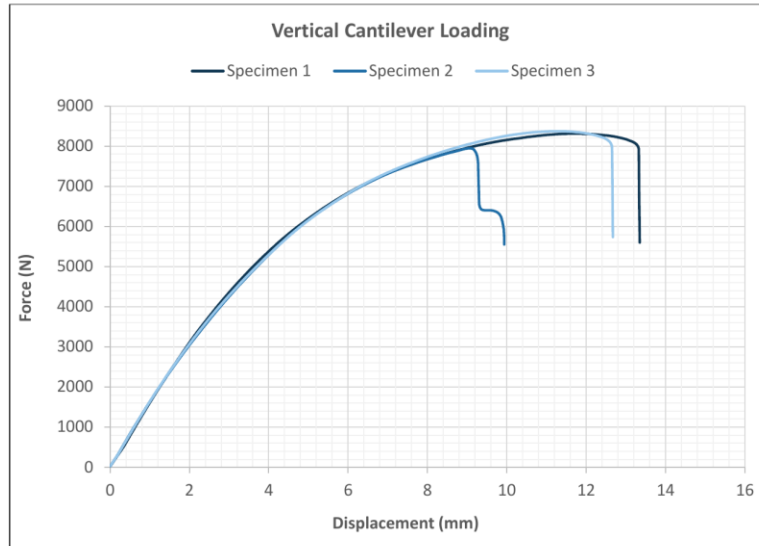


Figure 20: 40MM HD Corner Bracket Vertical Cantilever Loading

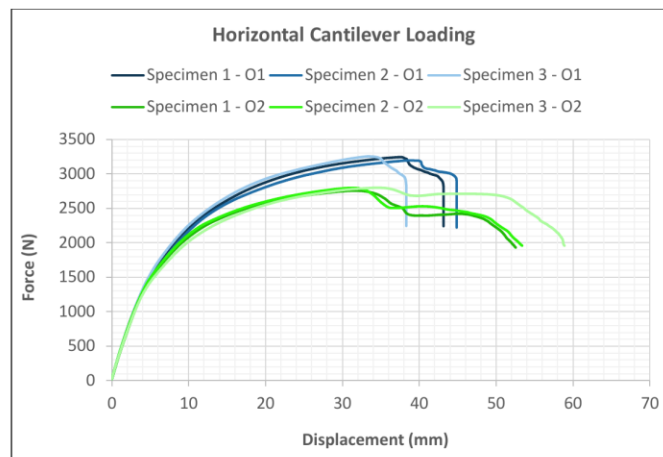


Figure 21: 40MM HD Corner Bracket Horizontal Cantilever Loading

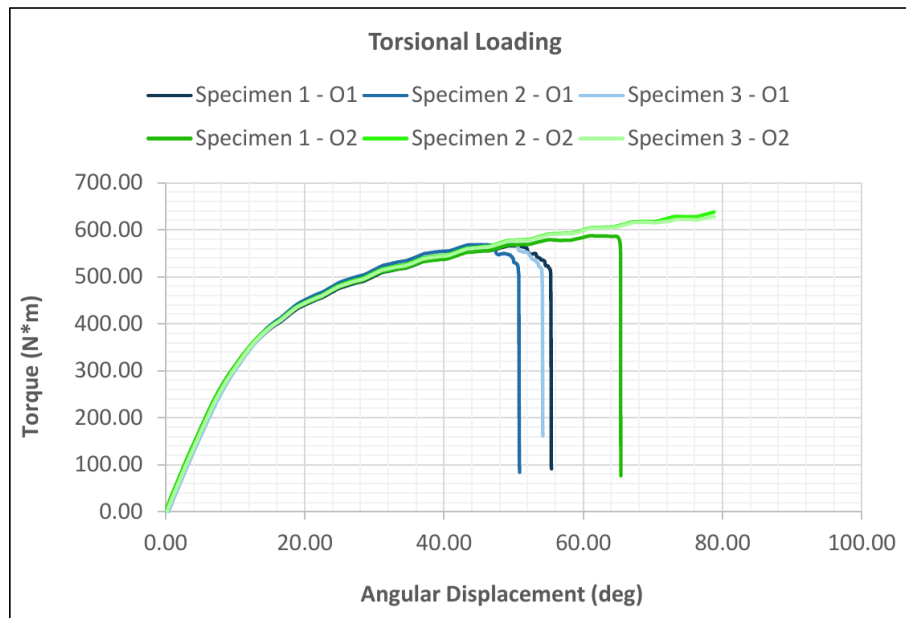


Figure 22: 40MM HD Corner Bracket Torsional Loading

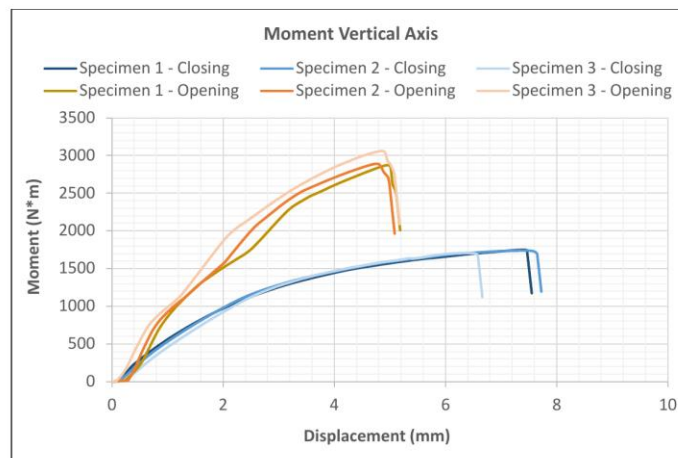


Figure 23: 40MM HD Corner Bracket Moment Vertical Direction

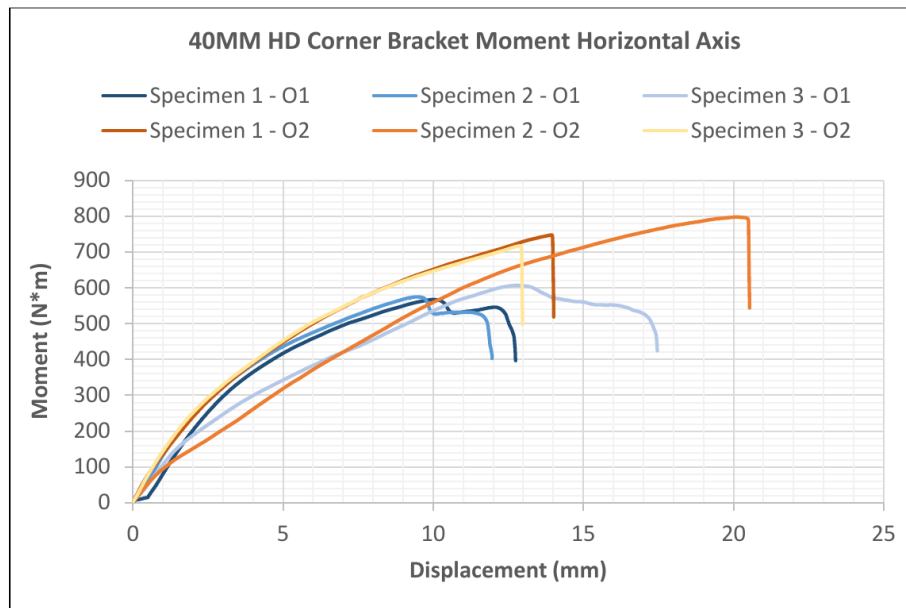


Figure 24: 40MM HD Corner Bracket Moment Horizontal Direction

Reconciliation with the Gerow FEA White Paper

This paper's analytical rail proof moment of 1,710 N·m (Figure 12) agrees closely (within 1%) with the rail limiting moment of 1,695 N·m independently reported in David Gerow, P.E.'s companion white paper, "Anglelock® Framing Can Be Analyzed with Beam-Element FEA," which tests the same 40×40 mm 4-Slot HD rail and heavy-duty corner bracket for its own purposes. Gerow's reported bracket moment capacity of approximately 2,900 N·m also falls within the joint proof-to-fracture range measured here for the Vertical orientations (1,800–3,690 N·m, Figure 17). Because both papers rely on the same underlying components, this agreement corroborates both data sets rather than presenting an apparent discrepancy to a reader who compares them directly.

Conclusion

The tests presented in this paper were conducted on the 40mm Heavy Duty Corner Bracket as an example of the many components Controlled Dynamics has to offer for various applications, shown in Figure 25.

Controlled Dynamics provided a unique solution to a long-existing design problem, which is overcoming the strength limitation of the abundantly used aluminum metal. The aluminum profiles and components Controlled Dynamics offers are specifically engineered for maximum strength and performance using the innovative Anglelock® design. The patented fastening system ensures assemblies stay together, providing a mechanical lock mechanism, self-aligning assembly and reassembly, and no ongoing maintenance. Such features give Controlled Dynamics products unmatched, superior performance, proven by various test modes that provide results that are repeatable and reliable.



Figure 25: Controlled Dynamics Components

Disclaimer

All the information on test data and analysis is presented to illustrate the performance of the CDI 40mm Corner Bracket assembly shown in this paper and is not to be used for bracket load reference. Customers will need to conduct their own tests and analysis based on their assembly load and configuration scenarios.

Appendix A: Change Log

This appendix documents the editorial and technical updates applied during the September 2026 review of Dr. Mera Horne's original July 13, 2022 white paper. The goal of this revision was to correct grammar, typographical errors, and factual inconsistencies while preserving Dr. Horne's original wording, section structure, and figure captions as closely as possible.

Location	Change	Rationale	Change by
Cover / Title	Trademark symbol standardized to "Anglelock®" (original used "ANGLE-LOCK™", "ANGL-LOCK™", and "ANGLE-LOCK ^{LM} " inconsistently across the document).	One canonical spelling throughout, consistent with the companion Gerow paper.	Carl Richter 9-15-2026
Test Methodology	Fixed broken cross-reference field "Error! Reference source not found." to read as a reference to Figure 4.	Corrects a legacy Word field-reference error present in the original document.	Carl Richter 9-15-2026
Test Results — Figure 10 caption	Corrected the figure caption from "...Cantilever Load and Tension Performance" to "...Cantilever Load and Torsional Performance."	The right-hand chart in Figure 10 plots Torsional Orientation 1 / 2 data (N·m), not Tension data; the original caption mislabeled it.	Carl Richter 9-15-2026
Torsional Test	Repaired an incomplete sentence ("Slot HD extrusion profile on both sides of the bracket forming a T-shape assembly.") into a complete sentence describing the test fixture.	Restores a dropped subject; copyediting only, no change in meaning.	Carl Richter 9-15-2026
Discussion	Added one paragraph ("Reconciliation with the Gerow FEA White Paper") cross-referencing David Gerow, P.E.'s companion FEA white paper.	Both papers test the same 40×40 mm 4-slot HD rail and heavy-duty corner bracket for the same underlying components; this paragraph shows the two data sets agree rather than leaving a reader to wonder.	Carl Richter 9-15-2026
Global	Grammar, spelling, and punctuation corrections throughout (e.g., "presentence" → "presence", "Controlled Dynamic offers" → "Controlled Dynamics offers", "were torques to" → "were torqued to", "it s aesthetic" → "its aesthetic", mismatched quotation marks around "Orientation 1" / "Orientation 2", and similar).	Copyediting only. Dr. Horne's original sentence structure, wording, section order, and figure captions are otherwise unchanged.	Carl Richter 9-15-2026
Global — units	Removed all parenthetical imperial unit conversions from the body text (lbf, in-lbf, and inches), leaving SI units only (N, N·m, mm). Example: "~5100 N (1146 lbf)" → "~5100 N"; "10 inches" → "254 mm".	Requested by Carl Richter: standardize the paper on SI units only.	Carl Richter 9-15-2026
Abstract	Fixed subject-verb agreement: "innovation...enable" → "innovation...enables."	Grammar error present in Dr. Horne's original document, caught on a dedicated grammar pass; copyediting only.	Carl Richter 10-2-2026