Facility Permit Program Deferred Submittal Requirements and Application

Minimum Submittal Requirements:

- ✔ A completed copy of this application.
- ✔ One PDF of plans stamped and signed by a Design Engineer or Architect registered in Oregon. NOTE: If a deferred submittal includes exterior elements, plan views and elevations approved by the Engineer and/or Architect of Record identifying the location must be included in the submittal.
- ✔ One PDF of calculations, if applicable.
- ✔ One PDF of product information, if applicable.
- ✔ **Submit to Email: PPDFPPIntake@portlandoregon.gov**
- ✔ Prior to submitting the deferred submittal, the Engineer of Record and/or Architect of Record responsible for the building shall review the deferred submittal plans and supporting materials and add a notation indicating that the deferred submittal documents have been reviewed and found to be in general conformance with the design of the building. The notation shall be made on the deferred submittal drawings. Review stamps on letters of transmission are not acceptable. Exception: the notation is not required on deferred submittals for roof trusses in residential construction when an Engineer or Architect of Record is not involved with the design of the building.

I certify this deferred submittal application meets the minimum submittal requirements as outlined above.

Applicant Signature Jianpeng Yang **Date** 5/12/2025

Contact Information

Contact name Jianpeng Yang

Address 9700 SW Capitol Hwy, Suite 110

City Portland **State** OR **Zip Code** 97219

Phone 503-290-1299 **Email** jyang@ameresco.com

Value of deferred submittal $0 **Issued FPP building permit #** 25-006099-000-00-FA

Job site address 3203 SE Woodstock Blvd, Portland, OR 97202

Description/Scope of work

Upgrade the existing central plant system in the boiler building to improve efficiency and reduce ongoing maintenance costs. Includes seismic upgrades, removal of existing boiler system and installation of three new boilers, upgrades electrical, and control systems. The scope also includes the interior renovations on the boiler building mezzanine, and level 1&2 of the office space. The deferred submittal includes details and calculations for Corebrace.

Engineer/Architect of Record for the building information

Name Peder Golberg **Phone** 503-226-1286

Design Engineer for the deferred items

Name Maria Eugenia Chumbita Garcia **Phone** 801-280-0701

Helpful Information:

Facility Permit Program

Portland Permitting & Development
1900 SW 4th Avenue, Portland, OR 97201
Submit to email:
PPDFPPIntake@portlandoregon.gov

Contact Information

Facility Permit Program main number: 503-832-5996
Email: PPDFPPIntake@portlandoregon.gov
Website: Facility Permit Program (FPP)

699 West Quinn Rd, Bldg. 28

Pocatello, ID 83202

(801)280-0701

Quality Assurance Procedures

For the

Buckling-Restrained Brace

Revision 7.6

15 August 2024

Proprietary & Confidential

DO NOT DUPLICATE

Controlled Copy ________ Number _______

Uncontrolled Copy _______

Table of Contents

List of Flow Charts

List of Check Charts

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

Corporate Quality Policy Statement

It is the intent of CoreBrace to produce steel products that are in compliance with all applicable codes, standards and job specifications. CoreBrace further certifies that they intend to manufacture Buckling Restrained Braces utilizing materials and processes that are essentially identical to test specimens in accordance with the Corebrace Quality Assurance Procedures and Manuals. All fabrication will be produced using **Engineer approved drawings and specifications**. At no time will modifications to the approved designs, or substitution of materials be made without the explicit approval of the Design Engineer. **Only approved materials shall be used**. All materials requiring traceability will be monitored with the appropriate documentation being maintained on file for review to verify compliance with material specifications. All departments shall comply with this policy.

CoreBrace has an independent **Quality Assurance Department** to monitor the production of Buckling Restrained Braces for compliance with code and job specifications. The department is **Independent** of the Production Departments and has final authority on all matters relating to quality and acceptance of the final product. The **Quality Assurance Manager** reports to the **President**.

It is the further goal of CoreBrace to provide a product that meets all of the customers' specifications and delivers it on time. All company policies and procedures will be initiated from West Jordan, Utah, including material trace-ability records and Quality Control Documentation. This Manual shall be reviewed as a minimum annually for revisions.

Approved:

Contact: Michael S. Linford, S.E.

President

mike.linford@corebrace.com

Project Specific Requirements

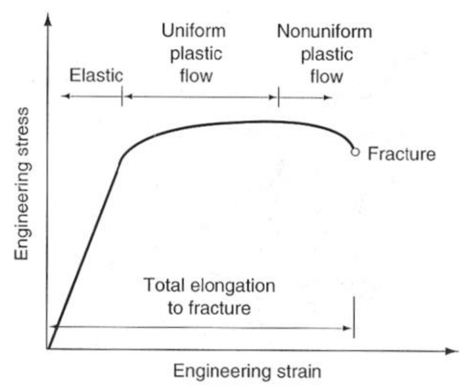
This manual covers Standard CoreBrace requirements. If a given project has specific requirements, they will be provided as a separate document.

Introduction

Steel used in structural design affords unique properties to the engineer. It is both strong and flexible. It's excellent elastic properties permit columns and beams to deflect under load and return to their original position. This elastic region, however, is only a small piece of steel's capabilities. As loads exceed the yield point of the steel alloy, the material can stretch or compress plastically. Permanent deformations in steel structures after a traumatic event, are evidence of steel's ability to deform without failure. The steel has "failed" in terms of allowable stress design, but the structure has not. The unanticipated stress has been effectively and safely removed due to the normal plastic deformation of the steel. Steel's ability to deform without fracture can be used by the designer to effectively absorb atypical stresses placed upon a structure by seismic activities.

One only needs to look at a stress-strain diagram of common structural steel to see why steel can safely plastically deform without catastrophic failure. The elastic region of the curve is only a small portion of steel's response during tensile stress. The area of uniform plastic flow represents a comparably large area of safe deformation for steel that is not normally utilized by the Engineer. The toughness of the steel permits the material to absorb the strain energy imposed by the particular load without cracking or failure. Utilizing the region of uniform plastic flow increases the engineering potential of this economical material. The COREBRACE Buckling-Restrained Brace effectively harnesses this potential.

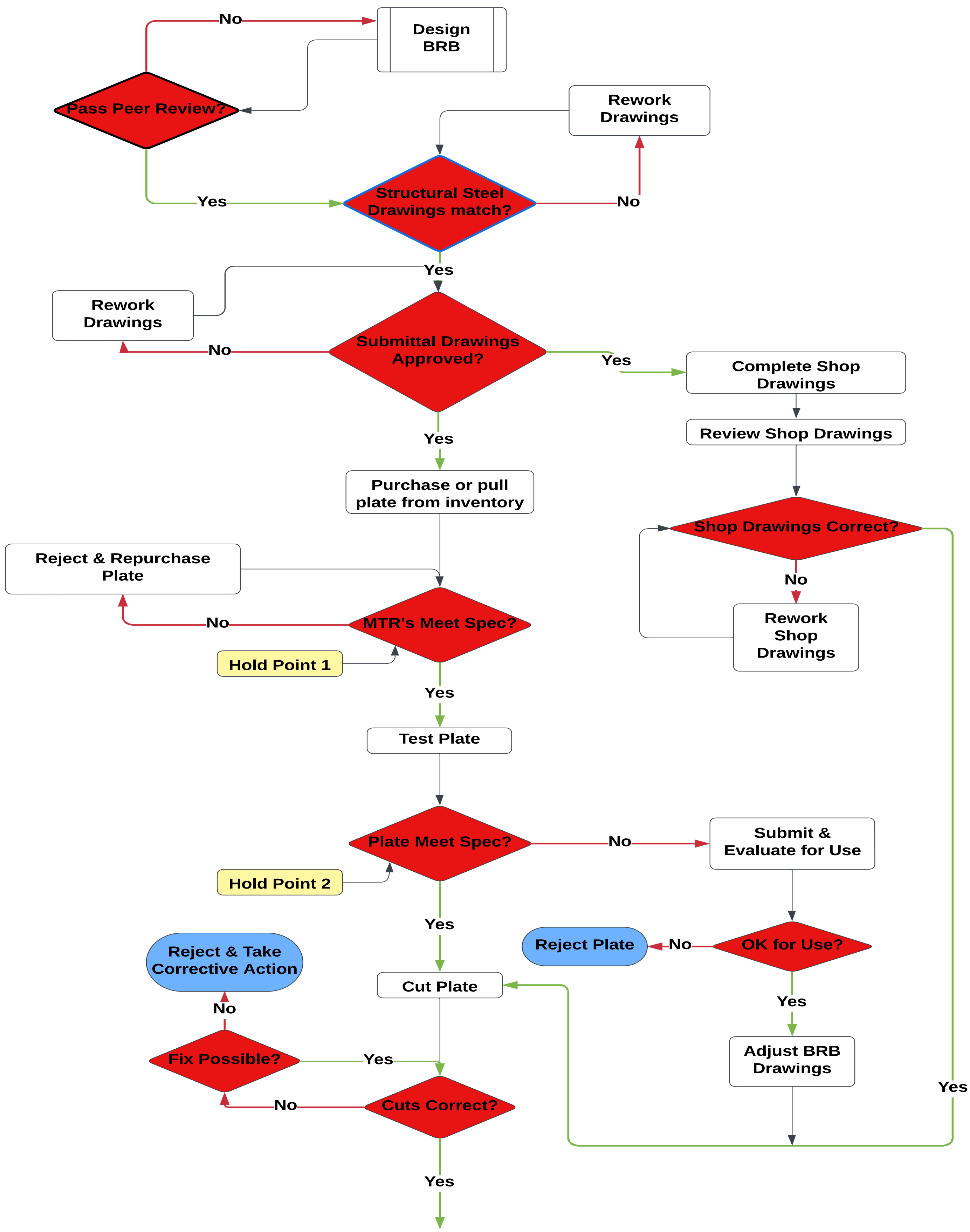
COREBRACE has developed the Buckling-Restrained Brace and characterized its properties through extensive testing of full-scale brace mock-ups. The repeatability of the tests and the quality of the actual product is assured through the company quality program.



Typical Steel Stress/Strain Curve

The designed plastic flow of the steel must be controlled and remain in plane to adequately support a given structure. The unique COREBRACE design surrounds the load carrying steel core in a Proprietary Fill Material (PFM) filled HSS casing. The strength and stiffness of the PFM and casing keeps the steel core from buckling out of plane while absorbing the stretching and compressing loads encountered during seismic activity. Special proprietary interface materials (PIM) isolate the steel from the PFM to permit the steel to slide within the casing elements without binding and thus optimizing uniform plastic flow.

The toughness is built into each heat of steel purchased. Properties are verified for each piece incorporated into the core of a Buckling-Restrained Brace. Welding is controlled following the requirements of the American Welding Society as modified by COREBRACE. PFM mix designs and placement are carefully controlled to assure uniform mechanical properties and repeatability. Every effort is taken to assure that each Buckling-Restrained Brace performs as designed.


Design BRB
Pass Peer Review?
No
Yes
Rework Drawings
Structural Steel Drawings match?
No
Yes
Rework Drawings
Submittal Drawings Approved?
No
Yes
Complete Shop Drawings
Review Shop Drawings
Shop Drawings Correct?
No
Rework Shop Drawings
Yes
Purchase or pull plate from inventory
Reject & Repurchase Plate
MTR's Meet Spec?
No
Hold Point 1
Yes
Test Plate
Plate Meet Spec?
No
Submit & Evaluate for Use
Hold Point 2
Yes
OK for Use?
No
Reject Plate
Yes
Adjust BRB Drawings
Cut Plate
Reject & Take Corrective Action
No
Fix Possible?
Yes
Cuts Correct?
No
Yes
Yes

PRODUCT ACCEPTANCE

Quality Assurance

The successful completion of the **Product Acceptance Plan** and Testing verify that the fabrication processes used to build the Buckling-Restrained Brace meet the designed performance specifications. By controlling certain critical fabrication operations, CoreBrace assures they will repeatedly provide a product that will perform as originally tested. Purchasing, material preparation, assembly and special processes are closely monitored, and the data recorded for examination. The data verifies company fabrication operations are within the tolerance limits needed to maintain product reliability.

The steel core component of the brace requires the most monitoring and in-process testing by CoreBrace. The materials are tailored into the Buckling-Restrained Brace by testing and heat number traceability. Certifications and qualifications are checked before any fabrication begins. Fabrication methods are modified to conform to the parameters established by testing in the **Product Acceptance Plan**. Only after complete acceptance of the steel core by CoreBrace inspectors, are these welded assemblies cast into their PFM sleeves.

The outer casing of the brace is made of three parts: an outer steel casing, a PFM matrix, and a proprietary interface material (PIM) between the PFM and assembled steel core. The steel core is carefully wrapped with the PIM. Precision assembly is required to provide the desired plastic deformation performance of the steel core. PFM is placed using the same techniques proven in the **Product Acceptance Plan**. Destructive tests are performed on samples taken from each batch of PFM used while casting the Buckling-Restrained Brace.

Verification of product quality is performed at various stages of CoreBrace fabrication. It is important to document acceptance of all fabrication activities critical to the performance of the Buckling-Restrained Brace before proceeding with subsequent operations that could make rework or repair more costly or difficult to perform. Inspection results are recorded on CoreBrace inspection report forms and stored in company archives as required by the Quality Assurance Procedures and Manuals. A documentation package is assembled for each individual Buckling-Restrained Brace to record the tests and inspections performed on each brace assembly. Braces and component pieces are tagged in accordance with the CoreBrace Steel Tagging Procedure. Red tags signify that a hold point has not yet been accepted or that other rework operations must be performed. If discontinuities or process discrepancies are found during inspection, the inspector documenting the situation for management review and corrective action writes nonconformance reports.

This manual designates procedures that are imposed on CoreBrace operations to assure quality. The supplemental Quality Assurance Manual specifies technical requirements for quality assurance. The Quality Assurance Procedures govern over the Quality Assurance Manual.

PLATE RECEIVING

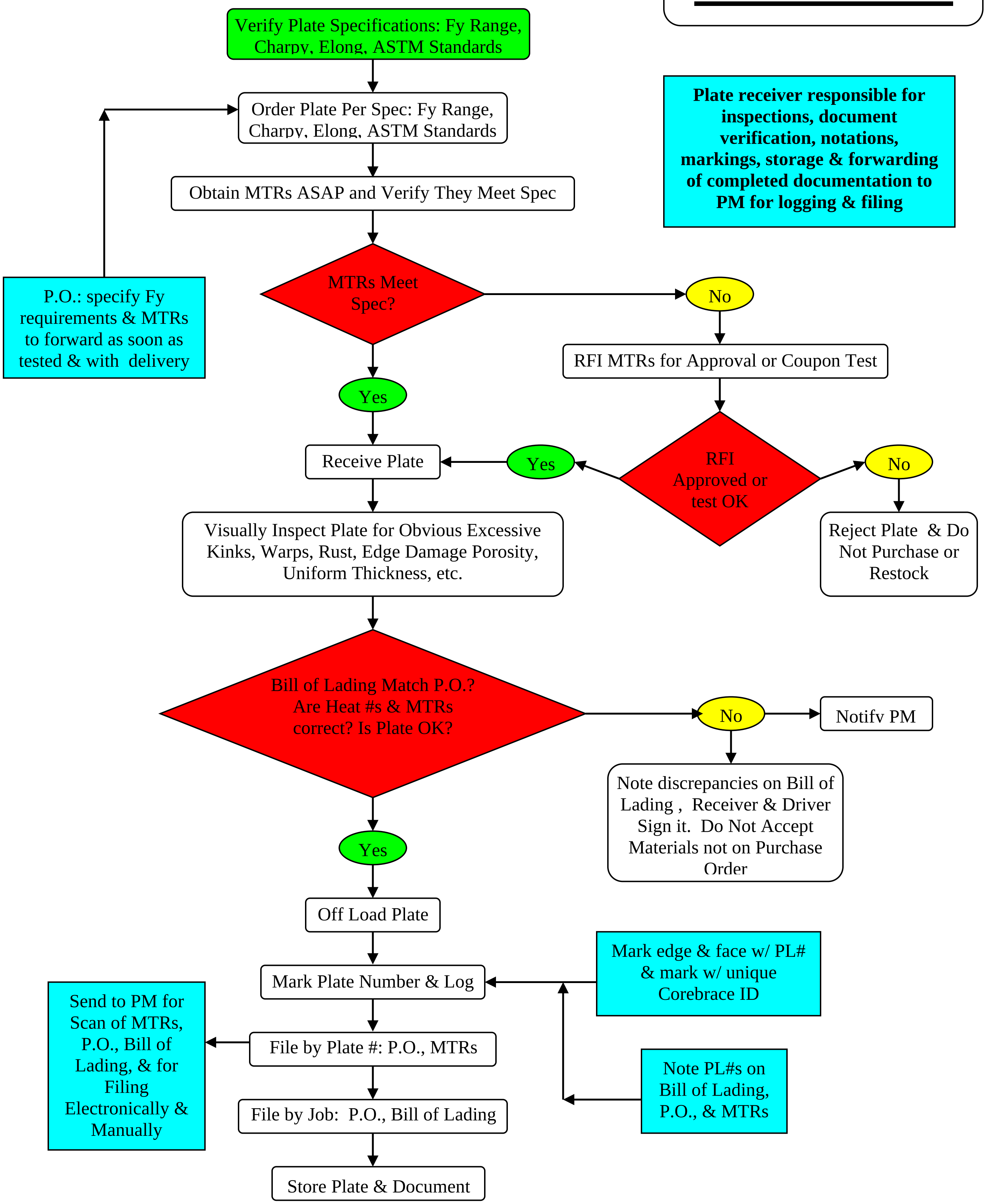


Plate Material Receiving

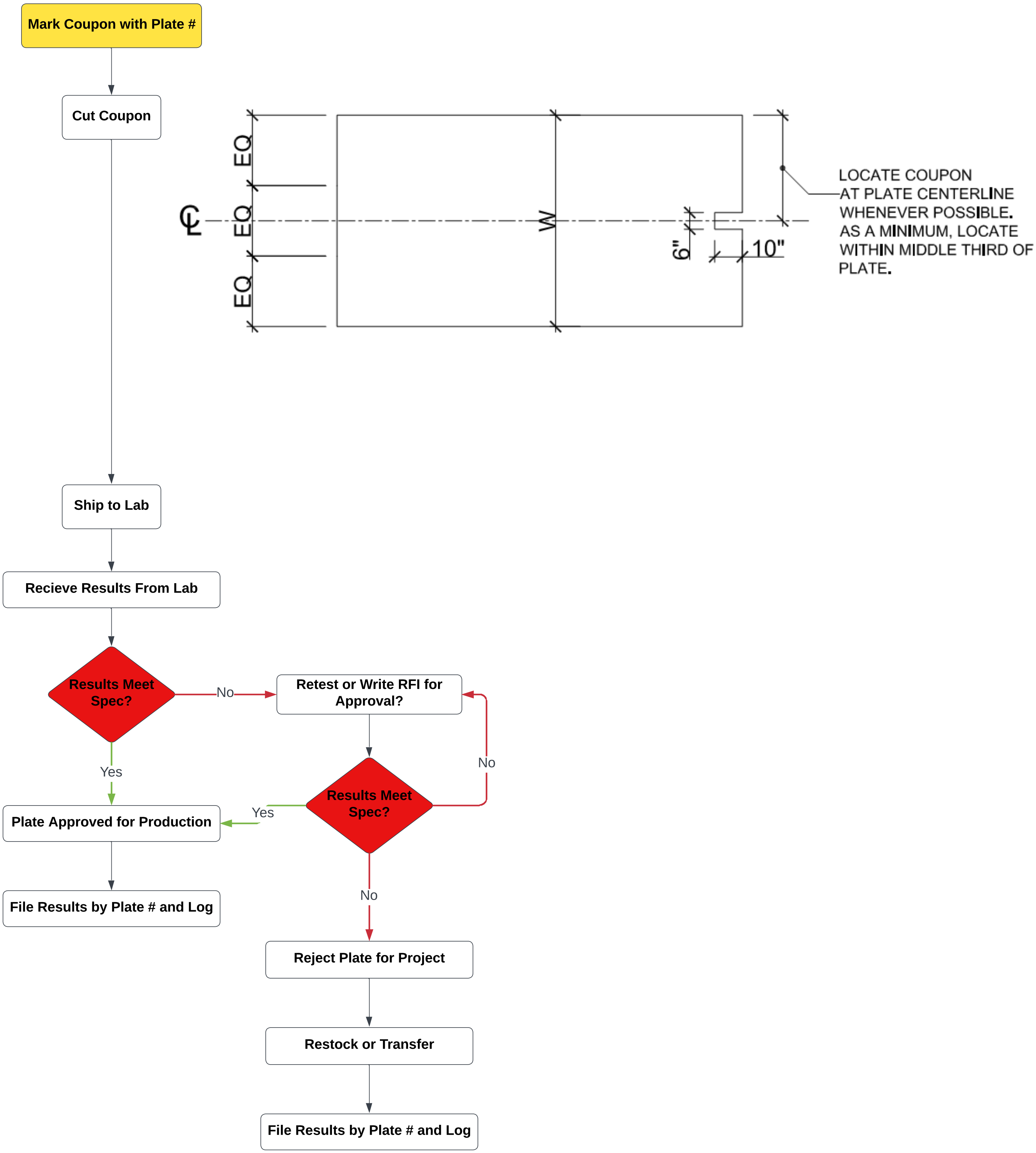
The steel plate used in the fabrication of the Buckling-Restrained Brace steel cores is purchased and controlled in accordance with The American Institute of Steel Construction Code of Standard Practice and the CoreBrace Quality Assurance Manual. The Code of Standard Practice requires that all structural material received by CoreBrace be traceable to its certifying documents. The CoreBrace Quality Assurance Manual further requires that the material used for the Buckling-Restrained Braces be readily traceable to its certifying documents during all phases of fabrication.

Once submittal drawings have been reviewed and the structural steel layout drawings match, the steel plate can be ordered. Material standards for the plate are verified for the order. The thickness and quantities of plate are verified for the order. Plate is ordered with issuance of Purchase Order (PO) agreement only. Purchase Order must specify the plate acceptable range for Fy as per specification and ASTM standards it must meet. The results of the Mill Test Reports (MTRs) shall be forwarded as soon as test results are recorded. Copies of the MTRs are also sent with the plate shipment. MTRs are verified that they meet material specifications for project and are data based, logged, scanned, and filed both electronically & manually in the Plate # folders by the Project Manager (PM). Then Project Manager shall submit MTRs for review. If MTRs do not meet material requirements, either perform coupon test, reject plate or write Request for Information (RFI) for acceptance of use and coreplate dimension adjustments. Additional coupon tests are performed as required on project specifications.

The received plate is inspected for obvious kinks, warps, excessive rust, damaged edges, contaminates, deformities, surface porosity, uniform thickness, etc. If any unacceptable traits are observed, they are reported to the QC inspector. Plate with noted problems is subject to rejection and may not be offloaded. Prior to offloading, the Bill of Lading is checked against original PO. Also, the Heat #s and MTRs are verified. Any discrepancies shall be noted on the bill of lading and signed both by the driver and receiver and the PM shall be notified of such ASAP. Non-conformity between Bill of Lading and PO may be cause for rejection of part or all of shipment. Receiver shall notify Project Management (PM) of any such discrepancies. The plate is off-loaded from the delivery trucks and stored in protective areas. It is verified that Heat numbers have been printed on these plates by the producing mill. The heat number is a unique identification code established by the producing mill to positively distinguish the plates received at CoreBrace from other plates produced by the mill. The heat number on the material corresponds with an identical heat number recorded on the material test reports (MTR) provided by the mill for documentation. The MTR records the results of the testing performed by the mill as they verify their materials meet the requirements of the controlling ASTM material specification and the CoreBrace purchase order. Each received plate is marked with next sequential and unique plate number (PL#). CoreBrace marks all of the components as they are cut from these plates with the corresponding PL#. All cut parts may then be traced back to the specific MTR as they are processed through company fabrication operations.

Receiver is responsible for all duties associated with receiving plate as noted here-in, including all inspections, markings, document verification, noting any dispositions, documenting stored location, and forwarding all such documentation to PM for records & filing. for resolution of all dispositions and recording and filing of information both electronically and manually.

COUPON TESTING



Coupon Testing

The governing ASTM specifications permit the producing mill to determine compliance of all plates rolled in one heat based upon tensile tests run on a representative sample of the heat. The mill test reports (MTRs) will be used to determine plate material compliance with specified requirements. If MTRs are not in compliance, or if required by the project specifications, COREBRACE may elect to perform additional tensile tests on at least one plate of steel in a heat in conformance with ASTM A370 and ASTM E8. The actual tensile and yield strength values obtained from these additional tests will be used to determine compliance with the specified requirements.

Test coupons are cut from the end of the plates at typically the midpoint in from the edge of the plates. From this coupon, two samples are milled by the testing lab, to be tested in the longitudinal direction. Specimens are marked with the COREBRACE plate # and then shipped to the lab.

Test results are received from the lab and the average of the two tests is compared to the project specifications. If test results meet specification the plate is approved for production. If test results do not meet specification resampling and testing may be performed. If test results still do not meet specification, the plate may be rejected or an RFI may be written to adjust BRB design per test results. If design adjustment is deemed acceptable the plate will be released for production and the shop drawings will be revised accordingly. Otherwise plate shall be rejected for the project. Rejected plate shall be restocked for future projects with different specifications or transferred out of inventory. All actions will be logged in the data base plate log and filed to the plate corresponding plate # file.

Welding Material Control

Welding materials are similarly controlled. Filler metals are purchased to conform to the requirements of the latest edition of American Welding Society (AWS) and CoreBrace welding procedures. Shielded metal arc welding electrodes conform to AWS A5.1/A5.1M, flux-cored arc welding electrodes conform to AWS A5.20/A5.29, and electrodes used for gas metal arc welding and metal cored arc welding or submerged arc conform to the requirements of AWS A5.18/A5.28 and A5.17/A5.17M respectively. Each container is printed with the manufacturer's statement of conformance to the appropriate AWS specification. Welding filler metals are produced in a continuous process, not subject to distinguishing identification that characterizes discreet batch runs common to structural steel members. The manufacturer, to comply with AWS specifications, tests the filler metal forming process regularly. The minimum tensile strength of the E70 class electrodes used in production is 70,000 psi [470 MPa]. The welding materials are also selected for toughness. These materials provide production welds with minimum Charpy V Notch (CVN) properties of 20 ft-lbs [27 J] @ -20°F [-30 C]. All filler materials used in joining are certified as "low-hydrogen" by the manufacturer. They meet H16 requirements of the filler metal specifications and are tested by the manufacturer to verify diffusible hydrogen levels are below 16mL per 100 g of deposited weld metal.

Production welds using low-hydrogen welding materials and techniques provide superior mechanical properties in the finished weld. Moisture contamination of the welding filler materials and submerged arc welding flux must be prevented and is controlled throughout all phases of fabrication. Welding materials are off-loaded and stored in a protected area in the manufacturer's original packaging to prevent atmospheric contamination. Welding materials are used and stored in accordance with the manufacturer's requirements to maintain the low-hydrogen condition of the materials.

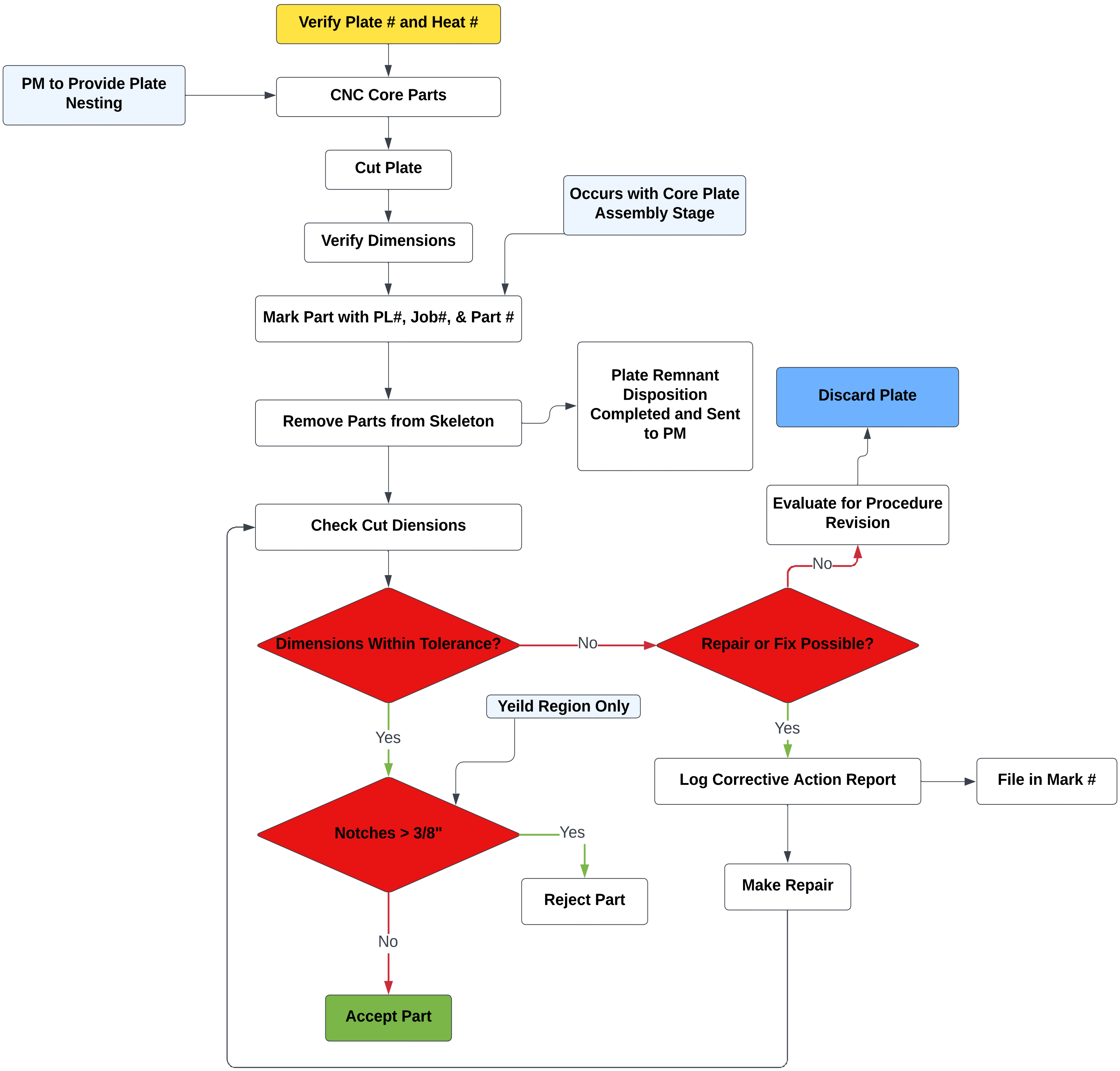
Welding electrodes used for shielded metal arc welding are stored in heated rod ovens after they have been removed from their original containers. They are held at a minimum holding temperature of 250°F [121 C] until they are released for use by the company leadman or quality control inspector. Typical shielded metal arc welding electrodes used to fabricate the steel brace are permitted to be exposed to atmospheric contamination for no more than 4 hours, though specially formulated "moisture resistant" electrodes are available that may be exposed for up to 9 hours without degrading the mechanical properties of the weld. Electrodes that have not been used within the allowable exposure time are reconditioned by baking a maximum of one time in a separate rebake oven held at a minimum of 500°F [260 C] for at least 2 hours or discarded.

The bare ends of the electrodes are painted to identify them as reconditioned. The reconditioned electrodes are placed back into the holding ovens for production use. Electrodes may only be reconditioned in this manner once. They are scrapped after being exposed to the atmosphere a second time.

Spooled or barreled welding electrodes used for flux-cored, gas-metal, metal cored, and submerged arc welding will be protected from atmospheric contamination during use. Condensation of moisture on the surface of the electrode must be minimized to maintain the low hydrogen properties of the filler metal. Spools of filler metal remaining on the wire feeding equipment will be covered when not in use to prevent moisture condensation on the wire overnight. Equivalent methods may also be employed to prevent moisture condensation, such as spool covers furnished with some wire feeding equipment. All covers should permit some airflow within the cover to prevent moisture condensation under the preventative cover. Ideally, spooled welding electrodes should be consumed within the exposure limitations specified by the manufacturer after removal from the original container.

Fluxes used for submerged arc welding must be dry and free of contamination from dirt and other foreign material. The flux is stored in covered containers that properly identify the type and brand of stored flux. Flux may be stored in the manufacturer's original hermetically sealed container for up to six months without degradation. Open bags of flux may remain in the work area while submerged arc welding operations are being performed. If flux is used from an open bag, the top one-inch of flux shall be discarded before use.

CORE PLATE FABRICATION



Core Plate Fabrication

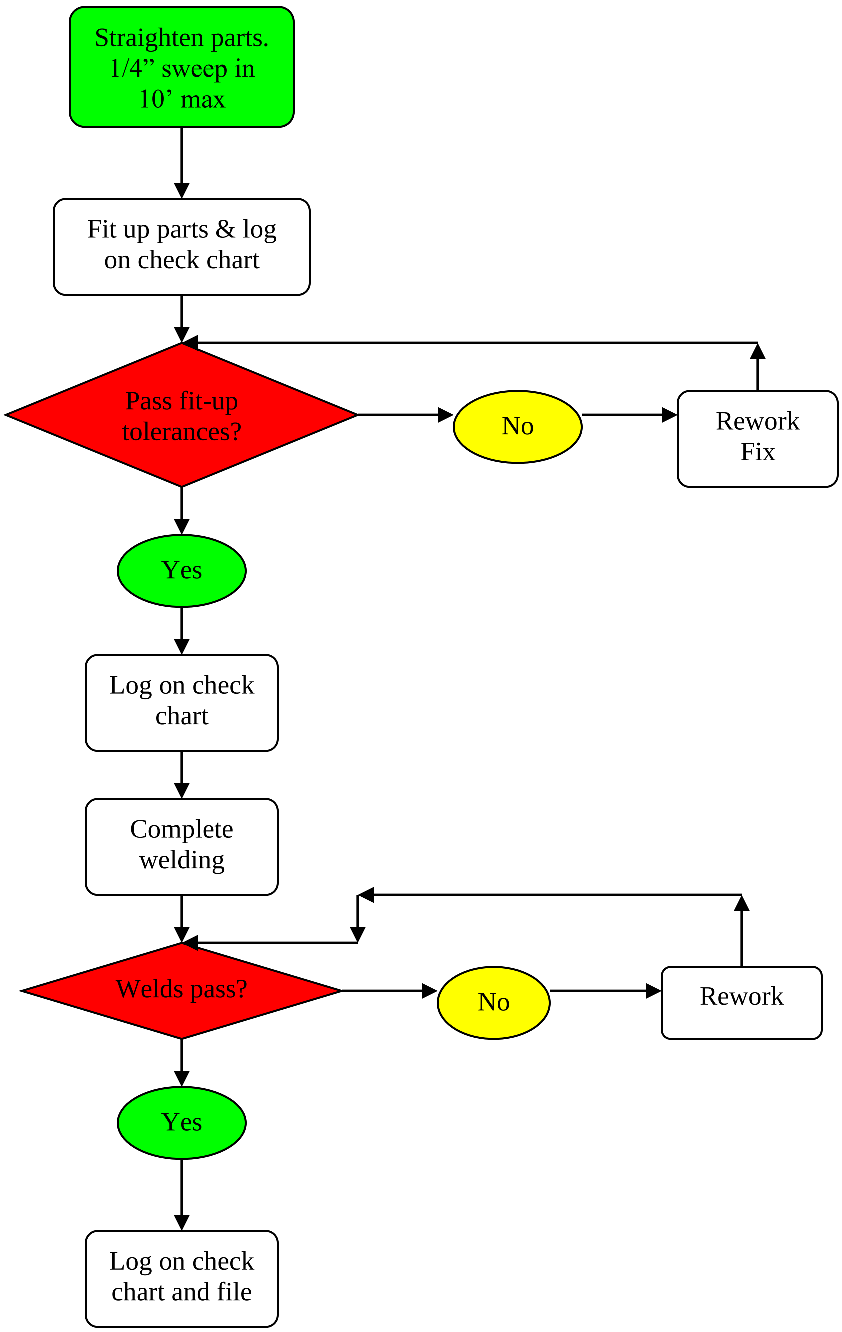
Steel brace components are laid out and "nested" on the plates before CNC cutting. The identifying material heat number is recorded onto each component piece in a location and manner that will not be obliterated or hidden by subsequent fabrication operations. CoreBrace operators verify the correct transfer of heat numbers to the components and release the plate for cutting.

The components are cut by oxy-fuel and plasma CNC cutting techniques. Plate # are verified. The oxy-fuel and plasma cutting process provides excellent dimensional accuracy with square cuts. The general roughness of the cut in the yielding length and elsewhere cannot exceed CoreBrace standard. The roughness is compared to base samples for acceptance. The cut edges are dressed by grinding to remove occasional notches and carburized metal. Notches are repaired by grinding or welding in accordance with CoreBrace repair procedures. The repairs in the yielding region may be subject to Magnetic Particle Testing (MT) procedures in conformance with AWS D1.1/ASTM E709. Notches greater than 3/8” in the yield length may be cause for rejection of the piece.

The cut edges of the components are also visually inspected for laminar discontinuities. If there is any evidence of such discontinuities the piece will be examined via UT process. Discontinuities are evaluated and repaired in conformance with the requirements of AWS D1.1 section 7.14, Preparation of Base Metal.

Dimensional tolerances are checked at fit-up. Parts are marked with Plate # and Part # and okayed for dimensional check. If parts are not acceptable, repair, fix or other use is considered. If so, a corrective action is logged. Repairs, fixes or reallocations are made and the parts are rechecked. Tolerance checks are recorded in the inspection reports. Inspection reports require indication of inspection and initial of inspector prior to BRB parts proceeding to next operation.

CORE PLATE ASSEMBLY



Core Plate Assembly

Fabrication of the Buckling-Restrained Brace begins after CoreBrace has accepted material preparation. After acceptance, material is released for further processing. CoreBrace QC inspector checks the piece mark numbers and plate numbers against the assembly list to verify the particular brace is assembled with the correct material.

The component pieces are assembled according to the shop detail drawings. Gaps between pieces are as required by AWS D1.1. Alignment, squareness and sweep checks shall be as per CoreBrace's proprietary standard.

The only welds permitted on the Buckling-Restrained Brace are shown on the shop detail drawings. No unauthorized welds are allowed. Temporary attachments to facilitate fit-up and welding are permitted outside of the yielding segment. All tacks used to assemble the braces must be incorporated in the final weld. All temporary attachment welds must be completely removed by grinding and the area visually checked by the fitter for excessive reduction in component thickness or cracking in the material. All final welds and reworked temporary attachment areas will be inspected in accordance with AWS D1.1 as modified by CoreBrace.

After assembly, the welder checks the tack welds before final welding to ensure the tack welds are clean and free of slag or foreign material that could prevent quality welding. The tack welds are also checked for cracks or other welding discontinuities at this time. Tack welds are performed to the same acceptance criteria as the final weld. Welding of the steel brace begins after the welder has determined the tack welds are acceptable.

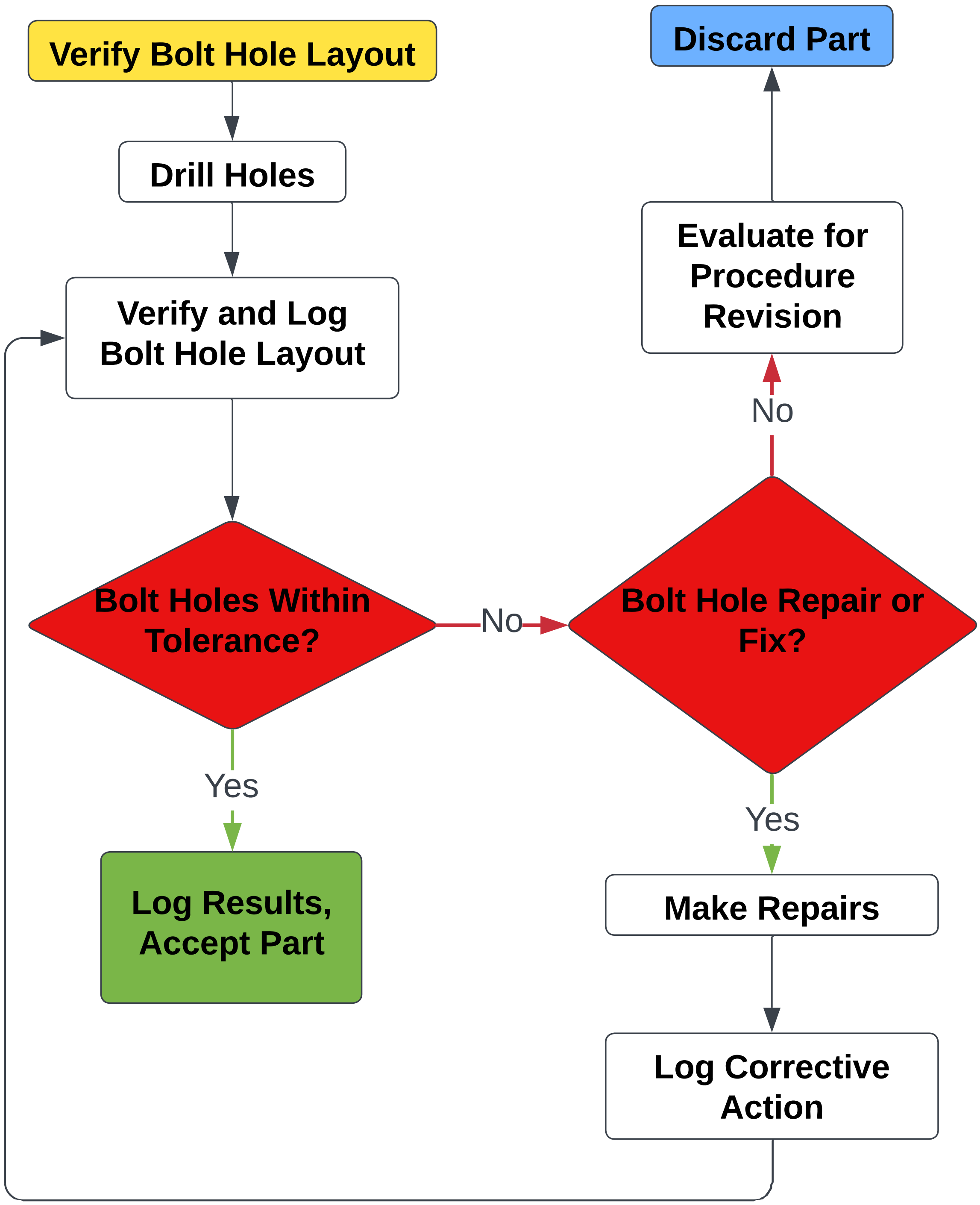
Final welding is performed in accordance with CoreBrace welding requirements. The necessary preheat and interpass temperatures, wire feed speed (wfs), voltage values, and other welding requirements are detailed on the applicable welding procedure specification (WPS). Monitoring and random verification by CoreBrace QC will be performed.

CoreBrace inspectors visually examine all welds after final welding has been completed, prior to assembly in the supporting PFM sleeve. The acceptance criteria for production welds are detailed in Table 6.1 of AWS D1.1 as modified by CoreBrace. Welds are measured to verify the correct weld size has been achieved. They are checked for welding discontinuities such as porosity, undercut, overlap, slag inclusions, and cracks. These discontinuities are repaired by the welder as permitted by AWS D1.1 as modified by CoreBrace.

Upon acceptance of the structural welding of the Buckling-Restrained Brace, fit-up is rechecked. If acceptable, the piece is tagged tag and released for PIM material assembly.

BOLT HOLE DRILLING

(When Required)



Bolt Hole Drilling (When Required)

Bolt hole drilling is performed on a high-speed Drill Line utilizing special drilling frame rig or other drilling tools. Centerlines of core parts are verified at each end of the core part or lug assembly. Then the parts are mounted into the drill frame rig and secured. Verification of alignment and clamping of assembly is made. If lug assembly is drilled separate from core plate, centerline verification is made when lug assembly is attached to core.

Parts are input into the program. And core parts are loaded to drill line. Hole locations are verified then holes are drilled. Alternatively holes are manually laid out and verified and drilled with other tools.

Bolt hole tolerances are checked and recorded. If parts are acceptable, initial of inspector shall be recorded on the check chart. If parts are not acceptable fixes, such as plug weld and redrill or connector adjustments, will be assessed. If repairable, log corrective action and make repairs.

Welding and Nondestructive Examination

Welding and nondestructive examination are considered special processes by various quality disciplines. Properly trained technicians, qualified to perform their special process by testing, work in conformance with CoreBrace procedures to repeatedly provide welds and testing that meet the requirements of the governing code.

Company welders are required to pass initial qualification tests to weld the components together. The welders test (QW) assures the welder has the ability to produce welds that meet the visual and testing requirements of AWS D1.1 within the process, position, and thickness limitations. They are requalified as required by the welding code every six months by either verifying the welder's use of the process within the six-month period or by qualification testing.

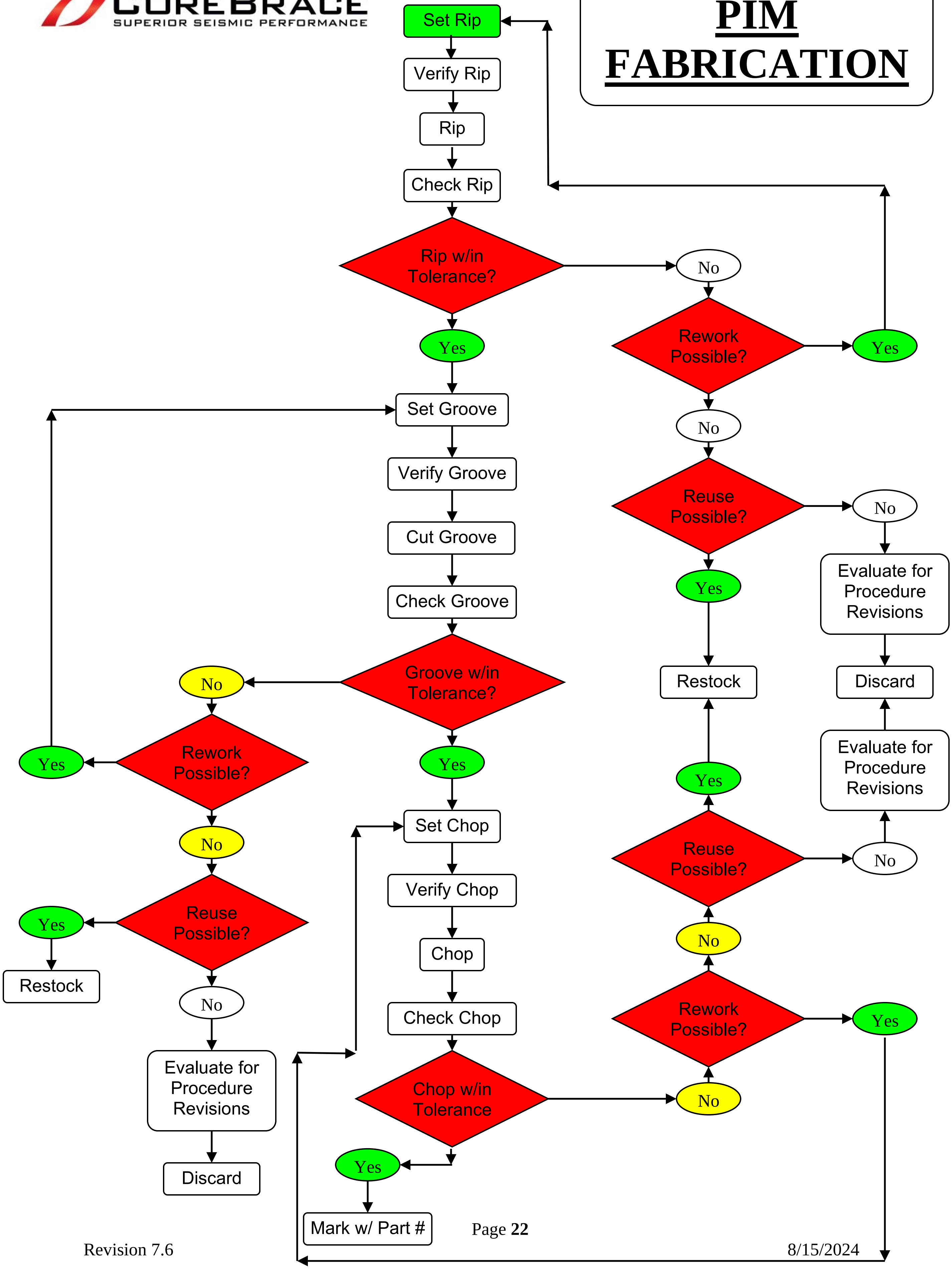
Company nondestructive testing technicians are initially qualified in accordance with ASNT. The tests include evaluation of general nondestructive testing concepts, concepts specific to the testing process and a practical examination to evaluate the ability to use the testing method correctly on a test piece with known discontinuities. Technicians are recertified every three years as recommended by SNT-TC.1A on the basis of continuing satisfactory performance or retesting. They have their eyesight tested every year. Technicians must be capable of reading Jaeger #2 test charts at a distance not less than 12 inches and be capable of differentiating and distinguishing contrast among colors.

CoreBrace inspectors are responsible for final acceptance of the welded assemblies. They have sound experience in quality welding operations and shop manufacturing techniques. They have been trained in the visual acceptance criteria of AWS D1.1 and methods of performing visual examination of welds. AWS D1.1, Section 8.1.4(3), Inspector Qualification Requirements, recognizes the qualification of the CoreBrace inspectors to perform welding inspection in accordance with the AWS Structural Steel Codes. CoreBrace also accepts national certifying agencies' qualifications, such as the AWS certified weld inspector program.

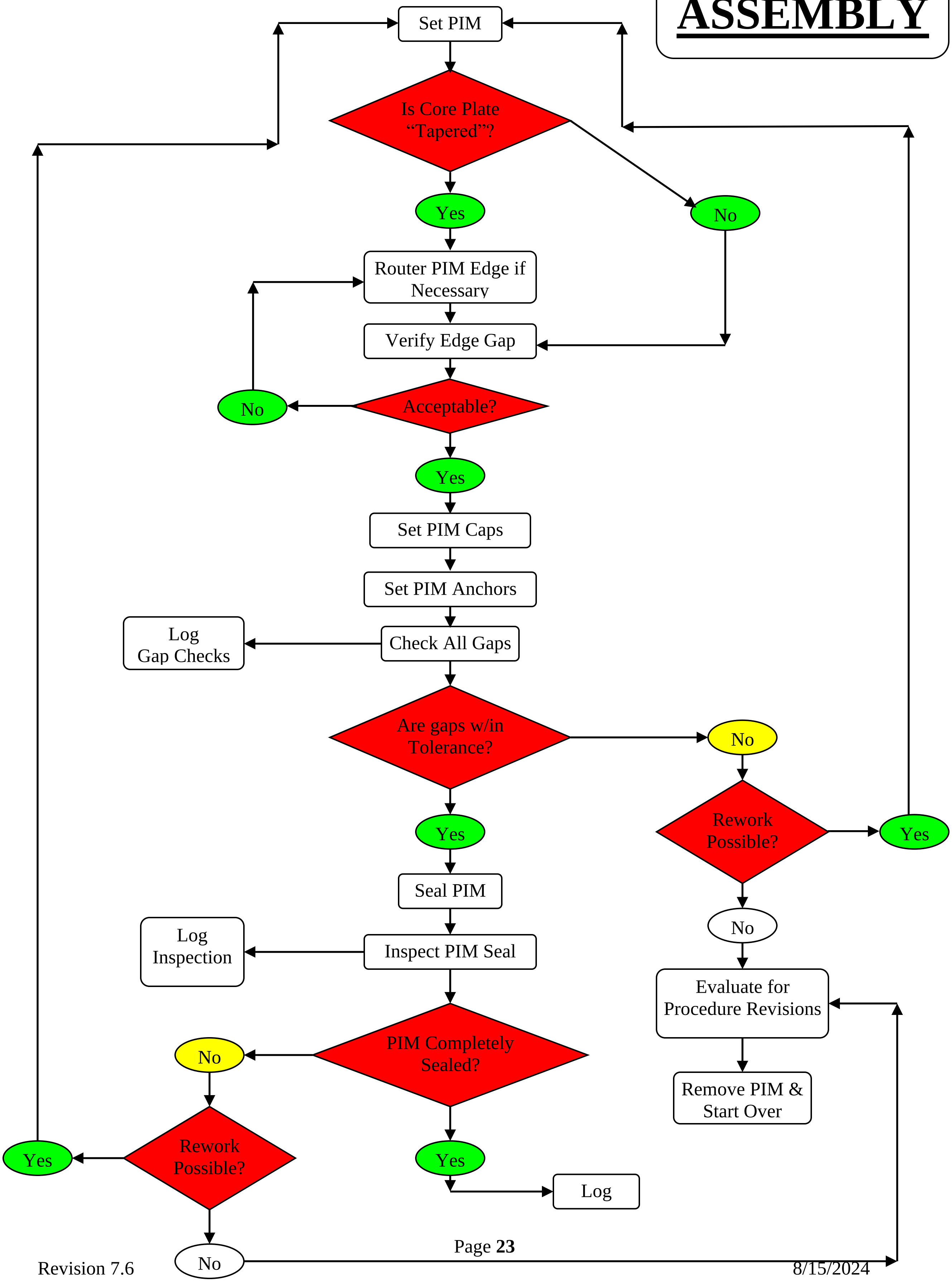
The CoreBrace welding procedures are developed to document the essential welding variables used when making the successful weld. They are written to conform to the requirements of AWS D1.1, Section 5, Prequalification of WPSs, or Section 6, Qualification, as applicable as modified by CoreBrace. The CoreBrace nondestructive examination procedures, like the welding procedures, also document the essential variables of the examination process for the qualified technician. The procedures are written to conform to AWS D1.1 and the appropriate ASTM specifications as modified by CoreBrace. All of the procedures establish the sequences and parameters the qualified welder or nondestructive testing technician must follow to produce repeatedly acceptable welds and valid examinations.

The steel components of the Buckling-Restrained Brace are joined together by welds. Destructive tests of numerous assemblies were performed in accordance with the Product Acceptance Plan for the BRB. The data collected and visual examinations of the braces after destructive testing have shown the welds perform well and meet product design requirements. Repair welds were also introduced into the test assemblies for evaluation. Welding repair had no noticeable effect on the performance of the Buckling-Restrained Braces. Repair welds are permitted after evaluation of the discontinuity by CoreBrace inspectors in accordance with the requirements of AISC, ASTM A6, AWS D1.1, as modified by CoreBrace. These Codes and procedures specify the extent of nondestructive testing to be performed on weld repairs. Methods and acceptance criteria will vary according to the severity of the permissible weld repair. The essential variable parameters for all company welds are documented in CoreBrace welding procedures.

PIM FABRICATION



PIM ASSEMBLY

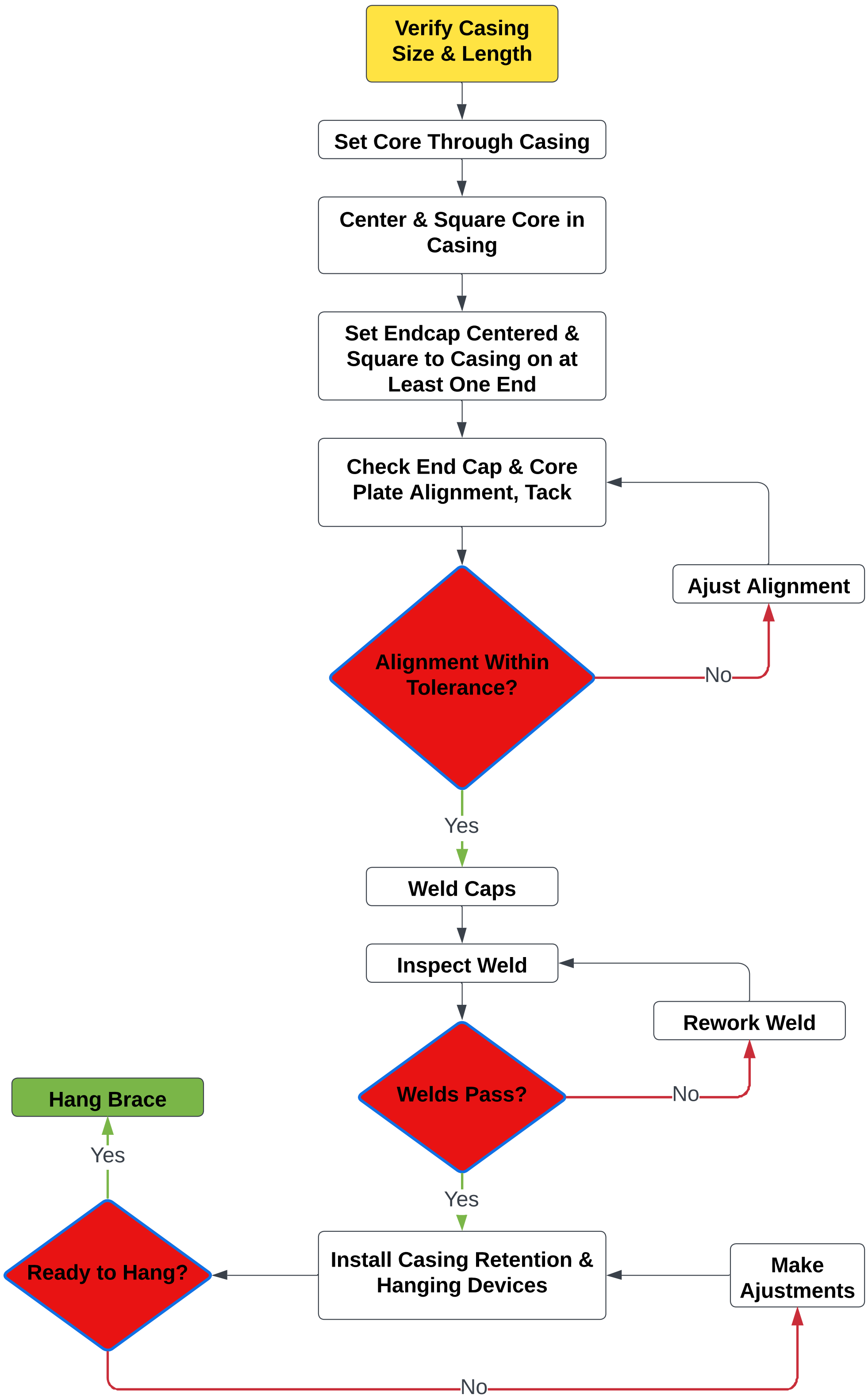


Proprietary Interface Material (PIM) Assembly

The PIM material is the same type of material used in CoreBrace testing. Parts are marked with Brace # and Part # and okayed for final dimensional check. PIM is dimensionally checked during the cutting process to conform with the individual part drawings including lengths, width, and thickness and that the proprietary fabrication tolerance for air gap will be maintained to within CoreBrace standards. If parts are not acceptable, fix or re-cutting is performed and a corrective action is logged. Repairs, fixes or re-cuts are made and the parts are rechecked. Tolerance checks are recorded in the PIM section of the inspection reports. Inspection reports require indication of inspection and initial of inspector prior to assembly. These reports are proprietary and can be viewed at the CoreBrace office or fabrication facility.

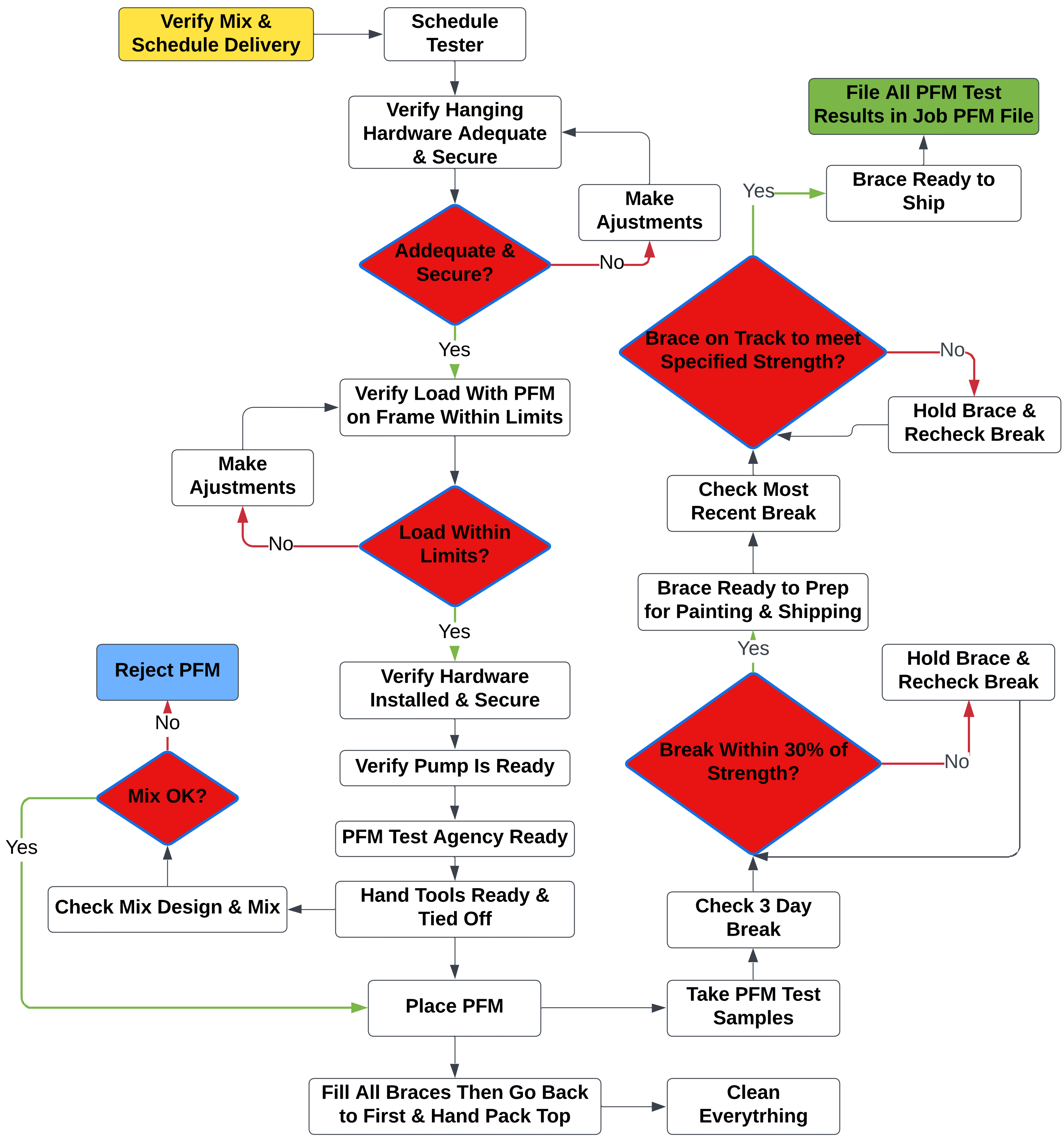
The PIM is then assembled to the core element of the brace. Upon completion the PIM is verified by qualified personnel to be within CoreBrace standards. Nonconformance assemblies are repaired or replaced. CoreBrace QA inspector performs random audits.

BRB ASSEMBLY



The casing element of the brace is checked for length. The brace core element is passed through the casing and centered via the end closure plate at one end of the casing and fit-up aids or Half endplate at the other end. The core element is checked for center of the casing at the casing ends. Also the end cap gap tolerance is checked.

PFM PLACEMENT



Proprietary Fill Material (PFM) Placement

Additional PFM placing aids are added to the brace assembly. Then the assembled core and casing unit is hung vertically for PFM placement via pump through the top end of the casing. Special proprietary mechanisms are utilized to insure the brace core does not deflect during PFM placement.

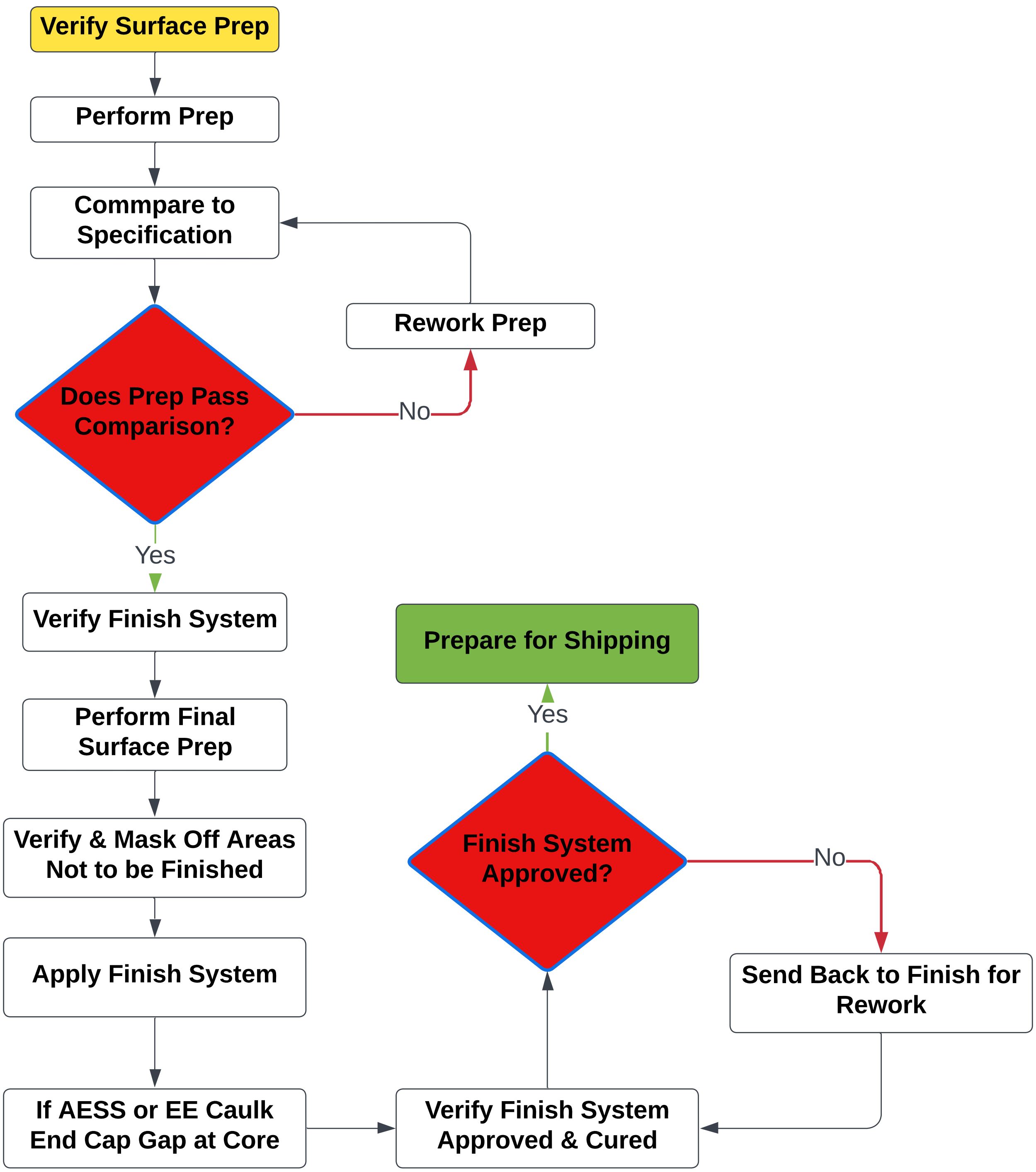
The required quantity of PFM is calculated and ordered from the supplier. Prior to placing PFM the batch ticket for each delivery truck is checked for conformance with mix design. The mix is checked visually and any necessary adjustments are made. A Spread test (ASTM C1611) is performed and Temperature (ASTM C1064) and Air Content (ASTM C231) measurements are taken by an independent testing agency qualified to perform the testing. Once these measurements are confirmed to be within acceptable limits PFM placement commences. A non-conforming batch of PFM is rejected and the delivery truck dismissed.

All personnel performing any fill material testing shall be qualified and all equipment used shall be calibrated in accordance with the applicable standards and code. If requested, independent agencies performing testing shall provide evidence of qualification and certification satisfying the code and Jurisdictional requirements. Reports and records of testing shall be submitted to CoreBrace on completion of the testing, for project submittal.

After PFM has been placed, a check is made for any minor PFM settlement and is topped off as necessary. Due to the natural "self-consolidating" properties of the PFM no extraneous consolidation procedures are necessary. Four test cylinders (ASTM C31) are made for every batch of PFM for future testing to verify the PFM compressive strength (ASTM C39). These cylinders are typically tested at 3-day, 7-day, and 28-day intervals as required to verify that the compressive strength is per standard. If the PFM does not come up to the requisite strength then the BRBs containing that batch of PFM are rejected and re-fabricated.

The CoreBraces are allowed to cure for a minimum of 1/2 day prior to removing from pour racks.

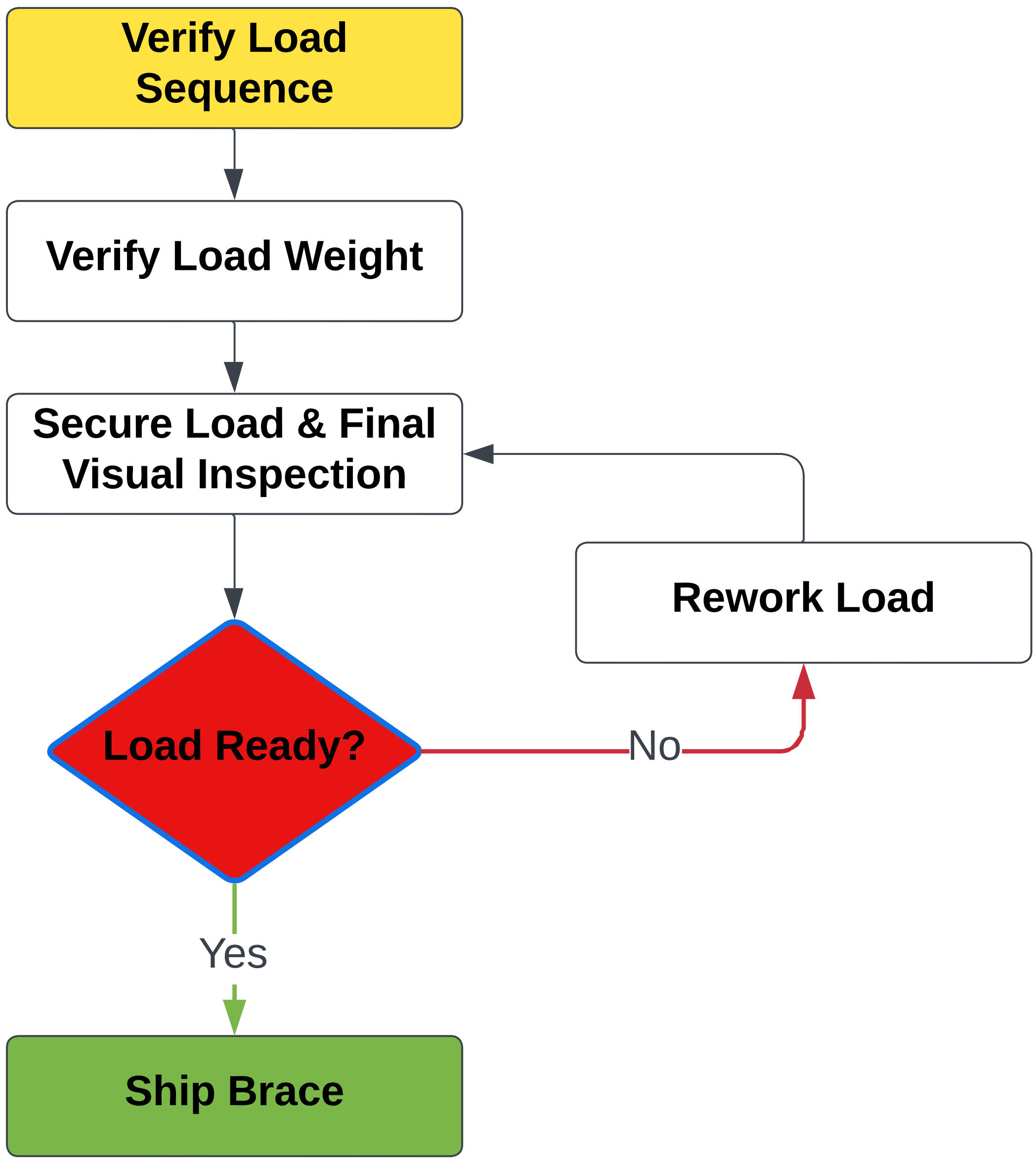
FINAL FINISH SYSTEM



Final Finish System

Prior to surface prep the end plate at the top end of the brace is placed and sealed and sealant is allowed to cure, if required. Then the brace is cleaned as per project specifications. At this time both the casing and the ends of the core that protrude beyond the casing are prepared. After surface preparation is visually inspected the brace is sent to paint with appropriate areas masked off.

SHIPPING & FINAL INSPECTION



Shipping and Final Inspection

One last visual check of the brace is made. Any objections are repaired, and the brace is prepared for shipment.

Site Quality Control

CoreBraces shall be stored on dunnage keeping them free from contacting site surfaces in order to protect finishes. Soft material between the dunnage and the CoreBrace is recommended to protect finishes. CoreBraces may be stacked with dunnage between levels. It is recommended that the stacks be covered with tarps to protect them from damage to finishes.

CoreBraces shall be handled in a manner to prevent impact loading to the brace. If CoreBraces are subjected to impact loading causing gouging or deformation to any of the steel components, CoreBrace shall be notified immediately for further evaluation.

Erection

Each CoreBrace will be provided with a piece mark identification that correlates to the erection drawings for determination of brace location in the field.

If requested, CoreBrace will provide lifting lugs on the braces. Removal of such lugs, if required, is not by CoreBrace. Remove lugs by torch cutting to within 1/16" of face of casing, then grind smooth. Do not gouge the casing or remove more material than the original casing had. In lieu of lugs Corebraces may be choked with slings. Soft non-metal straps are recommended for choking braces to minimize damage to finishes. The method of erection remains the responsibility of the erector.

During erection, CoreBraces shall be handled in a manner to prevent impact loading to the brace. If CoreBraces are subjected to impact loading causing gouging or deformation to any of the steel components, CoreBrace shall be notified immediately for further evaluation.

Any field modification to the CoreBraces shall not be permitted without written consent of Corebrace. Attachment of any items to the Corebraces shall not be permitted without written consent of CoreBrace. Utilize standard RFI procedures for the project if such conditions are necessary.

CoreBrace excludes touch up paint requirements due to handling and erection after delivery of braces.

Attachments

QA Plan Hold Point Check Tables

Sample Inspection Reports

- Core & Lug Cut Check Chart
- Core & Lug Edge Check Chart
- Bolt Hole Layout Check Chart
- Core Assembly Check Chart
- PIM Assembly Check Chart (Proprietary not included)
- CB Assembly Check Chart
- Casing Check Chart

Core Brace, LLC.

QA Plan Hold Point Check Table

#	Description	Standards	Tolerance
1	Verify Plate MTR	ASTM	As specified
2	Coupon tension test	ASTM A370 ASTM E8	As specified
3	Cut dimensions of brace core parts	CoreBrace	+/- 1/4" longitudinally +/- 1/8" transversely
3	Cut edge roughness		
	Yielding length	of Standard Practice	≦ 1000 μinches
	Remainder	AWS D1.1 Section 7.14	≦ 1000 μinches
	Notches yielding length	AWS D1.1 Section 7.14 & CoreBrace	≦ 3/16" flare grind or weld > 3/16" repair > 3/8" may reject
	Notches elsewhere	AWS D1.1 Section 7.14 & CoreBrace	≦ 3/16" flare grind or weld > 3/16" repair
3	Laminar discontinuities	See cut edge roughness, UT examination if observed	See cut edge roughness
3	Holes spacing & alignment	CoreBrace	+/- 1/16"
3	Core Assembly	CoreBrace	See check chart
3	Welds and Weld Repair of core	AWS D1.1 Sections 5, 7 & 8 as modified by CoreBrace	Pass visual by qualified inspector
4	Special fabrication of PIM	CoreBrace	Proprietary
4	Seal PIM	CoreBrace	Visual, no gaps
4	PIM & Fit-Up	CoreBrace	Proprietary
5	Casing length	CoreBrace	+/- ¼"
5	Center of core in casing	CoreBrace	+/- ¼ "
6	Surface preparation casing and ends	Specification Standard	As specified
6	Inspect paint	Specification standard	As specified
7	PFM strength	Proprietary	Proprietary

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Job#:	
Mark#:	
Plate# Main Core:	
Part# Main Core:	
Date:	

Hole to Hole:
Heat #:

Check at Fit-Up

Travels with Mark #

Lug Cut Check Chart

QC Initials:

Dim	Description	Tolerance	Pass
L_L	Overall length	+/-1/4"	
L_{SL}	End of lug to transition	+/-1/4"	
L_{Lg}	Length along lug	+/-1/4"	
a	Transition length	+/-1/4"	
L_{hpL}	Length of hairpin to start of radius	+/- 1/8"	
W_L	Width of lug at bolt group	+/-1/8"	
W'_{se}	Width of lug at end in casing	+/-1/8"	
W_{hpL}	Width of hairpin	+/-1/16"	
W_1	Width of lug at hairpin	+/-1/8"	
Surface	Faying surface of both ends clean and free of paint, silicone or metal burrs (both ends)	as stated	
	Verify correct surface preparation (i.e. Class A or B)	NA	

Core Cut Check Chart

QC Initials:

Dim	Description	Tolerance	Pass
L_b	Overall length	+/-1/4"	
L_{hp}; L_t	Slot Length-end of core to radius; transition length	+/-1/8"	
W_{sc}, W_t	Width along entire length of steel core	+/-1/8"	
W_{sg}	Hairpin width	0"~+1/16"	
W_{sg}	Centered	+/-1/16"	

Core & Lug Edge Check

QC Initials:

Dim	Description	Tolerance	Pass
L_b , L_L	Gouges from QC/QA manual	<= 3/8"	
L_y , L_L	Laminar discontinuities in yield section UT if observed	<= 3/8"	
Gouge	Gouge <=3/16" flare 1:10 or weld, >3/16" & <=3/8 weld	as stated	
Laminar	Laminar <=3/16" flare 1:10 or weld, >3/16" & <=3/8 weld	as stated	
Roughness	Repair as needed by grinding	1000µ"	

Lug Part #:

Lug Bolt Hole Layout Check Chart

QC Initials:

Dim	Description	Tolerance	Pass
g_1 , g_2	Gauge between bolt rows, check 1st and last bolts of row	+/-1/16"	
Align	Bolt row alignment, check all bolts in row	+/-1/16"	
s	Bolt spacing, check all bolts	+/-1/16"	
s/2	Bolt spacing between inner and outer line	+/-1/16"	
Hole	Size, Burrs, Elongation	AISC	

# of failures if any:

Potential Cause?:	
Disposition (Repair, Fix or Loss):	

Fitter:
Welder:

cc: Project Manager

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

Job#:	
Plate # (main):	
Mark #:	
Date:	
QC Initials:	

Travels with Mark #

Core Assembly Check Chart

Dim	Description	Tolerance	Pass
CL_x	Centering of lug plates. Check at both ends.	+/-1/16"	
SQ_e	Square of lugs. Set square to plates and measure maximum gap. Check at both ends of brace.	+/-1/16"	
Sweep Brace	Any 10' along plate edge, check both directions	+/-1/4"/10'	
Bolt Align	Alignment of bolt rows end to end of brace. Check with string along edge of holes	+/-1/8"	
Bolt Centers	Alignment of holes through both lug plates. Test bolts shall easily slide through both plies of each hole.	+/-1/16"	
Lh	Out to out dimension of outermost holes	+/-1/16”	
Lug Gap	At root of lug plates at center of lug	+1/32"	
	Additional flare at end of brace, (6) bolts total or less: 3/8" otherwise 1/2"	-1/8”, +1/4”	
Ws	Yield: Visual per AWS/AISC as modified by CoreBrace		
W_L	Lug: Visual per AWS/AISC & 1:1 taper at start & termination		
Gy	Yield gouge <= 3/16" flare 1:10 or weld, > 3/16" & <= 3/8" weld	Repair	
Ge	Elsewhere gouge <= 3/16" flare 1:10 or weld, >3/16" weld	Repair	
Ly	Yield: Laminar <= 3/16" flare 1:10 or weld, >3/16" & <= 3/8" weld	Repair	
Le	Elsewhere: Laminar <= 3/16" flare 1:10 or weld, >3/16" weld	Repair	
Ry	Yield: Roughness repair as needed by grinding	1000µ"	
Re	Elsewhere: Roughness repair as needed by grinding	1000µ"	
WW	Was the proper welding wire used?		
	0.045 Wire for 3/16" welds and./or 0.5" thick material		
	5/64 Welding wire for all larger welds and material		
Center Stiffener Location	ONLY REQUIRED FOR BRACES WITH CENTER STIFFS: Verify stiffener is at center of yield section and center of brace longitudinal axis	+/-1/8"	

# of failures if any:

Potential Cause?:	
Disposition (Repair, Fix or Loss):	

cc: Project Manager

QC initials in boxes

Ø - Ø and fit up OK	
Top Side visual OK	
Final visual OK	

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Job #:	
Mark #:	
Date:	
Part #	

Travels with Mark #

Casing Check Chart

QC Initials:

Dim	Description	Tolerance	Pass
Length	Overall length	+/-1/4"	
Width	Out to out width	Correct	
Thickness	Wall thickness	Correct	
Gap	Gap between end cap and core, check all sides	0-3/8”	
Seam Weld	Inspect entire exterior of the seam weld and interior @ each end	No Visible Discontinuities	
Exterior	Dents in casing, Check all sides and corners	0-1/16"	
Sweep Casing	Is the casing bowed, bent, bent or disformed? Check all side from end to end.	+/-1/4"/10	

CB Assembly Check

Part #:

QC Initials:

Dim	Description	Tolerance	Pass
CL HSS	Center HSS casing on core length wise	+/-1/4"	
Cap Weld	Continuous at flat faces, seal weld corners & seams if exposed. No overgrinding of cap weld.	Visual	
Pour End	Is the core properly supported and centered?		
Temp Cap Caulk Seal	Fill bottom joint completely with caulk	Visual	
	Place 12 hours prior to pour	Visual	
Support Tabs	Any gouges from support tab removal	Visual	
All welds	Any excessive grind or sanding marks?		
Lug Surface	Faying surface of both ends clean and free of paint, silicone or metal burrs (both ends-bolted surface between lugs)	as stated	
AESS?	Additional cleanup welds, sharp edges, fit-up, seam weld filling, and seam location. CHECK FAB DWG		

Finishes

QC Initials:

Dim	Description	Tolerance	Pass
Primer	Correct primer applied?		
Primer	Applied to manufacturer/specification requirements?		
AESS	Does the Brace have AESS Requirements? (See DWG)	Yes / No	
AESS	If yes, Does the brace meet Requirements? (See DWG)	AISC	

# of failures if any:

Potential Cause?:	
Disposition (Repair, Fix or Loss):	

cc: Project Manager

669 West Quinn Road, Building #28, Pocatello, ID 83201

DATE: 3/10/2025

Lone Mountain Temple
HA Fabricators

CoreBrace Job#: 6873

Subject: ***Certificate of Compliance - Weld Consumables***

This letter is to certify that all welding consumables supplied by CoreBrace for use on the referenced project, were and will be purchased, maintained, and used in strict accordance with the applicable contract documents, specifications, codes (AISC, ASTM and AWS), approved plans, and the Material Manufactures recommendations. The Manufacturers data sheets, certifications and product information sheets have been reviewed and those variables, requirements and instructions have been included within the CB Welding Procedure Specifications (WPS) within the appropriate tolerances allowed by code. Each WPS is written to comply with the AWS D1.1 and D1.8 requirements for seismic use and is prequalified for Demand Critical welds of the SFRS.

Each WPS indicates the approved ranges and code application of the specific wire listed therein. Each WPS provides for the additional requirements found in the AISC and AWS Seismic provisions for Heat Input for the given consumable specified therein.

CoreBrace certifies the above is true and all records pertaining to the above are on file at CoreBrace and are available for review upon request.

If you have any questions, please call.

Sincerely,

AWS
Roger R. Davis
CWI 24011831
QC1 EXP. 1/1/2027

Roger R Davis
CoreBrace QA Manager
208.339.5905
Roger.davis@corebrace.com

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

Welder qualification summary and continuity log

Welder Continuity Record		Shift and Date Qualified		GMAW													
LAST UPDATED: 12/9/2024				Qualified in Process	In GMAW	Welder Continuity Log 2024											
ID#	Employee Name	Shift	Date			Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
C1	ADRIAN ANGULO	1st	8/5/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C2	ALLAN LOVE	2nd	8/9/2022	X	2F 1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C4	BERNIE GERDES	1st	8/22/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C6	BRADLEE HELLIKSON	1st	8/15/2022	X	2F 1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C7	Brandon Renfro	1st	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C13	CODY RASMUSSEN	1st	3/29/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C17	DALE TAYLOR	1st	8/16/2022	X	2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C22	DOUGLAS LUKER	1ST	7/3/2023	X	2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C24	ELEUTERIO MANCILLA	1st	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C32	JESSE MOORE	2nd	8/4/2022	X	2F 1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C34	JULIO JIMENEZ	1st	8/17/2022	X	1G 2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C41	KIM BEEBE	2nd	1/17/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C44	MARIO ASTUHUAMAN	1st	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C47	NICK POPPLETON	1st	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C50	Peter Mitchell	1st	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C51	RANDY PHILLIPS	1st	11/17/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C54	RONY LOPEZ	1st	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C56	Sam Sotello	2nd	4/22/2024	X	1G				RD	RD	RD	RD	RD	RD	RD	RD	RD
C68	Trevor Valladolid	1st	8/17/2022	X	2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C74	Dalton Lee	1st	2/23/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C75	Spencer Henrickson	1st	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C86	Jose Varela	1st	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C88	Austin Garcia	1ST	8/15/2022	X	1G 2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C95	Kyle Jones	1ST	8/22/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C98	Darrick Lycklama	1ST	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C103	Levi Running Eagle	1st	8/18/2022	X	2F 1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C105	Armando Pena	1st	11/16/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C111	Ward Anderson JR	1st	2/17/2021	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C116	Bridger Sharp	1ST	11/16/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C124	Andrew Cox	1st	11/17/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C128	Sam Munk	1st	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C129	Santiago Resendiz Munoz	1st	8/16/2022	X	1G2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C132	Jake Rossen	1st	11/16/2022	X	2F 1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C138	Gustavo Garcia	2ND	9/16/2024	X	1G									RD	RD	RD	RD
C164	Jaren Larson	2nd	12/19/2022	X	1G 2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C166	Tyler Rowe	1ST	11/11/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C171	Cristian Hernandez	1st	1/25/2023	X	2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C173	Miguel Gonzales	1st	2/14/2023	X	1G 2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C176	Rigoberto Navamete	1st	3/30/2023	X	2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C178	Donyvon Hamilton	2nd	4/24/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD

CoreBrace

SUPERIOR SEISMIC PERFORMANCE

Welder qualification summary and continuity log

Welder Continuity Record		Shift and Date Qualified		GMAW													
LAST UPDATED: 12/9/2024				Qualified in	In	Welder Continuity Log 2024											
ID#	Employee Name	Shift	Date	Process	GMAW	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
C181	Garrick Atencio	2nd	6/23/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C183	Feliciano Astuaman	1st	7/3/2023	X	2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C184	John Vanderlieth	2nd	7/8/2023	X	2F 1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C185	Jeff Jenkins	2nd	8/3/2023	X	2F 1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C186	A.J. Neary	1st	8/25/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C188	Zach Chacon	2nd	1/24/2024	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C189	Rogelio Bravo	2nd	2/6/2024	X	1G		RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C190	Hailee Mills	1st	2/28/2024	X	1G 2F		RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C193	Julio Perez	2nd	4/16/2024	X	2F				RD	RD	RD	RD	RD	RD	RD	RD	RD
C194	Calvin Landon	2nd	6/6/2024	X	2F 1G						RD	RD	RD	RD	RD	RD	RD
C195	Anthony Rickard	2nd	6/6/2024	X	2F						RD	RD	RD	RD	RD	RD	RD
C196	Cody Mccoy	2nd	6/20/2024	X	2F						RD	RD	RD	RD	RD	RD	RD
C197	Kyson Morris	2nd	6/20/2024	X	2F						RD	RD	RD	RD	RD	RD	RD
C198	Paxton Chandler	2nd	6/20/2024	X	2F 1G						RD	RD	RD	RD	RD	RD	RD
C199	Alex Crawford	2nd	7/16/2024	X	2F							RD	RD	RD	RD	RD	RD
C200	Dathan Hall	2nd	7/16/2024	X	1G							RD	RD	RD	RD	RD	RD
C201	Juan Rosales	1ST	9/12/2024	X	1G									RD	RD	RD	RD
C202	Hezekiah Scovel	1ST	9/12/2024	X	2F 1G									RD	RD	RD	RD
C203	Leonel Arenas	2nd	9/17/2024	x	1G									RD	RD	RD	RD
C204	Kameron Hatch	2nd	9/16/2024	X	2F									RD	RD	RD	RD
C205	Josh Lenon	2nd	10/7/2024	X	1G										RD	RD	RD
C206	Bryant Johnston	2nd	10/7/2024	X	1G										RD	RD	RD
C207	Cortez Keifer	2nd	10/7/2024	X	1G										RD	RD	RD
C208	Raul Gonzalez	2nd	10/7/2024	X	1G										RD	RD	RD
C210	Ashton Hovey	2nd	10/7/2024	X	1G										RD	RD	RD
C211	Kaelan Osborne	2nd	10/7/2024	X	1G										RD	RD	RD
C212	Junior Sotelo	2nd	10/7/2024	X	1G											RD	RD
C213	Katherine Young	2nd	11/20/2024	X	2F											RD	RD

Verification of continuous service from inception of the original certification through update period noted. A review of records has shown continuous service within the process for each welder. The given records included, personal witness, inspector logs, payroll and / or production records. Original certification and portions of the documents reviewed are available for review at the CoreBrace QA Office, note some documents are sensitive and are not for general distribution.

This document shall serve as an affidavit of this review. To the best of my knowledge this document is accurate and true. This document serves as certification of continued service through each six month period documented here-in.

Q.A. Manager - Roger Davis

AWS

Roger R. Davis
CWI 24011831
QC1 EXP. 1/1/2027

Roger R Davis

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

Welder qualification summary and continuity log

Welder Continuity Record		Shift and Date Qualified		FCAW-G	POSITION												
LAST UPDATED: 12/9/2024				Qualified in	Qualified	Welder Continuity Log 2024											
ID#	Employee Name	Shift	Date	Process	FCAW-G	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
C1	ADRIAN ANGULO	1st	2/6/2017	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C2	ALLAN LOVE	2nd	8/6/2020	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C4	BERNIE GERDES	1st	10/26/2015	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C7	Brandon Renfro	1st	3/7/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C13	CODY RASMUSSEN	1st	1/11/2019	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C17	DALE TAYLOR	1st	5/31/2019	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C19	DAVE MADSEN	1st	12/17/2014	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C21	DON GREEN	1st	10/30/2018	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C22	DOUGLAS LUKER	1ST	10/26/2015	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C23	DUSTY RUPE	1st	5/23/2019	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C24	ELEUTERIO MANCILLA	1st	11/21/2014	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C32	JESSE MOORE	2nd	8/14/2017	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C34	JULIO JIMENEZ	1st	3/1/2016	X	1G 2G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C38	KENNETH CHAPLIN	1st	2/25/2015	X	2G 3G 6G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C39	KENNETH HOPKINS	1st	6/21/2017	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C41	KIM BEEBE	2nd	10/26/2011	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C44	MARIO ASTUHUAMAN	1st	2/9/2017	X	1G 2G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C45	MIGUEL HERNANDEZ	1st	4/25/2023	X	2G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C47	NICK POPPLETON	1st	11/17/2016	X	1G 2G 6G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C50	Peter Mitchell	1st	4/3/2017	X	1G 2G 6G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C51	RANDY PHILLIPS	1st	9/2/2015	X	2G 3G 6G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C54	RONY LOPEZ	1st	1/16/2018	X	1G 2G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C56	Sam Sotello	1st	4/22/2024	X	2G				RD	RD	RD	RD	RD	RD	RD	RD	RD
C57	SEAN COOK	1st	10/7/2015	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C74	Dalton Lee	1st	5/1/2019	X	1G 2G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C75	Spencer Henrickson	1st	6/26/2018	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C86	Jose Varela	1st	9/1/2020	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C95	Kyle Jones	1ST	10/12/2020	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C105	Armando Pena	1st	1/20/2021	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C111	Ward Anderson JR	1st	2/17/2021	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C124	Andrew Cox	1st	8/31/2021	X	2G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C128	Sam Munk	1st	10/15/2021	X	1G 2G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C132	Jake Rossen	1st	3/18/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C156	Doug Johnson	1st	9/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C164	Jaren Larson	2nd	12/16/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C166	Tyler Rowe	1ST	12/1/2022	X	1G 2G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C171	Cristian Hernandez	1st	6/3/2024	X	2G						RD	RD	RD	RD	RD	RD	RD

Verification of continuous service from inception of the original certification through update period noted. A review of records has shown continuous service within the process for each welder. The given records included, personal witness, inspector logs, payroll and / or production records. Original certification and portions of the documents reviewed are available for review at the CoreBrace QA Office, note some documents are sensitive and are not for general distribution.

This document shall serve as an affidavit of this review. To the best of my knowledge this document is accurate and true. This document serves as certification of continued service through each six month period documented here-in.

Q.A. Manager - Roger Davis

AWS®
Roger R. Davis
CWI 24011831
QC1 EXP. 1/1/2027

Roger R. Davis

Attach Joint Configurations

Structual Steel AWS D1.1 / D1.8
Welding Procedure Specification (WPS)

Welding Procedure Specification (WPS)	FabCOR Edge XP	Supporting P.Q.R #	Prequalified

Material Specification:	Group I & II Material in Table 5.3 AWS D1.1 (also Group III to Group I & II)
Welding Process:	GMAW - Spray transfer
Manual or Machine:	Semi-Automatic
Position of Weld	Flat and Horizontal
Filler Metal: Specification, Classification, Trade Name:	AWS A5.18, A5.28; SFA 5.18, 5.28 / E70C-6M H4, E80C-G H4, Hobart FabCOR Edge XP
Flux:	N/A
Shielding Gas: Mix, Type, Flow Rate, Wind Velocity	75 - 95% Argon/ 5 - 25% Co_2, 35 - 50 CFH, Wind Velocity ≤ 3 MPH DCW, ≤ 5 MPH all others
Welding Current:	DCEP (CV Output)
Root Treatment:	Clean to remove all contaminants (see QC plan)
Preheat and Interpass Temperature:	Min Preheat 32°F, Max interpass 550° F (See table below)
Post-Weld Heat Treatment:	Not required, UNO Written procedure required (see QC plan)
Heat Input Limits 0.045" (A x V x .06 / Travel Speed = KJ/in.)	Minimum HI - 27.8 kj/in Maximum HI - 82.5 kj/in
Heat Input Limits 0.052"	Minimum HI - 27.9 kj/in Maximum HI - 81.5 kj/in
Heat Input Limits 1/16"	Minimum HI - 29.3 kj/in Maximum HI - 81.8 kj/in
Joint Geometry	**See joint configurations, attached pages**

Electrical Characteristics

Pass No.	Weld Type	Weld Position	Electrode Diameter / CTWD	Welding Current		WFS	Travel Speed
				Volts	Amps	IPM	IPM
All	Groove or Fillet	Flat / Horizontal	0.045" Dia. CTWD 3/4"	20 -(23)- 26	180 -(200)- 220	216 -(240)- 264	5.8 - (7.6) - 9.5
All	Groove or Fillet	Flat / Horizontal	0.045" Dia. CTWD 3/4"	21 -(25)-28	225 -(250)- 275	306 -(340)-374	7.8 - (10.3) - 12.8
All	Groove or Fillet	Flat / Horizontal	0.045" Dia. CTWD 3/4"	22 -(26)-30	270 -(300)- 330	378 -(420)- 462	10 - (13.3) - 16.6
All	Groove or Fillet	Flat / Horizontal	0.045" Dia. CTWD 7/8"	24 -(28)-32	315 -(350)- 385	513 -(570)-627	14 - (18.6) - 23.2
All	Groove or Fillet	Flat / Horizontal	0.045" Dia. CTWD 7/8"	26 -(30)-34	360 -(400)- 440	653 -(725)- 797	17.5 - (23.2) - 29
All	Groove or Fillet	Flat / Horizontal	0.052" Dia. CTWD 3/4"	20 -(23)- 26	180 -(200)- 220	171 -(190)- 209	6 - (8) - 9.9
All	Groove or Fillet	Flat / Horizontal	0.052" Dia. CTWD 3/4"	20 -(24)- 27	225 -(250)- 275	216 -(240)- 264	7.8 - (10.5) - 13.1
All	Groove or Fillet	Flat / Horizontal	0.052" Dia. CTWD 3/4"	22 -(26)- 29	270 -(300)- 330	288 -(320)- 352	9.9 - (13.2) - 16.4
All	Groove or Fillet	Flat / Horizontal	0.052" Dia. CTWD 7/8"	24 -(28)- 32	315 -(350)- 385	364 -(405)- 445.5	12.7 - (16.9) - 21.1
All	Groove or Fillet	Flat / Horizontal	0.052" Dia. CTWD 7/8"	26 -(30)- 34	360 -(400)- 440	463 -(515)-566.5	16.7 - (22.2) - 27.7
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 7/8"	21 -(24)- 27	225 -(250)-275	139 -(155)-170	6.6 - (8.8) - 10.9
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 7/8"	22 -(25)- 28	270 -(300)- 330	184 -(205)- 225	9.1 - (12) - 15
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 7/8"	23 -(27)- 31	315 -(350)- 385	238 -(265)- 291	10.5 - (14) - 17.4
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	25 -(29)- 33	360 -(400)- 440	292 -(325)- 357	13.6 - (18) - 22.5
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	27 -(31)- 35	450 -(500)- 550	450 -(500)- 550	21.5 - (28.6) - 35.6

NOTES

1	For Fillets, where root separation is greater than 1/16" ≤ 3/16", the size of the fillet weld may be increased by the amount of the actual gap. Fillet and Groove welds may have excessive root openings "buttered up"/ repaired, up to a 1/4", to close a gap to within acceptable limits.
2	Electrode exposure limit - 7 days (per CoC), spools removed, bagged, and stored or stored in an oven, do not count as exposure time.
3	This procedure may vary due to fabrication sequence, fit-up, pass size, etc… within the limits of all mandatory variables given in AWS D1.1.
4	Weld layer thickness - root 5/16" max, fill passes 1/4" max, Single pass fillet 3/8" max. Max layer width 5/8" flat/horizontal.
5	Peening and caulking are not allowed, the use of pneumatic hand tools to remove slag and spatter shall not be considered peening.
6	For "as fit" tolerances see joint geometry pages
7	Backing may be steel, copper, ceramic or backing weld. Non-fusible backing shall be removed and backgouged to sound metal, then back welded.
8	Grind, chip, wire brush between passes and layers. Remove all slag and spatter. Remove noted discontinuities, do not weld over them.
9	This WPS may be used for any prequalified joint configuration not shown, without inclusion herein with QC verification.
10	CB QCM PR12.1 Shall be used in conjunction with this WPS for all other notes, instructions and foot note legend.
11	Stringer Beads only.
12	Voltage +/- 15%, Amperage & WFS +/- 10%, travel speed +/- 25% included in value range given. The number in parenthesis () is manufacturer's recommendation, to the right and left are with D1.1 variables included. Travel Speed was calculated Mathematically based on the deposition rate shown in the manufacturer's datasheet assuming a 5/16" fillet weld. Where Travel Speed = {(Deposition Rate) / (Weld Weight per foot x 5)}

Minimum Preheat/inter-pass Temperature for Material (refer to D1.1 Table 5.8 category and Grade of material)
When the base metal temperature is below 32°F, the base metal shall be preheated to a minimum of 70°F and maintained.

Category B	Category C
≤ 3/4" is 32° F	≤ 3/4" is 50° F
over 3/4" to 1 1/2" is 50° F	over 3/4" to 1 1/2" is 150° F
over 1 1/2" to 2 1/2" is 150° F	over 1 1/2" to 2 1/2" is 225° F
over 2 1/2" is 225° F	over 2 1/2" 300° F

Revision #	Description	Date	Status:
0	initial Issue	8/4/2023	Approved
1	format revised	2/14/2024	Approved
2	format revised	10/8/2024	Approved
3	Travel Speed Fixed	10/22/2024	Approved
4	Heat Input Updated	12/9/2024	Approved

Approved by: Roger Davis **Signed:**

Roger R. Davis
CWI 24011831
QC1 EXP. 1/1/2027

Roger R. Davis

Date: 12/9/2024

COREBRACE
SUPERIOR SEISMIC PERFORMANCE

Structual Steel AWS D1.1 / D1.8
Welding Procedure Specification (WPS)

Attach Joint Configurations

Welding Procedure Specification (WPS)	FabCO TR-70 Supporting P.Q.R # Prequalified
Material Specification:	Group I & II Material in Table 5.3 AWS D1.1 (also Group III to Group I & II)
Welding Process:	FCAW-G
Manual or Machine:	Semi-Automatic
Position of Weld	Flat and Horizontal
Filler Metal: Specification, Classification, Trade Name:	AWS A5.20/A5.20M - E70T-1C H8,E70T-9C H8, Hobart FabCO TR-70
Flux:	N/A
Shielding Gas: Mix, Type, Flow Rate, Wind Velocity	100% Co_2, 35 - 50 CFH, Wind Velocity ≤ 3 MPH DCW, ≤ 5 MPH all others
Welding Current:	DCEP (CV Output)
Root Treatment:	Clean to remove all contaminants (see QC plan)
Preheat and Interpass Temperature:	Min Preheat 32°F, Max interpass 550° F (See table below)
Post-Weld Heat Treatment:	Not required, UNO Written procedure required (see QC plan)
Heat Input Limits 1/16" (A x V x .06 / Travel Speed = KJ/in.)	Minimum HI - 28.5 kj/in Maximum HI - 75.5 kj/in
Heat Input Limits 5/64"	Minimum HI - 31.0 kj/in Maximum HI - 84.3 kj/in
Joint Geometry	See joint configurations, attached pages

Electrical Characteristics

Pass No.	Weld Type	Weld Position	Electrode Diameter / CTWD	Welding Current		WFS	Travel Speed
				Volts	Amps	IPM	IPM
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	22 -(25)- 28	153 -(170)- 187	126 -(140)- 154	4.6 - (6.1) - 7.6
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	23 -(26)-30	180 -(200)- 220	153 -(170)-187	5.6 - (7.4) - 9.2
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	23 -(27)-31	234 -(260)- 286	189 -(210)- 231	6.8 - (9) - 11.2
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	27 -(32)-36	315 -(350)- 385	311 -(345)-379	11.2 - (14.9) - 18.6
All	Groove or Fillet	Flat / Horizontal	5/64" Dia. CTWD 1"	22 -(26)- 30	225 -(250)- 275	99 -(110)- 121	5.7 - (7.5) - 9.3
All	Groove or Fillet	Flat / Horizontal	5/64" Dia. CTWD 1"	22 -(26)- 30	270 -(300)- 330	126 -(140)- 154	7.2 - (9.6) - 11.9
All	Groove or Fillet	Flat / Horizontal	5/64" Dia. CTWD 1"	23 -(27)- 31	315 -(350)- 385	153 -(170)- 187	8.7 - (11.6) - 14.4
All	Groove or Fillet	Flat / Horizontal	5/64" Dia. CTWD 1"	23 -(27)- 31	378 -(420)- 462	202 -(225)- 247	11.8 - (15.6) - 19.5
All	Groove or Fillet	Flat / Horizontal	5/64" Dia. CTWD 1"	27 -(32)- 36	495 -(550)- 605	310 -(345)-379	18.1 - (24) - 30

NOTES

1	For Fillets, where root separation is greater than 1/16" ≤ 3/16", the size of the fillet weld may be increased by the amount of the actual gap. Fillet and Groove welds may have excessive root openings "buttered up"/ repaired, up to a 1/4", to close a gap to within acceptable limits.
2	Electrode exposure limit - 7 days (per CoC), spools removed, bagged, and stored or stored in an oven, do not count as exposure time.
3	This procedure may vary due to fabrication sequence, fit-up, pass size, etc… within the limits of all mandatory variables given in AWS D1.1.
4	Weld layer thickness - root 5/16" max, fill passes 1/4" max, Single pass fillet 3/8" max. Max layer width 5/8" flat/horizontal.
5	Peening and caulking are not allowed, the use of pneumatic hand tools to remove slag and spatter shall not be considered peening.
6	For "as fit" tolerances see joint geometry pages
7	Backing may be steel, copper, ceramic or backing weld. Non-fusible backing shall be removed and backgouged to sound metal, then back welded.
8	Grind, chip, wire brush between passes and layers. Remove all slag and spatter. Remove noted discontinuities, do not weld over them.
9	This WPS may be used for any prequalified joint configuration not shown, without inclusion herein with QC verification.
10	CB QCM PR12.1 Shall be used in conjunction with this WPS for all other notes, instructions and foot note legend.
11	Stringer Beads only.
12	Voltage +/- 15%, Amperage & WFS +/- 10%, travel speed +/- 25% included in value range given. The number in parenthesis () is manufacturer's recommendation, to the right and left are with D1.1 variables included. Travel Speed was calculated Mathematically based on the deposition rate shown in the manufacturer's datasheet assuming a 5/16" fillet weld. Where Travel Speed = {(Deposition Rate) / (Weld Weight per foot x 5)}

Minimum Preheat/inter-pass Temperature for Material (refer to D1.1 Table 5.8 category and Grade of material)
When the base metal temperature is below 32°F, the base metal shall be preheated to a minimum of 70°F and maintained.

Category B	Category C
≤ 3/4" is 32° F	≤ 3/4" is 50° F
over 3/4" to 1 1/2" is 50° F	over 3/4" to 1 1/2" is 150° F
over 1 1/2" to 2 1/2" is 150° F	over 1 1/2" to 2 1/2" is 225° F
over 2 1/2" is 225° F	over 2 1/2" 300° F

Revision #	Description	Date	Status:
0	initial Issue	8/4/2023	Approved
1	format revised	2/14/2024	Approved
2	format revised	10/8/2024	Approved
3	Travel Speed Fixed	10/22/2024	Approved

Approved by: Roger Davis **Signed:**

AWS
Roger R. Davis
CWI 24011831
QC1 EXP. 1/1/2027

Roger R. Davis

Date: 10/22/2024

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

Structual Steel AWS D1.1 / D1.8
Welding Procedure Specification (WPS)

Attach Joint Configurations

Welding Procedure Specification (WPS)	FabCO 811N1 Supporting P.Q.R # Prequalified
Material Specification:	Group I & II Material in Table 5.3 AWS D1.1 (also Group III to Group I & II)
Welding Process:	FCAW-G
Manual or Machine:	Semi-Automatic
Position of Weld	All
Filler Metal: Specification, Classification, Trade Name:	AWS A5.29/A5.29M - E81T1-Ni1 MJ H4, Hobart FabCO 811N1
Flux:	N/A
Shielding Gas: Mix, Type, Flow Rate, Wind Velocity	100% $Co_{2,}$ 35 - 50 CFH, Wind Velocity ≤ 3 MPH DCW, ≤ 5 MPH all others
Welding Current:	DCEP (CV Output)
Root Treatment:	Clean to remove all contaminants (see QC plan)
Preheat and Interpass Temperature:	Min Preheat 32°F, Max interpass 550° F (See table below)
Post-Weld Heat Treatment:	Not required, UNO Written procedure required (see QC plan)
Heat Input Limits 1/16" (A x V x .06 / Travel Speed = KJ/in.)	Minimum HI - 28.9 kj/in Maximum HI - 80.8 kj/in
Joint Geometry	See joint configurations, attached pages

Electrical Characteristics

Pass No.	Weld Type	Weld Position	Electrode Diameter / CTWD	Welding Current		WFS	Travel Speed
				Volts	Amps	IPM	IPM
All	Groove or Fillet	All Positions	1/16" Dia. CTWD 3/4"	21 -(24)- 27	135 -(150)- 165	108 -(120)- 132	3.5 - (4.6) - 5.7
All	Groove or Fillet	All Positions	1/16" Dia. CTWD 3/4"	22 -(25)- 28	180 -(200)- 220	140 -(155)- 170	5 - (6.6) - 8.2
All	Groove or Fillet	All Positions	1/16" Dia. CTWD 1"	22 -(26)- 30	225 -(250)- 275	198 -(220)- 242	6.6 - (8.8) - 10.9
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	23 -(27)- 31	270 -(300)- 330	252 -(280)- 308	8.9 - (11.8) - 14.7

NOTES

1	For Fillets, where root separation is greater than 1/16" ≤ 3/16", the size of the fillet weld may be increased by the amount of the actual gap. Fillet and Groove welds may have excessive root openings "buttered up"/ repaired, up to a 1/4", to close a gap to within acceptable limits.
2	Electrode exposure limit - 7 days (per CoC), spools removed, bagged, and stored or stored in an oven, do not count as exposure time.
3	This procedure may vary due to fabrication sequence, fit-up, pass size, etc… within the limits of all mandatory variables given in AWS D1.1.
4	Weld layer thickness - root 5/16" max, fill passes 1/4" max, Single pass fillet 3/8" max. Max layer width 5/8" flat/horizontal 1" Vertical
5	Peening and caulking are not allowed, the use of pneumatic hand tools to remove slag and spatter shall not be considered peening.
6	For "as fit" tolerances see joint geometry pages
7	Backing may be steel, copper, ceramic or backing weld. Non-fusible backing shall be removed and backgouged to sound metal, then back welded.
8	Grind, chip, wire brush between passes and layers. Remove all slag and spatter. Remove noted discontinuities, do not weld over them.
9	This WPS may be used for any prequalified joint configuration not shown, without inclusion herein with QC verification.
10	CB QCM PR12.1 Shall be used in conjunction with this WPS for all other notes, instructions and foot note legend.
11	Weave (vertical only) or stringers may be used. Stringers is preferred for control of heat input where applicable.
12	Voltage +/- 15%, Amperage & WFS +/- 10%, travel speed +/- 25% included in value range given. The number in parenthesis () is manufacturer's recommendation, to the right and left are with D1.1 variables included. Travel Speed was calculated Mathematically based on the deposition rate shown in the manufacturer's datasheet assuming a 5/16" fillet weld. Where Travel Speed = {(Deposition Rate) / (Weld Weight per foot x 5)}

Minimum Preheat/inter-pass Temperature for Material (refer to D1.1 Table 5.8 category and Grade of material)
When the base metal temperature is below 32°F, the base metal shall be preheated to a minimum of 70°F and maintained.

Category B	Category C
≤ 3/4" is 32° F	≤ 3/4" is 50° F
over 3/4" to 1 1/2" is 50° F	over 3/4" to 1 1/2" is 150° F
over 1 1/2" to 2 1/2" is 150° F	over 1 1/2" to 2 1/2" is 225° F
over 2 1/2" is 225° F	over 2 1/2" 300° F

Revision #	Description	Date	Status:
0	initial Issue	8/4/2023	Approved
1	format revised	2/14/2024	Approved
2	format revised	10/8/2024	Approved
3	Travel Speed Fixed	10/22/2024	Approved
4	Heat Input Updated	12/9/2024	Approved

Approved by: Roger Davis **Signed:** AWS Roger R. Davis CWI 24011831 QC1 EXP. 1/1/2027 Roger R. Davis **Date: 12/9/2024**

CoreBrace — Superior Seismic Performance

Structural Steel AWS D1.1 / D1.8
Welding Procedure Specification (WPS)

Attach Joint Configurations

Welding Procedure Specification (WPS)	FabCo Excel-Arc 71 Supporting P.Q.R # Prequalified
Material Specification:	Group I & II Material in Table 5.3 AWS D1.1 (also Group III to Group I & II)
Welding Process:	FCAW-G
Manual or Machine:	Semi-Automatic
Position of Weld	All
Filler Metal: Specification, Classification, Trade Name:	AWS A5.20/A5.20M, E71T-1 C/M E71T-9 C/M H8, Hobart FabCO Excel-Arc 71
Flux:	N/A
Shielding Gas: Mix, Type, Flow Rate, Wind Velocity	100% $Co_{2,}$ 35 - 50 CFH, Wind Velocity ≤ 3 MPH DCW, ≤ 5 MPH all others
Welding Current:	DCEP (CV Output)
Root Treatment:	Clean to remove all contaminants (see QC plan)
Preheat and Interpass Temperature:	Min Preheat 32°F, Max interpass 550° F (See table below)
Post-Weld Heat Treatment:	Not required, UNO Written procedure required (see QC plan)
Heat Input Limits 1/16" (A x V x .06 / Travel Speed = KJ/in.)	Minimum HI - 30.6 kj/in Maximum HI - 82.5 kj/in
Joint Geometry	See joint configurations, attached pages

Electrical Characteristics

Pass No.	Weld Type	Weld Position	Electrode Diameter / CTWD	Welding Current Volts	Welding Current Amps	WFS IPM	Travel Speed IPM
All	Groove or Fillet	All Positions	1/16" Dia. CTWD 3/4"	20 -(23)- 26	162 -(180)- 198	117 -(130)- 143	4 - (5.3) - 6.6
All	Groove or Fillet	All Positions	1/16" Dia. CTWD 1"	22 -(25)-27	221 -(245)- 269	171 -(190)- 209	5.7 - (7.5) - 9.3
All	Groove or Fillet	All Positions	1/16" Dia. CTWD 1"	22 -(26)-28	248 -(275)- 302	203 -(225)- 247	6.8 - (9) - 11.2
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	23 -(27)-31	252 -(280)- 308	216 -(240)- 264	8.1 - (10.8) - 13.4
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	24 -(28)-32	324 -(360)- 396	297 -(330)- 363	10.4 - (13.9) - 17.3
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	26 -(30)- 34	360 -(400)- 440	387 -(430)- 473	14.4 - (19.1) - 23.8

NOTES

1	For Fillets, where root separation is greater than 1/16" ≤ 3/16", the size of the fillet weld may be increased by the amount of the actual gap. Fillet and Groove welds may have excessive root openings "buttered up"/ repaired, up to a 1/4", to close a gap to within acceptable limits.
2	Electrode exposure limit - 7 days (per CoC), spools removed, bagged, and stored or stored in an oven, do not count as exposure time.
3	This procedure may vary due to fabrication sequence, fit-up, pass size, etc… within the limits of all mandatory variables given in AWS D1.1.
4	Weld layer thickness - root 5/16" max, fill passes 1/4" max, Single pass fillet 3/8" max. Max layer width 5/8" flat/horizontal 1" Vertical
5	Peening and caulking are not allowed, the use of pneumatic hand tools to remove slag and spatter shall not be considered peening.
6	For "as fit" tolerances see joint geometry pages
7	Backing may be steel, copper, ceramic or backing weld. Non-fusible backing shall be removed and backgouged to sound metal, then back welded.
8	Grind, chip, wire brush between passes and layers. Remove all slag and spatter. Remove noted discontinuities, do not weld over them.
9	This WPS may be used for any prequalified joint configuration not shown, without inclusion herein with QC verification.
10	CB QCM PR12.1 Shall be used in conjunction with this WPS for all other notes, instructions and foot note legend.
11	Weave (vertical only) or stringers may be used. Stringers is preferred for control of heat input where applicable.
12	Voltage +/- 15%, Amperage & WFS +/- 10%, travel speed +/- 25% included in value range given. The number in parenthesis () is manufacturer's recommendation, to the right and left are with D1.1 variables included. Travel Speed was calculated Mathematically based on the deposition rate shown in the manufacturer's datasheet assuming a 5/16" fillet weld. Where Travel Speed = {(Deposition Rate) / (Weld Weight per foot x 5)}

Minimum Preheat/inter-pass Temperature for Material (refer to D1.1 Table 5.8 category and Grade of material)
When the base metal temperature is below 32°F, the base metal shall be preheated to a minimum of 70°F and maintained.

Category B	Category C
≤ 3/4" is 32° F	≤ 3/4" is 50° F
over 3/4" to 1 1/2" is 50° F	over 3/4" to 1 1/2" is 150° F
over 1 1/2" to 2 1/2" is 150° F	over 1 1/2" to 2 1/2" is 225° F
over 2 1/2" is 225° F	over 2 1/2" 300° F

Revision #	Description	Date	Status:
0	initial Issue	8/4/2023	Approved
1	format revised	2/14/2024	Approved
2	format revised	10/8/2024	Approved
3	Travel Speed Fixed	10/22/2024	Approved
4	Heat Input Updated	12/9/2024	Approved

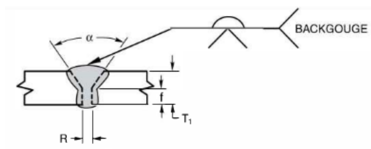
Approved by: Roger Davis **Signed:** AWS Roger R. Davis CWI 24011831 QC1 EXP. 1/1/2027 Roger R. Davis **Date: 12/9/2024**

D1.1 Joint Configurations

The joint configurations listed on this page apply to the following **WPS**s: **FabCOR Edge XP, FabCO TR-70, FabCO 811N1, and FabCo Excel-Arc 71**

B-U2-GF

Single-V-groove weld (2) - Butt joint (B)

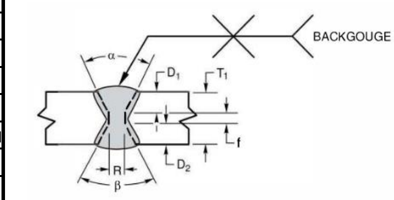


See AWS D1.1 Figure 5.1

Welding Process		
GMAW FCAW		
Base Metal Thickness		
T_1 = U	T_2 = --	
Root opening / Root Face / Groove angle	Tolerances	
	As detailed	As Fit-up
R = 0 to 1/8	+1/16, -0	.+1/16, -1/8
f = 0 to 1/8	.+1/16, -0	Not limited
α = 60°	.+10°, -0	.+10°, -5°
Allowed Welding Positions = ALL		
Notes: a, d, j		

B-U3-GF

Double-V-groove weld (3) - Butt joint (B)

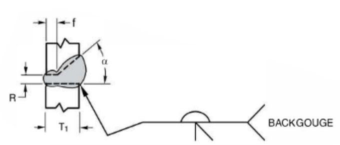


See AWS D1.1 Figure 5.1

Welding Process		
GMAW FCAW		
Base Metal Thickness		
T_1 = U	T_2 = --	
Root opening / Root Face / Groove angle	Tolerances	
	As detailed	As Fit-up
R = 0 to 1/8	+1/16, -0	.+1/16, -1/8
f = 0 to 1/8	.+1/16, -0	Not limited
α = β = 60°	.+10°, -0	.+10°, -5°
Allowed Welding Positions = ALL		
Notes: a, d, h, j		

B-U4b-GF

Single-bevel-groove weld (4) - Butt joint (B)

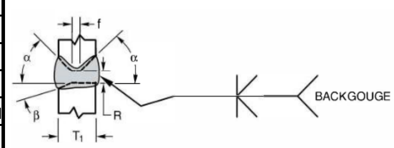


See AWS D1.1 Figure 5.1

Welding Process		
GMAW FCAW		
Base Metal Thickness		
T_1 = U	T_2 = --	
Root opening / Root Face / Groove angle	Tolerances	
	As detailed	As Fit-up
R = 0 to 1/8	+1/16, -0	.+1/16, -1/8
f = 0 to 1/8	.+1/16, -0	Not limited
α = 45°	.+10°, -0	.+10°, -5°
Allowed Welding Positions = ALL		
Notes: a, c, d, j		

B-U5-GF

Double-bevel-groove weld (5) - Butt joint (B)

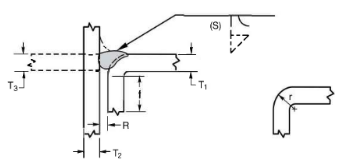


See AWS D1.1 Figure 5.1

Welding Process		
GMAW FCAW		
Base Metal Thickness		
T_1 = U	T_2 = --	
Root opening / Root Face / Groove angle	Tolerances	
	As detailed	As Fit-up
R = 0 to 1/8	+1/16, -0	.+1/16, -1/8
f = 0 to 1/8	.+1/16, -0	Not limited
α = 45°	α + β =	α + β =
β = 0° to 15°	+10°, -0°	+10°, -0°
Allowed Welding Positions = ALL		
Notes: a, c, d, h, j		

BTC-P10-GF

Flare-bevel-groove weld (10) - Butt joint (B) - T-joint (T) Corner joint (C)

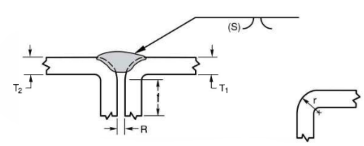


See AWS D1.1 Figure 5.2

GMAW FCAW-G		
Base Metal Thickness		
T_1 = 3/16 min.	T_2 = U	T_3 = T_1 min.
Root opening / Root Face / Bend Radius	Tolerances	
	As detailed	As Fit-up
R = 0	+1/16, -0	.+1/8, -1/16
f = 3/16 min.	.+U, -0	.+U, -1/16
r = $3T_1/2$ min.	.+U, -0	.+U, -0
Allowed Welding Positions = ALL		
Weld size (S) - 5/8 r		
Notes: a, g, j, l, m		

B-P11-GF

Flare-V-groove weld (11) - Butt joint (B)

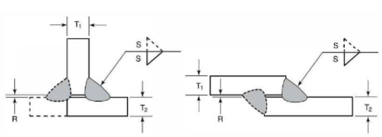


See AWS D1.1 Figure 5.2

GMAW FCAW-G		
Base Metal Thickness		
T_1 = 3/16 min.	T_2 = T_1 min.	
Root opening / Root Face / Bend Radius	Tolerances	
	As detailed	As Fit-up
R = 0	+1/16, -0	.+1/8, -1/16
f = 3/16 min.	.+U, -0	.+U, -1/16
r = $3T_1/2$ min.	.+U, -0	.+U, -0
Allowed Welding Positions = ALL		
Weld size (S) - 3/4 r		
Notes: e, g, l, m, n		

TC-F12-GF - L-F12-GF

Fillet weld (12) - T-joint (T) - Corner joint (C) - Lap joint (L)

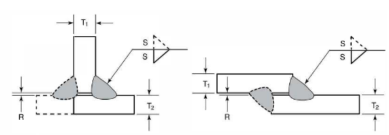


See AWS D1.1 Figure 5.3

GMAW FCAW		
Base Metal Thickness		
T_1 or T_2 = < 3		
	Tolerances	
Root opening	As detailed	As Fit-up
R = 0	.+1/16, -0	3/16 max.
Allowed Welding Positions = ALL		
TC-F12-GF Notes: a, b, d		
L-F12-GF Notes: a, b, c		

L-F12a-GF

Fillet weld (12) - T-joint (T) - Corner joint (C) - Lap joint (L)



See AWS D1.1 Figure 5.3

GMAW FCAW		
Base Metal Thickness		
T_1 or T_2 = ≥ 3		
	Tolerances	
Root opening	As detailed	As Fit-up
R = 0	.+1/16, -0	5/16 max.
Allowed Welding Positions = ALL		
Notes: a, b, c		

AWS
Roger R. Davis
CWI 24011831
QC1 EXP. 1/1/2027
Roger R. Davis

Attach Joint Configurations

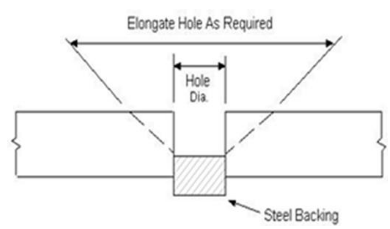
Structural Steel AWS D1.1 / D1.8
Welding Procedure Specification (WPS)

Welding Procedure Specification (WPS)	FabCOR Edge XP Hole Repair — Supporting P.Q.R # Prequalified
Material Specification:	Group I & II Material in Table 5.3 AWS D1.1 (also Group III to Group I & II)
Welding Process:	GMAW - Spray transfer
Manual or Machine:	Semi-Automatic
Position of Weld	Flat and Horizontal
Filler Metal: Specification, Classification, Trade Name:	AWS A5.18, A5.28; SFA 5.18, 5.28 / E70C-6M H4, E80C-G H4, Hobart FabCOR Edge XP
Flux:	N/A
Shielding Gas: Mix, Type, Flow Rate, Wind Velocity	75 - 95% Argon/ 5 - 25% Co_2, 35 - 50 CFH, Wind Velocity ≤ 3 MPH DCW, ≤ 5 MPH all others
Welding Current:	DCEP (CV Output)
Root Treatment:	Clean to remove all contaminants (see QC plan)
Preheat and Interpass Temperature:	Min Preheat 32°F, Max interpass 550° F (See table below)
Post-Weld Heat Treatment:	Not required, UNO Written procedure required (see QC plan)
Heat Input Limits 0.045" (A x V x .06 / Travel Speed = KJ/in.)	Minimum HI - 27.8 kj/in Maximum HI - 82.5 kj/in
Heat Input Limits 1/16"	Minimum HI - 29.3 kj/in Maximum HI - 81.8 kj/in

Instructions

1. This Procedure is for use only on mislocated holes approved by an engineer for repair welding.
2. Elongate the first side of the hole to allow fusion through the full cross-section and length.
3. Insert steel backing of the same material as the basemetal into the hole on the second side.
4. Weld the first side of the hole using longitudinal stringer passes.
5. Gouge the second side to sound metal and back-weld. Grind both Faces flush with the Basemetal.
6. Perform UT, MT, or RT as specified.

Joint Geometry



Electrical Characteristics

Pass No.	Weld Type	Weld Position	Electrode Diameter / CTWD	Welding Current Volts	Welding Current Amps	WFS IPM	Travel Speed IPM
All	Groove or Fillet	Flat / Horizontal	0.045" Dia. CTWD 3/4"	20 -(23)- 26	180 -(200)- 220	216 -(240)- 264	5.8 - (7.6) - 9.5
All	Groove or Fillet	Flat / Horizontal	0.045" Dia. CTWD 3/4"	21 -(25)-28	225 -(250)- 275	306 -(340)-374	7.8 - (10.3) - 12.8
All	Groove or Fillet	Flat / Horizontal	0.045" Dia. CTWD 3/4"	22 -(26)-30	270 -(300)- 330	378 -(420)- 462	10 - (13.3) - 16.6
All	Groove or Fillet	Flat / Horizontal	0.045" Dia. CTWD 7/8"	24 -(28)-32	315 -(350)- 385	513 -(570)-627	14 - (18.6) - 23.2
All	Groove or Fillet	Flat / Horizontal	0.045" Dia. CTWD 7/8"	26 -(30)-34	360 -(400)- 440	653 -(725)- 797	17.5 - (23.2) - 29
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 7/8"	21 -(24)- 27	225 -(250)-275	139 -(155)-170	6.6 - (8.8) - 10.9
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 7/8"	22 -(25)- 28	270 -(300)- 330	184 -(205)- 225	9.1 - (12) - 15
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 7/8"	23 -(27)- 31	315 -(350)- 385	238 -(265)- 291	10.5 - (14) - 17.4
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	25 -(29)- 33	360 -(400)- 440	292 -(325)- 357	13.6 - (18) - 22.5
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	27 -(31)- 35	450 -(500)- 550	450 -(500)- 550	21.5 - (28.6) - 35.6

NOTES

1	If the root separation is greater than 1/16" between the backing and base metal correction is required.
2	Electrode exposure limit - 7 days (per CoC), spools removed, bagged, and stored or stored in an oven, do not count as exposure time.
3	This procedure may vary due to fabrication sequence, fit-up, pass size, etc... within the limits of all mandatory variables given in AWS D1.1.
4	Weld layer thickness - root 5/16" max, fill passes 1/4" max, Single pass fillet 3/8" max. Max layer width 5/8" flat/horizontal.
5	Peening and caulking are not allowed, the use of pneumatic hand tools to remove slag and spatter shall not be considered peening.
6	Grind, chip, wire brush between passes and layers. Remove all slag and spatter. Remove noted discontinuities, do not weld over them.
7	CB QCM PR12.1 Shall be used in conjunction with this WPS for all other notes, instructions and foot note legend.
8	Voltage +/- 15%, Amperage & WFS +/- 10%, travel speed +/- 25% included in value range given. The number in parenthesis () is manufacturer's recommendation, to the right and left are with D1.1 variables included. Travel Speed was calculated Mathematically based on the deposition rate shown in the manufacturer's datasheet assuming a 5/16" fillet weld. Where Travel Speed = {(Deposition Rate) / (Weld Weight per foot x 5)}

Minimum Preheat/inter-pass Temperature for Material (refer to D1.1 Table 5.8 category and Grade of material)
When the base metal temperature is below 32°F, the base metal shall be preheated to a minimum of 70°F and maintained.

Category B	Category C
≤ 3/4" is 32° F	≤ 3/4" is 50° F
over 3/4" to 1 1/2" is 50° F	over 3/4" to 1 1/2" is 150° F
over 1 1/2" to 2 1/2" is 150° F	over 1 1/2" to 2 1/2" is 225° F
over 2 1/2" is 225° F	over 2 1/2" 300° F

Revision #	Description	Date	Status:
3	Updated Format	2/19/2024	Approved
4	TS fixed / Format	10/22/2024	Approved
5	Heat Input Updated	12/9/2024	Approved

Approved by: Roger Davis

Signed: AWS® Roger R. Davis CWI 24011831 QC1 EXP. 1/1/2027 — Roger R Davis

Date: 12/9/2024

Structual Steel AWS D1.1 / D1.8
Welding Procedure Specification (WPS)

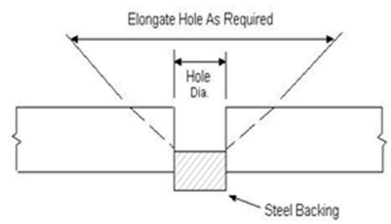
Attach Joint Configurations

Welding Procedure Specification (WPS)	FabCO TR-70 Hole Repair — Supporting P.Q.R # Prequalified
Material Specification:	Group I & II Material in Table 5.3 AWS D1.1 (also Group III to Group I & II)
Welding Process:	FCAW-G
Manual or Machine:	Semi-Automatic
Position of Weld	Flat and Horizontal
Filler Metal: Specification, Classification, Trade Name:	AWS A5.20/A5.20M - E70T-1C H8,E70T-9C H8, Hobart FabCO TR-70
Flux:	N/A
Shielding Gas: Mix, Type, Flow Rate, Wind Velocity	100% Co_2, 35 - 50 CFH, Wind Velocity ≤ 3 MPH DCW, ≤ 5 MPH all others
Welding Current:	DCEP (CV Output)
Root Treatment:	Clean to remove all contaminants (see QC plan)
Preheat and Interpass Temperature:	Min Preheat 32°F, Max interpass 550° F (See table below)
Post-Weld Heat Treatment:	Not required, UNO Written procedure required (see QC plan)
Heat Input Limits 1/16" (A x V x .06 / Travel Speed = KJ/in.)	Minimum HI - 28.5 kj/in Maximum HI - 75.5 kj/in
Heat Input Limits 5/64"	Minimum HI - 31.0 kj/in Maximum HI - 84.3 kj/in

Instructions

1. This Procedure is for use only on mislocated holes approved by an engineer for repair welding.
2. Elongate the first side of the hole to allow fusion through the full cross-section and length.
3. Insert steel backing of the same material as the basemetal into the hole on the second side.
4. Weld the first side of the hole using longitudinal stringer passes.
5. Gouge the second side to sound metal and back-weld. Grind both Faces flush with the Basemetal.
6. Perform UT, MT, or RT as specified.

Joint Geometry



Electrical Characteristics

Pass No.	Weld Type	Weld Position	Electrode Diameter / CTWD	Welding Current Volts	Welding Current Amps	WFS IPM	Travel Speed IPM
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	22 -(25)- 28	153 -(170)- 187	126 -(140)- 154	4.6 - (6.1) - 7.6
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	23 -(26)-30	180 -(200)- 220	153 -(170)-187	5.6 - (7.4) - 9.2
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	23 -(27)-31	234 -(260)- 286	189 -(210)- 231	6.8 - (9) - 11.2
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	27 -(32)-36	315 -(350)- 385	311 -(345)-379	11.2 - (14.9) - 18.6
All	Groove or Fillet	Flat / Horizontal	5/64" Dia. CTWD 1"	22 -(26)- 30	225 -(250)- 275	99 -(110)- 121	5.7 - (7.5) - 9.3
All	Groove or Fillet	Flat / Horizontal	5/64" Dia. CTWD 1"	22 -(26)- 30	270 -(300)- 330	126 -(140)- 154	7.2 - (9.6) - 11.9
All	Groove or Fillet	Flat / Horizontal	5/64" Dia. CTWD 1"	23 -(27)- 31	315 -(350)- 385	153 -(170)- 187	8.7 - (11.6) - 14.4
All	Groove or Fillet	Flat / Horizontal	5/64" Dia. CTWD 1"	23 -(27)- 31	378 -(420)- 462	202 -(225)- 247	11.8 - (15.6) - 19.5
All	Groove or Fillet	Flat / Horizontal	5/64" Dia. CTWD 1"	27 -(32)- 36	495 -(550)- 605	310 -(345)-379	18.1 - (24) - 30

NOTES

1	If the root separation is greater than 1/16" between the backing and base metal correction is required.
2	Electrode exposure limit - 7 days (per CoC), spools removed, bagged, and stored or stored in an oven, do not count as exposure time.
3	This procedure may vary due to fabrication sequence, fit-up, pass size, etc... within the limits of all mandatory variables given in AWS D1.1.
4	Weld layer thickness - root 5/16" max, fill passes 1/4" max, Single pass fillet 3/8" max. Max layer width 5/8" flat/horizontal.
5	Peening and caulking are not allowed, the use of pneumatic hand tools to remove slag and spatter shall not be considered peening.
6	Grind, chip, wire brush between passes and layers. Remove all slag and spatter. Remove noted discontinuities, do not weld over them.
7	CB QCM PR12.1 Shall be used in conjunction with this WPS for all other notes, instructions and foot note legend.
8	Voltage +/- 15%, Amperage & WFS +/- 10%, travel speed +/- 25% included in value range given. The number in parenthesis () is manufacturer's recommendation, to the right and left are with D1.1 variables included. Travel Speed was calculated Mathematically based on the deposition rate shown in the manufacturer's datasheet assuming a 5/16" fillet weld. Where Travel Speed = {(Deposition Rate) / (Weld Weight per foot x 5)}

Minimum Preheat/inter-pass Temperature for Material (refer to D1.1 Table 5.8 category and Grade of material)
When the base metal temperature is below 32°F, the base metal shall be preheated to a minimum of 70°F and maintained.

Category B	Category C
≤ 3/4" is 32° F	≤ 3/4" is 50° F
over 3/4" to 1 1/2" is 50° F	over 3/4" to 1 1/2" is 150° F
over 1 1/2" to 2 1/2" is 150° F	over 1 1/2" to 2 1/2" is 225° F
over 2 1/2" is 225° F	over 2 1/2" 300° F

Revision #	Description	Date	Status:
3	Updated Format	2/19/2024	Approved
4	TS fixed / Format	10/22/2024	Approved

Approved by: Roger Davis **Signed:** Roger R. Davis CWI 24011831 QC1 EXP. 1/1/2027 **Date: 10/22/2024**

Structual Steel AWS D1.1 / D1.8
Welding Procedure Specification (WPS)

Attach Joint Configurations

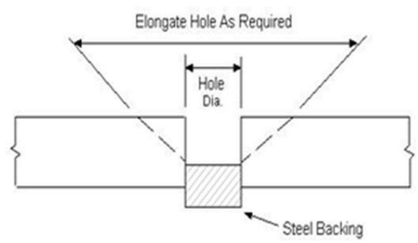
Welding Procedure Specification (WPS)	**FabCO 811N1 Hole Repair**	**Supporting P.Q.R #**	**Prequalified**

Material Specification:	Group I & II Material in Table 5.3 AWS D1.1 (also Group III to Group I & II)
Welding Process:	FCAW-G
Manual or Machine:	Semi-Automatic
Position of Weld	All
Filler Metal: Specification, Classification, Trade Name:	AWS A5.29/A5.29M - E81T1-Ni1 MJ H4, Hobart FabCO 811N1
Flux:	N/A
Shielding Gas: Mix, Type, Flow Rate, Wind Velocity	100% $Co_{2,}$ 35 - 50 CFH, Wind Velocity ≤ 3 MPH DCW, ≤ 5 MPH all others
Welding Current:	DCEP (CV Output)
Root Treatment:	Clean to remove all contaminants (see QC plan)
Preheat and Interpass Temperature:	Min Preheat 32^{o}F, Max interpass 550^{o} F (See table below)
Post-Weld Heat Treatment:	Not required, UNO Written procedure required (see QC plan)
Heat Input Limits 1/16" (A x V x .06 / Travel Speed = KJ/in.)	Minimum HI - 28.9 kj/in Maximum HI - 80.8 kj/in

Instructions

1. This Procedure is for use only on mislocated holes approved by an engineer for repair welding.
2. Elongate the first side of the hole to allow fusion through the full cross-section and length.
3. Insert steel backing of the same material as the basemetal into the hole on the second side.
4. Weld the first side of the hole using longitudinal stringer passes.
5. Gouge the second side to sound metal and back-weld. Grind both Faces flush with the Basemetal.
6. Perform UT, MT, or RT as specified.

Joint Geometry



Electrical Characteristics

Pass No.	Weld Type	Weld Position	Electrode Diameter / CTWD	Welding Current		WFS	Travel Speed
				Volts	Amps	IPM	IPM
All	Groove or Fillet	All Positions	1/16" Dia. CTWD 3/4"	21 -(24)- 27	135 -(150)- 165	108 -(120)- 132	3.5 - (4.6) - 5.7
All	Groove or Fillet	All Positions	1/16" Dia. CTWD 3/4"	22 -(25)- 28	180 -(200)- 220	140 -(155)- 170	5 - (6.6) - 8.2
All	Groove or Fillet	All Positions	1/16" Dia. CTWD 1"	22 -(26)- 30	225 -(250)- 275	198 -(220)- 242	6.6 - (8.8) - 10.9
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	23 -(27)- 31	270 -(300)- 330	252 -(280)- 308	8.9 - (11.8) - 14.7

NOTES

1	If the root separation is greater than 1/16" between the backing and base metal correction is required.
2	Electrode exposure limit - 7 days (per CoC), spools removed, bagged, and stored or stored in an oven, do not count as exposure time.
3	This procedure may vary due to fabrication sequence, fit-up, pass size, etc... within the limits of all mandatory variables given in AWS D1.1.
4	Weld layer thickness - root 5/16" max, fill passes 1/4" max, Single pass fillet 3/8" max. Max layer width 5/8" flat/horizontal 1" Vertical
5	Peening and caulking are not allowed, the use of pneumatic hand tools to remove slag and spatter shall not be considered peening.
6	Grind, chip, wire brush between passes and layers. Remove all slag and spatter. Remove noted discontinuities, do not weld over them.
7	CB QCM PR12.1 Shall be used in conjunction with this WPS for all other notes, instructions and foot note legend.
8	Voltage +/- 15%, Amperage & WFS +/- 10%, travel speed +/- 25% included in value range given. The number in parenthesis () is manufacturer's recommendation, to the right and left are with D1.1 variables included. Travel Speed was calculated Mathematically based on the deposition rate shown in the manufacturer's datasheet assuming a 5/16" fillet weld. Where Travel Speed = {(Deposition Rate) / (Weld Weight per foot x 5)}

Minimum Preheat/inter-pass Temperature for Material (refer to D1.1 Table 5.8 category and Grade of material)
When the base metal temperature is below 32^{o}F, the base metal shall be preheated to a minimum of 70^{o}F and maintained.

Category B	Category C
≤ 3/4" is 32^{o} F	≤ 3/4" is 50^{o} F
over 3/4" to 1 1/2" is 50^{o} F	over 3/4" to 1 1/2" is 150^{o} F
over 1 1/2" to 2 1/2" is 150^{o} F	over 1 1/2" to 2 1/2" is 225^{o} F
over 2 1/2" is 225^{o} F	over 2 1/2" 300^{o} F

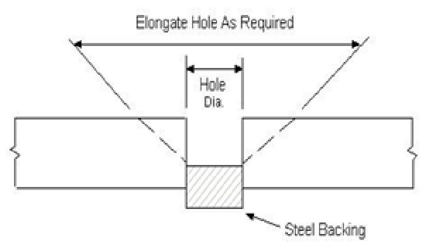
Revision #	Description	Date	Status:
3	Updated Format	2/19/2024	Approved
4	TS fixed / Format	10/22/2024	Approved
5	Heat Input Updated	12/9/2024	Approved

Approved by: Roger Davis **Signed:** AWS Roger R. Davis CWI 24011831 QC1 EXP. 1/1/2027 Roger R Davis **Date: 12/9/2024**

Attach Joint Configurations

Structural Steel AWS D1.1 / D1.8
Welding Procedure Specification (WPS)

Welding Procedure Specification (WPS)	FabCo Excel-Arc 71 Hole Repair Supporting P.Q.R # Prequalified
Material Specification:	Group I & II Material in Table 5.3 AWS D1.1 (also Group III to Group I & II)
Welding Process:	FCAW-G
Manual or Machine:	Semi-Automatic
Position of Weld	All
Filler Metal: Specification, Classification, Trade Name:	AWS A5.20/A5.20M, E71T-1 C/M E71T-9 C/M H8, Hobart FabCO Excel-Arc 71
Flux:	N/A
Shielding Gas: Mix, Type, Flow Rate, Wind Velocity	100% Co_2, 35 - 50 CFH, Wind Velocity ≤ 3 MPH DCW, ≤ 5 MPH all others
Welding Current:	DCEP (CV Output)
Root Treatment:	Clean to remove all contaminants (see QC plan)
Preheat and Interpass Temperature:	Min Preheat 32^{o}F, Max interpass 550^o F (See table below)
Post-Weld Heat Treatment:	Not required, UNO Written procedure required (see QC plan)
Heat Input Limits 1/16" (A x V x .06 / Travel Speed = KJ/in.)	Minimum HI - 30.6 kj/in Maximum HI - 82.5 kj/in

Instructions	Joint Geomerty
1. This Procedure is for use only on mislocated holes approved by an engineer for repair welding. 2. Elongate the first side of the hole to allow fusion through the full cross-section and length. 3. Insert steel backing of the same material as the basemetal into the hole on the second side. 4. Weld the first side of the hole using longitudinal stringer passes. 5. Gouge the second side to sound metal and back-weld. Grind both Faces flush with the Basemetal. 6. Perform UT, MT, or RT as specified.	

Electrical Characteristics

Pass No.	Weld Type	Weld Position	Electrode Diameter / CTWD	Welding Current		WFS	Travel Speed
				Volts	Amps	IPM	IPM
All	Groove or Fillet	All Positions	1/16" Dia. CTWD 3/4"	20 -(23)- 26	162 -(180)- 198	117 -(130)- 143	4 - (5.3) - 6.6
All	Groove or Fillet	All Positions	1/16" Dia. CTWD 1"	22 -(25)-27	221 -(245)- 269	171 -(190)- 209	5.7 - (7.5) - 9.3
All	Groove or Fillet	All Positions	1/16" Dia. CTWD 1"	22 -(26)-28	248 -(275)- 302	203 -(225)- 247	6.8 - (9) - 11.2
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	23 -(27)-31	252 -(280)- 308	216 -(240)- 264	8.1 - (10.8) - 13.4
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	24 -(28)-32	324 -(360)- 396	297 -(330)- 363	10.4 - (13.9) - 17.3
All	Groove or Fillet	Flat / Horizontal	1/16" Dia. CTWD 1"	26 -(30)- 34	360 -(400)- 440	387 -(430)- 473	14.4 - (19.1) - 23.8

NOTES

1	If the root separation is greater than 1/16" between the backing and base metal correction is required.
2	Electrode exposure limit - 7 days (per CoC), spools removed, bagged, and stored or stored in an oven, do not count as exposure time.
3	This procedure may vary due to fabrication sequence, fit-up, pass size, etc... within the limits of all mandatory variables given in AWS D1.1.
4	Weld layer thickness - root 5/16" max, fill passes 1/4" max, Single pass fillet 3/8" max. Max layer width 5/8" flat/horizontal 1" Vertical
5	Peening and caulking are not allowed, the use of pneumatic hand tools to remove slag and spatter shall not be considered peening.
6	Grind, chip, wire brush between passes and layers. Remove all slag and spatter. Remove noted discontinuities, do not weld over them.
7	CB QCM PR12.1 Shall be used in conjunction with this WPS for all other notes, instructions and foot note legend.
8	Voltage +/- 15%, Amperage & WFS +/- 10%, travel speed +/- 25% included in value range given. The number in parenthesis () is manufacturer's recommendation, to the right and left are with D1.1 variables included. Travel Speed was calculated Mathematically based on the deposition rate shown in the manufacturer's datasheet assuming a 5/16" fillet weld. Where Travel Speed = {(Deposition Rate) / (Weld Weight per foot x 5)}

Minimum Preheat/inter-pass Temperature for Material (refer to D1.1 Table 5.8 category and Grade of material)
When the base metal temperature is below 32^{o}F, the base metal shall be preheated to a minimum of 70^{o}F and maintained.

Category B	Category C
≤ 3/4" is 32^o F	≤ 3/4" is 50^o F
over 3/4" to 1 1/2" is 50^o F	over 3/4" to 1 1/2" is 150^o F
over 1 1/2" to 2 1/2" is 150^o F	over 1 1/2" to 2 1/2" is 225^o F
over 2 1/2" is 225^o F	over 2 1/2" 300^o F

Revision #	Description	Date	Status:
3	Updated Format	2/19/2024	Approved
4	TS fixed / Format	10/22/2024	Approved
5	Heat Input Updated	12/9/2024	Approved

Approved by: Roger Davis **Signed:** Roger R. Davis CWI 24011831 QC1 EXP. 1/1/2027 **Date: 12/9/2024**

FabCO® 811N1

AWS A5.29: E81T1-Ni1CJ H4, E81T1-Ni1MJ H4

Welding Positions:

Features:
- Fast-freezing slag
- Nominal 1% nickel deposit
- Excellent impact toughness
- Low-hydrogen deposit
- Low spatter and excellent slag removal

Benefits:
- Excellent out-of-position performance
- Suitable to replacement to E8018-C3 stick (SMAW) electrodes
- Resists cracking in severe applications
- Assists in minimizing the risk of hydrogen-induced cracking
- Improves operator appeal, reduces clean-up time

Applications:
- High-strength low-alloy steels
- Single and multi-pass welding
- Weathering steels (ASTM A588, A709, etc.)
- Bridge fabrication
- Heavy equipment fabrication
- Structural fabrication
- Shipbuilding

Slag System: Fast-freezing, rutile-type, flux-cored wire

Shielding Gas: 100% Carbon Dioxide (CO_2), 75-80% Argon (Ar)/Balance Carbon Dioxide (CO_2), 35-50 cfh (17-24 l/min)

Type of Current: Direct Current Electrode Positive (DCEP)

Standard Diameters: 0.045” (1.2 mm), 1/16” (1.6 mm)

Re-Drying: Not recommended

Storage: Product should be stored in a dry, enclosed environment, and in its original intact packaging

Typical Weld Metal Chemistry* (Chem Pad):

Weld Metal Analysis (%)	100% CO_2	75% Ar/25% CO_2	AWS Spec
Carbon (C)	0.03	0.06	0.12
Manganese (Mn)	1.09	1.39	1.50
Phosphorus (P)	0.007	0.009	0.030
Sulphur (S)	0.005	0.008	0.030
Silicon (Si)	0.32	0.53	0.80
Nickel (Ni)	1.01	1.00	0.80-1.10

Note: AWS specification single values are maximums.

Typical Diffusible Hydrogen*:

Hydrogen Equipment	100% CO_2	75% Ar/25% CO_2	AWS Spec
(Gas Chromatography)	2.4 ml/100g	3.0 ml/100g	4.0 ml/100g Maximum

Typical Mechanical Properties* (As Welded):

Mechanical Tests	100% CO_2	75% Ar/25% CO_2	AWS Spec
Tensile Strength	83,000 psi (572 MPa)	93,000 psi (641 MPa)	80,000-100,000 psi (552-689 MPa)
Yield Strength	73,000 psi (503 MPa)	85,000 psi (586 MPa)	68,000 psi (470 MPa) Minimum
Elongation % in 2” (50 mm)	26%	25%	19% Minimum

Typical Charpy V-Notch Impact Values* (As Welded):

CVN Temperatures	100% CO_2	75% Ar/25% CO_2	AWS Spec
CVN @-40°F (-40°C)	65 ft•lbs (88 Joules)	40 ft•lbs (54 Joules)	20 ft•lbs (27 Joules) Minimum “J” Requirement

*The information contained or otherwise referenced herein is presented only as “typical” without guarantee or warranty, and Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Typical data are those obtained when welded and tested in accordance with the AWS A5.29 specification. Other tests and procedures may produce different results. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers LLC.

Hobart Brothers LLC ▪ 101 Trade Square East ▪ Troy, OH 45373
PH: (800) 424-1543 ▪ FX: 800-541-6607 ▪ www.hobartbrothers.com

FabCO® 811N1

Diameter Inches	(mm)	Weld Position	Amps	Volts	Wire Feed Speed in/min	(m/min)	Deposition Rate lbs/hr	(kg/hr)	Contact Tip to Work Distance Inches	(mm)
0.045	(1.2)	All Position	100	17	120	(3.81)	1.6	(0.7)	5/8	(16)
0.045	(1.2)	All Position	125	24	200	(5.1)	2.0	(0.9)	5/8	(16)
0.045	(1.2)	All Position	200	26	390	(9.9)	7.0	(3.2)	5/8	(16)
0.045	(1.2)	All Position	225	27	455	(11.6)	8.8	(4.0)	3/4	(19)
0.045	(1.2)	Flat & Horizontal	250	28	530	(13.5)	10.0	(4.5)	3/4	(19)
1/16	(1.6)	All Position	150	24	120	(3.0)	4.0	(1.8)	3/4	(19)
1/16	(1.6)	All Position	200	25	155	(3.9)	5.7	(2.6)	3/4	(19)
1/16	(1.6)	All Position	250	26	220	(5.6)	7.6	(3.4)	1	(25)
1/16	(1.6)	Flat & Horizontal	300	27	280	(7.1)	10.2	(4.6)	1	(25)

- **Maintaining a proper welding procedure - including pre-heat and interpass temperatures - may be critical depending on the type and thickness of steel being welded.**
- The above information was determined by welding using 100% CO_2 shielding gas with a flow rate between 35-50 cfh (17-24 l/min). When welding using 75% Argon (Ar)/25% Carbon Dioxide (CO_2) shielding gas, decrease voltage by 1-2 volts.
- All positions include: Flat, Horizontal, Vertical Up, and Overhead.
- 100 Amp parameters for 1/8" plate thickness and lower.

Standard Diameters and Packages: For a complete list of diameters and packaging, please contact Hobart Brothers at (800) 424-1543 or (937) 332-5188 for International Customer Service.

Diameter Inches	(mm)	33-lb. (15kg) Spool	50-lb. (22.6kg) Spool	60-lb. (27.2kg) Coil
Net Pallet Weight		**2376-lb (1078kg)**	**1600-lb (726kg)**	**1920-lb (871kg)**
0.045	(1.2)	S283612-029	—	—
1/16	(1.6)	S283619-029	S283619-027	S283619-002

Conformance and Approvals:
- **AWS A5.29,** E81T1-Ni1CJ H4, E81T1-Ni1MJ H4
- **AWS A5.29M,** E551T1-Ni1CJ H4, E551T1-Ni1MJ H4

Technical Questions? For technical support of Hobart Filler Metals products, contact the Applications Engineering department by phone toll-free at 1-800-532-2618 or by e-mail at Applications.Engineering@hobartbrothers.com

Caution:
Consumers should be thoroughly familiar with the safety precautions on the warning label posted in each shipment and in the American National Standard Z49.1, "Safety in Welding and Cutting," published by the American Welding Society, 8669 NW 36th St., Miami, FL 33166 (can also be downloaded online at www.aws.org); OSHA Safety and Health Standards 29 CFR 1910 is available from the U.S. Department of Labor, Washington, D.C. 20210

Safety Data Sheets on any Hobart Brothers LLC product may be obtained from Hobart Customer Service or at www.hobartbrothers.com.

Revision Date: 230222 (Replaces **220407**)

HOBART FILLER METALS

HOBART FILLER METALS

Certificate of Conformance to Requirements for Welding Electrode

Product Type:	**FabCO 811N1**
Classification:	**E81T1-Ni1CJ H4; E81T1-Ni1MJ H4**
Specifications:	**AWS A5.29/A5.29M; ASME SFA 5.29**
Diameter Tested:	**1/16"**
Date Tested:	**1/12/2024**
Date Generated:	**1/29/2024**

This is to certify that the product named above and supplied on the referenced order number is of the same classification, manufacturing process, and material requirements as the material which was used for the test that was concluded on the date shown, the results of which are shown below. All tests required by the specifications shown for classification were performed at that time and the material tested met all requirements. It was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001, ANSI/AWS A5.01, and other specification and Military requirements, as applicable. This document supplies actual test results of non-specific inspection in conformance with the requirements of EN 10204, type 2.2 certification.

THE STEEL USED IN THIS LOT OF MATERIAL WAS MELTED AND MANUFACTURED IN THE U.S.A.

Test Settings

Shielding Medium	Amps / Polarity	Volts	WFS in/min(m/min)	ESO in(mm)	Preheat F(C)	Interpass F(C)	Travel Speed in/min(cm/min)
M21-ArC-25	260-290 / DCEP	27	250 (6.4)	3/4 (19)	300(149)	300(149)	10.7 (27.2)
C1	260-290 / DCEP	27	250 (6.4)	3/4 (19)	300(149)	300(149)	10.8 (27.4)

Mechanical Properties - Tensile

Shielding Medium	Ref. No.	Testing Conditions	Ult. Tensile Strength psi (MPa)	Yield Strength psi (MPa)	Elong.% in 2"
C1	PE7390	Aged 48 Hrs 220F	86,000 (590)	78,000 (536)	27
M21-ArC-25	PE7414	Aged 48 Hrs 220F	98,000 (674)	87,000 (599)	24

Mechanical Properties - Impact

Shielding Medium	Ref. No.	Testing Conditions	Temp. F (C)	Individuals ft.lb.(J)	Avg. ft.lb.(J)	Type
M21-ArC-25	PE7387	As Welded	-40 (-40)	58,70,52 (79,95,70)	60 (81)	Charpy-V-Notch
C1	PE7390	As Welded	-40 (-40)	116,118,115 (157,160,156)	116 (158)	Charpy-V-Notch

Ref.No.	Radiographic Inspection	Fillet Weld Test					
PE7387	Conforms	Horizontal :		Overhead :	Conforms	Vertical :	Conforms
PE7390	Conforms	Horizontal :		Overhead :	Conforms	Vertical :	Conforms

Chemical Analysis

Shielding Medium / Ref. No	C	Mn	P	S	Si	Cu	Cr	V	Ni	Mo	Al	Ti	Nb	Co	B	W	Sn	Fe	Sb	N	Mg	Zn	Be	Sb	As
M21-ArC-25 / PE7387	0.05	1.64	0.009	0.006	0.37	0.01	0.04	0.02	0.97	< .01	< .01				0.0056										
C1 / PE7390	0.05	1.36	0.009	0.006	0.24	0.01	0.04	0.02	0.92	< .01	< .01				0.0043										

Diffusible Hydrogen Collected per AWS A4.3

M21-ArC-25	3.0 ml/100g of weld metal for 1/16 in diameter 17% relative humidity
C1	3.9 ml/100g of weld metal for 1/16 in diameter 21.9% relative humidity

James A. Owens, Q.A. Specialist

Certification and Limited Warranty - Data for the above supplied product are those obtained when welded and tested in accordance with the above specification. All tests for the above classification were satisfied. Other tests and procedures may produce different results.

HOBART FILLER METALS

Product: FabCO 811N1
Diameter: 1/16”
Shielding Gas: C1 (100% CO_2)
Current/Polarity: DCEP
Classification: E81T1-Ni1CJ H4
Specification: AWS A5.29/A5.29M:2010
Test Completed: 2/9/2024

Certificate of Conformance

For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named is of the same classification, manufacturing process, and material requirements as the material, which was used for the test which was concluded on the date shown, the results of which are shown below. All test required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input
	64.3 kJ/in	**30.0 kJ/in**
Voltage	24	26
Current (amps)	210	250
WFS (ipm)	169	220
Travel Speed (ipm)	4.65	13
Stick Out	3/4”	3/4”
# of passes	8	13
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # D015372016733	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**64.3 kJ/in**	**30.0 kJ/in**
Test Reference #		PE1796	PE1564
Tensile Strength (psi)	80,000	80,500	85,500
Yield Strength (psi)	68,000	69,900	79,500
Elongation (%)	19	27	26
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	124	163

Test Settings	High Heat Input	Low Heat Input
	80.8 kJ/in	**30.0 kJ/in**
Voltage	25	26
Current (amps)	220	250
WFS (ipm)	175	220
Travel Speed (ipm)	4.1	13
Stick Out	3/4“	3/4”
# of passes	7	13
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # D015672001732	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**80.8 kJ/in**	**30.0 kJ/in**
Test Reference #		PE1567	PE1566
Tensile Strength (psi)	80,000	80,200	87,900
Yield Strength (psi)	68,000	69,600	81,200
Elongation (%)	19	29	26
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	154	156

Test Settings	High Heat Input	Low Heat Input
	78.1.0 kJ/in	**29.4 kJ/in**
Voltage	25	24
Current (amps)	200	220
WFS (ipm)	170	170
Travel Speed (ipm)	4.0	10.7
Stick Out	3/4“	3/4“
# of passes	8	21
# of layers	4	8
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # H03922	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**78.1 kJ/in**	**29.4 kJ/in**
Test Reference #		PE7543	PE7540
Tensile Strength (psi)	80,000	79,900	84,400
Yield Strength (psi)	68,000	69,000	77,900
Elongation (%)	19	29	27
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	157	143

Diffusible Hydrogen - Tested in accordance with AWS A5.29/A5.29M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	**H03922**	HB7385	3.7 (ml/100g)
7 Day Exposure	**H03922**	HB7442	4.2 (ml/100g)

James Owens, Quality Assurance Specialist

HOBART
FILLER METALS

Product: FabCO 811N1
Diameter: 1/16”
Shielding Gas: M21-ArC-25
Current/Polarity: DCEP
Classification: E81T1-Ni1 MJ H4
Specification: AWS A5.29/A5.29M:2010
Test Completed: 12/19/2022

Certificate of Conformance

For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named is of the same classification, manufacturing process, and material requirements as the material, which was used for the test which was concluded on the date shown, the results of which are shown below. All test required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input
	78.4 kJ/in	**28.9** kJ/in
Voltage	25	23
Current (amps)	230	220
WFS (ipm)	170	170
Travel Speed (ipm)	4.4	10.5
Stick Out	3/4”	3/4”
# of passes	8	20
# of layers	5	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # C003240601463	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**78.4** kJ/in	**28.9** kJ/in
Test Reference #		PD7580	PD7734
Tensile Strength (psi)	80,000	90,000	104,000
Yield Strength (psi)	68,000	78,000	97,000
Elongation (%)	19	25	20
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	117	92

Test Settings	High Heat Input	Low Heat Input
	80.5 kJ/in	**30.4** kJ/in
Voltage	25	23
Current (amps)	220	220
WFS (ipm)	170	170
Travel Speed (ipm)	4.1	10
Stick Out	3/4“	3/4”
# of passes	9	21
# of layers	5	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # Z026471824041	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**80.5** kJ/in	**30.4** kJ/in
Test Reference #		PD2728	PD2727
Tensile Strength (psi)	80,000	100,000	113,000
Yield Strength (psi)	68,000	87,000	108,000
Elongation (%)	19	24	21
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	111	77

Test Settings	High Heat Input	Low Heat Input
	79.5 kJ/in	**29.0** kJ/in
Voltage	25	23
Current (amps)	222	223
WFS (ipm)	180	180
Travel Speed (ipm)	4.18	10.7
Stick Out	1/2"-5/8“	3/4“
# of passes	9	21
# of layers	5	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # F05959	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**79.5** kJ/in	**29.0** kJ/in
Test Reference #		PE4814	PE4813
Tensile Strength (psi)	80,000	91,100	108,000
Yield Strength (psi)	68,000	73,500	103,000
Elongation (%)	19	25	21
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	134	93

Diffusible Hydrogen - Tested in accordance with AWS A5.29/A5.29M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	**G02493**	HB6005	3.7 (ml/100g)
7 Day Exposure	**G02493**	HB6403	7.3 (ml/100g)

James Owens, Quality Assurance Specialist

FabCOR® Edge™ XP

HOBART FILLER METALS

AWS A5.18: E70C-6M H4
AWS A5.28: E80C-G H4
EN ISO 17632-A: T46 3 M M21 H5

WELDING POSITIONS:

FEATURES:

- Higher deposition rates and efficiencies than solid wires.
- Smooth arc Characteristics
- Formulation specifically addresses silicon island formation and distribution when welding scale-free base metal.
- Excellent bead appearance and contour when welding over mill scale.

BENEFITS

- Allows for improved welding travel speeds and productivity.
- Provides good operator appeal and produces welds with uniform appearance.
- Reduces time spent on post-weld silicon removal in preparation for paint/coating application or other weld passes.
- Helps minimize the need for pre-weld cleaning.

APPLICATIONS:

- Automatic and mechanized welding
- Semi-automatic welding
- Truck and trailer fabrication
- Non-alloyed and fine grain steels
- Structural steel fabrication
- Rail cars
- Earthmoving equipment
- Agricultural equipment
- General fabrication

WIRE TYPE: Gas-shielded, metal-powder, metal cored wire
SHIELDING GAS: 75-95% Argon (Ar)/Balance Carbon Dioxide (CO_2), 35-50 cfh (19-24 l/min)
TYPE OF CURRENT: Direct Current Electrode Positive (DCEP)
STANDARD DIAMETERS: 0.035” (0.9), 0.045” (1.2 mm), 0.052” (1.4 mm), 1/16” (1.6 mm)
RE-DRYING: Not Recommended
STORAGE: Product should be stored in a dry, enclosed environment and in its original intact packaging

TYPICAL WELD METAL CHEMICAL COMPOSITION* (Chem Pad):

Weld Metal Analysis (%)	75% Ar/25% CO_2	90% Ar/10% CO_2	95% Ar/5% CO_2	AWS Spec.
Carbon (C)	0.04	0.04	0.04	0.12
Manganese (Mn)	1.43	1.52	1.62	1.75
Silicon (Si)	0.62	0.72	0.77	0.90
Sulphur (S)	0.009	0.010	0.011	0.030
Phosphorus (P)	0.006	0.008	0.008	0.030

Note: AWS Specification single values are maximums

TYPICAL WELD METAL DIFFUSIBLE HYDROGEN*:

Hydrogen Equipment	75% Ar/25% CO_2	90% Ar/10% CO_2	95% Ar/5% CO_2	AWS Spec.
(GAS CHROMOTOGRAPHY)	2.8 ml/100 g	2.8 ml/100 g	2.9 ml/100 g	4.0 ml/100 g Maximum

TYPICAL MECHANICAL PROPERTIES (As Welded)*:

Mechanical Tests	75% Ar/25% CO_2	90% Ar/10% CO_2	95% Ar/5% CO_2	AWS Spec.
Tensile Strength	85,000 psi (586 MPa)	87,000 psi (600 MPa)	90,000 psi (634 MPa)	70,000 psi (480 MPa) Min.
Yield Strength	73,000 psi (503 MPa)	75,000 psi (517 MPa)	81,000 psi (558 MPa)	58,000 psi (400 MPa) Min.
Elongation % in 2” (50 mm)	28%	28%	25%	22% Minimum

TYPICAL CHARPY V-NOTCH IMPACT VALUES* (As Welded):

CVN Temperatures	75% Ar/25% CO_2	90% Ar/10% CO_2	95% Ar/5% CO_2	AWS Spec.
Avg. @ -20°F (-30°C)	40 ft-lbs (54 Joules)	36 ft-lbs (49 Joules)	30 ft-lbs (41 Joules)	20 ft-lbs (27 Joules)

*The information contained or otherwise referenced herein is presented only as “typical” without guarantee or warranty, and Hobart Brothers Company expressly disclaims any liability incurred from any reliance thereon. Typical data are those obtained when welded and tested in accordance with the AWS A5.18 specification. Other tests and procedures may produce different results. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers LLC.

FabCOR® Edge™ XP

Typical Operating Parameters*:

Diameter Inches	(mm)	Weld Position	Amps	Volts	Wire Feed Speed in/min	(m/min)	Deposition Rate lbs/hr	(kg/hr)	Contact Tip to Work Distance Inches	(mm)
0.035	(0.9)	Flat & Horizontal	150	24	320	(8.1)	4.6	(2.1)	1/2	(13)
0.035	(0.9)	Flat & Horizontal	200	26	450	(11.4)	6.9	(3.1)	1/2	(13)
0.035	(0.9)	Flat & Horizontal	250	29	590	(15.0)	9.2	(4.2)	1/2	(13)
0.045	(1.2)	Flat & Horizontal	200	23	240	(6.1)	6.6	(3.0)	3/4	(19)
0.045	(1.2)	Flat & Horizontal	250	25	340	(8.6)	8.9	(4.0)	3/4	(19)
0.045	(1.2)	Flat & Horizontal	300	26	420	(10.7)	11.5	(5.2)	3/4	(19)
0.045	(1.2)	Flat & Horizontal	350	28	570	(14.5)	16.1	(7.3)	7/8	(22)
0.045	(1.2)	Flat & Horizontal	400	30	725	(18.4)	20.1	(9.1)	7/8	(22)
0.052	(1.4)	Flat & Horizontal	200	23	190	(4.8)	6.9	(3.1)	3/4	(19)
0.052	(1.4)	Flat & Horizontal	250	24	240	(6.1)	9.1	(4.1)	3/4	(19)
0.052	(1.4)	Flat & Horizontal	300	26	320	(8.1)	11.4	(5.2)	3/4	(19)
0.052	(1.4)	Flat & Horizontal	350	28	405	(10.3)	14.6	(6.6)	7/8	(22)
0.052	(1.4)	Flat & Horizontal	400	30	515	(13.1)	19.2	(8.7)	7/8	(22)
1/16	(1.6)	Flat & Horizontal	250	24	155	(3.9)	7.6	(3.4)	7/8	(22)
1/16	(1.6)	Flat & Horizontal	300	25	205	(5.2)	10.4	(4.7)	7/8	(22)
1/16	(1.6)	Flat & Horizontal	350	27	265	(6.7)	12.1	(5.5)	7/8	(22)
1/16	(1.6)	Flat & Horizontal	400	29	325	(8.3)	15.6	(7.1)	1	(25)
1/16	(1.6)	Flat & Horizontal	500	31	500	(12.7))	24.7	(11/2)	1	(25)

- **Maintaining a proper welding procedure - including pre-heat and interpass temperatures - may be critical depending on the type and thickness of the steel being welded.**
- **For out of position welding, short circuit or pulsed spray transfer mode must be used.**
  Pulse waveforms are designed with nominal operating points that may result in average voltage and current values that differ from the table above. Generally, pulse processes can be expected to produce lower heat inputs than a standard CV process.
- **See Above:** This information was determined by welding using 90% Ar/10% CO2 shielding gas with a flow rate between 35-50 cfh (17-24 l/min). When welding using 75% Ar/25% CO_2 shielding gas, increase voltage by 1-3 volts.

Available Diameters and Packages: For a complete list of diameters and packaging, please contact Hobart Brothers at (800) 424-1543 or (937) 332-5188

Diameter Inches	(mm)	33-lb. (15kg) Spool	50-lb. (22.7kg) Spool	500-lb. (226.8kg) X-Pak	1000-lb. (453.6kg) Recyclable X-Pak
Net Pallet Weight		2376-lb (1078 kg)	1600-lb (726 kg)	2000-lb (907 kg)	2000-lb. (907 kg)
0.035	(0.9)	S250608-029	S250608-029	—	—
0.045	(1.2)	S250612-029	S250612-027	S250612-050	S250612-058
0.052	(1.4)	S250615-029	S250615-027	S250615-050	S250615-058
1/16	(1.6)	S250619-029	S250619-027	—	S250619-058

Conformances And Approvals

- **AWS A5.18,** E70C-6M H4
- **AWS A5.18M,** E49C-6M H4
- **AWS A5.28,** E80C-G H4
- **AWS A5.28M,** E55C-G H4
- **ASME SFA 5.18,** E70C-6M H4
- **CWB,** E491T15-(M12, M20, M21)A3-CS1-H4
- **EN ISO 17632-A,** T46 3 M M21 H5
- **AWS D1.8,** See Approval Certificate for Details [0.045” (1.2 mm) - 1/16” (1.6 mm) diameters]
- **CE Marked** per CPR 305/2011 (1.2 mm - 1.6 mm diameter electrodes)

Technical Questions? For technical support of Hobart Filler Metals products, contact the Applications Engineering department by phone toll-free at 1-800-532-2618 or by e-mail at Applications.Engineering@HobartBrothers.com

Caution:
Consumers should be thoroughly familiar with the safety precautions on the warning label posted in each shipment and in the American National Standard Z49.1, “Safety in Welding and Cutting,” published by the American Welding Society, 8669 NW 36 St, Miami, FL 33166-6672 (can also be downloaded online at www.aws.org); OSHA Safety and Health Standards 29 CFR 1910 is available from the U.S. Department of Labor, Washington, D.C. 20210

Safety Data Sheets on any Hobart Brothers LLC product may be obtained from Hobart Customer Service or at www.hobartbrothers.com.

Because Hobart Brothers Company is constantly improving products, Hobart reserves the right to change design and/or specifications without notice.

Revision Date: 230616 (Replaces 221010)

HOBART FILLER METALS

Certificate of Conformance to Requirements for Welding Electrode

HOBART FILLER METALS

Product Type:	**FabCOR Edge XP**
Classification:	**E70C-6M H4, E80C-G H4**
Specifications:	**AWS A5.18, A5.28; SFA 5.18, 5.28**
Diameter Tested:	**1/16**
Date Tested:	**02/23/2023**
Date Generated:	**3/21/2023**

This is to certify that the product named above and supplied on the referenced order number is of the same classification, manufacturing process, and material requirements as the material which was used for the test that was concluded on the date shown, the results of which are shown below. All tests required by the specifications shown for classification were performed at that time and the material tested met all requirements. It was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001, ANSI/AWS A5.01, and other specification and Military requirements, as applicable. This document supplies actual test results of non-specific inspection in conformance with the requirements of EN 10204, type 2.2 certification.

THE STEEL USED IN THIS LOT OF MATERIAL WAS MELTED AND MANUFACTURED IN THE U.S.A.

Test Settings

Shielding Medium	Amps / Polarity	Volts	WFS in/min(m/min)	ESO in(mm)	Preheat F(C)	Interpass F(C)	Travel Speed in/min(cm/min)
M21-ArC-25	325 / DCEP	29	240 (6.1)	3/4 (19)	Room Temp	300(149)	14 (35.6)
M20-ArC-10	325 / DCEP	27	240 (6.1)	3/4 (19)	Room Temp	300(149)	14 (35.6)
M12-ArC-5	325 / DCEP	26	240 (6.1)	3/4 (19)	Room Temp	300(149)	14 (35.6)

Mechanical Properties - Tensile

Shielding Medium	Ref. No.	Testing Conditions	Ult. Tensile Strength psi (MPa)	Yield Strength psi (MPa)	Elong.% in 2"
M21-ArC-25	PE5718	Aged 48 Hrs 220F	77,000 (528)	65,000 (447)	30
M20-ArC-10	PE5721	Aged 48 Hrs 220F	80,000 (555)	70,000 (485)	29
M12-ArC-5	PE5726	Aged 48 Hrs 220F	83,000 (570)	70,000 (483)	29

Mechanical Properties - Impact

Shielding Medium	Ref. No.	Testing Conditions	Temp. F (C)	Individuals ft.lb.(J)	Avg. ft.lb.(J)	Type
M21-ArC-25	PE5718	As Welded	-20 (-29)	16,40,42 (22,54,57)	33 (44)	Charpy-V-Notch
M20-ArC-10	PE5721	As Welded	-20 (-29)	31,17,20 (42,23,27)	23 (31)	Charpy-V-Notch
M12-ArC-5	PE5726	As Welded	-20 (-29)	43,42,45 (58,57,61)	43 (59)	Charpy-V-Notch

Ref.No.	Radiographic Inspection	Fillet Weld Test					
PE5718	Conforms	Horizontal :		Overhead :		Vertical :	
PE5721	Conforms	Horizontal :		Overhead :		Vertical :	
PE5726	Conforms	Horizontal :		Overhead :		Vertical :	

Chemical Analysis

Shielding Medium / Ref. No	C	Mn	P	S	Si	Cu	Cr	V	Ni	Mo	Al	Ti	Nb	Co	B	W	Sn	Fe	Sb	N	Mg	Zn	Be	Sb	As
M21-ArC-25 / PE5718	0.04	1.28	0.012	0.011	0.59	0.06	0.05	< .01	0.03	0.01		0.010			0.0007										
M20-ArC-10 / PE5721	0.03	1.48	0.013	0.011	0.73	0.05	0.05	< .01	0.03	0.01		0.014			0.0007										
M12-ArC-5 / PE5726	0.03	1.60	0.012	0.010	0.80	0.05	0.04	< .01	0.02	0.01		0.018			0.0009										

Diffusible Hydrogen Collected per AWS A4.3

M20-ArC-10	3.3 ml/100g of weld metal for 1/16 in diameter 15% relative humidity
M12-ArC-5	3.3 ml/100g of weld metal for 1/16 in diameter 15% relative humidity
M21-ArC-25	2.0 ml/100g of weld metal for 1/16 in diameter 15% relative humidity

James A. Owens, Q.A. Specialist

Certification and Limited Warranty - Data for the above supplied product are those obtained when welded and tested in accordance with the above specification. All tests for the above classification were satisfied. Other tests and procedures may produce different results.

Product: FabCOR Edge XP
Diameter: .045”
Shielding Gas: M20-ArC-10
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 6/13/2024

Certificate of Conformance

For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named herein is of the same classification, manufacturing process, and material requirements as the material used for the tests completed on the date shown, the results of which are recorded below. All tests required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality Management System of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input
	78.8 kJ/in	**27.8 kJ/in**
Voltage	27	25.5
Current (amps)	350	280
WFS (ipm)	575	385
Travel Speed (ipm)	7.2	15.4
Stick Out	3/4”	3/4”
# of passes	8	16
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # D670911005	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**78.8 kJ/in**	**27.8 kJ/in**
Test Reference #		PE2254	PE2257
Tensile Strength (psi)	70,000	81,000	88,600
Yield Strength (psi)	58,000	65,900	77,400
Elongation (%)	22	27	26
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	97	92

Test Settings	High Heat Input	Low Heat Input
	81.1 kJ/in	**29.8 kJ/in**
Voltage	27	25.5
Current (amps)	350	280
WFS (ipm)	560	385
Travel Speed (ipm)	7.0	14.44
Stick Out	3/4”	3/4”
# of passes	6	16
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # F62327	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**81.1 kJ/in**	**29.8 kJ/in**
Test Reference #		PE2212	PE2210
Tensile Strength (psi)	70,000	77,600	84,500
Yield Strength (psi)	58,000	60,800	72,500
Elongation (%)	22	30	28
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	80	68

Test Settings	High Heat Input	Low Heat Input
	79.5 kJ/in	**27.4 kJ/in**
Voltage	28	28
Current (amps)	300	265
WFS (ipm)	425	380
Travel Speed (ipm)	6.3	16.2
Stick Out	3/4”	3/4”
# of passes	7	18
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # J90215	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**79.5 kJ/in**	**27.4 kJ/in**
Test Reference #		PE8132	PE2195
Tensile Strength (psi)	70,000	77,700	90,400
Yield Strength (psi)	58,000	60,000	80,200
Elongation (%)	22	31	25
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	98	76

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	**J90215**	HB7504	2 (ml/100g)
7 Day Exposure	**J90215**	HB7525	2 (ml/100g)

James Owens, Quality Assurance Specialist

HOBART
FILLER METALS

Product: FabCOR Edge XP
Diameter: .045"
Shielding Gas: M21-ArC-25
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 6/11/2024

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named herein is of the same classification, manufacturing process, and material requirements as the material used for the tests completed on the date shown, the results of which are recorded below. All tests required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality Management System of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input
	81.6 kJ/in	**27.5 kJ/in**
Voltage	28	26
Current (amps)	340	270
WFS (ipm)	560	400
Travel Speed (ipm)	7.0	15.3
Stick Out	3/4"	3/4"
# of passes	8	16
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # D670911005	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**81.6 kJ/in**	**27.5 kJ/in**
Test Reference #		PE2252	PE2261
Tensile Strength (psi)	70,000	79,100	85,500
Yield Strength (psi)	58,000	62,600	74,100
Elongation (%)	22	29	26
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	88	78

Test Settings	High Heat Input	Low Heat Input
	82.5 kJ/in	**29.2 kJ/in**
Voltage	28	26
Current (amps)	350	275
WFS (ipm)	560	370
Travel Speed (ipm)	7.14	14.83
Stick Out	3/4"	3/4"
# of passes	6	18
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # F62327	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**82.5 kJ/in**	**29.2 kJ/in**
Test Reference #		PE2211	PE2209
Tensile Strength (psi)	70,000	76,300	82,200
Yield Strength (psi)	58,000	59,900	71,500
Elongation (%)	22	29	27
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	71	54

Test Settings	High Heat Input	Low Heat Input
	81.75 kJ/in	**28.4 kJ/in**
Voltage	29	29
Current (amps)	300	265
WFS (ipm)	425	380
Travel Speed (ipm)	6.4	16.2
Stick Out	3/4"	3/4"
# of passes	7	18
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # J90215	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**81.75 kJ/in**	**28.4 kJ/in**
Test Reference #		PE7889	PE8118
Tensile Strength (psi)	70,000	73,800	87,100
Yield Strength (psi)	58,000	59,500	74,800
Elongation (%)	22	32	25
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	90	76

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	**J90215**	HB7503	1 (ml/100g)
7 Day Exposure	**J90215**	HB7526	2 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC ("Hobart") expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart. Please refer to the Hobart Brothers Company website at www.hobartbrothers.com for current Safety Data Sheets ("`SDS").

James Owens, Quality Assurance Specialist

Product: FabCOR Edge XP
Diameter: .052”
Shielding Gas: M20-ArC-10
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 6/26/2024

Certificate of Conformance

For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named herein is of the same classification, manufacturing process, and material requirements as the material used for the tests completed on the date shown, the results of which are recorded below. All tests required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality Management System of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input
	80.4 kJ/in	**28.2 kJ/in**
Voltage	29.5	26
Current (amps)	350	275
WFS (ipm)	415	265
Travel Speed (ipm)	7.7	15.2
Stick Out	3/4”	3/4”
# of passes	6	16
# of layers	3	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # F624251201	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**80.4 kJ/in**	**28.2 kJ/in**
Test Reference #		PE2262	PE2253
Tensile Strength (psi)	70,000	75,900	83,300
Yield Strength (psi)	58,000	59,800	71,800
Elongation (%)	22	31	26
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	103	76

Test Settings	High Heat Input	Low Heat Input
	79.3 kJ/in	**29.4 kJ/in**
Voltage	27	25
Current (amps)	375	275
WFS (ipm)	420	270
Travel Speed (ipm)	7.68	14.1
Stick Out	3/4”	3/4”
# of passes	7	17
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # D670121202031	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**79.3 kJ/in**	**29.4 kJ/in**
Test Reference #		PE2229	PE2227
Tensile Strength (psi)	70,000	76,100	85,700
Yield Strength (psi)	58,000	61,500	75,100
Elongation (%)	22	33	26
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	107	82

Test Settings	High Heat Input	Low Heat Input
	79.1 kJ/in	**27.9 kJ/in**
Voltage	27	26
Current (amps)	375	275
WFS (ipm)	415	275
Travel Speed (ipm)	7.85	15.3
Stick Out	3/4”	3/4”
# of passes	7	18
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # H94483	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**79.1 kJ/in**	**27.9 kJ/in**
Test Reference #		PE8190	PE8182
Tensile Strength (psi)	70,000	79,500	88,100
Yield Strength (psi)	58,000	63,800	77,300
Elongation (%)	22	31	27
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	77	48

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	**H94483**	HB7492	4 (ml/100g)
7 Day Exposure	**H94483**	HB7527	3 (ml/100g)

James Owens, Quality Assurance Specialist

HOBART FILLER METALS

Product: FabCOR Edge XP
Diameter: .052”
Shielding Gas: M20-ArC-15
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 6/26/2024

Certificate of Conformance

For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named herein is of the same classification, manufacturing process, and material requirements as the material used for the tests completed on the date shown, the results of which are recorded below. All tests required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality Management System of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input
	80.2 kJ/in	29.6 kJ/in
Voltage	27.5	25.5
Current (amps)	375	275
WFS (ipm)	420	270
Travel Speed (ipm)	7.72	14.34
Stick Out	3/4”	3/4”
# of passes	7	18
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # F62931	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		80.2 kJ/in	29.6 kJ/in
Test Reference #		PE2286	PE2287
Tensile Strength (psi)	70,000	72,500	80,400
Yield Strength (psi)	58,000	58,500	68,600
Elongation (%)	22	32	27
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	84	64

Test Settings	High Heat Input	Low Heat Input
	80.0 kJ/in	29.2 kJ/in
Voltage	27.5	25.5
Current (amps)	375	275
WFS (ipm)	420	275
Travel Speed (ipm)	7.74	14.47
Stick Out	3/4”	3/4”
# of passes	7	18
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # D670121202031	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		80.0 kJ/in	29.2 kJ/in
Test Reference #		PE2276	PE2275
Tensile Strength (psi)	70,000	75,200	82,600
Yield Strength (psi)	58,000	59,500	70,700
Elongation (%)	22	30	27
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	95	81

Test Settings	High Heat Input	Low Heat Input
	79.5 kJ/in	30 kJ/in
Voltage	28	27
Current (amps)	350	275
WFS (ipm)	420	275
Travel Speed (ipm)	7.1	14.8
Stick Out	3/4”	3/4”
# of passes	6	18
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # H94483	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		79.5 kJ/in	30 kJ/in
Test Reference #		PE8194	PE8196
Tensile Strength (psi)	70,000	78,200	85,000
Yield Strength (psi)	58,000	61,700	73,400
Elongation (%)	22	31	28
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	87	75

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	H94483	HB7490	4 (ml/100g)
7 Day Exposure	H94483	HB7528	3 (ml/100g)

James Owens, Quality Assurance Specialist

HOBART FILLER METALS

Product: FabCOR Edge XP
Diameter: .052”
Shielding Gas: M21-ArC-25
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 6/26/2024

Certificate of Conformance

For AWS D1.8/D1.8M, Seismic Supplement

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Test Settings	High Heat Input	Low Heat Input
	81.2 kJ/in	**29.5** kJ/in
Voltage	29.5	27
Current (amps)	350	275
WFS (ipm)	410	270
Travel Speed (ipm)	7.65	15.2
Stick Out	3/4”	3/4”
# of passes	7	17
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # D670121201031	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**81.2 kJ/in**	**29.5** kJ/in
Test Reference #		PE2228	PE2226
Tensile Strength (psi)	70,000	71,800	82,900
Yield Strength (psi)	58,000	57,600	72,300
Elongation (%)	22	32	26
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	102	71

Test Settings	High Heat Input	Low Heat Input
	78.4 kJ/in	**28.7** kJ/in
Voltage	29.5	27
Current (amps)	350	275
WFS (ipm)	410	265
Travel Speed (ipm)	7.9	15.5
Stick Out	3/4”	3/4”
# of passes	6	17
# of layers	3	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # F624251201	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**78.4** kJ/in	**28.7** kJ/in
Test Reference #		PE2200	PE2198
Tensile Strength (psi)	70,000	72,600	81,200
Yield Strength (psi)	58,000	58,100	69,800
Elongation (%)	22	31	26
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	81	51

Test Settings	High Heat Input	Low Heat Input
	81.5 kJ/in	**29.4** kJ/in
Voltage	29	27
Current (amps)	350	275
WFS (ipm)	425	265
Travel Speed (ipm)	7.4	14.72
Stick Out	3/4”	3/4”
# of passes	6	17
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # H94483	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**81.5** kJ/in	**29.4** kJ/in
Test Reference #		PE8209	PE8220
Tensile Strength (psi)	70,000	76,700	82,800
Yield Strength (psi)	58,000	60,900	69,800
Elongation (%)	22	30	29
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	91	74

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	**H94483**	HB7493	3 (ml/100g)
7 Day Exposure	**H94483**	HB7529	3 (ml/100g)

James Owens, Quality Assurance Specialist

HOBART FILLER METALS

Product: FabCOR Edge XP
Diameter: .052”
Shielding Gas: Ozoline C8
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 6/26/2024

Certificate of Conformance

For AWS D1.8/D1.8M, Seismic Supplement

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Test Settings	High Heat Input	Low Heat Input
	77.3 kJ/in	**29.5 kJ/in**
Voltage	29	26
Current (amps)	350	300
WFS (ipm)	410	300
Travel Speed (ipm)	7.89	15.91
Stick Out	1”	3/4”
# of passes	7	15
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # F64777	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**77.3 kJ/in**	**29.5 kJ/in**
Test Reference #		PE3175	PE3176
Tensile Strength (psi)	70,000	73,000	85,000
Yield Strength (psi)	58,000	58,000	74,000
Elongation (%)	22	30	26
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	56	68

Test Settings	High Heat Input	Low Heat Input
	78.5 kJ/in	**29.7 kJ/in**
Voltage	29	26
Current (amps)	350	300
WFS (ipm)	410	300
Travel Speed (ipm)	7.92	15.83
Stick Out	1”	1”
# of passes	7	15
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # F65403	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**78.5 kJ/in**	**29.7 kJ/in**
Test Reference #		PE3189	PE3190
Tensile Strength (psi)	70,000	76,000	88,000
Yield Strength (psi)	58,000	60,000	77,000
Elongation (%)	22	33	26
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	65	88

Test Settings	High Heat Input	Low Heat Input
	78.7 kJ/in	**30.9 kJ/in**
Voltage	28	26
Current (amps)	350	300
WFS (ipm)	410	340
Travel Speed (ipm)	7.4	15.1
Stick Out	3/4”	3/4”
# of passes	7	15
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # H94483	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**78.7 kJ/in**	**30.9 kJ/in**
Test Reference #		PE8226	PE8227
Tensile Strength (psi)	70,000	80,400	88,300
Yield Strength (psi)	58,000	64,100	75,200
Elongation (%)	22	31	26
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	77	80

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	**H94483**	HB7502	3 (ml/100g)
7 Day Exposure	**H94483**	HB7530	4 (ml/100g)

James Owens, Quality Assurance Specialist

HOBART FILLER METALS

Product: FabCOR Edge XP
Diameter: 1/16”
Shielding Gas: M20-ArC-10
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 6/19/2024

Certificate of Conformance

For AWS D1.8/D1.8M, Seismic Supplement

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Test Settings	High Heat Input	Low Heat Input
	79.7 kJ/in	**31.4 kJ/in**
Voltage	26	26
Current (amps)	375	300
WFS (ipm)	295	220
Travel Speed (ipm)	7.3	14.9
Stick Out	3/4”	3/4”
# of passes	7	16
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # J60188	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**79.7 kJ/in**	**31.4 kJ/in**
Test Reference #		PE8170	PE8169
Tensile Strength (psi)	70,000	78,200	86,400
Yield Strength (psi)	58,000	61,100	7,100
Elongation (%)	22	32	27
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	97	84

Test Settings	High Heat Input	Low Heat Input
	80.3 kJ/in	**30.8 kJ/in**
Voltage	26.5	30
Current (amps)	375	350
WFS (ipm)	295	200
Travel Speed (ipm)	7.45	15.0
Stick Out	3/4”	7/8”
# of passes	7	16
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # F623171301	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**80.3 kJ/in**	**30.8 kJ/in**
Test Reference #		PE2339	PE2299
Tensile Strength (psi)	70,000	73,400	79,400
Yield Strength (psi)	58,000	58,500	67,000
Elongation (%)	22	31	27
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	80	67

Test Settings	High Heat Input	Low Heat Input
	81.4 kJ/in	**29.8 kJ/in**
Voltage	26.5	26
Current (amps)	375	300
WFS (ipm)	295	220
Travel Speed (ipm)	7.38	15.7
Stick Out	1”	1”
# of passes	7	17
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # F62351	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**81.4 kJ/in**	**29.8 kJ/in**
Test Reference #		PE2387	PE2372
Tensile Strength (psi)	70,000	75,300	85,400
Yield Strength (psi)	58,000	59,800	73,800
Elongation (%)	22	30	27
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	85	79

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	J60188	HB7470	4 (ml/100g)
7 Day Exposure	J60188	HB7507	4 (ml/100g)

James Owens, Quality Assurance Specialist

Product: FabCOR Edge XP
Diameter: 1/16”
Shielding Gas: M20-ArC-15
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 6/19/2024

Certificate of Conformance

For AWS D1.8/D1.8M, Seismic Supplement

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Test Settings	High Heat Input	Low Heat Input
	80.3 kJ/in	29.3 kJ/in
Voltage	27	27
Current (amps)	350	275
WFS (ipm)	275	190
Travel Speed (ipm)	7	14.9
Stick Out	3/4”	3/4”
# of passes	7	18
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # J60188	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		80.3 kJ/in	29.3 kJ/in
Test Reference #		PE8152	PE8147
Tensile Strength (psi)	70,000	76,500	82,700
Yield Strength (psi)	58,000	60,900	71,400
Elongation (%)	22	34	27
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	94	88

Test Settings	High Heat Input	Low Heat Input
	80.6 kJ/in	30.6 kJ/in
Voltage	27	26.5
Current (amps)	360	285
WFS (ipm)	275	191
Travel Speed (ipm)	7.24	14.85
Stick Out	3/4”	3/4”
# of passes	7	17
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # F623171301	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		80.6 kJ/in	30.6 kJ/in
Test Reference #		PE2344	PE2358
Tensile Strength (psi)	70,000	72,400	78,600
Yield Strength (psi)	58,000	58,600	65,700
Elongation (%)	22	32	27
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	74	87

Test Settings	High Heat Input	Low Heat Input
	78.0 kJ/in	30.3 kJ/in
Voltage	27	26.5
Current (amps)	360	285
WFS (ipm)	275	191
Travel Speed (ipm)	7.52	15.0
Stick Out	3/4”	3/4”
# of passes	7	17
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # F62351	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		78.0 kJ/in	30.3 kJ/in
Test Reference #		PE2385	PE2384
Tensile Strength (psi)	70,000	73,600	80,300
Yield Strength (psi)	58,000	59,400	68,900
Elongation (%)	22	30	27
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	77	82

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	J60188	HB7469	4 (ml/100g)
7 Day Exposure	J60188	HB7509	5 (ml/100g)

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James Owens, Quality Assurance Specialist

HOBART FILLER METALS

Product: FabCOR Edge XP
Diameter: 1/16”
Shielding Gas: M21-ArC-25
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 6/19/2024

Certificate of Conformance

For AWS D1.8/D1.8M, Seismic Supplement

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Test Settings	High Heat Input	Low Heat Input
	78.1 kJ/in	**29.7** kJ/in
Voltage	28	28
Current (amps)	350	275
WFS (ipm)	275	200
Travel Speed (ipm)	6.3	15.5
Stick Out	3/4”	3/4”
# of passes	7	18
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # J60188	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**78.1 kJ/in**	**29.7** kJ/in
Test Reference #		PE8156	PE8163
Tensile Strength (psi)	70,000	74,700	81,000
Yield Strength (psi)	58,000	58,500	67,300
Elongation (%)	22	33	28
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	87	86

Test Settings	High Heat Input	Low Heat Input
	79.9 kJ/in	**30.5** kJ/in
Voltage	28	26.5
Current (amps)	350	275
WFS (ipm)	265	195
Travel Speed (ipm)	7.37	14.35
Stick Out	3/4”	3/4”
# of passes	7	18
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # F623171301	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**79.9** kJ/in	**30.5** kJ/in
Test Reference #		PE2346	PE2352
Tensile Strength (psi)	70,000	71,200	81,400
Yield Strength (psi)	58,000	57,900	68,600
Elongation (%)	22	33	26
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	65	74

Test Settings	High Heat Input	Low Heat Input
	81.8 kJ/in	**29.8** kJ/in
Voltage	28	26.5
Current (amps)	350	285
WFS (ipm)	255	191
Travel Speed (ipm)	7.2	14.73
Stick Out	7/8”	3/4”
# of passes	7	17
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # F62351	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**81.8** kJ/in	**29.8** kJ/in
Test Reference #		PE2381	PE2388
Tensile Strength (psi)	70,000	71,200	80,700
Yield Strength (psi)	58,000	58,100	69,600
Elongation (%)	22	33	26
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	98	71

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	**J60188**	HB7471	4 (ml/100g)
7 Day Exposure	**J60188**	HB7508	2 (ml/100g)

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James Owens, Quality Assurance Specialist

FabCO®Excel-Arc™ 71

HOBART FILLER METALS

AWS A5.20: E71T-1C H8, E71T-1M H8,
E71T-9C H8, E71T-9M H8
EN ISO 17632-A: T46 3 P C1 2 H10, T46 3 P M21 2 H10

Welding Positions:

Features:

- Fast-freezing slag
- Low fumes and spatter
- Easy slag removal
- Able to bridge poor fit-up without burn-through
- Good impact toughness

Benefits:

- Excellent out-of-position capability
- Increases welder appeal and productivity
- Reduces clean-up time, minimizes risk of inclusions
- Increases productivity, reduces part rework/rejection
- Resists cracking in severe applications

Applications:

- Non-alloyed and fine grain steels
- Single and multi-pass welding
- Structural fabrication
- General Fabrication
- Heavy equipment

Slag System: Fast-freezing, rutile-type, flux-cored wire

Shielding Gas: 100% Carbon Dioxide (CO_2), 75-80% Argon (Ar)/Balance Carbon Dioxide (CO_2), 35-50 cfh (17-24 l/min)

Type of Current: Direct Current Electrode Positive (DCEP)

Standard Diameters: 0.035” (0.9 mm), 0.045” (1.2 mm), 0.052” (1.4 mm), 1/16” (1.6 mm)

Re-Drying: Not recommended

Storage: Product should be stored in a dry, enclosed environment, and in its original intact packaging

Typical Weld Metal Chemistry* (Chem Pad):

Weld Metal Analysis (%)	100% CO_2	75% Ar/25% CO_2	AWS Spec
Carbon (C)	0.021	0.022	0.12
Manganese (Mn)	1.30	1.60	1.75
Silicon (Si)	0.69	0.82	0.90
Sulphur (S)	0.011	0.010	0.03
Phosphorus (P)	0.015	0.014	0.03

Note: AWS specification single values are maximums.

Typical Diffusible Hydrogen*:

Hydrogen Equipment	100% CO_2	75% Ar/25% CO_2	AWS Spec
(Gas Chromatography)	3.8 ml/100g	4.8 ml/100g	8.0 ml/100g Maximum

Typical Mechanical Properties* (As Welded):

Mechanical Tests	100% CO_2	75% Ar/25% CO_2	AWS Spec
Tensile Strength	84,000 psi (579 MPa)	90,000 psi (619 MPa)	70,000-95,000 psi (490-670 MPa)
Yield Strength	77,000 psi (531 MPa)	83,000 psi (571 MPa)	58,000 psi (390 MPa) Minimum
Elongation % in 2” (50 mm)	28%	26%	22% Minimum

CVN Temperatures	100% CO_2	75% Ar/25% CO_2	AWS Spec
Avg. at 0°F (-20°C)	101 ft•lbs (137 Joules)	91 ft•lbs (123 Joules)	20 ft•lbs (27 Joules) Minimum
Avg. at -20°F (-30°C)	48 ft•lbs (65 Joules)	72 ft•lbs (98 Joules)	20 ft•lbs (27 Joules) Minimum

*The information contained or otherwise referenced herein is presented only as “typical” without guarantee or warranty, and Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Typical data are those obtained when welded and tested in accordance with AWS A5.20 specification. Other tests and procedures may produce different results. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers LLC.

FabCO®Excel-Arc™ 71

Diameter Inches	(mm)	Weld Position	Amps	Volts	Wire-Feed Speed in/min	(m/min)	Deposition Rate lbs/hr	(kg/hr)	Contact Tip to Work Distance Inches	(mm)
0.035	(0.9)	All Position	125	23	330	(8.4)	3.8	(1.7)	1/2	(13)
0.035	(0.9)	All Position	150	24	410	(10.4)	4.7	(2.1)	1/2	(13)
0.035	(0.9)	All Position	175	25	545	(13.5)	6.3	(2.9)	1/2	(13)
0.035	(0.9)	Flat & Horizontal	200	26	645	(16.4)	7.6	(3.4)	1/2	(13)
0.035	(0.9)	Flat & Horizontal	225	28	785	(19.9)	9.4	(4.3)	1/2	(13)
0.045	(1.2)	All Position	170	23	260	(6.6)	4.4	(2.0)	5/8	(16)
0.045	(1.2)	All Position	185	24	310	(7.9)	6.1	(2.7)	5/8	(16)
0.045	(1.2)	All Position	200	25	340	(7.7)	6.2	(2.8)	5/8	(16)
0.045	(1.2)	All Position	220	25	380	(9.7)	7.5	(3.4)	3/4	(19)
0.045	(1.2)	Flat & Horizontal	260	27	500	(12.7)	8.9	(4.0)	3/4	(19)
0.045	(1.2)	Flat & Horizontal	300	29	590	(15.0)	12.3	(5.6)	3/4	(19)
0.052	(1.4)	All Position	170	24	190	(4.8)	5.0	(2.3)	3/4	(19)
0.052	(1.4)	All Position	200	25	210	(5.3)	5.6	(2.5)	3/4	(19)
0.052	(1.4)	All Position	250	26	275	(7.0)	7.5	(3.4)	3/4	(19)
0.052	(1.4)	Flat & Horizontal	260	27	320	(8.1)	8.1	(3.7)	3/4	(19)
0.052	(1.4)	Flat & Horizontal	300	28	380	(9.6)	9.5	(4.3)	1	(25)
0.052	(1.4)	Flat & Horizontal	350	30	570	(14.5)	14.4	(6.5)	1	(25)
1/16	(1.6)	All Position	180	23	130	(4.1)	4.6	(2.1)	3/4	(19)
1/16	(1.6)	All Position	245	25	190	(4.8)	6.5	(3.0)	1	(25)
1/16	(1.6)	All Position	275	26	225	(5.7)	7.8	(3.5)	1	(25)
1/16	(1.6)	Flat & Horizontal	280	27	240	(6.0)	9.3	(4.2)	1	(25)
1/16	(1.6)	Flat & Horizontal	360	28	330	(8.4)	12.0	(5.4)	1	(25)
1/16	(1.6)	Flat & Horizontal	400	30	430	(10.9)	16.5	(7.5)	1	(25)

- **Maintaining a proper welding procedure - including pre-heat and interpass temperatures - may be critical depending on the type and thickness of steel being welded.**
- **See Above:** This information was determined by welding using 100% CO_2 shielding gas with a flow rate between 35-50 cfh (17-24 l/min). When using 75% Ar/25% CO_2 shielding gas, reduce voltage by 1 volt.
- **All positions include:** Flat, Horizontal, Vertical Up, and Overhead.

Standard Diameters And Packages: For a complete list of diameters and packaging, please contact Hobart Brothers at (800) 424-1543 or (937) 332-5188 for International Customer Service.

Diameter Inches	(mm)	15-lb. (7kg) Spool	33-lb. (15kg) Spool	44-lb. (20kg) Spool	50-lb. (22.7kg) Spool	60-lb. (27.2kg) Coil	500-lb. (227kg) Exacto-Pak	600-lb. (272kg) Drum
Net Pallet Weight		2400 lbs (1089 kg)	2376 lbs (1078 kg)	2376 lbs (1078 kg)	1600 lbs (726 kg)	1920 lbs (871 kg)	2000 lbs (907 kg)	2400 lbs (1089 kg)
0.035	(0.9)	—	S247108-029	—	—	—	—	—
0.045	(1.2)	S247112-023	S247112-029	S247112-044	—	S247112-002	S247112-050	—
0.052	(1.4)	S247115-023	S247115-029	—	S247115-027	—	—	S247115-056
1/16	(1.6)	—	S247119-029	S247119-044	S247119-027	S247119-002	—	S247119-056

Conformances and Approvals:

- **AWS A5.20,** E71T-1C H8, E71T-1M H8, E71T-9C H8, E71T-9M H8
- **AWS A5.20M,** E491T-1C H8, E491T-1M H8, E491T-9C H8, E491T-9M H8
- **ASME SFA 5.20,** E71T-1C H8, E71T-1M H8, E71T-9C H8, E71T-9M H8
- **ABS,** 100% CO_2 3YSA H10, 75% Ar/25% CO_2, 3YSA H10 (0.045" - 1/16" diameter electrodes)
- **Burea Veritas,** 100% CO_2, S3YM HH (0.045" - 1/16" diameter electrodes)
- **CWB,** 100% CO_2 E491T-9-H8, 75-80% Ar/Balance CO_2, E491T-9M-H8 (1.2 mm - 1.6 mm diameter electrodes)
- **CWB,** E491T1-(C1A3, M20A3, M21A3, GA3)-CS1-H8 (E491T-9-H8, E491T-9M-H8)
- **DNV-GL,** 100% CO_2, III YMS(H10)
- **EN ISO 17632-A:** T46 3 P C1 2 H10, T46 3 P M21 2 H10
- **CE Marked** per CPR 305/2011
- **Lloyd's Register,** 100% CO_2, 3YS H10
- **AWS D1.8/D1.8M,** 100% CO_2 & 75% Ar/25% CO_2, (0.045" [1.2 mm] & 1/16" [1.6 mm] diameter electrodes)

Technical Questions? For technical support of Hobart Filler Metals products, contact the Applications Engineering department by phone toll-free at 1-800-532-2618 or by e-mail at Applications.Engineering@hobartbrothers.com

Caution:

Consumers should be thoroughly familiar with the safety precautions on the warning label posted in each shipment and in the American National Standard Z49.1, "Safety in Welding and Cutting," published by the American Welding Society, 8669 NW 36th St., Miami, FL 33166 (can also be downloaded online at www.aws.org); OSHA Safety and Health Standards 29 CFR 1910 is available from the U.S. Department of Labor, Washington, D.C. 20210

Safety Data Sheets on any Hobart Brothers LLC product may be obtained from Hobart Customer Service or at www.hobartbrothers.com.

Because Hobart Brothers LLC is constantly improving products, Hobart reserves the right to change design and/or specifications without notice.

Revision Date: 230629 (Replaces 230427)

636-Y, INDEX

HOBART FILLER METALS

Certificate of Conformance to Requirements for Welding Electrode

HOBART FILLER METALS

Product Type:	**FabCO Excel-Arc 71**
Classification:	**E71T-1C, E71T-1M, E71T-9C, E71T-9M H8**
Specifications:	**AWS A5.20/A5.20M; ASME SFA 5.20**
Diameter Tested:	**.045"**
Date Tested:	**4/10/2023**
Date Generated:	**12/6/2023**

This is to certify that the product named above and supplied on the referenced order number is of the same classification, manufacturing process, and material requirements as the material which was used for the test that was concluded on the date shown, the results of which are shown below. All tests required by the specifications shown for classification were performed at that time and the material tested met all requirements. It was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001, ANSI/AWS A5.01, and other specification and Military requirements, as applicable. This document supplies actual test results of non-specific inspection in conformance with the requirements of EN 10204, type 2.2 certification.

THE STEEL USED IN THIS LOT OF MATERIAL WAS MELTED AND MANUFACTURED IN THE U.S.A.

Test Settings

Shielding Medium	Amps / Polarity	Volts	WFS in/min(m/min)	ESO in(mm)	Preheat F(C)	Interpass F(C)	Travel Speed in/min(cm/min)
M21-ArC-25	275 / DCEP	27	540 (13.7)	5/8 (16)	Room Temp	300(149)	11 (27.9)
C1 (100% CO2)	275 / DCEP	28	540 (13.7)	5/8 (16)	Room Temp	300(149)	11 (27.9)

Mechanical Properties - Tensile

Shielding Medium	Ref. No.	Testing Conditions	Ult. Tensile Strength psi (MPa)	Yield Strength psi (MPa)	Elong.% in 2"
C1 (100% CO2)	PE6052	Aged 48 Hrs 220F	87,000 (599)	83,000 (572)	27
M21-ArC-25	PE6065	Aged 48 Hrs 220F	93,000 (643)	88,000 (605)	26

Mechanical Properties - Impact

Shielding Medium	Ref. No.	Testing Conditions	Temp. F (C)	Individuals ft.lb.(J)	Avg. ft.lb.(J)	Type
M21-ArC-25	PE6046	As Welded	0 (-18)	63,69,79 (85,94,107)	70 (95)	Charpy-V-Notch
M21-ArC-25	PE6046	As Welded	-20 (-29)	60,59,53 (81,80,72)	57 (78)	Charpy-V-Notch
C1 (100% CO2)	PE6052	As Welded	0 (-18)	107,104,97 (145,141,132)	103 (139)	Charpy-V-Notch
C1 (100% CO2)	PE6052	As Welded	-20 (-29)	89,89,84 (121,121,114)	87 (118)	Charpy-V-Notch

Ref.No.	Radiographic Inspection	Fillet Weld Test					
PE6046	Conforms	Horizontal :		Overhead :	Conforms	Vertical :	Conforms
PE6052	Conforms	Horizontal :		Overhead :	Conforms	Vertical :	Conforms

Chemical Analysis

Shielding Medium / Ref. No	C	Mn	P	S	Si	Cu	Cr	V	Ni	Mo	Al	Ti	Nb	Co	B	W	Sn	Fe	Sb	N	Mg	Zn	Be	Sb	As
M21-ArC-25 / PE6046	0.02	1.57	0.009	0.008	0.80	0.03	0.05	0.02	0.01	< .01					0.0048										
C1 (100% CO2) / PE6052	0.02	1.41	0.009	0.008	0.70	0.03	0.04	0.02	0.01	< .01					0.0048										

Diffusible Hydrogen Collected per AWS A4.3

M21-ArC-25	7.6 ml/100g of weld metal for .045 in diameter 41% relative humidity
C1	6.5 ml/100g of weld metal for .045 in diameter 44% relative humidity

James A. Owens, Q.A. Specialist

Certification and Limited Warranty - Data for the above supplied product are those obtained when welded and tested in accordance with the above specification. All tests for the above classification were satisfied. Other tests and procedures may produce different results.

HOBART FILLER METALS

Product: FabCO Excel-Arc 71
Diameter: .045”
Shielding Gas: C1 (100% CO2)
Current/Polarity: DCEP
Classification: E71T-1 H8, E71T-9 H8
Specification: AWS A5.20/A5.20M:2005
Test Completed: 8/16/2024

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named herein is of the same classification, manufacturing process, and material requirements as the material used for the tests completed on the date shown, the results of which are recorded below. All tests required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality Management System of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input
	84.4 kJ/in	26.7 kJ/in
Voltage	25	26
Current (amps)	225	250
WFS (ipm)	380	450
Travel Speed (ipm)	4	14.6
Stick Out	3/4“	3/4“
# of passes	8	20
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # F000852301	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		84.4 kJ/in	26.7 kJ/in
Test Reference #		PE2544	PE2551
Tensile Strength (psi)	70,000	80,400	93,100
Yield Strength (psi)	58,000	69,900	87,000
Elongation (%)	22	27	22
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	116	106

Test Settings	High Heat Input	Low Heat Input
	80.4 kJ/in	27.9 kJ/in
Voltage	25	26
Current (amps)	225	250
WFS (ipm)	385	450
Travel Speed (ipm)	4.2	14
Stick Out	3/4“	3/4“
# of passes	8	20
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # B611752703191	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		80.4 kJ/in	27.9 kJ/in
Test Reference #		PD6265	P6266
Tensile Strength (psi)	70,000	80,920	89,800
Yield Strength (psi)	58,000	72,700	83,500
Elongation (%)	22	28	23
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	122	109

Test Settings	High Heat Input	Low Heat Input
	80.4 kJ/in	30.3 kJ/in
Voltage	25	26
Current (amps)	225	250
WFS (ipm)	385	450
Travel Speed (ipm)	4	13.2
Stick Out	3/4“	3/4“
# of passes	8	16
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # J60547	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		80.4 kJ/in	30.3 kJ/in
Test Reference #		PE8214	PE8515
Tensile Strength (psi)	70,000	83,100	91,300
Yield Strength (psi)	58,000	73,300	85,600
Elongation (%)	22	27	24
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	120	118

Diffusible Hydrogen - Tested in accordance with AWS A5.20/A5.20M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	J60547	HB7665	6 (ml/100g)
7 Day Exposure	J60547	HB7738	9 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets ("SDS").

James Owens, Quality Assurance Specialist

HOBART FILLER METALS

Product: FabCO Excel-Arc 71
Diameter: .045”
Shielding Gas: M21-ArC-25
Current/Polarity: DCEP
Classification: E71T-1M H8, E71T-9M H8
Specification: AWS A5.20/A5.20M:2005
Test Completed: 8/16/2024

Certificate of Conformance

For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named herein is of the same classification, manufacturing process, and material requirements as the material used for the tests completed on the date shown, the results of which are recorded below. All tests required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality Management System of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input
	82.3 kJ/in	**26.8** kJ/in
Voltage	25	25
Current (amps)	225	250
WFS (ipm)	380	450
Travel Speed (ipm)	4.1	14
Stick Out	3/4“	3/4“
# of passes	8	20
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # F000852301	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**82.3** kJ/in	**26.8** kJ/in
Test Reference #		PE2546	PE2555
Tensile Strength (psi)	70,000	82,500	98,900
Yield Strength (psi)	58,000	72,000	95,500
Elongation (%)	22	27	22
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	127	107

Test Settings	High Heat Input	Low Heat Input
	80.4 kJ/in	**28.4** kJ/in
Voltage	25	26.5
Current (amps)	225	250
WFS (ipm)	385	460
Travel Speed (ipm)	4.2	14
Stick Out	3/4“	3/4“
# of passes	8	18
# of layers	4	8
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # B614611305181	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**80.4** kJ/in	**28.4** kJ/in
Test Reference #		PD6466	PD6465
Tensile Strength (psi)	70,000	90,500	99,400
Yield Strength (psi)	58,000	79,000	93,900
Elongation (%)	22	32	23
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	120	81

Test Settings	High Heat Input	Low Heat Input
	78.6 kJ/in	**29.2** kJ/in
Voltage	25	25
Current (amps)	225	250
WFS (ipm)	385	450
Travel Speed (ipm)	4	14
Stick Out	3/4“	3/4“
# of passes	8	19
# of layers	4	5
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # J60547	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**78.6** kJ/in	**29.2** kJ/in
Test Reference #		PE8212	PE8213
Tensile Strength (psi)	70,000	88,700	100,000
Yield Strength (psi)	58,000	77,300	94,100
Elongation (%)	22	31	23
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	114	98

Diffusible Hydrogen - Tested in accordance with AWS A5.20/A5.20M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	**J60547**	HB7596	6 (ml/100g)
7 Day Exposure	**J60547**	HB7739	8 (ml/100g)

James Owens, Quality Assurance Specialist

HOBART FILLER METALS

Product: FabCO Excel-Arc 71
Diameter: .052”
Shielding Gas: C1 (100% CO_2)
Current/Polarity: DCEP
Classification: E71T-1C; E71T-9C H8
Specification: AWS A5.20/A5.20M:2005
Test Completed: 6/14/2024

Certificate of Conformance

For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named is of the same classification, manufacturing process, and material requirements as the material, which was used for the test which was concluded on the date shown, the results of which are shown below. All test required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input
	80.9 kJ/in	**29.7** kJ/in
Voltage	24	26
Current (amps)	220	260
WFS (ipm)	245	360
Travel Speed (ipm)	4	14.5
Stick Out	3/4”	3/4”
# of passes	8	18
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # J01328	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**80.9** kJ/in	**29.7** kJ/in
Test Reference #		PE8109	PE8108
Tensile Strength (psi)	70,000	81,500	92,800
Yield Strength (psi)	58,000	71,100	85,900
Elongation (%)	22	31	26
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	93	120

Test Settings	High Heat Input	Low Heat Input
	81.5 kJ/in	**30.9** kJ/in
Voltage	24	26
Current (amps)	220	260
WFS (ipm)	245	360
Travel Speed (ipm)	4	14
Stick Out	3/4”	3/4”
# of passes	8	15
# of layers	4	6
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # J01257	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**81.5** kJ/in	**30.9** kJ/in
Test Reference #		PE8120	PE8119
Tensile Strength (psi)	70,000	79,600	93,100
Yield Strength (psi)	58,000	69,300	86,500
Elongation (%)	22	30	23
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	78	113

Test Settings	High Heat Input	Low Heat Input
	78.3 kJ/in	**29** kJ/in
Voltage	24	26
Current (amps)	216	260
WFS (ipm)	255	360
Travel Speed (ipm)	4	14
Stick Out	5/8“	5/8“
# of passes	7	18
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # J00119	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**78.3** kJ/in	**29** kJ/in
Test Reference #		PE7602	PE7601
Tensile Strength (psi)	70,000	75,800	88,300
Yield Strength (psi)	58,000	65,900	81,700
Elongation (%)	22	31	25
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	103	111

Diffusible Hydrogen - Tested in accordance with AWS A5.20/A5.20M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	**J00119**	HB7440	8 (ml/100g)
7 Day Exposure	**J00119**	HB4739	7 (ml/100g)

James Owens, Quality Assurance Specialist

HOBART FILLER METALS

Product: FabCO Excel-Arc 71
Diameter: .052”
Shielding Gas: M21-ArC-25
Current/Polarity: DCEP
Classification: E71T-1M; E71T-9M H8
Specification: AWS A5.20/A5.20M:2005
Test Completed: 6/14/2024

Certificate of Conformance

For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named is of the same classification, manufacturing process, and material requirements as the material, which was used for the test which was concluded on the date shown, the results of which are shown below. All test required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input
	81.4 kJ/in	**29.8** kJ/in
Voltage	24.5	27
Current (amps)	225	250
WFS (ipm)	240	350
Travel Speed (ipm)	4	13.6
Stick Out	3/4”	3/4”
# of passes	8	17
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # J01257	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**81.4**kJ/in	**29.8** kJ/in
Test Reference #		PE8122	PE8665
Tensile Strength (psi)	70,000	88,700	94,500
Yield Strength (psi)	58,000	76,200	87,900
Elongation (%)	22	30	23
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	107	116

Test Settings	High Heat Input	Low Heat Input
	81.0 kJ/in	**29.2** kJ/in
Voltage	24.5	26
Current (amps)	225	260
WFS (ipm)	240	360
Travel Speed (ipm)	4	15
Stick Out	3/4”	3/4”
# of passes	8	17
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # J01328	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**81.0** kJ/in	**29.2** kJ/in
Test Reference #		PE8107	PE8106
Tensile Strength (psi)	70,000	89,300	104,000
Yield Strength (psi)	58,000	78,200	97,500
Elongation (%)	22	27	23
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	114	79

Test Settings	High Heat Input	Low Heat Input
	81.6 kJ/in	**29.4** kJ/in
Voltage	24.5	26.1
Current (amps)	222	259.1
WFS (ipm)	255	360
Travel Speed (ipm)	4	13.8
Stick Out	5/8“	3/4“
# of passes	7	18
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # J00119	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**81.6** kJ/in	**29.4** kJ/in
Test Reference #		PE7599	PE7600
Tensile Strength (psi)	70,000	81,400	93,200
Yield Strength (psi)	58,000	70,500	86,800
Elongation (%)	22	28	23
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	110	65

Diffusible Hydrogen - Tested in accordance with AWS A5.20/A5.20M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	**J00119**	HB7462	4 (ml/100g)
7 Day Exposure	**J00119**	HB7441	6 (ml/100g)

James Owens, Quality Assurance Specialist

Product: FabCO Excel-Arc 71
Diameter: 1/16”
Shielding Gas: C1 (100% CO_2)
Current/Polarity: DCEP
Classification: E71T-1 C/M, E71T-9 C/M H8
Specification: AWS A5.20/A5.20M:2005
Test Completed: 9/26/2022

Certificate of Conformance

For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named is of the same classification, manufacturing process, and material requirements as the material, which was used for the test which was concluded on the date shown, the results of which are shown below. All test required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input
	78.8 kJ/in	**31.0 kJ/in**
Voltage	24	26
Current (amps)	230	282
WFS (ipm)	170	240
Travel Speed (ipm)	4.2	13.9
Stick Out	3/4”	3/4”
# of passes	8	17
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # C604351904291	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**78.8 kJ/in**	**31.0 kJ/in**
Test Reference #		PD7581	PD7733
Tensile Strength (psi)	70,000	83,000	86,000
Yield Strength (psi)	58,000	73,000	82,000
Elongation (%)	22	26	25
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	144	111

Test Settings	High Heat Input	Low Heat Input
	82.5 kJ/in	**31.0 kJ/in**
Voltage	28	27
Current (amps)	275	279
WFS (ipm)	235	240
Travel Speed (ipm)	4.0	15
Stick Out	3/4”	3/4”
# of passes	7	21
# of layers	4	8
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # Z601232203162	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**82.5 kJ/in**	**31.0 kJ/in**
Test Reference #		PD2034	PD2033
Tensile Strength (psi)	70,000	72,600	83,100
Yield Strength (psi)	58,000	63,400	76,200
Elongation (%)	22	31	25
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	197	134

Test Settings	High Heat Input	Low Heat Input
	79.7 kJ/in	**31.2 kJ/in**
Voltage	24	27
Current (amps)	220	290
WFS (ipm)	170	245
Travel Speed (ipm)	4.02	14.8
Stick Out	5/8“	3/4“
# of passes	7	17
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # F04119	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**79.7 kJ/in**	**31.2 kJ/in**
Test Reference #		PE4413	PE4416
Tensile Strength (psi)	70,000	71,400	82,700
Yield Strength (psi)	58,000	62,700	77,000
Elongation (%)	22	31	25
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	116	115

Diffusible Hydrogen - Tested in accordance with AWS A5.20/A5.20M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	C600301902292	HB6002	6.7 (ml/100g)
7 Day Exposure	C600301902292	HB6100	7.9 (ml/100g)

James Owens, Quality Assurance Spec

Product: FabCO Excel-Arc 71
Diameter: 1/16”
Shielding Gas: M21-ArC-25
Current/Polarity: DCEP
Classification: E71T-1M H8, E71T-9M H8
Specification: AWS A5.20/A5.20M:2005
Test Completed: 9/27/2022

Certificate of Conformance

For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named is of the same classification, manufacturing process, and material requirements as the material, which was used for the test which was concluded on the date shown, the results of which are shown below. All test required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input
	78.8 kJ/in	**31.0** kJ/in
Voltage	24	25.5
Current (amps)	230	282
WFS (ipm)	170	240
Travel Speed (ipm)	4.2	13.9
Stick Out	3/4”	3/4”
# of passes	8	17
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # C604351904291	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**78.8** kJ/in	**31.0** kJ/in
Test Reference #		PD7581	PD7733
Tensile Strength (psi)	70,000	83,000	90,000
Yield Strength (psi)	58,000	73,000	82,000
Elongation (%)	22	26	24
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	144	126

Test Settings	High Heat Input	Low Heat Input
	79.2 kJ/in	**31.0** kJ/in
Voltage	24	25.5
Current (amps)	220	282
WFS (ipm)	170	230
Travel Speed (ipm)	4.0	13.9
Stick Out	3/4”	3/4”
# of passes	8	19
# of layers	4	8
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # Z601232203162	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**79.2** kJ/in	**31.0** kJ/in
Test Reference #		PD1878	PD1876
Tensile Strength (psi)	70,000	84,000	94,000
Yield Strength (psi)	58,000	72,000	84,000
Elongation (%)	22	30	24
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	128	126

Test Settings	High Heat Input	Low Heat Input
	79.4 kJ/in	**30.6** kJ/in
Voltage	24.5	25.6
Current (amps)	225	289
WFS (ipm)	170	245
Travel Speed (ipm)	4.03	14.3
Stick Out	3/4“	3/4“
# of passes	8	17
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	3G	1G

Lot- # F04119	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**79.4** kJ/in	**30.6** kJ/in
Test Reference #		PE4417	PE4418
Tensile Strength (psi)	70,000	78,100	89,000
Yield Strength (psi)	58,000	66,900	84,100
Elongation (%)	22	30	25
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	122	134

Diffusible Hydrogen - Tested in accordance with AWS A5.20/A5.20M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	**F04119**	HB6003	7.0 (ml/100g)
7 Day Exposure	**F04119**	HB6025	10.3 (ml/100g)

James Owens, Quality Assurance Specialist

FabCO® TR-70

HOBART FILLER METALS

AWS A5.20: E70T-1C H8, E70T-9C H8

WELDING POSITIONS:

FEATURES:	**BENEFITS:**
• Low fume generation rate	• Provides cleaner work environment, enhances welder appeal
• High deposition rates	• Increases productivity, more parts per hour
• Flat bead profile with fillet welds	• Assists in producing high-quality welds
• Easy slag removal	• Reduces clean-up time, excellent for deep groove applications
• Smooth stable arc, tolerant to changes in stick-out	• Assists in compensating for gaps and producing welds of uniform appearance and quality
• Weld deposit with low diffusible hydrogen and good impact toughness	• Minimizes risk of cracking in restrained joints, thick sections, and critical applications
• Very flexible amperage/voltage range	• Promotes versatility

APPLICATIONS:

- Earthmoving equipment
- Steel structures
- Non-alloyed and fine grain steels
- Heavy fabrication
- Storage vessels
- Rail cars

SLAG SYSTEM: Slow freezing, rutile-type, flux-cored wire

SHIELDING GAS: 100% Carbon Dioxide (CO_2), 35-50 cfh (17-24 l/min)

TYPE OF CURRENT: Direct Current Electrode Positive (DCEP)

STANDARD DIAMETERS: 0.045" (1.2 mm), 1/16" (1.6 mm), 5/64" (2.0 mm), 3/32" (2.4 mm)

RE-DRYING: Not recommended

STORAGE: Product should be stored in a dry, enclosed environment, and in its original intact packaging

TYPICAL WELD METAL CHEMISTRY* (Chem Pad):

Weld Metal Analysis	100% CO_2	AWS Spec
Carbon (C)	0.02	0.12
Manganese (Mn)	1.62	1.75
Silicon (Si)	0.57	0.90
Sulphur (S)	0.006	0.03
Phosphorus (P)	0.013	0.03

Note: AWS specification single values are maximums.

TYPICAL DIFFUSIBLE HYDROGEN*:

Hydrogen Equipment	100% CO_2	AWS Spec
(GAS CHROMATOGRAPHY)	6.3ml/100g	8.0ml/100g Maximum

TYPICAL MECHANICAL PROPERTIES* [Aged 48 Hrs. @ 200°F (93°C)]:

Mechanical Tests	100% CO_2	AWS Spec
Tensile Strength	84,000 psi (579 MPa)	70,000-95,000 (490-670 MPa)
Yield Strength	77,000 psi (531 MPa)	58,000 psi (390 MPa) Minimum
Elongation % in 2" (50 mm)	28%	22% Minimum

TYPICAL CHARPY V-NOTCH IMPACT VALUES* (As Welded):

CVN Temperatures	100% CO_2	AWS Spec
Avg. at 0°F (-20°C)	55 ft•lbs (75 Joules)	20 ft•lbs (27 Joules) Minimum
Avg. at -20°F (-30°C)	44 ft•lbs (60 Joules)	20 ft•lbs (27 Joules) Minimum

*The information contained or otherwise referenced herein is presented only as "typical" without guarantee or warranty, and Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Typical data are those obtained when welded and tested in accordance with the AWS A5.20 specification. Other tests and procedures may produce different results. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers LLC.

FabCO® TR-70

Diameter Inches	(mm)	Weld Position	Amps	Volts	Wire-Feed Speed in/min	(m/min)	Deposition Rate lbs/hr	(kg/hr)	Contact Tip to Work Distance Inches	(mm)
0.045	(1.2)	Flat & Horizontal	150	25	245	(6.2)	5.3	(2.4)	3/4	(19)
0.045	(1.2)	Flat & Horizontal	200	26	365	(9.3)	7.7	(3.5)	3/4	(19)
0.045	(1.2)	Flat & Horizontal	250	26	540	(13.7)	10.9	(4.9)	3/4	(19)
0.045	(1.2)	Flat & Horizontal	280	27	635	(16.1)	13.7	(6.2)	3/4	(19)
1/16	(1.6)	Flat & Horizontal	170	25	140	(3.6)	5.3	(2.4)	1	(25)
1/16	(1.6)	Flat & Horizontal	200	26	170	(4.3)	6.4	(2.9)	1	(25)
1/16	(1.6)	Flat & Horizontal	260	27	210	(5.3)	7.8	(3.5)	1	(25)
1/16	(1.6)	Flat & Horizontal	350	32	345	(8.8)	12.9	(5.9)	1	(25)
5/64	(2.0)	Flat & Horizontal	250	26	110	(2.8)	6.5	(3.0)	1	(25)
5/64	(2.0)	Flat & Horizontal	300	26	140	(3.6)	8.3	(3.8)	1	(25)
5/64	(2.0)	Flat & Horizontal	350	27	170	(4.3)	10.0	(4.6)	1	(25)
5/64	(2.0)	Flat & Horizontal	420	27	225	(5.7)	13.5	(6.1)	1	(25)
5/64	(2.0)	Flat & Horizontal	550	32	345	(8.8)	20.8	(9.4)	1	(25)
3/32	(2.4)	Flat & Horizontal	350	27	125	(3.2)	10.4	(4.7)	1	(25)
3/32	(2.4)	Flat & Horizontal	450	30	174	(4.4)	15.3	(6.9)	1	(25)
3/32	(2.4)	Flat & Horizontal	550	32	245	(6.2)	20.2	(9.2)	1	(25)

- **Maintaining a proper welding procedure - including pre-heat and interpass temperatures - may be critical depending on the type and thickness of steel being welded.**

STANDARD DIAMETERS AND PACKAGES: For a complete list of diameters and packaging, please contact Hobart Brothers at (800) 424-1543 or (937) 332-5188 for International Customer Service.

Diameter Inches	(mm)	33-lb. (15kg) Spool	60-lb. (27.2kg) Coil	600-lb. (272.2kg) Drum / X-Pak	800-lb. (363kg) Flat Reel
Net Pallet Weight		**2376-lb. (1078kg)**	**1920-lb. (871kg)**	**2400-lb. (1089kg)**	**1600-lb. (726kg)**
0.045	(1.2)	S247012-029	—	—	—
1/16	(1.6)	S247019-029	S247019-002	S247019-056	—
5/64	(2.0)	—	S247025-002	S247025-008	—
3/32	(2.4)	—	S247029-002	S247029-008	S247029-069

CONFORMANCES AND APPROVALS:
- **AWS A5.20,** E70T-1C H8, E70T-9C H8
- **AWS A5.20M**, E490T-1C H8, E490T-9C H8
- **ASME SFA 5.20,** E70T-1C H8, E70T-9C H8
- **ABS,** 100% CO_2, E70T-1CJ
- **CWB,** E490T1-C1A3-CS1-H8 (E492T-9-H8)
- **AWS D1.8 Conformance**: 100% CO_2 [1.6 mm, 2.0 mm & 2.4 mm diameter electrodes]

TECHNICAL QUESTIONS? For technical support of Hobart Filler Metals products, contact the Applications Engineering department by phone toll-free at 1-800-532-2618 or by e-mail at Applications.Engineering@hobartbrothers.com

CAUTION:
Consumers should be thoroughly familiar with the safety precautions on the warning label posted in each shipment and in the American National Standard Z49.1, "Safety in Welding and Cutting," published by the American Welding Society, 8669 NW 36th St., Miami, FL 33166 (can also be downloaded online at www.aws.org); OSHA Safety and Health Standards 29 CFR 1910 is available from the U.S. Department of Labor, Washington, D.C. 20210

Safety Data Sheets on any Hobart Brothers LLC product may be obtained from Hobart Customer Service or at www.hobartbrothers.com.

Because Hobart Brothers LLC is constantly improving products, Hobart reserves the right to change design and/or specifications without notice.

Revision Date: 220718 (Replaces 210923)
636-X, INDEX

HOBART FILLER METALS

Certificate of Conformance
to Requirements for Welding Electrode

HOBART FILLER METALS

Product Type:	**FabCO TR-70**
Classification:	**E70T-1C H8, E70T-9C H8**
Specifications:	**AWS A5.20/A5.20M; ASME SFA 5.20**
Diameter Tested:	**045"; 3/32"**
Date Tested:	**6/29/2023**
Date Generated:	**7/5/2023**

This is to certify that the product named above and supplied on the referenced order number is of the same classification, manufacturing process, and material requirements as the material which was used for the test that was concluded on the date shown, the results of which are shown below. All tests required by the specifications shown for classification were performed at that time and the material tested met all requirements. It was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001, ANSI/AWS A5.01, and other specification and Military requirements, as applicable. This document supplies actual test results of non-specific inspection in conformance with the requirements of EN 10204, type 2.2 certification.

THE STEEL USED IN THIS LOT OF MATERIAL WAS MELTED AND MANUFACTURED IN THE U.S.A.

Test Settings

Shielding Medium	Amps / Polarity	Volts	WFS in/min(m/min)	ESO in(mm)	Preheat F(C)	Interpass F(C)	Travel Speed in/min(cm/min)
C1	260-290 / DCEP	29	540 (13.7)	5/8 (16)	Room Temp	300(149)	13.7 (34.8)
C1	425 / DCEP	28	155 (3.9)	1 (25)	Room Temp	300(149)	14 (35.6)

Mechanical Properties - Tensile

Shielding Medium	Ref. No.	Testing Conditions	Ult. Tensile Strength psi (MPa)	Yield Strength psi (MPa)	Elong.% in 2"
C1	PE6222	Aged 48 Hrs 220F	84,000 (583)	80,000 (555)	27
C1	PE6292	Aged 48 Hrs 220F	89,000 (612)	80,000 (549)	25

Mechanical Properties - Impact

Shielding Medium	Ref. No.	Testing Conditions	Temp. F (C)	Individuals ft.lb.(J)	Avg. ft.lb.(J)	Type
C1	PE6222	As Welded	-20 (-29)	54,36,49 (73,49,66)	46 (63)	Charpy-V-Notch
C1	PE6222	As Welded	0 (-18)	63,60,38 (85,81,52)	54 (73)	Charpy-V-Notch
C1	PE6292	As Welded	0 (-18)	36,41,40 (49,56,54)	39 (53)	Charpy-V-Notch
C1	PE6292	As Welded	-20 (-29)	28,29,27 (38,39,37)	28 (38)	Charpy-V-Notch

Ref.No.	Radiographic Inspection	Fillet Weld Test					
PE6222	Conforms	Horizontal :	Conforms	Overhead :		Vertical :	
PE6354	Conforms	Horizontal :	Conforms	Overhead :		Vertical :	

Chemical Analysis

Shielding Medium / Ref. No	C	Mn	P	S	Si	Cu	Cr	V	Ni	Mo	Al	Ti	Nb	Co	B	W	Sn	Fe	Sb	N	Mg	Zn	Be	Sb	As
C1 / PE6222	0.02	1.75	0.007	0.007	0.68	0.02	0.03	0.01	0.01	< .01					0.0057										
C1 / PE6292	0.02	1.63	0.009	0.008	0.64	0.04	0.04	0.01	0.02	0.01					0.0055										

Diffusible Hydrogen Collected per AWS A4.3

C1	5.8 ml/100g of weld metal for 3/32 in diameter 36% relative humidity
C1	4.9 ml/100g of weld metal for .045 in diameter 42% relative humidity

James A. Owens, Q.A. Specialist

Certification and Limited Warranty - Data for the above supplied product are those obtained when welded and tested in accordance with the above specification. All tests for the above classification were satisfied. Other tests and procedures may produce different results.

HOBART FILLER METALS

Product: FabCO TR-70
Diameter: 1/16”
Shielding Gas: C1 (100% CO_2)
Current/Polarity: DCEP
Classification: E70T-1C H8, E70T-9C H8
Specification: AWS A5.20/A5.20M:2005
Test Completed: 10/24/2022

Certificate of Conformance

For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named is of the same classification, manufacturing process, and material requirements as the material, which was used for the test which was concluded on the date shown, the results of which are shown below. All test required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input
	73.0 kJ/in	28.7 kJ/in
Voltage	28	26
Current (amps)	300	230
WFS (ipm)	285	190
Travel Speed (ipm)	6.9	12.5
Stick Out	3/4”	3/4”
# of passes	8	19
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # C000251805321	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		73.0 kJ/in	28.7 kJ/in
Test Reference #		PD8116	PD8115
Tensile Strength (psi)	70,000	77,700	84,100
Yield Strength (psi)	58,000	67,200	77,300
Elongation (%)	22	26	26
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	111	69

Test Settings	High Heat Input	Low Heat Input
	73.7 kJ/in	29.0 kJ/in
Voltage	28	26
Current (amps)	285	232
WFS (ipm)	285	185
Travel Speed (ipm)	6.5	12.5
Stick Out	1”	1”
# of passes	8	19
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # Z025131224322	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		73.7 kJ/in	29.0 kJ/in
Test Reference #		PD2350	PD2349
Tensile Strength (psi)	70,000	82,100	88,200
Yield Strength (psi)	58,000	69,600	80,800
Elongation (%)	22	29	25
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	93	82

Test Settings	High Heat Input	Low Heat Input
	75.5 kJ/in	28.5 kJ/in
Voltage	28	26
Current (amps)	285	232
WFS (ipm)	285	185
Travel Speed (ipm)	6.5	12.5
Stick Out	3/4“	3/4“
# of passes	8	19
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # G00030	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		75.5 kJ/in	28.5 kJ/in
Test Reference #		PE4663	PE4664
Tensile Strength (psi)	70,000	76,100	86,200
Yield Strength (psi)	58,000	65,200	80,600
Elongation (%)	22	32	27
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	114	50

Diffusible Hydrogen - Tested in accordance with AWS A5.20/A5.20M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	**G00030**	HB6157	7.0 (ml/100g)
7 Day Exposure	**G00030**	HB6203	9.1 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets ("SDS").

James Owens, Quality Assurance Specialist

HOBART FILLER METALS

Product: FabCO TR-70
Diameter: 5/64”
Shielding Gas: C1 (100% CO2)
Current/Polarity: DCEP
Classification: E70T-1C H8, E70T-9C H8
Specification: AWS A5.20/A5.20M:2005
Test Completed: 10/21/2022

Certificate of Conformance

For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named is of the same classification, manufacturing process, and material requirements as the material, which was used for the test which was concluded on the date shown, the results of which are shown below. All test required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot- # B024530813303	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	80.7 kJ/in	**31.6** kJ/in	**Mechanical Properties**		**80.7** kJ/in	**31.6** kJ/in
Voltage	30.5	26	Test Reference #		PD8119	PD8121
Current (amps)	450	290				
WFS (ipm)	280	150				
Travel Speed (ipm)	10.2	14.3	Tensile Strength (psi)	70,000	89,300	86,800
Stick Out	1”	1”	Yield Strength (psi)	58,000	77,600	776200
# of passes	7	17	Elongation (%)	22	25	27
# of layers	4	7	Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	57	75
Preheat Temp. ºF	300+/-25	RT				
Interpass Temp. ºF	500+/-50	200+/-25				
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot- # Z028041021391	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	84.3 kJ/in	**31.0** kJ/in	**Mechanical Properties**		**84.3** kJ/in	**31.0** kJ/in
Voltage	30.5	26	Test Reference #		PD2419	PD2417
Current (amps)	447	290				
WFS (ipm)	296	157				
Travel Speed (ipm)	9.7	14.6	Tensile Strength (psi)	70,000	87,700	95,400
Stick Out	3/4”	1”	Yield Strength (psi)	58,000	73,400	87,200
# of passes	7	17	Elongation (%)	22	27	25
# of layers	4	7	Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	43	73
Preheat Temp. ºF	300+/-25	RT				
Interpass Temp. ºF	500+/-50	200+/-25				
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot- # G00114	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	80.0 kJ/in	**32.9** kJ/in	**Mechanical Properties**		**80.0** kJ/in	**32.9** kJ/in
Voltage	30.5	26	Test Reference #		PE4810	PE4811
Current (amps)	447	301				
WFS (ipm)	296	157				
Travel Speed (ipm)	9.7	14.3	Tensile Strength (psi)	70,000	84,000	85,500
Stick Out	1“	1“	Yield Strength (psi)	58,000	70,800	80,300
# of passes	8	18	Elongation (%)	22	25	26
# of layers	4	8	Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	57	70
Preheat Temp. ºF	300+/-25	RT				
Interpass Temp. ºF	500+/-50	200+/-25				
Weld Position	1G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.20/A5.20M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	**G00114**	HB6159	6.4 (ml/100g)
7 Day Exposure	**G00114**	HB6204	8.6 (ml/100g)

James Owens, Quality Assurance Specialist

HOBART FILLER METALS

Product: FabCO TR-70
Diameter: 3/32”
Shielding Gas: C1 (100% CO_2)
Current/Polarity: DCEP
Classification: E70T-1C H8, E70T-9C H8
Specification: AWS A5.20/A5.20M:2005
Test Completed: 10/21/2022

Certificate of Conformance

For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named is of the same classification, manufacturing process, and material requirements as the material, which was used for the test which was concluded on the date shown, the results of which are shown below. All test required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input
	80.0 kJ/in	**30.9** kJ/in
Voltage	32	26
Current (amps)	450	300
WFS (ipm)	180	108
Travel Speed (ipm)	10.8	15.1
Stick Out	1”	1”
# of passes	8	17
# of layers	5	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # C003051514302	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**80.0** kJ/in	**30.9** kJ/in
Test Reference #		PD8169	PD8170
Tensile Strength (psi)	70,000	78,800	87,200
Yield Strength (psi)	58,000	65,500	79,600
Elongation (%)	22	30	25
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	76	61

Test Settings	High Heat Input	Low Heat Input
	80.3 kJ/in	**30.3** kJ/in
Voltage	32	26
Current (amps)	435	299
WFS (ipm)	180	108
Travel Speed (ipm)	10.4	15.4
Stick Out	1”	1”
# of passes	7	17
# of layers	4	8
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # Z003331507301	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**80.3** kJ/in	**30.3** kJ/in
Test Reference #		PD2352	PD2348
Tensile Strength (psi)	70,000	81,800	90,600
Yield Strength (psi)	58,000	68,300	85,200
Elongation (%)	22	29	27
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	54	90

Test Settings	High Heat Input	Low Heat Input
	80.3 kJ/in	**31.6** kJ/in
Voltage	31	26
Current (amps)	450	300
WFS (ipm)	180	100
Travel Speed (ipm)	10.4	14.8
Stick Out	1“	1“
# of passes	7	17
# of layers	4	7
Preheat Temp. ºF	300+/-25	RT
Interpass Temp. ºF	500+/-50	200+/-25
Weld Position	1G	1G

Lot- # F027330928	AWS D1.8 Requirements	High Heat Input	Low Heat Input
Mechanical Properties		**80.3** kJ/in	**31.6** kJ/in
Test Reference #		PE4902	PE4825
Tensile Strength (psi)	70,000	80,800	84,600
Yield Strength (psi)	58,000	66,900	78,000
Elongation (%)	22	27	27
Average Charpy V-notch Impact Properties ft•lbs @ +70 ºF	40	63	75

Diffusible Hydrogen - Tested in accordance with AWS A5.20/A5.20M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	**F027330928**	HB5397	7.7 (ml/100g)
7 Day Exposure	**F027330928**	HB6197	10.0 (ml/100g)

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James Owens, Quality Assurance Specialist

Airgas
an Air Liquide company

Quality Management Systems
Confidential - For Customer Use Only

Certificate of Conformance

Effective Date: January 1, 2023 - December 31, 2025

The product identified below satisfies the specifications listed which meets and exceeds the specifications for Argon.

The information presented on the Certificate of Conformance is based on evaluation of process capabilities and plant periodic data on product delivered by
Airgas USA, LLC.

Liquid Argon	
Test Requirement	**Specification**
Assay*	≥ 99.998%
Oxygen	≤ 5.0 ppm
Nitrogen	≤ 15.0 ppm

Produced by Air Liquefaction process and in compliance with cGMP requirements.

This Certificate of Conformance (COC) does not add to or replace the warranty, limitations of liability or other provisions of the agreement between the parties.

* Assay results are reported to five significant digits by difference of tested impurities.

Approved By:

Mark Jorgensen
Airgas USA, LLC
Sr. Director of Quality & Food Safety

Airgas
an Air Liquide company

Quality Management Systems
Confidential - For Customer Use Only

Certificate of Conformance

Effective Date: January 1, 2023 - December 31, 2025

The liquid carbon dioxide produced at our plants meet and/or exceeds the specification limits set by the Compressed Gas Association G-6.2-2011, Quality Verification Level G [General Commercial Uses).

Liquid Carbon Dioxide	
Test Requirement	**Specification**
Carbon Dioxide (Assay)	99.00 % Min
Acetaldehyde	0.50 ppm
Total Sulfur	0.50 ppm
Oxygen	50.0 ppm
Moisture (Water)	32.0 ppm (-61°F Dewpoint)
Total Hydrocarbon Content (as methane)	50.0 ppm
Non Volatile Residues (wt/wt)	10.0 ppm
Odor/Taste	No foreign odor/taste

Specification limit in ppm (v\v) maximum allowable unless otherwise stated. N/A: Not Applicable.

Approved By:

Mark Jorgensen
Airgas USA, LLC
Sr. Director of Quality & Food Safety

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

Welder qualification summary and continuity log

Welder Continuity Record		Shift and Date Qualified		GMAW													
LAST UPDATED: 12/9/2024				Qualified in Process	In GMAW	Welder Continuity Log 2024											
ID#	Employee Name	Shift	Date			Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
C1	ADRIAN ANGULO	1st	8/5/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C2	ALLAN LOVE	2nd	8/9/2022	X	2F 1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C4	BERNIE GERDES	1st	8/22/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C6	BRADLEE HELLIKSON	1st	8/15/2022	X	2F 1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C7	Brandon Renfro	1st	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C13	CODY RASMUSSEN	1st	3/29/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C17	DALE TAYLOR	1st	8/16/2022	X	2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C22	DOUGLAS LUKER	1ST	7/3/2023	X	2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C24	ELEUTERIO MANCILLA	1st	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C32	JESSE MOORE	2nd	8/4/2022	X	2F 1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C34	JULIO JIMENEZ	1st	8/17/2022	X	1G 2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C41	KIM BEEBE	2nd	1/17/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C44	MARIO ASTUHUAMAN	1st	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C47	NICK POPPLETON	1st	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C50	Peter Mitchell	1st	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C51	RANDY PHILLIPS	1st	11/17/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C54	RONY LOPEZ	1st	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C56	Sam Sotello	2nd	4/22/2024	X	1G				RD	RD	RD	RD	RD	RD	RD	RD	RD
C68	Trevor Valladolid	1st	8/17/2022	X	2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C74	Dalton Lee	1st	2/23/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C75	Spencer Henrickson	1st	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C86	Jose Varela	1st	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C88	Austin Garcia	1ST	8/15/2022	X	1G 2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C95	Kyle Jones	1ST	8/22/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C98	Darrick Lycklama	1ST	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C103	Levi Running Eagle	1st	8/18/2022	X	2F 1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C105	Armando Pena	1st	11/16/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C111	Ward Anderson JR	1st	2/17/2021	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C116	Bridger Sharp	1ST	11/16/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C124	Andrew Cox	1st	11/17/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C128	Sam Munk	1st	8/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C129	Santiago Resendiz Munoz	1st	8/16/2022	X	1G2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C132	Jake Rossen	1st	11/16/2022	X	2F 1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C138	Gustavo Garcia	2ND	9/16/2024	X	1G									RD	RD	RD	RD
C164	Jaren Larson	2nd	12/19/2022	X	1G 2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C166	Tyler Rowe	1ST	11/11/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C171	Cristian Hernandez	1st	1/25/2023	X	2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C173	Miguel Gonzales	1st	2/14/2023	X	1G 2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C176	Rigoberto Navamete	1st	3/30/2023	X	2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C178	Donyvon Hamilton	2nd	4/24/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

Welder qualification summary and continuity log

Welder Continuity Record		Shift and Date Qualified		GMAW													
LAST UPDATED: 12/9/2024				Qualified in	In	Welder Continuity Log 2024											
ID#	Employee Name	Shift	Date	Process	GMAW	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
C181	Garrick Atencio	2nd	6/23/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C183	Feliciano Astuaman	1st	7/3/2023	X	2F	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C184	John Vanderlieth	2nd	7/8/2023	X	2F 1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C185	Jeff Jenkins	2nd	8/3/2023	X	2F 1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C186	A.J. Neary	1st	8/25/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C188	Zach Chacon	2nd	1/24/2024	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C189	Rogelio Bravo	2nd	2/6/2024	X	1G		RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C190	Hailee Mills	1st	2/28/2024	X	1G 2F		RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C193	Julio Perez	2nd	4/16/2024	X	2F				RD	RD	RD	RD	RD	RD	RD	RD	RD
C194	Calvin Landon	2nd	6/6/2024	X	2F 1G						RD	RD	RD	RD	RD	RD	RD
C195	Anthony Rickard	2nd	6/6/2024	X	2F						RD	RD	RD	RD	RD	RD	RD
C196	Cody Mccoy	2nd	6/20/2024	X	2F						RD	RD	RD	RD	RD	RD	RD
C197	Kyson Morris	2nd	6/20/2024	X	2F						RD	RD	RD	RD	RD	RD	RD
C198	Paxton Chandler	2nd	6/20/2024	X	2F 1G						RD	RD	RD	RD	RD	RD	RD
C199	Alex Crawford	2nd	7/16/2024	X	2F							RD	RD	RD	RD	RD	RD
C200	Dathan Hall	2nd	7/16/2024	X	1G							RD	RD	RD	RD	RD	RD
C201	Juan Rosales	1ST	9/12/2024	X	1G									RD	RD	RD	RD
C202	Hezekiah Scovel	1ST	9/12/2024	X	2F 1G									RD	RD	RD	RD
C203	Leonel Arenas	2nd	9/17/2024	x	1G									RD	RD	RD	RD
C204	Kameron Hatch	2nd	9/16/2024	X	2F									RD	RD	RD	RD
C205	Josh Lenon	2nd	10/7/2024	X	1G										RD	RD	RD
C206	Bryant Johnston	2nd	10/7/2024	X	1G										RD	RD	RD
C207	Cortez Keifer	2nd	10/7/2024	X	1G										RD	RD	RD
C208	Raul Gonzalez	2nd	10/7/2024	X	1G										RD	RD	RD
C210	Ashton Hovey	2nd	10/7/2024	X	1G										RD	RD	RD
C211	Kaelan Osborne	2nd	10/7/2024	X	1G										RD	RD	RD
C212	Junior Sotelo	2nd	10/7/2024	X	1G											RD	RD
C213	Katherine Young	2nd	11/20/2024	X	2F											RD	RD

Verification of continuous service from inception of the original certification through update period noted. A review of records has shown continuous service within the process for each welder. The given records included, personal witness, inspector logs, payroll and / or production records. Original certification and portions of the documents reviewed are available for review at the CoreBrace QA Office, note some documents are sensitive and are not for general distribution.

This document shall serve as an affidavit of this review. To the best of my knowledge this document is accurate and true. This document serves as certification of continued service through each six month period documented here-in.

Q.A. Manager - Roger Davis

AWS
Roger R. Davis
CWI 24011831
QC1 EXP. 1/1/2027

Roger R Davis

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

Welder qualification summary and continuity log

Welder Continuity Record		Shift and Date Qualified		FCAW-G	POSITION												
LAST UPDATED: 12/9/2024				Qualified in	Qualified	Welder Continuity Log 2024											
ID#	Employee Name	Shift	Date	Process	FCAW-G	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
C1	ADRIAN ANGULO	1st	2/6/2017	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C2	ALLAN LOVE	2nd	8/6/2020	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C4	BERNIE GERDES	1st	10/26/2015	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C7	Brandon Renfro	1st	3/7/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C13	CODY RASMUSSEN	1st	1/11/2019	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C17	DALE TAYLOR	1st	5/31/2019	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C19	DAVE MADSEN	1st	12/17/2014	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C21	DON GREEN	1st	10/30/2018	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C22	DOUGLAS LUKER	1ST	10/26/2015	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C23	DUSTY RUPE	1st	5/23/2019	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C24	ELEUTERIO MANCILLA	1st	11/21/2014	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C32	JESSE MOORE	2nd	8/14/2017	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C34	JULIO JIMENEZ	1st	3/1/2016	X	1G 2G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C38	KENNETH CHAPLIN	1st	2/25/2015	X	2G 3G 6G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C39	KENNETH HOPKINS	1st	6/21/2017	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C41	KIM BEEBE	2nd	10/26/2011	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C44	MARIO ASTUHUAMAN	1st	2/9/2017	X	1G 2G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C45	MIGUEL HERNANDEZ	1st	4/25/2023	X	2G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C47	NICK POPPLETON	1st	11/17/2016	X	1G 2G 6G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C50	Peter Mitchell	1st	4/3/2017	X	1G 2G 6G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C51	RANDY PHILLIPS	1st	9/2/2015	X	2G 3G 6G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C54	RONY LOPEZ	1st	1/16/2018	X	1G 2G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C56	Sam Sotello	1st	4/22/2024	X	2G				RD	RD	RD	RD	RD	RD	RD	RD	RD
C57	SEAN COOK	1st	10/7/2015	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C74	Dalton Lee	1st	5/1/2019	X	1G 2G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C75	Spencer Henrickson	1st	6/26/2018	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C86	Jose Varela	1st	9/1/2020	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C95	Kyle Jones	1ST	10/12/2020	X	2G 3G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C105	Armando Pena	1st	1/20/2021	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C111	Ward Anderson JR	1st	2/17/2021	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C124	Andrew Cox	1st	8/31/2021	X	2G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C128	Sam Munk	1st	10/15/2021	X	1G 2G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C132	Jake Rossen	1st	3/18/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C156	Doug Johnson	1st	9/15/2022	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C164	Jaren Larson	2nd	12/16/2023	X	1G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C166	Tyler Rowe	1ST	12/1/2022	X	1G 2G	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD
C171	Cristian Hernandez	1st	6/3/2024	X	2G						RD	RD	RD	RD	RD	RD	RD

Verification of continuous service from inception of the original certification through update period noted. A review of records has shown continuous service within the process for each welder. The given records included, personal witness, inspector logs, payroll and / or production records. Original certification and portions of the documents reviewed are available for review at the CoreBrace QA Office, note some documents are sensitive and are not for general distribution.

This document shall serve as an affidavit of this review. To the best of my knowledge this document is accurate and true. This document serves as certification of continued service through each six month period documented here-in.

Q.A. Manager - Roger Davis

AWS® Roger R. Davis
CWI 24011831
QC1 EXP. 1/1/2027

Roger R. Davis

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

669 West Quinn Road, Building #28, Pocatello, ID 83201

DATE: 4/28/2025

Reed College CUP
Fabrication Products Inc.

CoreBrace Job#: 6903

Subject: ***Certificate of Compliance - Weld Consumables***

This letter is to certify that all welding consumables supplied by CoreBrace for use on the referenced project, were and will be purchased, maintained, and used in strict accordance with the applicable contract documents, specifications, codes (AISC, ASTM and AWS), approved plans, and the Material Manufactures recommendations. The Manufacturers data sheets, certifications and product information sheets have been reviewed and those variables, requirements and instructions have been included within the CB Welding Procedure Specifications (WPS) within the appropriate tolerances allowed by code. Each WPS is written to comply with the AWS D1.1 and D1.8 requirements for seismic use and is prequalified for Demand Critical welds of the SFRS.

Each WPS indicates the approved ranges and code application of the specific wire listed therein. Each WPS provides for the additional requirements found in the AISC and AWS Seismic provisions for Heat Input for the given consumable specified therein.

CoreBrace certifies the above is true and all records pertaining to the above are on file at CoreBrace and are available for review upon request.

If you have any questions, please call.

Sincerely,

AWS
Roger R. Davis
CWI 24011831
QC1 EXP. 1/1/2027

Roger R Davis
CoreBrace QA Manager
208.339.5905
Roger.davis@corebrace.com

Protective & Marine Coatings
PRODUCT DATA SHEET

ZINC CLAD® IV (85)
ORGANIC ZINC RICH COATING

Revised: March 19, 2019

PRODUCT DESCRIPTION

ZINC CLAD IV (85) is a two-component, polyamide epoxy, zinc-rich coating. It contains 85% by weight of zinc dust pigment in the dried film.

- Coating self-heals to resume protection if damaged
- Provides cathodic/sacrificial

INTENDED USES

- For use over properly prepared blasted steel
- Areas exposed to fresh and salt water
- Areas exposed to brackish water
- Areas exposed to chemical fumes
- Topcoating is recommended for maximum protection
- Not recommended for immersion service

PRODUCT DATA

Finish: Flat

Colors: Gray-Green

Volume Solids: 68% ± 2%, ASTM D2697, mixed

VOC (mixed): <340 g/L; 2.8 lb/gal, unreduced
<340 g/L; 2.8 lb/gal, reduced 5%

Mix Ratio: 2 components, premeasured; 8:1
2.25 gallons (8.5L) total

Typical Thickness:

Recommended Spreading Rate per coat:

	Minimum	Maximum
Wet mils (microns)	**5.0** (125)	**8.0** (200)
Dry mils (microns)	**3.0** (75)	**5.0** (125)
~Coverage sq ft/gal (m²/L)	**218** (5.4)	**363** (8.9)
Theoretical coverage **sq ft/gal** (m²/L) @ 1 mil / 25 microns dft	**1090** (26.8)	

NOTE: Brush or roll application may require multiple coats to achieve maximum film thickness and uniformity of appearance.

Shelf Life: 18 months, unopened
Store indoors at 40°F (4.5°C) to 100°F (38°C).

Flash Point: 80°F (27°C), PMCC, mixed

Reducer/Clean Up:
Above 80°F (27°C): M.E.K.
Below 80°F (27°C): Reducer #58 or M.E.K.

Weight: 26.45 ± 0.2 lb/gal ; 3.17 Kg/L, mixed

Average Drying Times @ 5.0 mils wet (125 microns):

	40°F (4.5°C)	77°F (25°C) *50% RH*	110°F (43°C)
Touch:	45 minutes	30 minutes	15 minutes
Handle:	1.5 hours	1 hour	45 minutes
Recoat*:			
minimum:	6 hours	4 hours	2 hours
maximum:**	none	none	none
Cure:	10 days	10 days	7-10 days
Pot Life:	8 hours	6 hours	4 hours
Sweat-in-time:	1 hour	30 minutes	15 minutes

*NOTE: Film must be free of solvent, hard and firm. When rubbed with the face of a coin or knife the film should polish but not flake or chip.

**Maximum Recoat: Unlimited. Must have a clean, dry surface for topcoating."Loose" chalk or salts must be removed in accordance with good painting practice.

Drying time is temperature, humidity, and film thickness dependent.

SURFACE PREPARATION

Surface must be clean, dry, and in sound condition. Remove all oil, dust, grease, dirt, loose rust, and other foreign material to ensure adequate adhesion.

Zinc rich coatings require direct contact between the zinc pigment in the coating and the metal substrate for optimum performance.

Minimum recommended surface preparation:
Iron & Steel: Atmospheric: SSPC-SP6/NACE 3/ ISO8501-1:2007 Sa 2, 2 mil (50 micron) profile

Note: If blast cleaning with steel media is used, an appropriate amount of steel grit may be incorporated into the work mix to render a dense, angular 1.5-3.0 mil (38-75 micron) surface profile.

ZINC CLAD® IV (85)
ORGANIC ZINC RICH COATING

APPLICATION

Airless Spray
(use Teflon packings and continuous agitation)
Pressure........................2000-2300 psi (138-158 bar)
Hose..............................3/8" ID (9.5 mm)
Tip ....019" (0.48 mm)
Reduction......................As needed, up to 10% by volume

Conventional Spray
(continuous agitation required)
Gun ....Binks 95
Fluid Nozzle 68
Air Nozzle......................68P
Atomization Pressure.....50 psi (3.4 bar)
Fluid Pressure................10-20 psi (0.7-1.4 bar)
Reduction......................As needed, up to 10% by volume

Keep pressure pot at level of applicator to avoid blocking of fluid line due to weight of material. Blow back coating in fluid line at intermittent shutdowns, but continue agitation at pressure pot.

Brush
Brush.............................For touch-up only (reduction not recommended)

If specific application equipment is not listed above, equivalent equipment may be substituted.

RECOMMENDED SYSTEMS

Dry Film Thickness / ct.		**Mils**	**(Microns)**
Steel, Organic Zinc/Epoxy			
1 Ct.	Zinc Clad IV (85)	3.0-5.0	(75-125)
1-2 Cts.	Macropoxy 646	5.0-10.0	(125-250)
Steel, Organic Zinc/Epoxy/Urethane			
1 Ct.	Zinc Clad IV (85)	3.0-5.0	(75-125)
1-2 Cts.	Macropoxy 646	5.0-10.0	(125-250)
1 Ct.	Acrolon 7300	2.0-4.0	(50-100)
Steel, Organic Zinc/Epoxy/Urethane			
1 Ct.	Zinc Clad IV (85)	3.0-5.0	(75-125)
1 Ct.	Macropoxy 267	5.0	(125)
1 Ct.	Acrolon 7300	2.0-4.0	(50-100)
Steel, Organic Zinc/Polysiloxane			
1 Ct.	Zinc Clad IV (85)	3.0-5.0	(75-125)
1-2 Cts.	Sher-Loxane 800	2.0-4.0	(50-100)

The systems listed above are representative of the product's use, other systems may be appropriate.

WARRANTY

The Sherwin-Williams Company warrants our products to be free of manufacturing defects in accord with applicable Sherwin-Williams quality control procedures. Liability for products proven defective, if any, is limited to replacement of the defective product or the refund of the purchase price paid for the defective product as determined by Sherwin-Williams. NO OTHER WARRANTY OR GUARANTEE OF ANY KIND IS MADE BY SHERWIN-WILLIAMS, EXPRESSED OR IMPLIED, STATUTORY, BY OPERATION OF LAW OR OTHERWISE, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.

APPLICATION CONDITIONS

Temperature (air, surface, material):
40°F (4.5°C) minimum, 120°F (49°C) maximum
At least 5°F (2.8°C) above dew point

Relative humidity: 85% maximum

APPROVALS

- Meets SSPC-Paint 20 Type II, Organic, Level 1
- Meets Class A requirements for Slip Coefficient and Creep Resistance, .49

ADDITIONAL NOTES

Mixing Instructions: Mix contents of each component thoroughly with a low speed power agitator. Make certain no pigment remains on the bottom of the can. Then combine 8 parts by volume of Part U with 1 part by volume of Part V. Thoroughly agitate the mixture with power agitation. After mixing, pour through a 30-60 mesh screen. Allow the material to sweat-in as indicated. Re-stir before using. If reducer solvent is used, add only after both components have been thoroughly mixed, after sweat-in. Continuous agitation of mixture during application is required, otherwise zinc dust will quickly settle out.

Do not tint.

HEALTH AND SAFETY

Refer to the SDS sheet before use.

Published technical data and instructions are subject to change without notice. Contact your Sherwin-Williams representative for additional technical data and instructions.

DISCLAIMER

The information and recommendations set forth in this Product Data Sheet are based upon tests conducted by or on behalf of The Sherwin-Williams Company. Such information and recommendations set forth herein are subject to change and pertain to the product offered at the time of publication. Consult your Sherwin-Williams representative to obtain the most recent Product Data Sheet.

STRUCTURAL SYSTEMS

RESEARCH PROJECT

Report No.
TR-12/03

Subassemblage Testing of CoreBrace Buckling-Restrained Braces (P Series)

by

Joel Lanning

Chia-Ming Uang

Gianmario Benzoni

Final Report to CoreBrace, LLC.

June 2012

Department of Structural Engineering
University of California, San Diego
La Jolla, California 92093-0085

University of California, San Diego
Department of Structural Engineering
Structural Systems Research Project

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SUBASSEMBLAGE TESTING OF COREBRACE BUCKLING-RESTRAINED BRACES (P SERIES)

by

Joel Lanning
Graduate Student Researcher

Chia-Ming Uang
Professor

Gianmario Benzoni
Research Scientist

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June 2012

ABSTRACT

Testing of four full-scale buckling-restrained braces (BRBs) for CoreBrace was conducted using a shake table facility at the University of California, San Diego. All specimens were tested in a subassemblage condition. The specimens each featured an A36 steel yielding core plate with grout fill in hollow structural section (HSS). Each specimen was bolt connected to gusset plates which were bolt connected to adapting brackets at each end of the brace. One end of the brace was connected to a strong-wall, and the shake table imposed both axial and transverse displacements to the other end of the specimens. The AISC Standard Loading Protocol for BRB qualification and additional High-Amplitude Loading Protocol tests were conducted for each specimen. The Standard Loading Protocol was based on the 2010 AISC Seismic Provisions for Structural Steel Buildings. The High-Amplitude Loading Protocol imposed deformation demand on the BRB specimens that was significantly greater than that prescribed in the AISC Seismic Provisions. In addition to axial deformation, transverse deformation was imposed to the specimens to simulate the rotational deformation demand on the brace within a frame subassemblage.

All specimens preformed well under the Standard Loading Protocol by exhibiting stable hysteretic behavior and dissipating a significant amount of energy. Under the High-Amplitude Loading Protocol, stable hysteretic response was maintained up to core fracture or test termination. The steel core plates of Specimens 2P, 3P, and 5P ruptured during the High-Amplitude Loading Protocol. Specimen 4P completed the full High-Amplitude Loading Protocol but was not taken to failure.

All specimens achieved cumulative inelastic axial deformation values significantly higher than $200\Delta_{by}$ required by the AISC Seismic Provisions for uniaxial brace specimens. All BRB subassemblage test specimens satisfied the acceptance criteria given in Section K3.8 of the AISC Seismic Provisions.

ACKNOWLEDGEMENTS

Funding for this project was provided by CoreBrace, LLC of West Jordan, Utah. CoreBrace provided test specimens and loading protocols as well as additional installation assistance. Special thanks to Danny Innamorato and Edward Stovin, staff members of Seismic Response Modification Device (SRMD) Test Facility at the University of California, San Diego, for their technical assistance and long hours spent towards the completion of this testing.

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A_{sc} Area of yielding element

E_h Total hysteretic energy dissipated by brace

E_{hi} Total hysteretic energy dissipated by brace for the ith cycle

E_s Young's modulus of elasticity of steel

E_{si} Elastic strain energy for the ith cycle

F_{ya} Actual or measured yield strength of steel core (average of coupon tests)

F_{yn} Nominal yield strength of steel core

$K_{eff,i}$ Secant stiffness for the ith cycle

L_b Total length of brace

L_y Length of yielding element

P_{max} Maximum brace compressive force at effective or peak cyclic deformation

P_{ya} Actual brace yield force, $F_{ya}A_{sc}$

P_{yn} Nominal brace yield force, $F_{yn}A_{sc}$

P_r Resultant axial brace force

R_y Material overstrength factor, F_{ya}/F_{yn}

T_{max} Maximum brace tensile force at effective or peak cyclic displacement

β Compression strength adjustment factor, P_{max}/T_{max}

Δ Axial brace deformation

Δ_b Deformation quantity used to control loading of test specimen

Δ_{bm} Value of deformation quantity, Δ_b, corresponding to the design story drift

Δ_{by} Value of deformation quantity, Δ_b, at first significant yield of test specimen

Δ^+ Maximum tensile axial deformation for the i^{th} cycle

Δ^- Absolute value of the maximum compressive axial deformation for the i^{th} cycle

Δ_{eff} Effective cyclic axial deformation amplitude for the i^{th} cycle

ε Axial brace strain

η_D Cumulative inelastic axial deformation (CID), based on cyclic deformation

η_E Cumulative inelastic axial deformation (CID), based on hysteretic energy

μ_i Inelastic axial deformation of the i^{th} cycle

ω Tension strength adjustment factor, T_{max}/P_{ya}

ζ_{eq} Equivalent viscous damping

1. INTRODUCTION

1.1 General

Provisions for buckling-restrained braced frames (BRBF) design and buckling-restrained braces (BRB) qualifying cyclic testing have been incorporated into the AISC *Seismic Provisions for Structural Steel Buildings* (AISC 341-10). The AISC provisions require subassemblage testing to verify the performance of BRBs. The subassemblage testing demonstrates a BRB's ability to accommodate combined axial and rotational deformation demands imposed during a seismic event.

1.2 Scope and Objectives

Four full-scale BRBs developed by CoreBrace, LLC were tested at the University of California, San Diego. The objective of this testing program was to evaluate the cyclic performance of these BRBs based on the acceptance criteria of the AISC *Seismic Provisions*.

2. TESTING PROGRAM

2.1 Test Specimens

A total of four BRB specimens were tested. Each specimen was constructed with a bolted connection at each end, and was composed of a steel core plate confined by a minimum 5,000 psi grout inside an HSS section. Figure 2.1 shows the overall geometry of test specimens. Table 2.1 provides specimen dimensions and the sizes of HSS sections.

2.2 Material Properties

A36 steel was specified for the core plates, and A500 Grade B was specified for the HSS. The results of tensile coupon tests of the core plates are summarized in Table 2.2. Based on the average measured yield strength (F_{ya}), the values of the material overstrength factor, R_y (= F_{ya}/F_{yn}), and the brace yield force, as listed in Table 2.3, were calculated.

2.3 Test Setup

The Seismic Response Modification Device (SRMD) Test Facility, a shake table facility at the University of California, San Diego, was employed to subject the test brace specimens to deformations prescribed by the AISC Seismic Provisions (AISC 341-10). The SRMD facility, which has a shake table platen capable of imposing displacement in six degrees of freedom, is shown in Figure 2.2. Figure 2.3 shows one specimen installed in the setup and ready for testing. One end of the specimen was attached to the strong-wall at the west end of the SRMD facility. The other end of the brace was attached to the SRMD platen as shown in Figure 2.4. Movement of the shake table platen imposed both axial and transverse deformations to the specimens.

2.4 End Connections

The BRBs were connected to gusset plates with a pair of connection plates, or lugs, which were welded to the extended core plate at the ends of each brace. The lugs were connected with 1-1/8in diameter ASTM F2280 grade tension controlled bolts (TC bolts) to the gusset plate to create a slip-critical connection. Figure 2.5 provides a view of the connection before and after the TC bolts are tensioned. This connection is designed to resist slip up to the yield force of the brace. Therefore, bolt slip is encountered when subjecting a brace to deformation amplitudes into the inelastic range. The implications of the slip are discussed further in Section 2.5, and the slip amount was measured on all braces with the instrumentation described in Section 2.6.

Figure 2.6 shows the end connection details of brace specimens, while Figure 2.7 shows the gusset details. The gusset plates were connected to adapting bracket by 1-1/2 in. diameter A490 high-strength bolts in double shear. The TC bolts connecting the brace and gusset are the twist-off type typically used in the field and were used to minimize the difference between the testing and as-built configurations of the braces. Bolt holes in the lug plates were standard sized while those in the gusset plates were oversized, which closely resembles the field condition.

2.5 Loading Protocol

According to the AISC *Seismic Provisions*, the design of BRBs shall be based upon results from qualifying cyclic tests. Qualifying test results shall consist of at least two successful cyclic tests: one is required to be a test of a brace subassemblage that includes brace connection rotational demands and the other may be either a uniaxial or a subassemblage test. In this testing program all tests were subassemblage tests, including the transverse deformation associated with connection rotational demand.

According to Section K3.4c of the AISC *Seismic Provisions,* the following loading sequence shall be applied to the test specimen, where the deformation is the steel core axial deformation of the test specimen:

(1) 2 cycles of loading at the deformation corresponding to $\Delta_b = 1.0\Delta_{by}$,

(2) 2 cycles of loading at the deformation corresponding to $\Delta_b = 0.5\Delta_{bm}$,

(3) 2 cycles of loading at the deformation corresponding to $\Delta_b = 1.0\Delta_{bm}$,

(4) 2 cycles of loading at the deformation corresponding to $\Delta_b = 1.5\Delta_{bm}$,

(5) 2 cycles of loading at the deformation corresponding to $\Delta_b = 2.0\Delta_{bm}$,

(6) Additional complete cycles of loading at the deformation corresponding to $\Delta_b = 1.5\Delta_{bm}$ as required for the brace test specimen to achieve a cumulative inelastic axial deformation of at least 200 times the yield.

Note that the requirement of cumulative inelastic axial deformation is for uni-axial brace testing, not subassemblage testing. The above loading sequence requires two quantities: Δ_{by} and Δ_{bm}. Δ_{by} is defined as the axial deformation at first significant yield of the specimen, and Δ_{bm} corresponds to the axial deformation of the specimen at the design story drift. In this testing program Δ_{bm} was assumed to equal $5.0\Delta_{by}$. This assumption was based on the ASCE 7-10 value of $C_d = 5.0$ while conservatively using $\phi = 1.0$ (assuming full utilization of brace). This is equivalent to using the previous provisions, ASCE 7-05, with a C_d=5.5 and ϕ=0.9 (assuming 90% utilization of brace). Strictly speaking, for C_d = 5.0 (as set in ASCE 7-10) the value of $2\Delta_{bm}$ would be slightly lower at $9.0\Delta_{by}$ (= $2\times5.0\Delta_{by}\times0.9$). The additional amount of conservatism from using $\phi = 1.0$ was used to provide loading protocols comparable to previous tests by the manufacturer.

The loading sequences for the AISC Standard Protocol are shown in Figure 2.8 and the target brace axial deformation of each specimen is provided in Table 2.4(a). Although not required for the subassemblage testing, additional cycles (Item 6 above) were applied to achieve the target cumulative inelastic axial deformations. An additional High-Amplitude Loading Protocol sequence was then applied to impose greater deformation demand on the BRB specimens. This High-Amplitude Loading Protocol is shown in Figure 2.9 and Table 2.4(b). In the case that the brace does not fail during the High-Amplitude Loading Protocol, the last amplitude cycle would be repeated until fracture.

The calculation of Δ_{by} was based on the deformation expected over the brace length. The effective brace length is taken as the length from the center of the gusset-to-lug bolted connections at each end of the brace. To establish the value of Δ_{by}, the following components were considered at the actual yield force level P_{ya}:

(1) Deformation of the core plate in the yielding length, L_y (see Figure 2.1 and Table 2.1(b) for L_y), and

(2) Deformation at each end of the core plate outside the yielding length.

Using the calculated Δ_{by} value for each specimen (see Table 2.3), the total shake table input displacement was established by adding additional components to account for the following:

(1) Elastic deformation of the gusset plates,
(2) Elastic deformation due to flexibility of the end supports and reaction wall at the SRMD facility based on a known total system stiffness, and
(3) Anticipated bolt slippage within the oversized holes in the gusset and standard holes in the lug plates.

The bolt slippage, although foreseen as an additional necessary displacement, was difficult to predict. The exact force level at which the slip would occur and the exact slip displacement amount were uncertain. The error between the predicted and the actual behavior caused some brace deformation cycles to be slightly unsymmetrical.

Transverse displacements corresponding to the prescribed axial displacements were calculated based on the plastic-hinge-to-plastic-hinge length, which is approximately equal to the length L_c shown in Figure 2.1, and represents the length between the effective center of lateral rotation at each end of the brace. The brace is assumed to be oriented within a frame at an angle of 50° from horizontal, with peak rotations limited to 0.03 radians. With this assumption, the corresponding amplitudes for the transverse movement of the shake table were established, as given in Tables 2.4. Since the loading system is nominally rigid in the transverse direction, no additional transverse displacement, accounting for system flexibility, was added when adapting the target transverse deformations to shake table input transverse displacements.

Shake table peak input displacements for each cycle are provided in Table 2.5. Figure 2.8 and Figure 2.9 show that the transverse movement is in phase with the axial movement in order to simulate realistic frame action effects at the gusset connections.

2.6 Instrumentation

Two string potentiometers labeled *L1* and *L2* and several linear voltage displacement transducers were used to measure the axial deformation of the brace specimens. The linear displacement transducers *L3* through *L10* served as redundant measures of the deformations, and proved useful when some instrument mountings were compromised during large sudden force changes during the bolt slip of the lug-to-gusset connections. The bolt slip transducers, which are labeled *L12* and *L13*, measure the relative displacement of the gusset plate and lug plate on either side of the brace.

Additional displacement transducers, *L11* and *L12*, were also used to measure deformation of the brace lug, which is insignificant with respect to the brace deformation. Figure 2.10 provides a schematic layout of the instrumentation while Figure 2.11 displays a photo of a typical brace instrumentation setup.

The brace forces were measured by the load cell in each of the four actuators that drove the shake table and were recorded by the system. The resultant force components in both the axial and transverse directions were then computed from these measured forces, however the transverse forces were found to be insignificant for all specimens.

2.7 Data Reduction

Brace Axial Deformation, Δ

In the following chapter, the brace axial deformation, Δ, corresponding to the average of those measured by displacement transducers is reported. The brace axial strain was calculated as:

$$\varepsilon = \frac{\Delta}{L_y} \tag{2.1}$$

where L_y equals the length of the steel core plate yielding zone (see Figure 2.1). The brace axial deformation is also normalized by the yield deformation. Note that Δ includes some minor elastic deformation of the brace beyond the yielding length, L_y.

Brace End Rotation

The brace end rotation is computed by dividing the measured table transverse movement by the brace plastic-hinge-to-plastic-hinge length.

Resultant Brace Force, P_r

The resultant axial force in the brace, P_r, was calculated as the square root of the sum of the squares of the measured axial and transverse forces. However, the lateral force component was found to be an insignificant influence on the overall resultant force for each brace.

Tension and Compression Strength Adjustment Factors, ω and β

The AISC *Seismic Provisions* defines the tension and compression strength adjustment factors ω and β, respectively, as follows:

$$\omega = \frac{T_{\max}}{P_{ya}} = \frac{T_{\max}}{F_{ya} A_{sc}} \tag{2.2}$$

$$\beta = \frac{P_{\max}}{T_{\max}} \tag{2.3}$$

where F_{ya} = measured yield stress, and A_{sc} = area of the yielding segment of core plate.

The forces $T_{\max}$ and $P_{\max}$ are typically the tension and compression forces achieved at equal and opposite peak tensile and compressive deformations during a symmetric axial deformation cycle, as shown in Figure 2.12(a). As discussed in Section 2.4, connection bolt slip often lead to non-symmetric cycles in testing, and a combination of $T_{\max}$ or $P_{\max}$ and $T^*_{\max}$ or $P^*_{\max}$, as defined in Figure 2.12(b) and (c), are used to calculate the strength adjustment factors per Equations 2.2 and 2.3.

Note that the forces $T^*_{\max}$ and $P^*_{\max}$ differ only slightly from the actual maximum compressive force achieved in this test program. Specimen 4P, however, was subjected to non-symmetric cycles where the peak tensile and compressive deformations differ by a non-trivial amount (see Section 3.4). Therefore, it is not appropriate to report the strength adjustment factors with respect to the typical axial deformation amplitude. Instead, β and ω are reported with respect to an effective axial deformation, Δ_{eff}, as defined in Figure 2.13.

AISC *Seismic Provisions* limit β to a value of 1.3 within the AISC Standard Loading Protocol cycles with deformation greater than Δ_{by}. The observed β, and ω, at all axial deformation levels are provided in Section 3.

Hysteretic Energy, E_h

The area enclosed by the P_r versus Δ hysteresis loops represents the hysteretic energy dissipated by the brace:

$$E_h = \int P_r d\Delta \tag{2.4}$$

Cumulative Inelastic Axial Deformations, η_D and η_E

Consider the i^th cycle at a deformation level greater than the yield deformation. The normalized total inelastic axial deformation for that cycle is given by:

$$\mu_i = \frac{2\left|\Delta_i^+ + \Delta_i^-\right|}{\Delta_{by}} - 4 \tag{2.5}$$

where Δ_i^+ and Δ_i^- are the values of the maximum and minimum deformations, respectively, for the i^th cycle, and Δ_{by} is the brace yield deformation. The deformation-based cumulative inelastic axial deformation, η_D, is determined by the summation of the normalized inelastic axial deformation for each of the i^th cycles:

$$\eta_D = \sum \mu_i \tag{2.6}$$

For uniaxial testing of BRBs, the AISC *Seismic Provisions* requires that a value of η at least 200 be achieved for brace qualification. For comparison purposes, the η values will be presented in the following section.

Alternatively, the cumulative inelastic deformation (CID) is also calculated as a normalization of the cumulative dissipated energy,

$$\eta_E = \frac{E_h}{P_y \Delta_y} \tag{2.7}$$

Figure 2.14 provides a diagram describing the energy-based ductility measure. The calculation assumes an elastic-perfectly-plastic hysteretic response, while the deformation-based approach (Equations 2.5 and 2.6) neglects the Bauschinger effect of the hysteretic response. The energy-based approach may be more appropriate for tracking a damage index for predictive failure. The deformation-based approach is the typical measure utilized in the AISC 2010 prequalification of BRBs for use in BRBF buildings.

Equivalent Viscous Damping, $\zeta_{eq,i}$

The hysteretic energy within the i[th] cycle, E_{hi}, can be thought of as providing an amount of structural damping, or the equivalent viscous damping, for that cycle. This relationship is proportional to the ratio of E_{hi} and the elastic strain energy, E_{si}, for each cycle and is calculated as (Chopra 2007):

$$\zeta_{eq,i} = \frac{E_{hi}}{4\pi E_{si}} = \frac{E_{hi}}{2\pi K_{eff,i}\Delta_{avg,i}^{2}} \tag{2.7}$$

where E_{si} = elastic strain energy at peak deformation, $K_{eff,i}$ = secant stiffness, and $\Delta_{avg,i}$ is the average brace deformation. Figure 2.15 displays these parameters graphically.

Table 2.1 Specimen Dimensions

(a) Core Plate and Casing Size

Specimen	W_1 (in.)	W_L (in.)	W_2 (in.)	t_{sc} (in.)	Core Plate	HSS Size (in.)
2P	4-3/4	7-1/8	4	3/4	Flat	HSS 8×8×3/16
3P	8-9/16	8-7/8	7-3/16	1-1/4	Flat	HSS 10×10×1/4
4P	7-3/8	11-3/8	10-5/16	1-3/4	Flat	HSS 14×14×5/16
5P	8 1/2	13-1/2	12	2-1/4	Flat	HSS 16×16×5/16

(b) Lengths

Specimen	L_b (in.)	L_c (in.)	L_y (in.)	L_L (in.)	a (in.)	L_T (in.)
2P	255-3/4	222-3/4	199-3/4	9-1/4	3	15-3/4
3P	255-1/16	204-15/16	177-11/16	17-13/16	4	16-7/8
4P	254	189-1/8	166-1/16	25-3/16	4	14-13/16
5P	253-2/16	185-3/16	160-9/16	25-3/4	5	15-9/16

(c) Bolting

Specimen	Lug PL Hole Diam. (in.)	Gusset PL Hole Diam. (in.)	Rows of Bolts	s (in.)	g_i (in.)	g_o (in.)
2P	1-3/16	1-7/16	2	5	1-15/16	-
3P	1-3/16	1-7/16	5	3-1/4	2-13/16	-
4P	1-3/16	1-7/16	9	2-5/8	2-9/16	1-1/2
5P	1-3/16	1-7/16	12	1-15/16	2-13/16	2-5/16

Table 2.2 Mechanical Properties of Core Plates

Specimen	Heat No.	Coupon Average		F_{ua}/F_{ya}	Elong.[a] (%)
		F_{ya} (ksi)	F_{ua} (ksi)		
2P	NW2189	44.6	68.2	1.53	36.0
3P	NW1859	41.8	66.9	1.60	39.5
4P	NT4530	40.2	69.7	1.74	30.8
5P	S10122	39.9	66.9	1.68	35.0

[a]Elongation is based on 2 in. gage length

Table 2.3 Yield Strength and Deformation

Specimen	A_{sc} (in.²)	F_{ya} (ksi)	R_y	P_{yn} (kips)	P_{ya} (kips)	Δ_{by} (in.)
2P	3.0	44.6	1.24	108	133.8	0.34
3P	9.0	41.8	1.16	324	376.2	0.29
4P	18.0	40.2	1.12	648	723.6	0.27
5P	27.0	39.9	1.11	972	1077.3	0.26

Table 2.4 Target BRB Deformations

(a) Standard Loading Protocol

Specimen	Axial Deformation (in.)						Transverse Deformation (in.)					
	Number of Cycles						Number of Cycles					
	2	2	2	2	2	2	2	2	2	2	2	2
2P	0.34	0.84	1.68	2.52	3.35	2.52	0.40	1.00	2.02	3.04	4.08	3.04
3P	0.29	0.73	1.45	2.18	2.90	2.18	0.35	0.87	1.75	2.63	3.53	2.63
4P	0.27	0.67	1.34	2.02	2.69	2.02	0.32	0.80	1.62	2.44	3.26	2.44
5P	0.26	0.65	1.31	1.96	2.62	1.96	0.29	0.73	1.47	2.21	2.96	2.21

(b) High-Amplitude Loading Protocol

Specimen	Axial Deformation (in.)					Transverse Deformation (in.)				
	Number of Cycles					Number of Cycles				
	2	2	2	2	Until fracture	2	2	2	2	Until fracture
2P	4.19	5.03	5.87	6.71	6.71	5.12	6.18	6.87	6.89	6.89
3P	3.63	4.35	5.08	5.81	5.81	4.43	5.34	6.26	6.32	6.32
4P	3.36	4.03	4.70	5.37	5.37	4.10	4.94	5.79	5.86	5.86
5P	3.27	3.93	4.58	5.24	5.24	3.72	4.48	5.25	5.85	5.85

Table 2.5 Shake Table Input Displacements

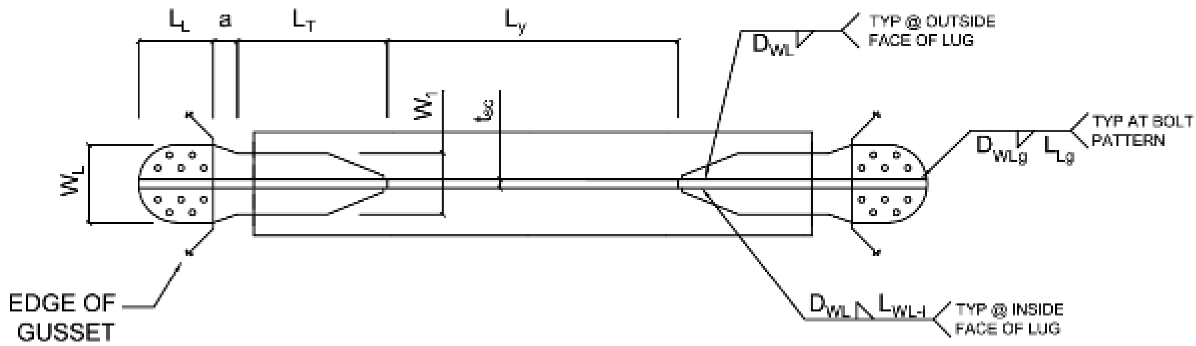
(a) Standard Loading Protocol

Specimen	Axial Deformation (in.)						Transverse Deformation (in.)					
	Number of Cycles						Number of Cycles					
	2	2	2	2	2	2	2	2	2	2	2	2
2P	0.42	1.24	2.08	2.92	3.75	2.92	0.40	1.00	2.02	3.04	4.08	3.04
3P	0.60	1.54	2.40	2.74	3.46	2.74	0.35	0.87	1.75	2.63	3.53	2.63
4P	0.62	1.35	2.04	2.72	3.39	2.72	0.32	0.80	1.62	2.44	3.26	2.44
5P	0.55	1.34	2.03	2.70	3.37	2.70	0.31	0.78	1.58	2.37	3.18	2.37

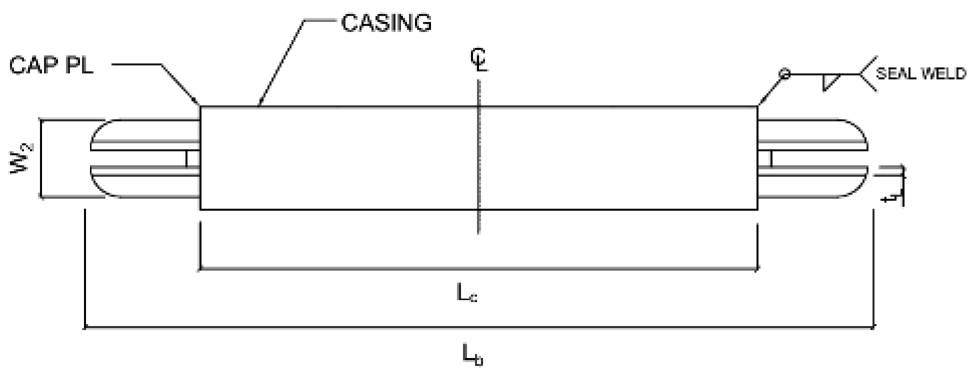
(b) High-Amplitude Loading Protocol

Specimen	Axial Deformation (in.)					Transverse Deformation (in.)				
	Number of Cycles[a]					Number of Cycles[a]				
	2	2	2	2	Until fracture	2	2	2	2	Until fracture
2P	4.58	5.41	6.18	NA	NA	5.12	6.18	6.87	NA	NA
3P	5.02	5.94	6.31	NA	NA	3.58	4.29	6.32	NA	6.32
4P	3.93	4.59	5.24	5.92	NA	4.10	4.94	5.79	5.86	NA
5P	4.02	4.78	NA	NA	NA	4.00	4.65	NA	NA	NA

[a] NA = Not Applied



(a) Side View



(b) Top View

Figure 2.1 Overall Geometry of Specimens

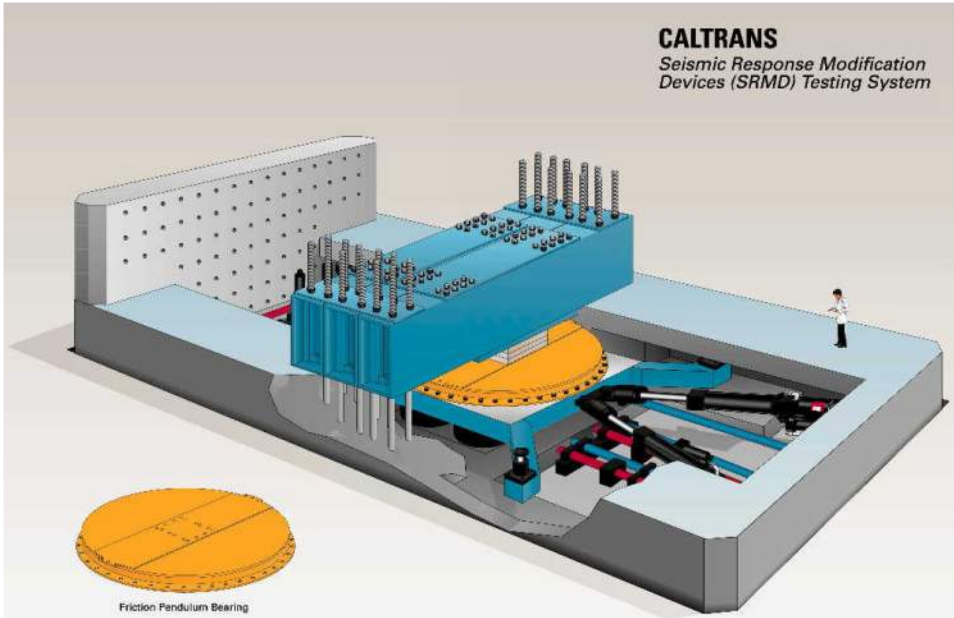
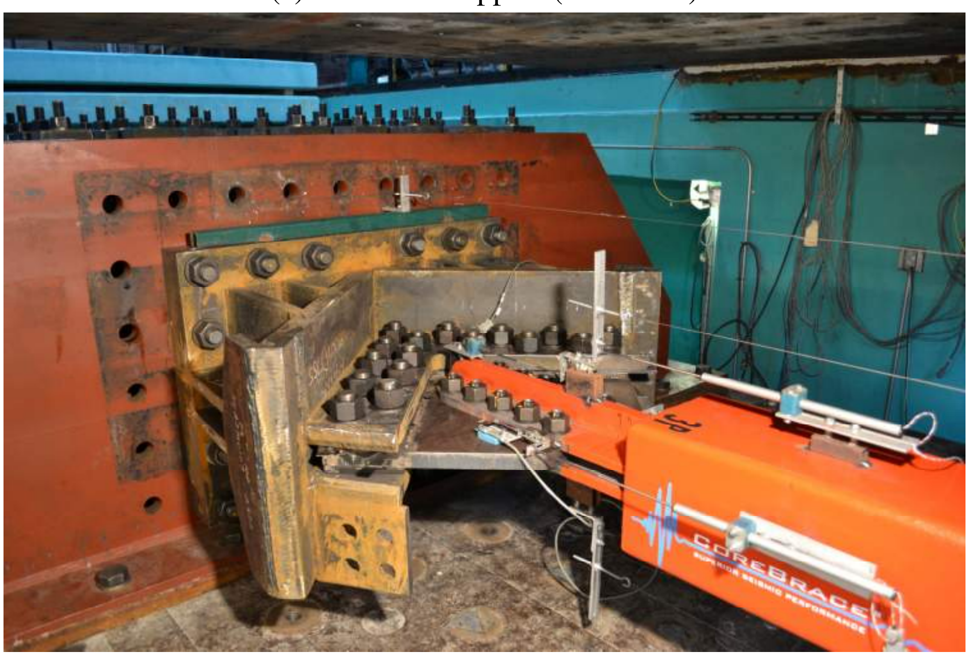


Figure 2.2 SRMD Test Facility

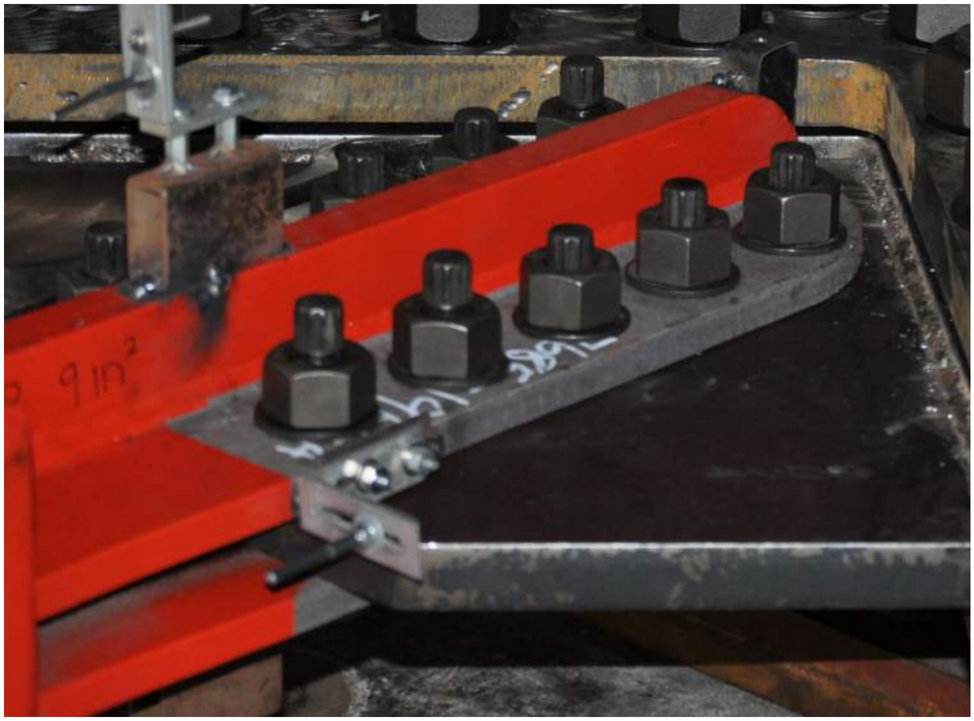
Figure 2.3 Overall View of Specimen and SRMD

(a) Wall End Support (West End)

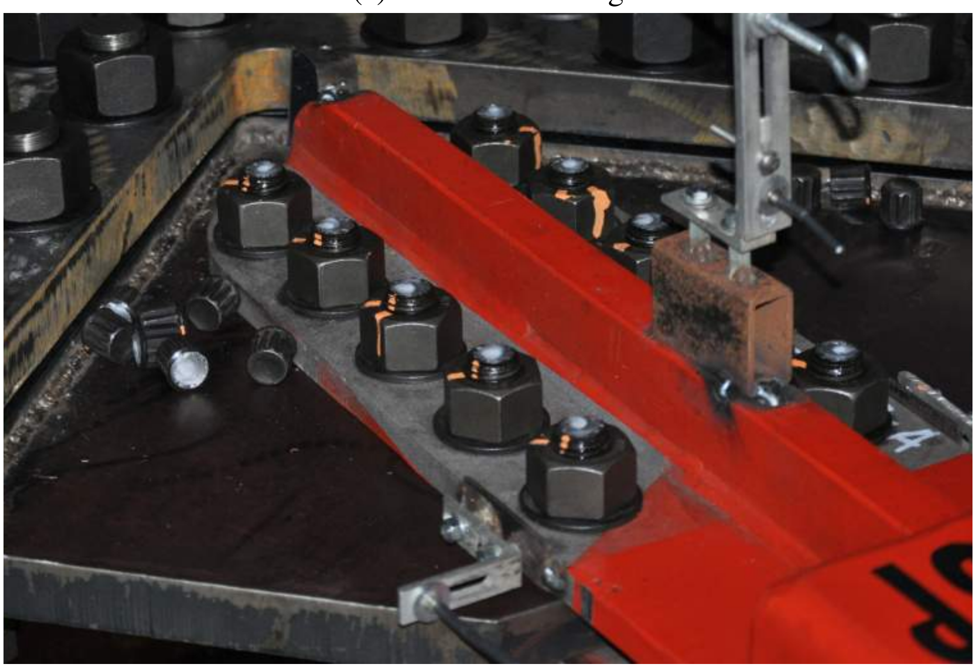


(b) Platen End Support (East End)

Figure 2.4 Specimen End Conditions

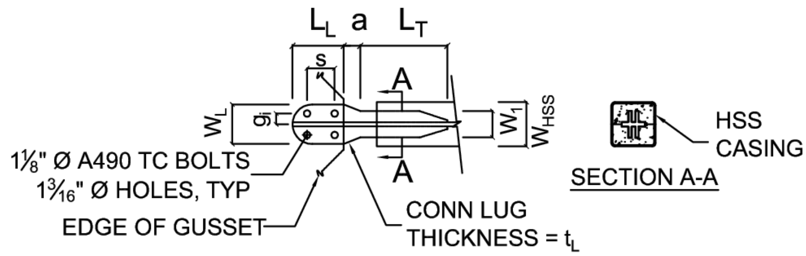


(a) Before tensioning

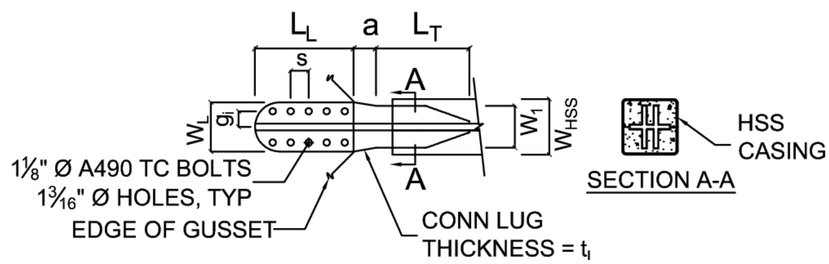


(b) After tensioning

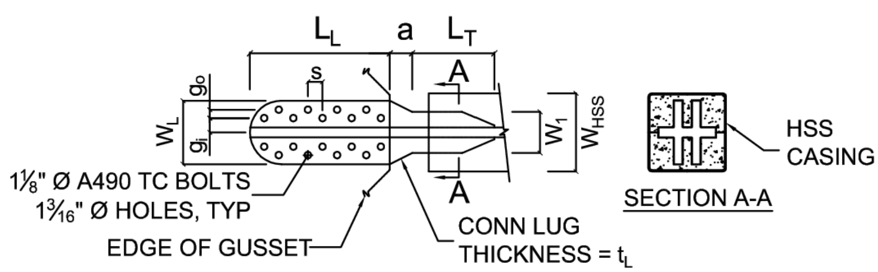
Figure 2.5 Lug-to-Gusset TC Bolt Tensioning



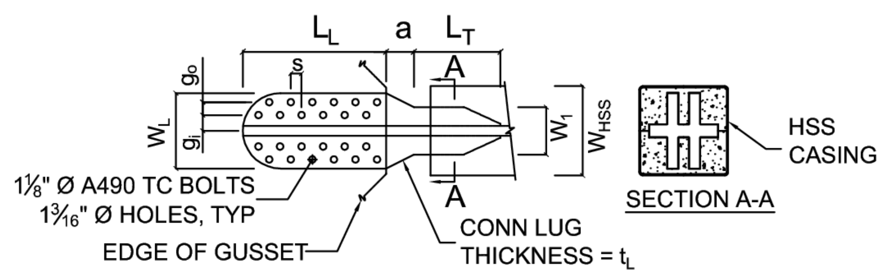
(a) Specimen 2P



(b) Specimen 3P

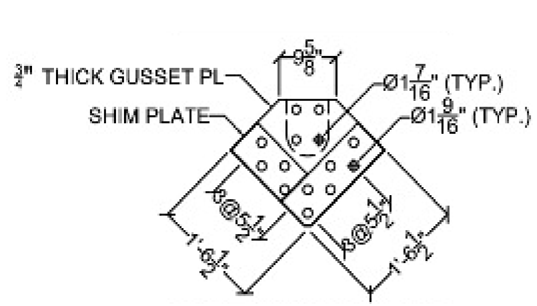


(c) Specimen 4P

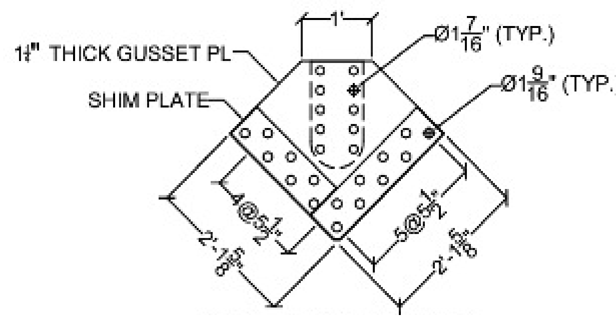


(d) Specimen 5P

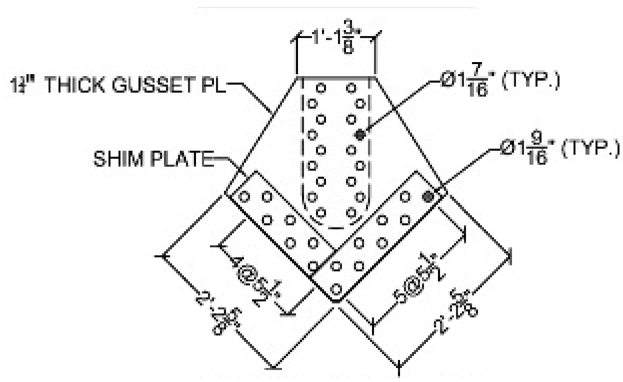
Figure 2.6 Detail of Specimen Connection and Cross Section



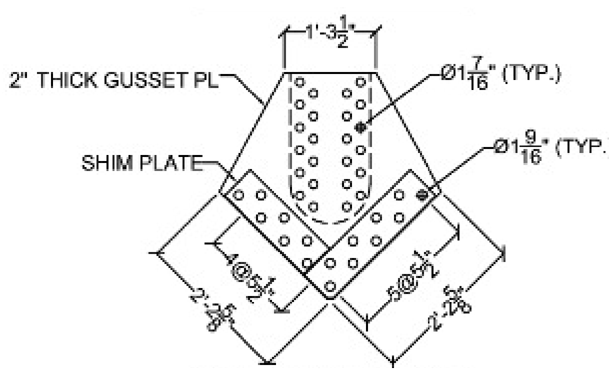
(a) Specimen 2P



(b) Specimen 3P

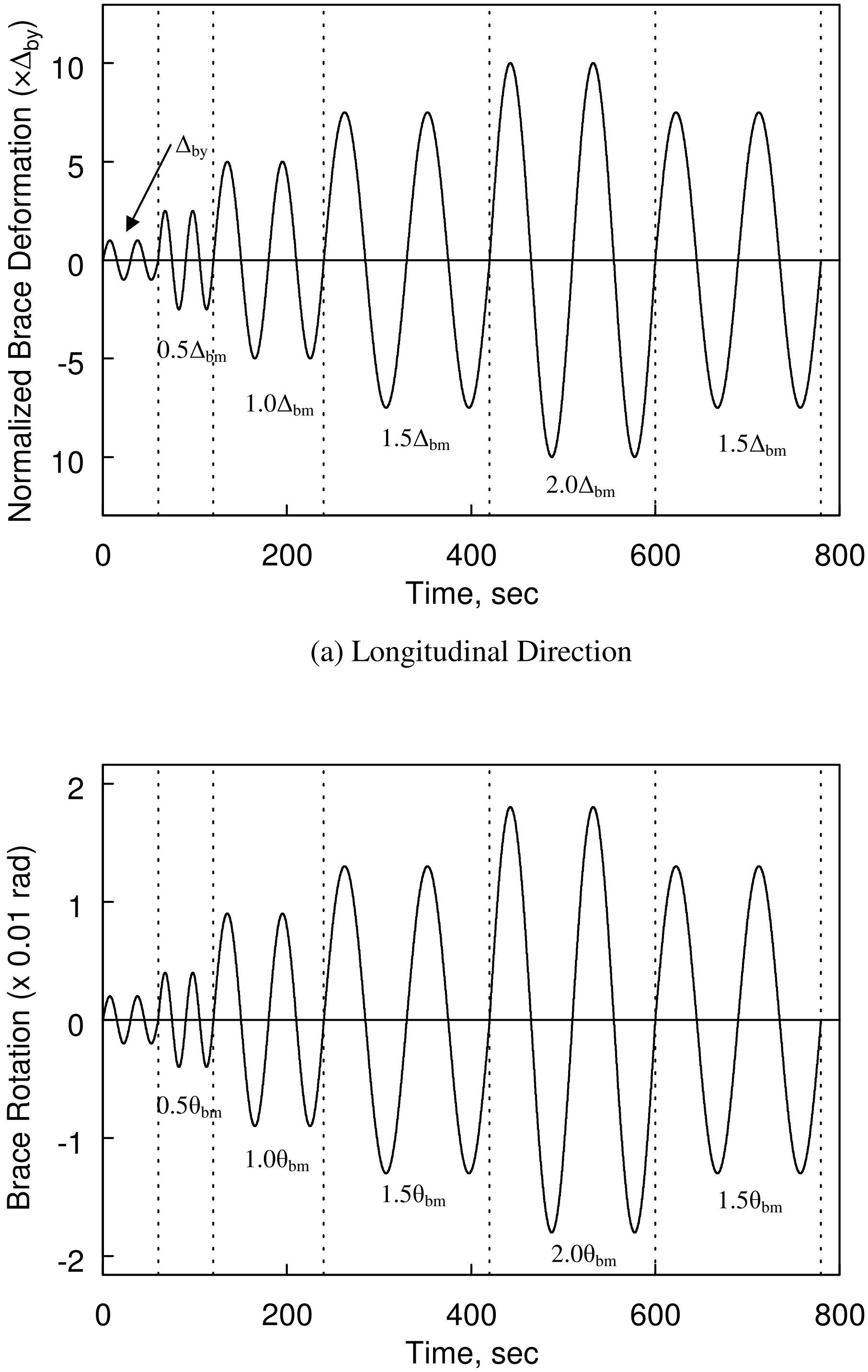


(c) Specimen 4P



(d) Specimen 5P

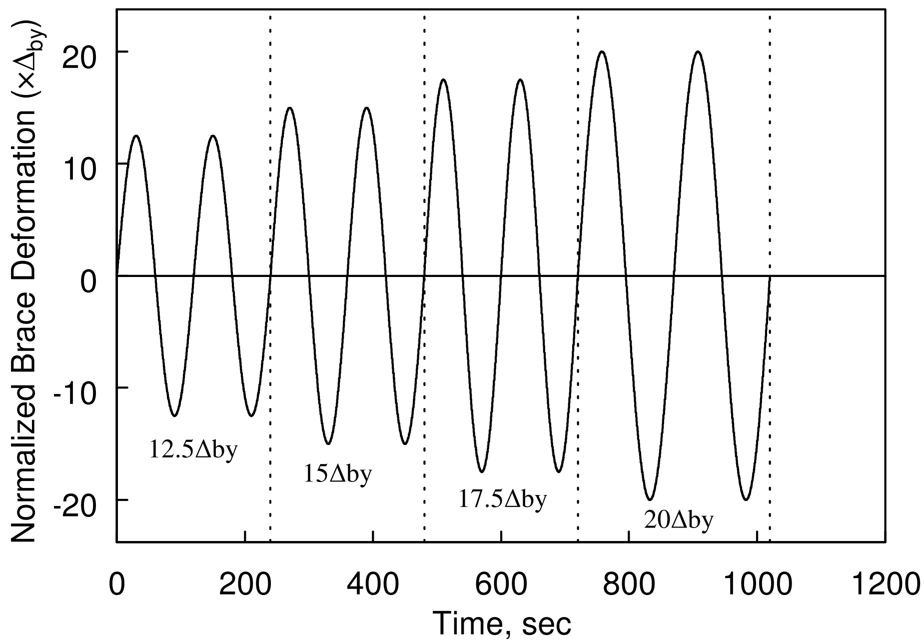
Figure 2.7 Detail of Specimen Gusset



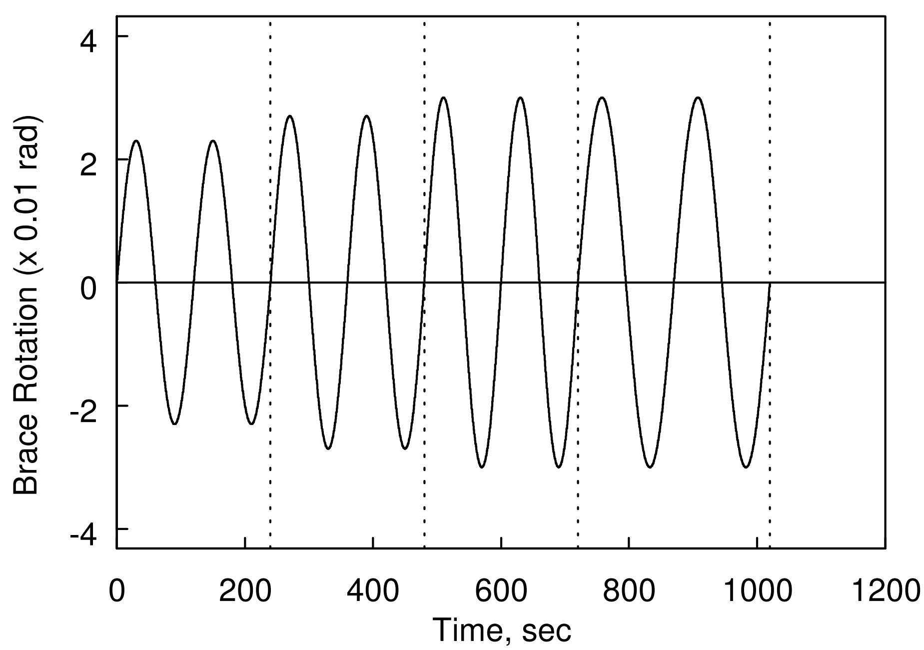
(a) Longitudinal Direction

(b) Transverse Direction

Figure 2.8 Loading Sequence: Standard Loading Protocol

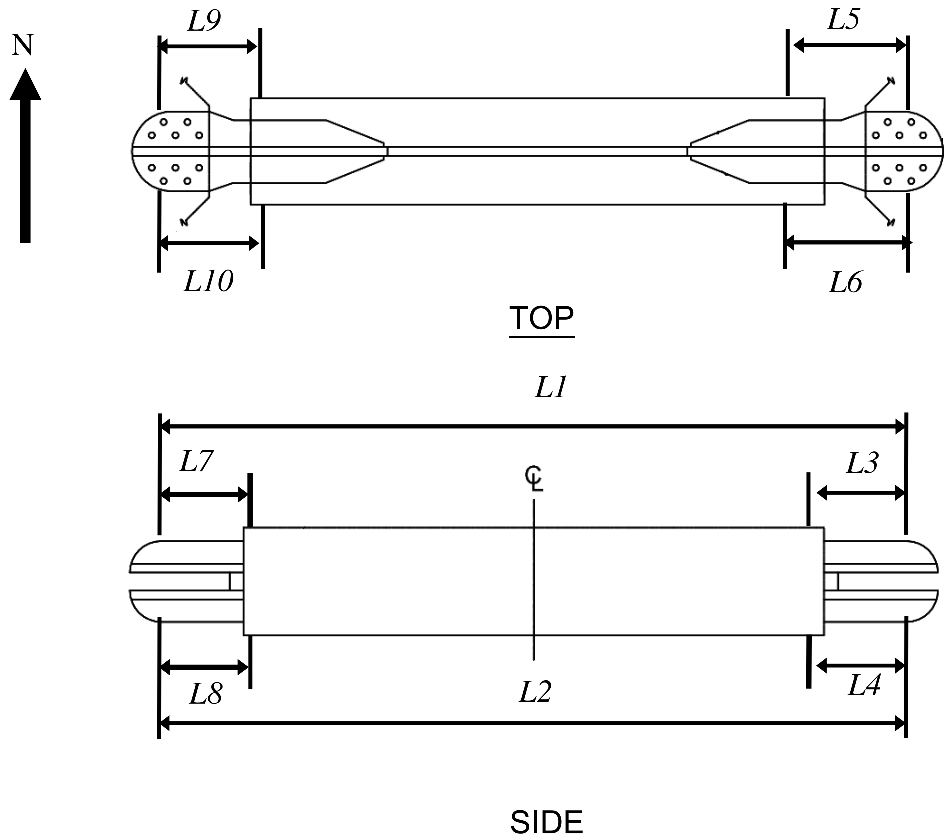


(a) Longitudinal Direction

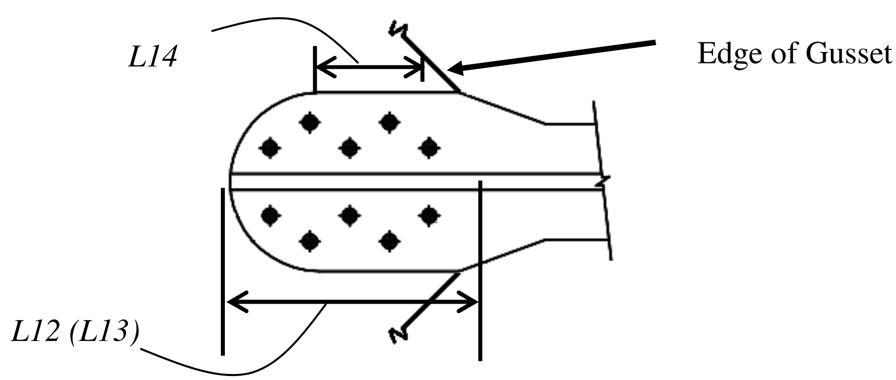


(b) Transverse Direction

Figure 2.9 Loading Sequence: High-Amplitude Loading Protocol

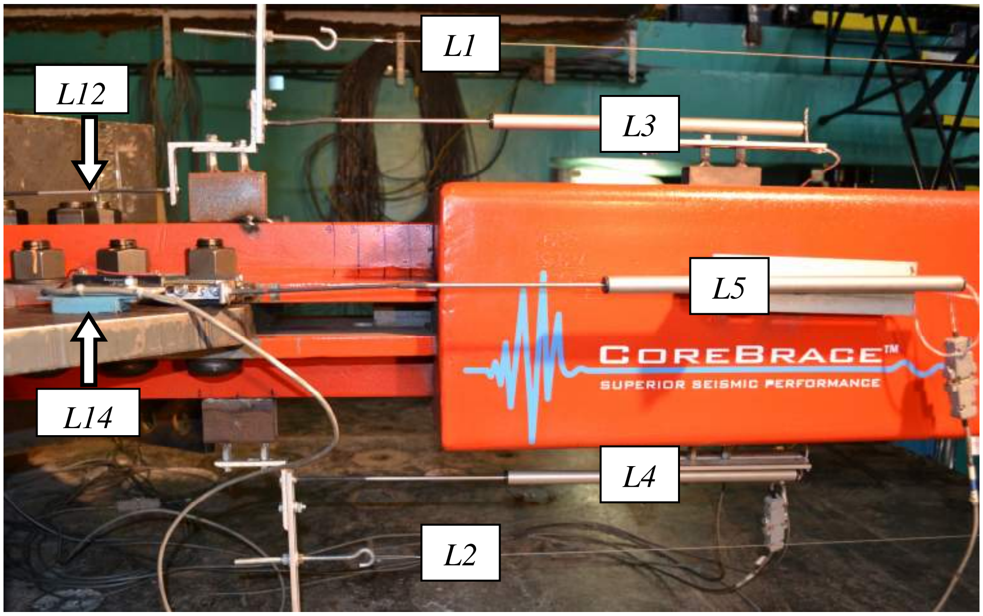


(a) Main Displacement Transducers

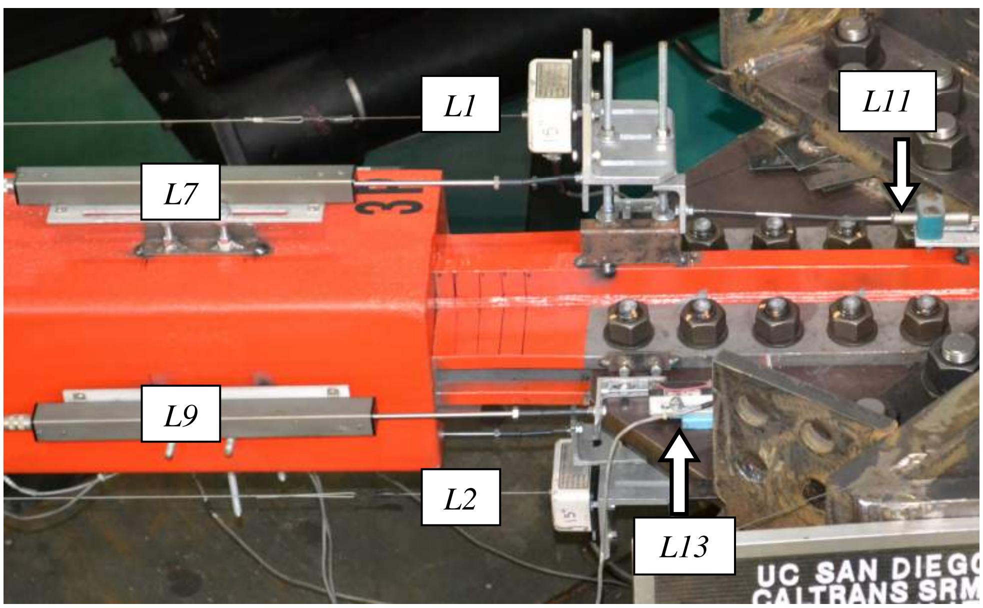


(b) Secondary Displacement Transducers

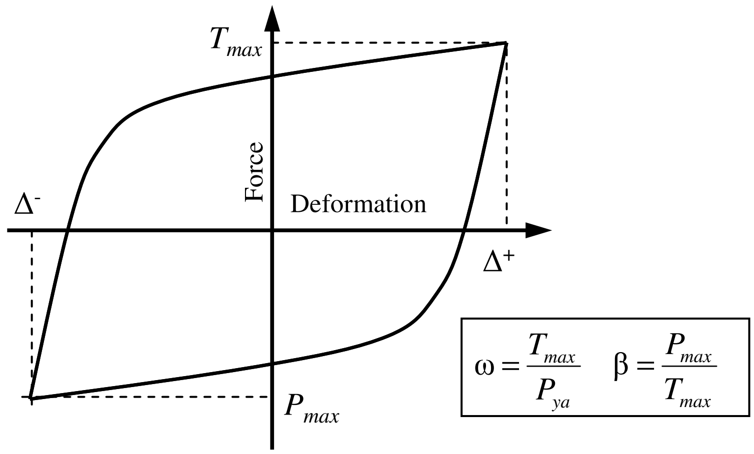
Figure 2.10 Schematic of Displacement Transducer Instrumentation



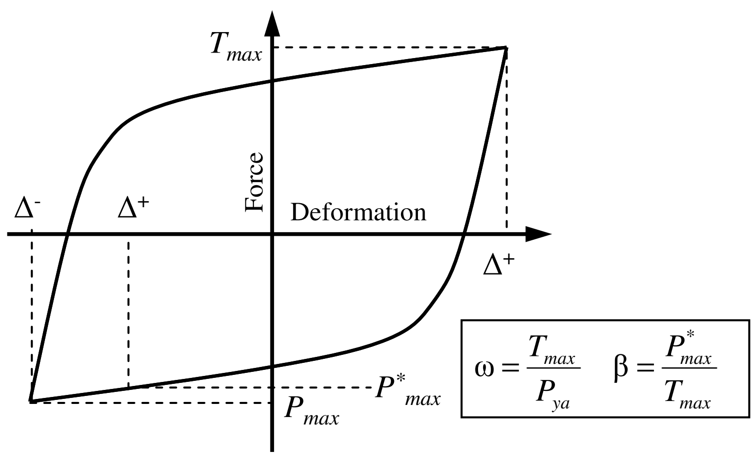
(a) Platen Side



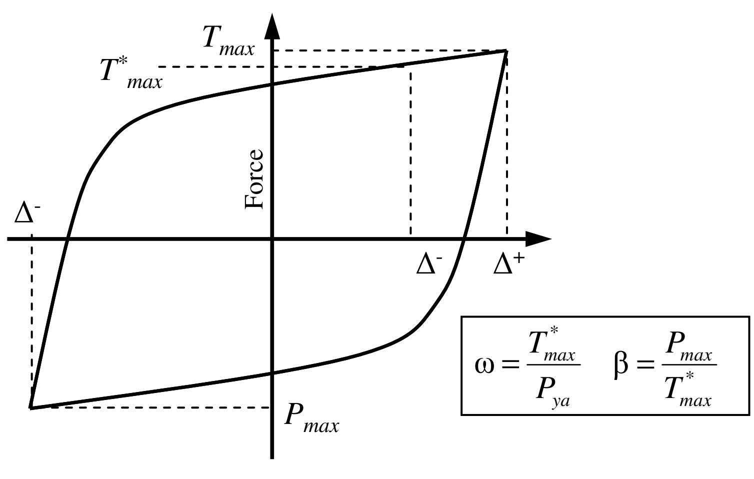
(b) Strong Wall Side
Figure 2.11 Displacement Transducer Instrumentation



(a) Definition of ω and β when $\Delta^+ = \Delta^-$



(b) Definition of ω and β when $\Delta^+ < \Delta^-$



(c) Definition of ω and β when $\Delta^+ > \Delta^-$

Figure 2.12 Strength Adjustment Factor Definitions for the i-th Cycle

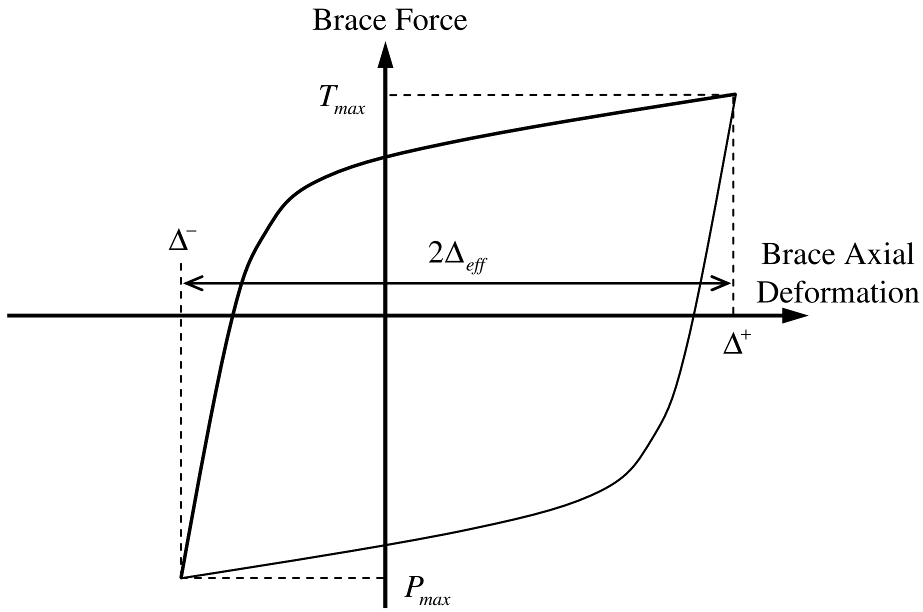


Figure 2.13 Definition of Effective Axial Deformation Cyclic Amplitude, Δ_{eff}

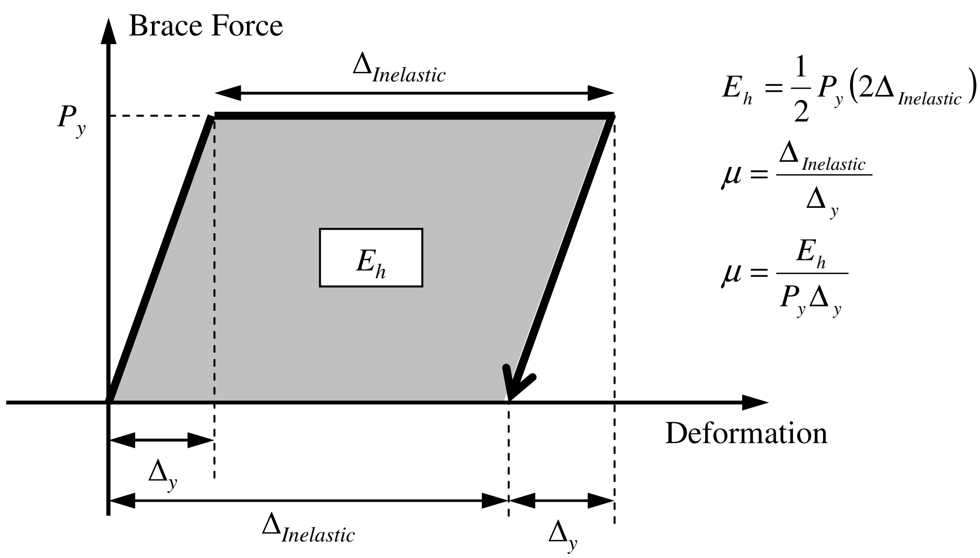


Figure 2.14 Energy Based Ductility Calculation

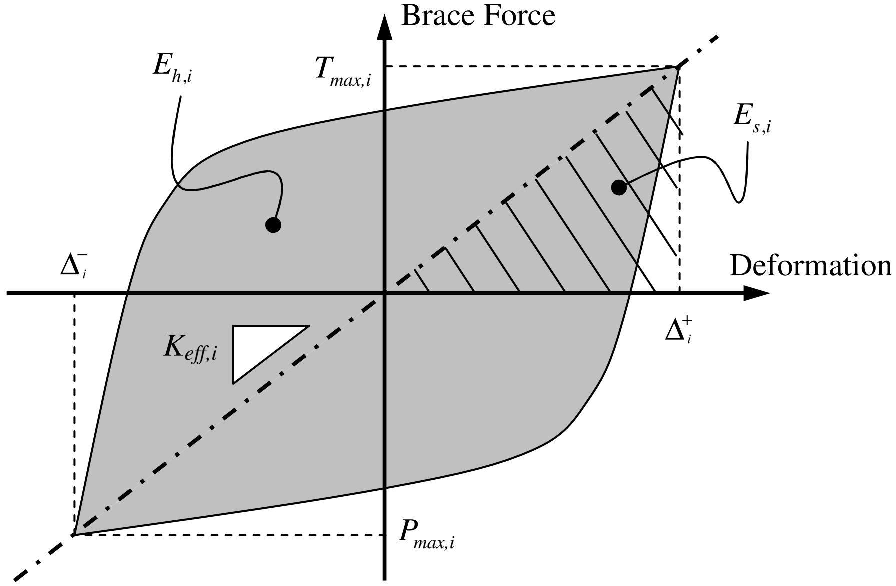


Figure 2.15 Equivalent Viscous Damping Parameters for the i-th Cycle

3. TEST RESULTS

3.1 Introduction

For each of the test specimens, the following results are presented for the Standard and High-Amplitude Loading Protocols. In addition to showing results for each loading protocol for each specimen, these results are also combined in another set of plots to demonstrate the accumulative effects.

(1) A table summarizing the forces and their corresponding strength adjustment factors, as described in Section 2.7. In general, the brace axial deformation refers to the average deformation measured by displacement transducers *L1* and *L2* shown in Figure 2.11. The table also reports the deformation in terms of core axial strain and multiple of brace yield deformation. Some specimens utilize the displacement transducers attached to the sides, top, and bottom of the brace casing, see Section 2.6.

(2) A table reporting the cumulative ductility and equivalent viscous damping values associated with each cycle.

(3) Measured brace displacement time histories in the axial and transverse directions: These displacements represent the actual axial deformation and end rotation demand experienced by the brace specimen.

(4) Brace resultant force (P_r) versus brace axial deformation (Δ) plot: The calculation of the brace resultant force was presented in Section 2.7.

(5) Hysteretic energy (E_h) time history: The hysteretic energy was computed in accordance with Eq. 2.4.

(6) Tension strength adjustment factor (ω) versus brace axial deformation plot: The calculation of ω is based on Eq. 2.2. and described in Section 2.7

(7) Compression strength adjustment factor (β) versus brace axial deformation plot: See Eq. 2.3 for the description of the calculation of β, and Section 2.7 for a description of variations of this parameter. The fluctuation of β with respect to the brace axial deformation (Δ) beyond Δ_{by} for the Standard and High-Amplitude Loading Protocols is also presented.

3.2 Specimen 2P

Specimen 2P was tested on April 12, 2012. Figure 3.1 shows the specimen prior to testing. The specimen performed well during the Standard Loading Protocol test. Stable hysteretic response was observed during the High-Amplitude Loading Protocol test until a slight decline in the tensile strength was observed at peak tension of the first $17.5\Delta_{by}$ cycle, indicating that the core plate had began to experience necking The following compression excursion exhibited a significant drop in the resisting force, and therefore the test was terminated (see Figure 3.8). The value of β for the final cycle is not meaningful, since the peak compressive table displacement was not attained before the test was stopped.

An adjustment to the force, recorded during testing, was required for this specimen which involves the SRMD shake table facility. The SRMD shake table is primarily a steel platen which rests on hydrostatic bearings that vertically support it and the specimen. This system has an inherent friction force that must be overcome by the machine in order to move the platen and deform the specimen. Figure 3.3 shows this friction force as recorded while the machine moved the table, without a specimen installed, through the Standard Protocol (an empty table run). The average friction forces of 5.8 kips and 9.3 kips in the tension direction compression directions, respectively, are each a small fraction of the SRMD capacity of approximately 2,000 kips. However, the 3 in^2 core plate of Specimen 2P exhibited yield and maximum brace forces of approximately 133.8 and 213 kips, respectively. Therefore, it was necessary to remove the friction forces from the recorded brace forces as they were deemed non-trivial with respect to the yield and maximum forces. The idealized friction force, shown in Figure 3.3, was used to adjust the resultant brace force for Specimen 2P. It should be noted that removal of this idealized force is a simplification and may have some effect on the reported overstrength values for this particular brace.

The following results are presented for Specimen 2P:

(1) Standard Loading Protocol test: Figure 3.4 to Figure 3.6,

(2) High-Amplitude Loading Protocol test: Figure 3.7 to Figure 3.9,

(3) Combined tests: Figure 3.10 to Figure 3.12,

(4) Response envelope: Figure 3.13,

(5) β, ω, and $\beta\omega$ values: Table 3.1, Figure 3.14, Figure 3.15, and

(6) η_D and ζ_{eq} values: Table 3.2.

3.3 Specimen 3P

Specimen 3P was tested on March 29, 2012. Figure 3.16 shows the specimen prior to testing. The specimen performed well during the Standard Loading Protocol test. Note, a value for β is not meaningful for the 2nd cycle of the Standard Protocol test. The gusset-to-lug connection bolt slip occurred earlier than predicted and the $1\Delta_{by}$ brace deformation target was not obtained, as the input motion did not account for the hole-oversize at this amplitude. Therefore, the peak compression force and deformation are much lower than the corresponding tension values.

A mistake was made during displacement input to the machine for the High-Amplitude Loading Protocol test. The prescribed longitudinal table displacements were input as transverse, and vice versa. After four stable hysteretic cycles of the modified High-Amplitude Loading Protocol, the test was stopped, and restarted with a Fracture Protocol which was composed of $20\Delta_{by}$ constant amplitude cycles, and included transverse displacements corresponding to a brace rotation of 0.03 rad. When testing resumed, slight necking was observed at the first tension peak at $20\Delta_{by}$. Then upon very nearly completing the cycle the core plate fractured, and the test was terminated.

The following results are presented for Specimen 3P:

(1) Standard Loading Protocol test: Figure 3.18 to Figure 3.20,

(2) High-Amplitude Loading Protocol test: Figure 3.21 to Figure 3.23,

(3) Fracture Loading Protocol test: Figure 3.24 to Figure 3.26,

(4) Combined tests: Figure 3.27 to Figure 3.29,

(5) Response envelope: Figure 3.30,

(6) β, ω, and $\beta\omega$ values: Table 3.3, Figure 3.31, Figure 3.32, and

(7) η_D and ζ_{eq} values: Table 3.4.

3.4 Specimen 4P

Specimen 4P was tested on April 5, 2012. Figure 3.33 shows the specimen prior to testing. The specimen performed well during the Standard Loading Protocol test and also provided stable hysteretic response through the full High-Amplitude Loading Protocol test. Note the large sudden force drops throughout the test (see Figure 3.36 and Figure 3.39), caused by the gusset-to-lug connection bolt slip. Because the very large release of energy associated with fracturing a brace at a very large force, the brace was not taken to fracture. This was decided in consideration of the SRMD machine, as the released energy can potentially damage the system.

During the Standard Loading Protocol, bolt slip caused many instruments, measuring brace deformation, to become disconnected. The Standard Protocol ended with a tensile excursion from the final compression peak towards zero, therefore the bolts remained in bearing at the end of the first test. This permitted a residual tensile force in the brace. The remaining tensile force was required to be released in order to safely repair the instruments for the remaining protocols. Additionally, it was decided to begin the High Amplitude Protocol from zero residual brace deformation, and therefore the brace was subjected to a small tensile deformation and then permitted to relax elastically to approximately zero residual deformation. The instrumentation was then repaired and adjustments to the High Amplitude Protocol machine input file were made in an attempt to achieve symmetric brace deformation cycles. During these adjustments, it was assumed that the bolt slip would continue to occur approximately equal on both tension and compression excursions. However, since the Standard Protocol ended with the bolts in bearing in the tension direction, the entire slip, equal to the total bolt hole oversize for both connections, actually occurred on the compression excursions only. This resulted in fairly non-symmetrical cycles in the High Amplitude Protocol Test, which were skewed to the tension deformation side of each cycle.

A consequence of the skewed cycles is an abnormal measure of the compression strength adjustment factor, β, as typically measured (see Figure 2.12). In an effort to provide an estimate of β which is more comparable to those of typical symmetric cycles, Table 3.7 reports a β value which is measured from the maximum and minimum forces recorded for each cycle. This measure is then associated with an effective cyclic deformation amplitude calculated as:

$$\Delta_{eff} = \frac{\Delta^{+} + \Delta^{-}}{2} \tag{3.1}$$

where Δ^{+} and Δ^{-} are defined in Figure 2.13. Table 3.7 reports these strength adjustment factors with respect to the effective axial deformation amplitude, Δ_{eff}, for the High Amplitude Loading Protocol as well as the factors from the Standard Loading Protocol. Therefore, the values in Table 3.7 are exactly those in Table 3.5 for the Standard Protocol.

The following results are presented for Specimen 4P:

(1) Standard Loading Protocol test: Figure 3.35 to Figure 3.37,

(2) High-Amplitude Loading Protocol test: Figure 3.38 to Figure 3.40,

(3) Combined tests: Figure 3.41 to Figure 3.43,

(4) Response envelope: Figure 3.44,

(5) β, ω, and $\beta\omega$ values: Table 3.5, Figure 3.45, Figure 3.46,

(6) η_D and ζ_{eq} values: Table 3.6, and

(7) ω and β values corresponding to Δ_{eff}: Table 3.7.

3.5 Specimen 5P

Specimen 5P was tested on April 10, 2012. Figure 3.47 shows the specimen prior to testing. The specimen performed well during the Standard Loading Protocol test. The specimen exhibited stable hysteretic response during the High-Amplitude Loading Protocol test until the core plate ruptured, within the restraining HSS portion, during the second cycle at $15\Delta_{bm}$. Afterwards, it was decided to compress the specimen to the corresponding $15\Delta_{bm}$ deformation without returning to zero displacement (see Figure 3.53). This facilitated removal of the brace, as there was a significant compressive residual force, and in a sense completed the $15\Delta_{bm}$ cycle thereby achieving more cumulative ductility. This also demonstrates that the specimen retained its compressive strength despite having clearly fractured in tension.

The following results are presented for Specimen 5P:

(1) Standard Loading Protocol test: Figure 3.49 to Figure 3.51,

(2) High-Amplitude Loading Protocol test: Figure 3.52 to Figure 3.54,

(3) Combined tests: Figure 3.55 to Figure 3.57,

(4) Response envelope: Figure 3.58,

(5) β, ω, and $\beta\omega$ values: Table 3.8, Figure 3.59, Figure 3.60, and

(6) η_D and ζ_{eq} values: Table 3.9.

Table 3.1 Specimen 2P Strength Adjustment Factors

Test	Cycle No.	T_{max} [a] (kips)	P_{max} [a] (kips)	β	ω	βω	Brace Deformations: Longitudinal Effective Cycle Amplitude (in.)	Longitudinal Effective Cycle Amplitude (%)	Longitudinal Effective Cycle Amplitude (Δ_{by})	Transverse Cycle Amplitude (in.)	Transverse Cycle Amplitude (rad)
AISC Standard Loading Protocol	1	133	-135	1.02	0.99	1.01	0.39	0.20	1.1	0.40	0.002
	2	129	-134	1.04	0.96	1.00	0.39	0.20	1.1	0.40	0.002
	3	131	-144	1.10	0.98	1.08	1.21	0.61	3.6	1.00	0.004
	4	131	-152	1.16	0.98	1.14	1.21	0.61	3.6	1.00	0.004
	5	148	-174	1.18	1.11	1.30	2.04	1.02	6.0	2.02	0.009
	6	156	-177	1.13	1.17	1.32	2.04	1.02	6.0	2.02	0.009
	7	164	-195	1.19	1.23	1.46	2.85	1.43	8.4	3.04	0.014
	8	171	-196	1.15	1.28	1.46	2.86	1.43	8.4	3.04	0.014
	9	175	-210	1.20	1.31	1.57	3.66	1.83	10.8	4.08	0.018
	10	178	-212	1.19	1.33	1.58	3.67	1.83	10.8	4.08	0.018
	11 [b]	173	-191	1.10	1.29	1.43	2.85	1.43	8.4	3.04	0.014
	12 [b]	171	-191	1.12	1.28	1.43	2.86	1.43	8.4	3.04	0.014
High-Amp. Protocol	13	184	-228	1.24	1.38	1.70	4.47	2.24	13.1	5.12	0.023
	14	189	-233	1.23	1.41	1.74	4.47	2.24	13.1	5.12	0.023
	15	193	-256	1.33	1.44	1.91	5.25	2.63	15.4	6.18	0.028
	16	194	-266	1.37	1.45	1.99	5.24	2.62	15.4	6.18	0.028
	17	181	-213	-	1.35	-	2.97	1.48	8.7	6.87	0.031

[a] See Section 2.7 and Figure 2.12

[b] Can be neglected in regression analysis

Table 3.2 Specimen 2P Cumulative Ductility and Equivalent Viscous Damping

Test	Cycle No.	Brace Axial Forces		Longitudinal Brace Deformations				η_D (Δ_{by})	Δ_{avg} (in)	K_{eff} (kip/in)	E_{hi} (kip-in)	ζ_{eq} (%)
		T_{max} (kips)	P_{max} (kips)	Δ_{max}		Δ_{min}						
				(in.)	(%)	(in.)	(%)					
AISC Standard Loading Protocol	1	133	-136	0.39	0.19	-0.39	-0.20	0	0.39	345.5	41	12.5
	2	129	-134	0.39	0.20	-0.39	-0.20	0	0.39	337.2	48	14.9
	3	133	-143	1.21	0.61	-1.21	-0.61	10	1.21	114.0	419	39.9
	4	132	-152	1.21	0.61	-1.21	-0.61	20	1.21	117.4	408	37.8
	5	149	-174	2.04	1.02	-2.04	-1.02	40	2.04	79.2	874	42.2
	6	156	-177	2.05	1.02	-2.04	-1.02	61	2.05	81.60	899	41.9
	7	164	-195	2.86	1.43	-2.85	-1.43	90	2.86	62.8	1435	44.6
	8	171	-196	2.86	1.43	-2.86	-1.43	120	2.86	64.0	1456	44.3
	9	175	-210	3.71	1.86	-3.67	-1.84	159	3.69	52.2	2035	45.6
	10	179	-212	3.71	1.86	-3.67	-1.84	199	3.69	52.9	2055	45.4
	11	174	-191	2.86	1.43	-2.86	-1.43	228	2.86	63.9	1472	44.8
	12	172	-190	2.87	1.44	-2.86	-1.43	258	2.87	63.3	1463	44.8
High-Amp. Protocol	13	185	-227	4.53	2.27	-4.47	-2.24	307	4.50	45.8	2691	46.2
	14	190	-232	4.53	2.27	-4.47	-2.24	356	4.50	46.9	2746	46.0
	15	194	-255	5.37	2.69	-5.26	-2.63	414	5.32	42.3	3470	46.2
	16	196	-266	5.38	2.69	-5.25	-2.63	473	5.32	43.3	3552	46.2
	17	196	-213	6.24	3.12	-4.41	-2.21	532	5.33	38.4	2994	43.8

Table 3.3 Specimen 3P Strength Adjustment Factors

Test	Cycle No.	T_{max} [a] (kips)	P_{max} [a] (kips)	β	ω	βω	Brace Deformations: Longitudinal Cycle Amplitude (in.)	(%)	(Δ_{by})	Transverse Cycle Amplitude (in.)	(rad)
AISC Standard Loading Protocol	1	373	-367	0.98	0.99	0.98	0.31	0.17	1.1	0.35	0.002
	2*	337	-171	-	0.90	0.45	0.18	0.10	0.6	0.35	0.002
	3	370	-377	1.02	0.98	1.00	0.79	0.44	2.7	0.87	0.004
	4	372	-385	1.03	0.99	1.02	0.78	0.44	2.7	0.87	0.004
	5	380	-430	1.13	1.01	1.14	1.50	0.84	5.2	1.75	0.009
	6	414	-444	1.07	1.10	1.18	1.50	0.84	5.2	1.75	0.009
	7	435	-485	1.11	1.16	1.29	2.18	1.22	7.5	2.63	0.013
	8	449	-494	1.1	1.19	1.31	2.17	1.22	7.5	2.63	0.013
	9	467	-529	1.13	1.24	1.41	2.86	1.61	9.9	3.53	0.017
	10	477	-537	1.13	1.27	1.43	2.86	1.61	9.8	3.53	0.017
	11[b]	468	-506	1.08	1.24	1.35	2.16	1.21	7.4	2.63	0.013
	12[b]	459	-501	1.09	1.22	1.33	2.16	1.21	7.4	2.63	0.013
High-Amp. Protocol*	13	499	-604	1.21	1.33	1.61	4.37	2.46	15.1	3.58	0.017
	14	522	-616	1.18	1.39	1.64	4.37	2.46	15.1	3.58	0.017
	15	538	-651	1.21	1.43	1.73	5.26	2.96	18.1	4.29	0.021
	16	545	-663	1.22	1.45	1.76	5.28	2.97	18.2	4.29	0.021
Fract.	17	537	-721	1.34	1.43	1.92	5.55	3.12	19.1	4.29	0.021

* See Section 3.3 for details.

[a] See Section 2.7 and Figure 2.12

[b] Can be neglected in regression analysis

Table 3.4 Specimen 3P Cumulative Ductility and Equivalent Viscous Damping

Test	Cycle No.	Brace Axial Forces		Longitudinal Brace Deformations				η_D (Δ_{by})	Δ_{avg} (in)	K_{eff} (kip/in)	E_{hi} (kip-in)	ζ_{eq} (%)
		T_{max} (kips)	P_{max} (kips)	Δ_{max}		Δ_{min}						
				(in.)	(%)	(in.)	(%)					
AISC Standard Loading Protocol	1	373	-371	0.31	0.18	-0.53	-0.30	2	0.42	880.8	176	18.0
	2	337	-364	0.18	0.10	-0.53	-0.30	2	0.36	992.1	119	15.2
	3	373	-380	0.79	0.44	-0.83	-0.47	9	0.81	461.8	698	36.7
	4	375	-386	0.78	0.44	-0.83	-0.47	16	0.81	467.4	693	36.4
	5	381	-431	1.64	0.92	-1.50	-0.85	34	1.57	258.6	1744	43.5
	6	415	-444	1.61	0.91	-1.50	-0.85	51	1.56	275.5	1779	42.5
	7	438	-485	2.33	1.31	-2.19	-1.23	78	2.26	204.3	2951	45.0
	8	452	-494	2.31	1.30	-2.17	-1.22	105	2.24	210.2	3000	45.3
	9	469	-530	3.02	1.70	-2.86	-1.61	142	2.94	169.8	4297	46.6
	10	480	-538	3.00	1.69	-2.86	-1.61	178	2.93	173.7	4327	46.2
	11	469	-507	2.28	1.29	-2.16	-1.22	205	2.22	219.5	3038	44.7
	12	461	-502	2.29	1.29	-2.16	-1.21	232	2.23	216.4	2992	44.5
High-Amp. Protocol*	13	499	-606	4.56	2.57	-4.36	-2.46	289	4.46	123.8	7534	48.7
	14	524	-617	4.54	2.56	-4.37	-2.46	346	4.46	128.0	7787	48.8
	15	539	-652	5.46	3.07	-5.26	-2.96	416	5.36	111.0	9896	49.4
	16	546	-664	5.46	3.08	-5.26	-2.96	486	5.36	112.7	10033	49.3
Fract.	17	566	-721	5.85	3.29	-5.55	-3.12	561	5.70	112.7	11259	48.9

* See Section 3.3 for details.

Table 3.5 Specimen 4P Strength Adjustment Factors

Test	Cycle No.	T_{max} [a] (kips)	P_{max} [a] (kips)	β	ω	βω	Brace Deformations: Longitudinal Cycle Amplitude (in.)	Longitudinal Cycle Amplitude (%)	Longitudinal Cycle Amplitude (Δ_{by})	Transverse Cycle Amplitude (in.)	Transverse Cycle Amplitude (rad)
AISC Standard Loading Protocol	1	748	-705	0.94	1.03	0.97	0.47	0.28	1.7	0.32	0.002
	2	720	-720	1.00	1.00	1.00	0.46	0.28	1.7	0.32	0.002
	3	766	-817	1.07	1.06	1.13	1.18	0.71	4.4	0.80	0.004
	4	820	-869	1.06	1.13	1.20	1.16	0.70	4.3	0.80	0.004
	5	883	-961	1.09	1.22	1.33	1.81	1.09	6.7	1.62	0.009
	6	917	-975	1.06	1.27	1.35	1.83	1.10	6.8	1.62	0.009
	7	943	-1024	1.09	1.30	1.42	2.25	1.35	8.3	2.43	0.013
	8	962	-1034	1.07	1.33	1.43	2.28	1.37	8.4	2.44	0.013
	9	984	-1083	1.10	1.36	1.50	2.68	1.61	9.9	3.26	0.017
	10	1001	-1081	1.08	1.38	1.49	2.67	1.61	9.9	3.26	0.017
	11 [b]	984	-1015	1.03	1.36	1.40	2.00	1.20	7.4	2.44	0.013
	12 [b]	964	-1008	1.05	1.33	1.39	2.00	1.20	7.4	2.43	0.013
High-Amp. Protocol*	13	1015	-1147	1.13	1.40	1.59	2.68	1.61	9.9	4.10	0.022
	14	1041	-1149	1.10	1.44	1.59	2.68	1.61	9.9	4.10	0.022
	15	1057	-1202	1.14	1.46	1.66	3.32	2.00	12.3	4.94	0.026
	16	1071	-1204	1.12	1.48	1.66	3.32	2.00	12.3	4.94	0.026
	17	1088	-1246	1.15	1.50	1.72	3.95	2.38	14.6	5.79	0.03
	18	1099	-1242	1.13	1.52	1.72	3.96	2.38	14.6	5.79	0.03
	19	1104	-1277	1.16	1.53	1.76	4.63	2.79	17.1	5.86	0.031
	20	1114	-1275	1.14	1.54	1.76	4.64	2.79	17.2	5.84	0.031

* See Section 3.4 for details.

[a] See Section 2.7 and Figure 2.12

[b] Can be neglected in regression analysis

Table 3.6 Specimen 4P Cumulative Ductility and Equivalent Viscous Damping

Test	Cycle No.	Brace Axial Forces		Longitudinal Brace Deformations				η_D (Δ_{by})	Δ_{avg} (in)	K_{eff} (kip/in)	E_{hi} (kip-in)	ζ_{eq} (%)
		T_{max} (kips)	P_{max} (kips)	Δ_{max}		Δ_{min}						
				(in.)	(%)	(in.)	(%)					
AISC Standard Loading Protocol	1	765	-757	0.47	0.28	-0.51	-0.29	3	0.49	1588.6	517	22.6
	2	721	-728	0.46	0.28	-0.51	-0.29	6	0.49	1507.4	539	24.6
	3	770	-818	1.18	0.71	-1.23	-0.70	19	1.21	657.9	2428	40.3
	4	820	-870	1.17	0.70	-1.22	-0.69	32	1.20	707.0	2420	38.2
	5	883	-966	1.85	1.04	-1.90	-1.07	55	1.88	492.0	4650	42.7
	6	919	-976	1.85	1.10	-1.90	-1.09	78	1.88	506.2	4747	42.6
	7	945	-1029	2.31	1.35	-2.37	-1.35	107	2.34	421.9	6488	44.7
	8	964	-1036	2.31	1.37	-2.37	-1.37	137	2.34	426.8	6584	44.7
	9	985	-1092	2.72	1.62	-2.92	-1.65	173	2.82	367.5	8441	45.8
	10	1003	-1093	2.73	1.61	-2.92	-1.65	208	2.83	370.5	8553	45.9
	11	986	-1027	2.04	1.20	-2.28	-1.28	234	2.16	465.8	5992	43.9
	12	966	-1020	2.04	1.20	-2.28	-1.28	259	2.16	458.4	5916	43.8
High-Amp. Protocol*	13	1047	-1149	4.06	2.45	-2.67	-1.61	295	3.37	325.7	10870	46.8
	14	1066	-1151	4.05	2.44	-2.68	-1.61	331	3.37	329.5	11071	47.3
	15	1082	-1204	4.75	2.86	-3.31	-1.99	376	4.03	283.5	13881	47.9
	16	1093	-1205	4.75	2.86	-3.32	-2.00	421	4.04	284.8	13992	48.0
	17	1106	-1248	5.43	3.27	-3.95	-2.38	475	4.69	250.8	17023	49.1
	18	1113	-1244	5.43	3.27	-3.95	-2.38	530	4.69	250.9	17066	49.1
	19	1117	-1279	6.10	3.67	-4.63	-2.79	595	5.37	223.1	20137	49.8
	20	1124	-1277	6.09	3.67	-4.64	-2.79	659	5.37	223.7	20134	49.7

* See Section 2.7 and Figure 2.15

Table 3.7 Specimen 4P Alternative Strength Adjustment Factors

Test	Cycle No.	T_{max}[a] (kips)	P_{max}[a] (kips)	β	ω	βω	Brace Deformations: Longitudinal Cycle Amplitude (in.)	Longitudinal Cycle Amplitude (%)	Longitudinal Cycle Amplitude (Δ_{by})	Transverse Cycle Amplitude (in.)	Transverse Cycle Amplitude (rad)
AISC Standard Loading Protocol	1	748	-705	0.94	1.03	0.97	0.47	0.28	1.7	0.32	0.002
	2	720	-720	1.00	1.00	1.00	0.46	0.28	1.7	0.32	0.002
	3	766	-817	1.07	1.06	1.13	1.18	0.71	4.4	0.80	0.004
	4	820	-869	1.06	1.13	1.20	1.16	0.70	4.3	0.80	0.004
	5	883	-961	1.09	1.22	1.33	1.81	1.09	6.7	1.62	0.009
	6	917	-975	1.06	1.27	1.35	1.83	1.10	6.8	1.62	0.009
	7	943	-1024	1.09	1.30	1.42	2.25	1.35	8.3	2.43	0.013
	8	962	-1034	1.07	1.33	1.43	2.28	1.37	8.4	2.44	0.013
	9	984	-1083	1.10	1.36	1.50	2.68	1.61	9.9	3.26	0.017
	10	1001	-1081	1.08	1.38	1.49	2.67	1.61	9.9	3.26	0.017
	11[b]	984	-1015	1.03	1.36	1.40	2.00	1.20	7.4	2.44	0.013
	12[b]	964	-1008	1.05	1.33	1.39	2.00	1.20	7.4	2.43	0.013
High-Amp. Protocol*	13	1047	-1149	1.10	1.44	1.58	*3.37*[a]	*2.03*	*12.5*	4.10	0.022
	14	1066	-1151	1.08	1.47	1.59	*3.37*	*2.03*	*12.5*	4.10	0.022
	15	1082	-1204	1.11	1.49	1.66	*4.03*	*2.43*	*14.9*	4.94	0.026
	16	1093	-1205	1.10	1.51	1.66	*4.04*	*2.43*	*14.9*	4.94	0.026
	17	1106	-1248	1.13	1.52	1.72	*4.69*	*2.82*	*17.4*	5.79	0.03
	18	1113	-1244	1.12	1.53	1.71	*4.69*	*2.82*	*17.4*	5.79	0.03
	19	1117	-1279	1.14	1.54	1.76	*5.37*	*3.23*	*19.9*	5.86	0.031
	20	1124	-1277	1.14	1.55	1.76	*5.37*	*3.23*	*19.9*	5.84	0.031

* Italicized values are based on effective axial deformation, defined in Figure 2.13

[a] See Section 2.7 and Figure 2.12

[b] Can be neglected in regression analysis

Table 3.8 Specimen 5P Strength Adjustment Factors

Test	Cycle No.	T_{max} [a] (kips)	P_{max} [a] (kips)	β	ω	$\beta\omega$	Brace Deformations: Longitudinal Cycle Amplitude (in.)	Longitudinal Cycle Amplitude (%)	Longitudinal Cycle Amplitude (Δ_{by})	Transverse Cycle Amplitude (in.)	Transverse Cycle Amplitude (rad)
AISC Standard Loading Protocol	1	999	-1017	1.02	0.93	0.94	0.28	0.17	1.1	0.31	0.002
	2	956	-969	1.01	0.89	0.90	0.29	0.18	1.1	0.31	0.002
	3	1028	-1128	1.10	0.95	1.05	1.07	0.67	4.1	0.78	0.004
	4	1111	-1166	1.05	1.03	1.08	0.85	0.53	3.3	0.78	0.004
	5	1203	-1291	1.07	1.12	1.20	1.30	0.81	5.0	1.58	0.008
	6	1261	-1324	1.05	1.17	1.23	1.29	0.80	4.9	1.58	0.008
	7	1327	-1452	1.09	1.23	1.35	1.91	1.19	7.3	2.37	0.013
	8	1376	-1469	1.07	1.28	1.36	1.92	1.19	7.4	2.37	0.013
	9	1427	-1577	1.11	1.32	1.46	2.55	1.59	9.8	3.18	0.017
	10	1469	-1589	1.08	1.36	1.47	2.54	1.58	9.8	3.18	0.017
	11 [b]	1450	-1504	1.04	1.35	1.40	1.92	1.19	7.4	2.37	0.013
	12 [b]	1426	-1493	1.05	1.32	1.39	1.92	1.19	7.4	2.37	0.013
High-Amp. Protocol	13	1485	-1669	1.12	1.38	1.55	3.18	1.98	12.2	4.00	0.021
	14	1532	-1687	1.10	1.42	1.57	3.18	1.98	12.2	4.00	0.021
	15	1577	-1781	1.13	1.46	1.65	3.80	2.37	14.6	4.82	0.026
	16*	1606	-	-	1.49	0	1.86	1.16	7.2	4.58	0.025
*	17*	-	-1849	-	-	-	-	-	-	-	-

* See Section 3.5 for details

[a] See Section 2.7 and Figure 2.12

[b] Can be neglected in regression analysis

Table 3.9 Specimen 5P Cumulative Ductility and Equivalent Viscous Damping

Test	Cycle No.	Brace Axial Forces		Longitudinal Brace Deformations				η_D (Δ_{by})	Δ_{avg} (in)	K_{eff} (kip/in)	E_{hi} (kip-in)	ζ_{eq} (%)
		T_{max} (kips)	P_{max} (kips)	Δ_{max}		Δ_{min}						
				(in.)	(%)	(in.)	(%)					
AISC Standard Loading Protocol	1	999	-1019	0.28	0.18	-0.32	-0.20	0	0.30	3342.0	251	13.3
	2	956	-981	0.29	0.18	-0.31	-0.19	0	0.30	3200.2	275	15.2
	3	1029	-1130	1.07	0.67	-1.09	-0.68	13	1.08	997.9	2957	40.4
	4	1112	-1168	0.85	0.53	-0.87	-0.54	22	0.86	1328.7	2196	35.6
	5	1205	-1293	1.34	0.83	-1.30	-0.81	38	1.32	947.9	4229	40.8
	6	1263	-1326	1.34	0.84	-1.29	-0.80	54	1.32	984.9	4365	40.8
	7	1329	-1454	2.01	1.26	-1.92	-1.20	81	1.97	708.0	7664	44.6
	8	1378	-1472	2.00	1.25	-1.92	-1.20	107	1.96	726.7	7796	44.4
	9	1429	-1579	2.66	1.65	-2.55	-1.59	143	2.61	578.1	11493	46.6
	10	1471	-1591	2.65	1.65	-2.54	-1.58	179	2.60	589.5	11653	46.7
	11	1452	-1506	1.99	1.24	-1.91	-1.19	205	1.95	758.4	7985	44.1
	12	1428	-1496	1.99	1.24	-1.92	-1.19	231	1.96	747.6	7969	44.4
High-Amp. Protocol	13	1487	-1672	3.32	2.07	-3.18	-1.98	277	3.25	486.4	15401	47.7
	14	1540	-1690	3.30	2.06	-3.18	-1.98	323	3.24	498.3	15743	47.9
	15	1579	-1783	3.96	2.46	-3.80	-2.37	378	3.88	433.5	20049	48.9
	16*	1607	-	3.72	2.32	0	0	403	4.59	376.8	17124	34.4
*	17*	-	-1849	-	-	-3.76	-2.34	428				

* See Section 3.5 for details

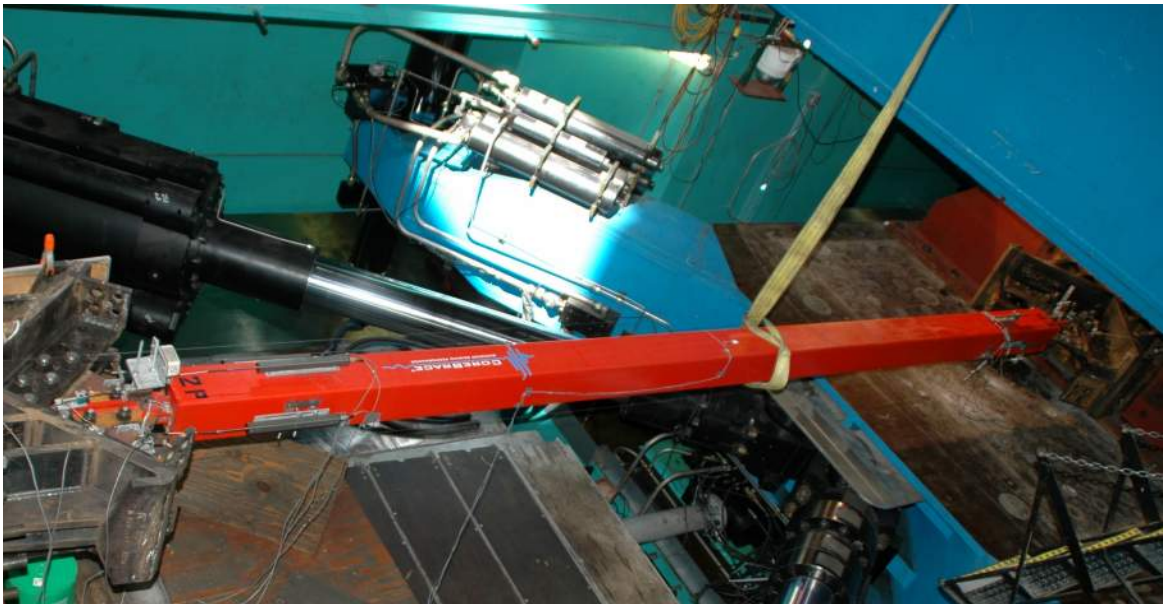


Figure 3.1 Specimen 2P: Test Setup

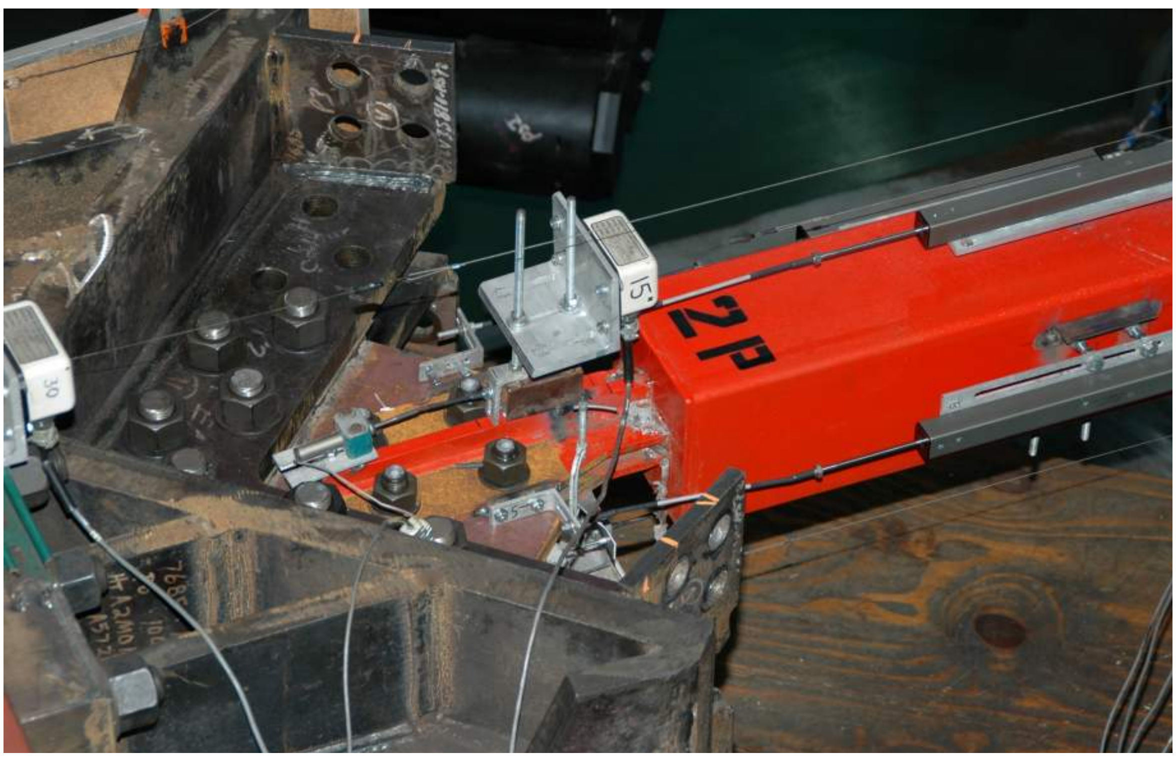


Figure 3.2 Specimen 2P End Connection During Testing

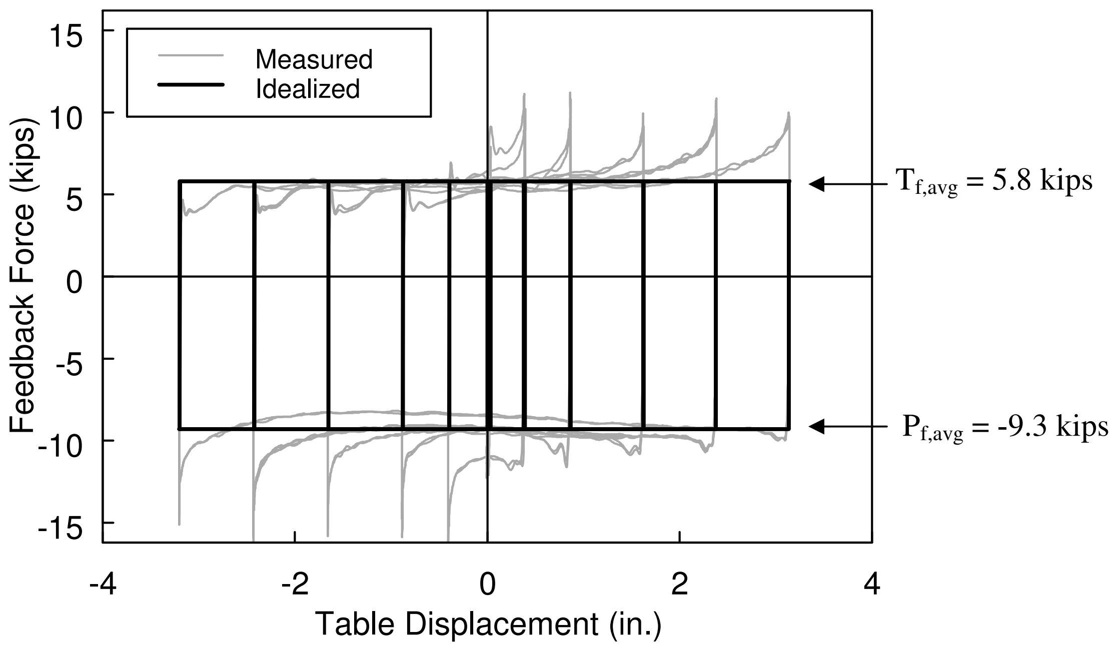
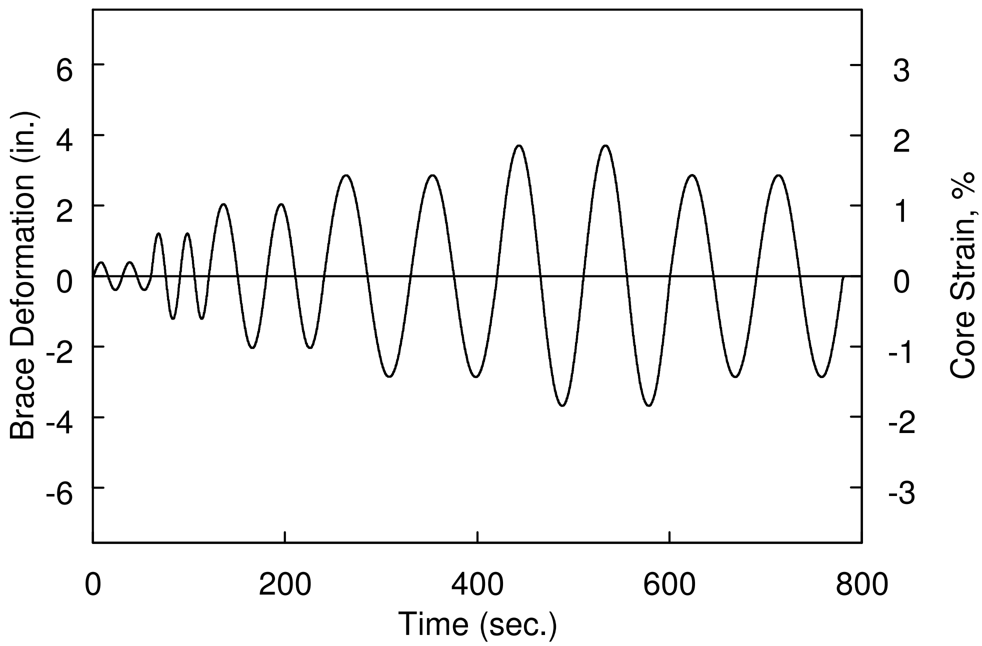
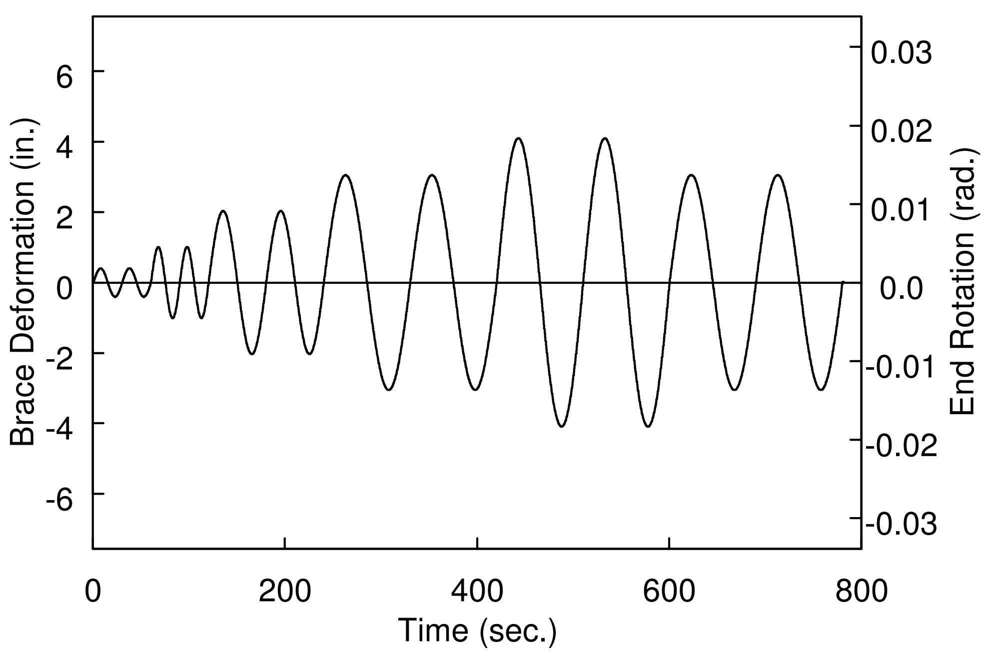


Figure 3.3: Empty Platen Displacement vs. Friction Force (Standard Protocol)



(a) Longitudinal Direction



(b) Transverse Direction

Figure 3.4 Specimen 2P: Brace Deformation Time Histories (Standard Protocol)

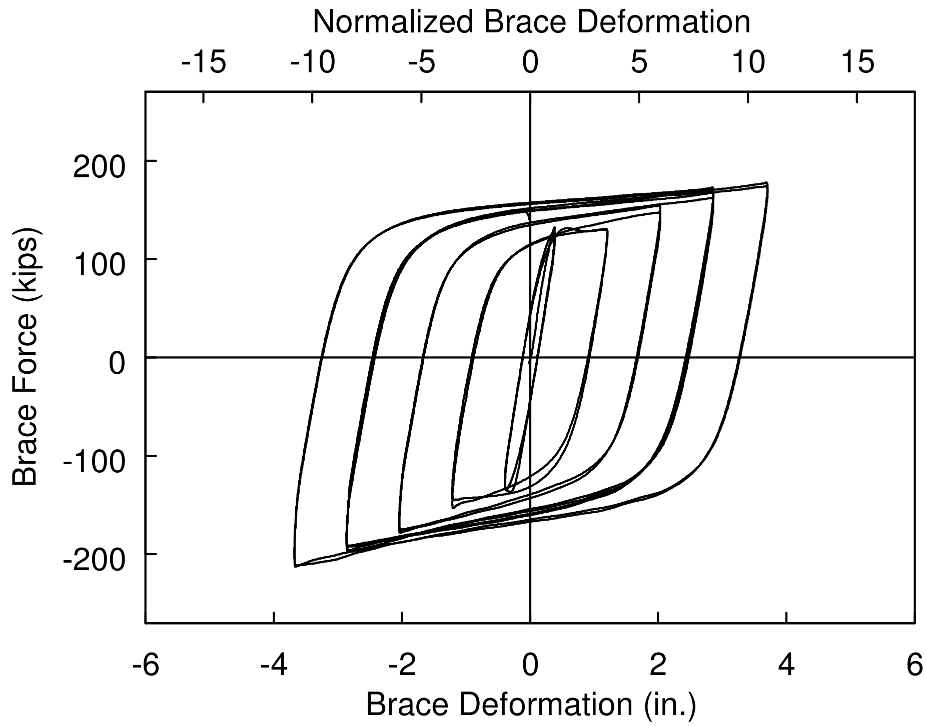


Figure 3.5 Specimen 2P: Brace Force vs. Axial Deformation (Standard Protocol)

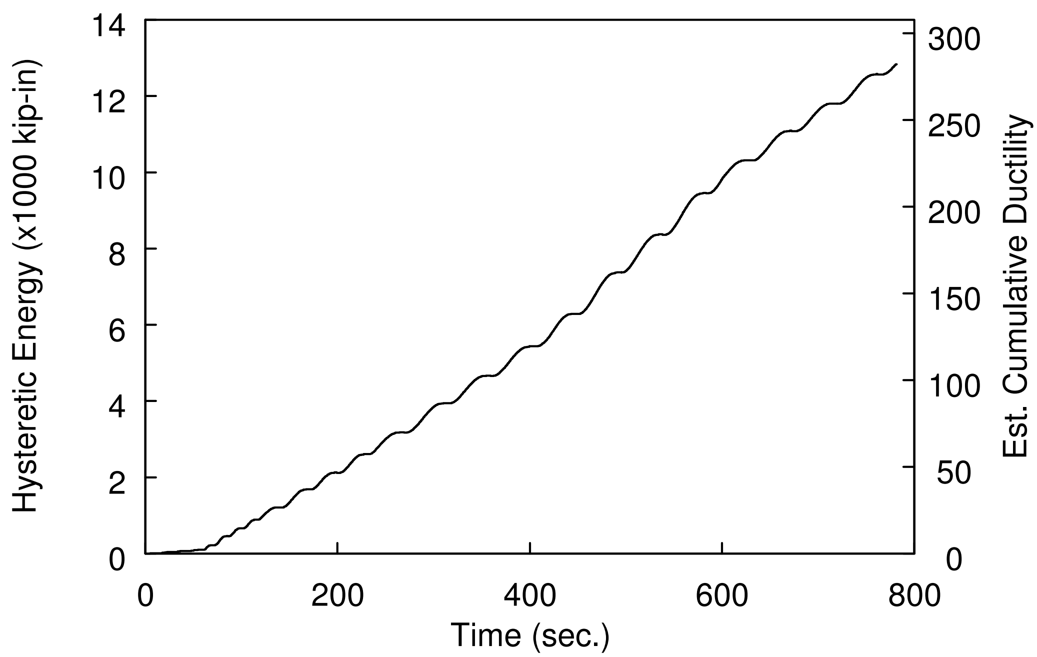
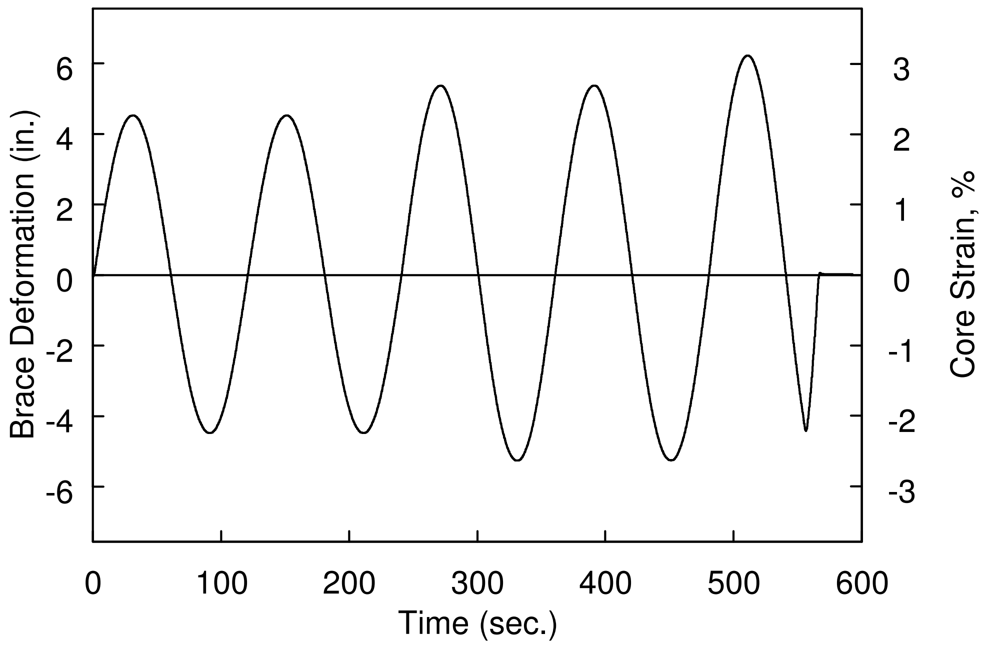
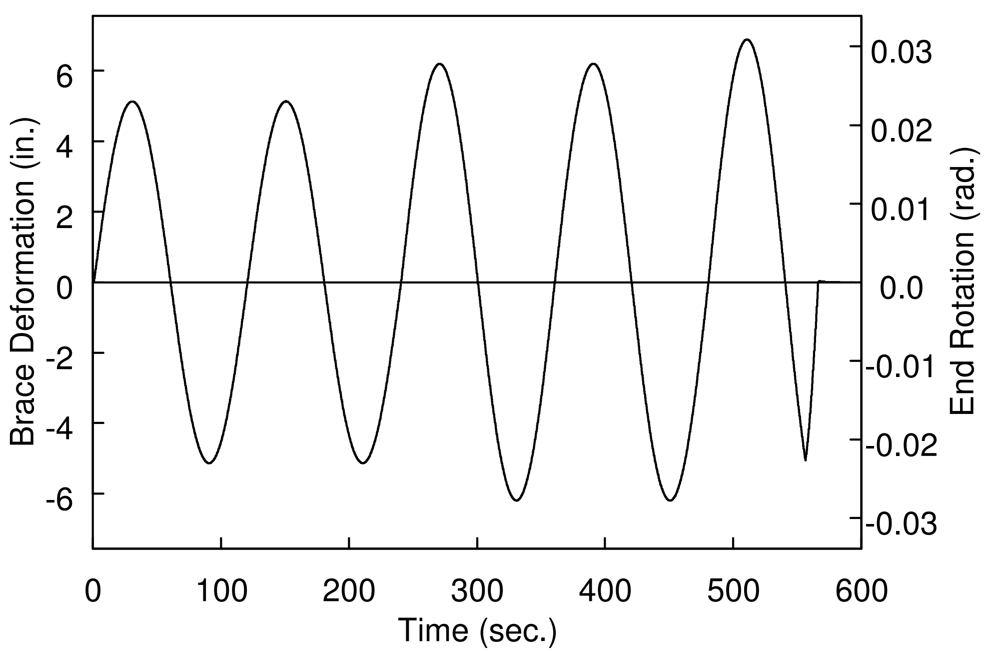


Figure 3.6 Specimen 2P: Hysteretic Energy Time History (Standard Protocol)



(a) Longitudinal Direction



(b) Transverse Direction

Figure 3.7 Specimen 2P: Brace Deformation Time Histories (High-Amplitude Protocol)

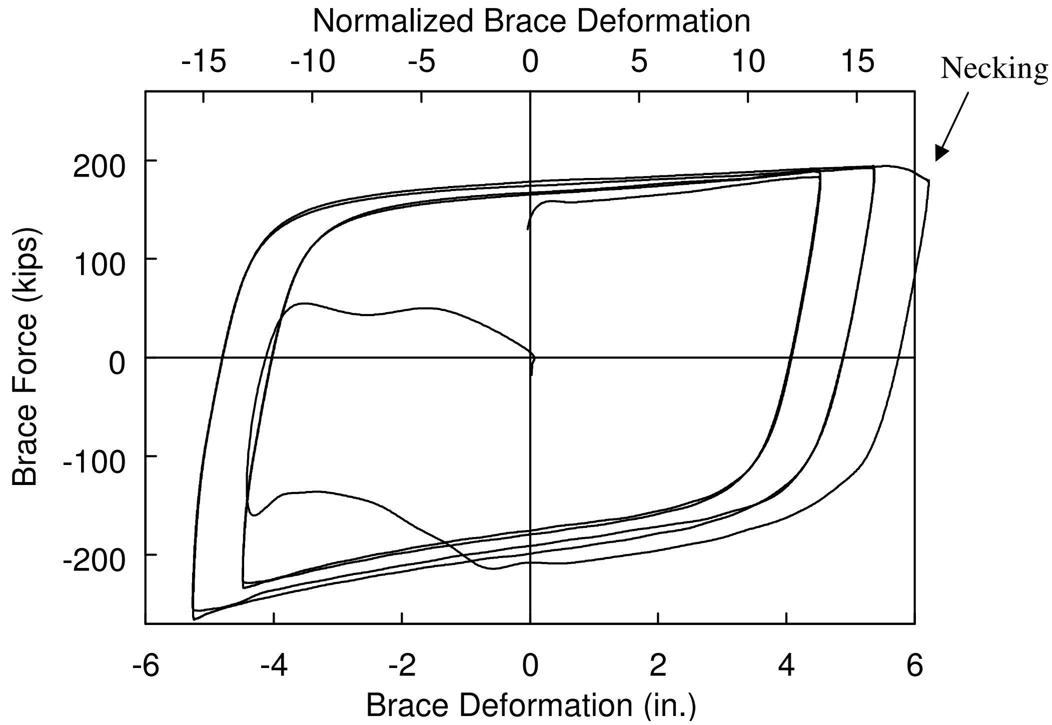


Figure 3.8 Specimen 2P: Brace Force vs. Axial Deformation (High-Amplitude Protocol)

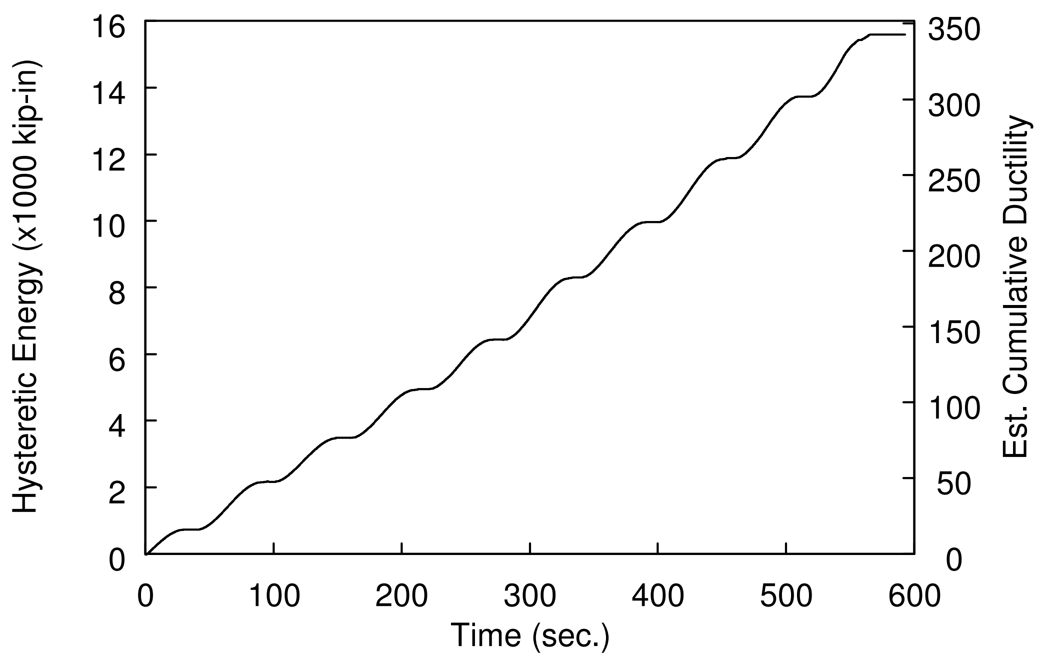
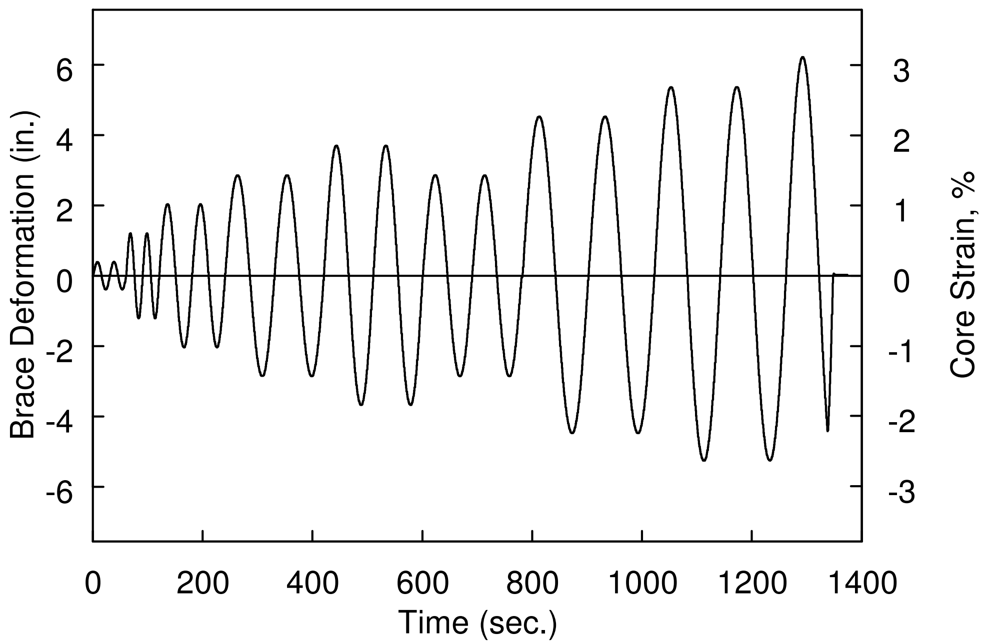
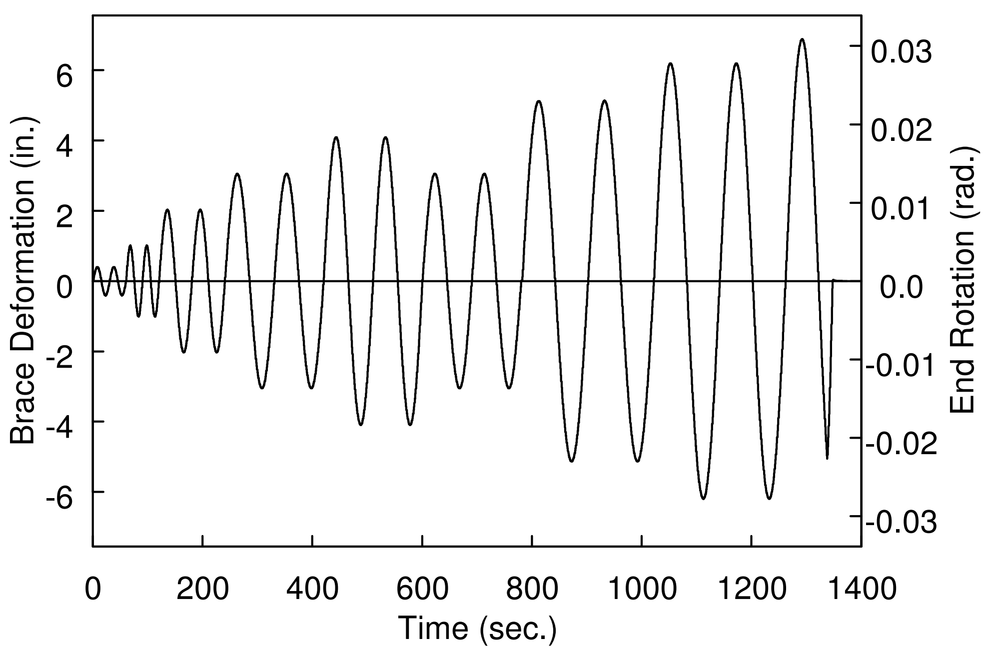


Figure 3.9 Specimen 2P: Hysteretic Energy Time History (High-Amplitude Protocol)



(a) Longitudinal Direction



(b) Transverse Direction

Figure 3.10 Specimen 2P: Brace Deformation Time Histories (All Cycles)

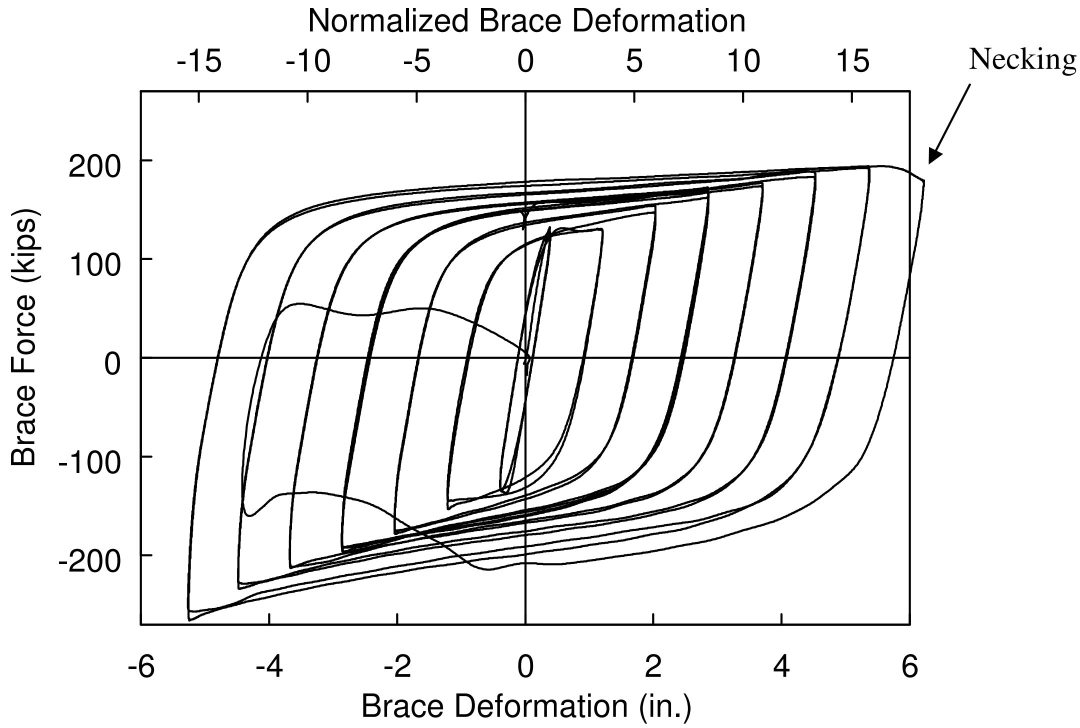


Figure 3.11 Specimen 2P: Brace Force vs. Axial Deformation (All Cycles)

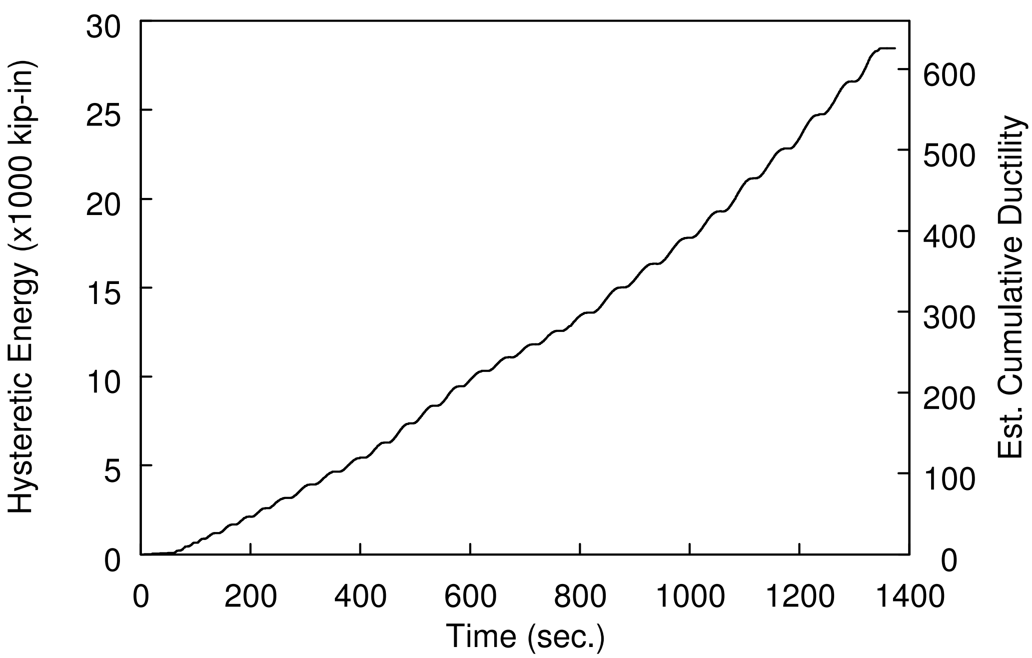


Figure 3.12 Specimen 2P: Hysteretic Energy Time History (All Cycles)

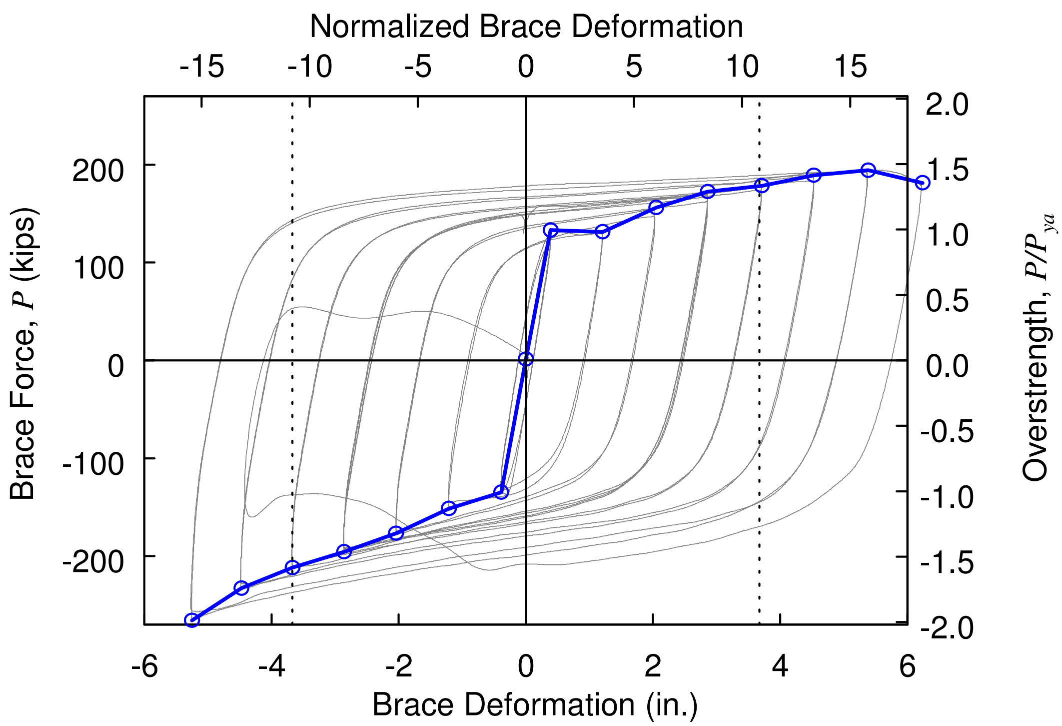


Figure 3.13 Specimen 2P: Brace Response Envelope

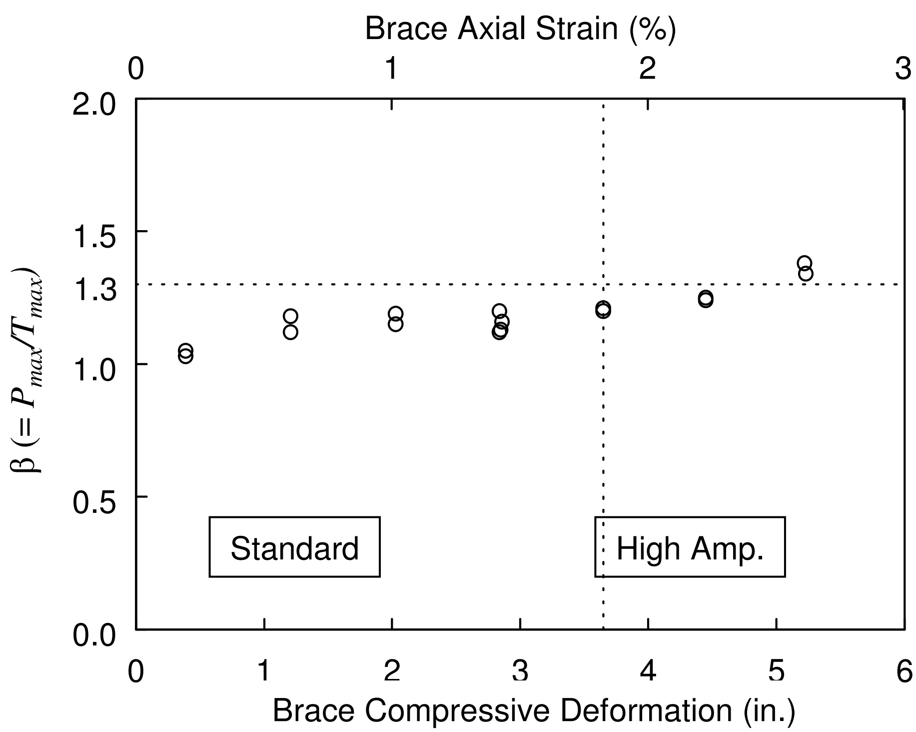
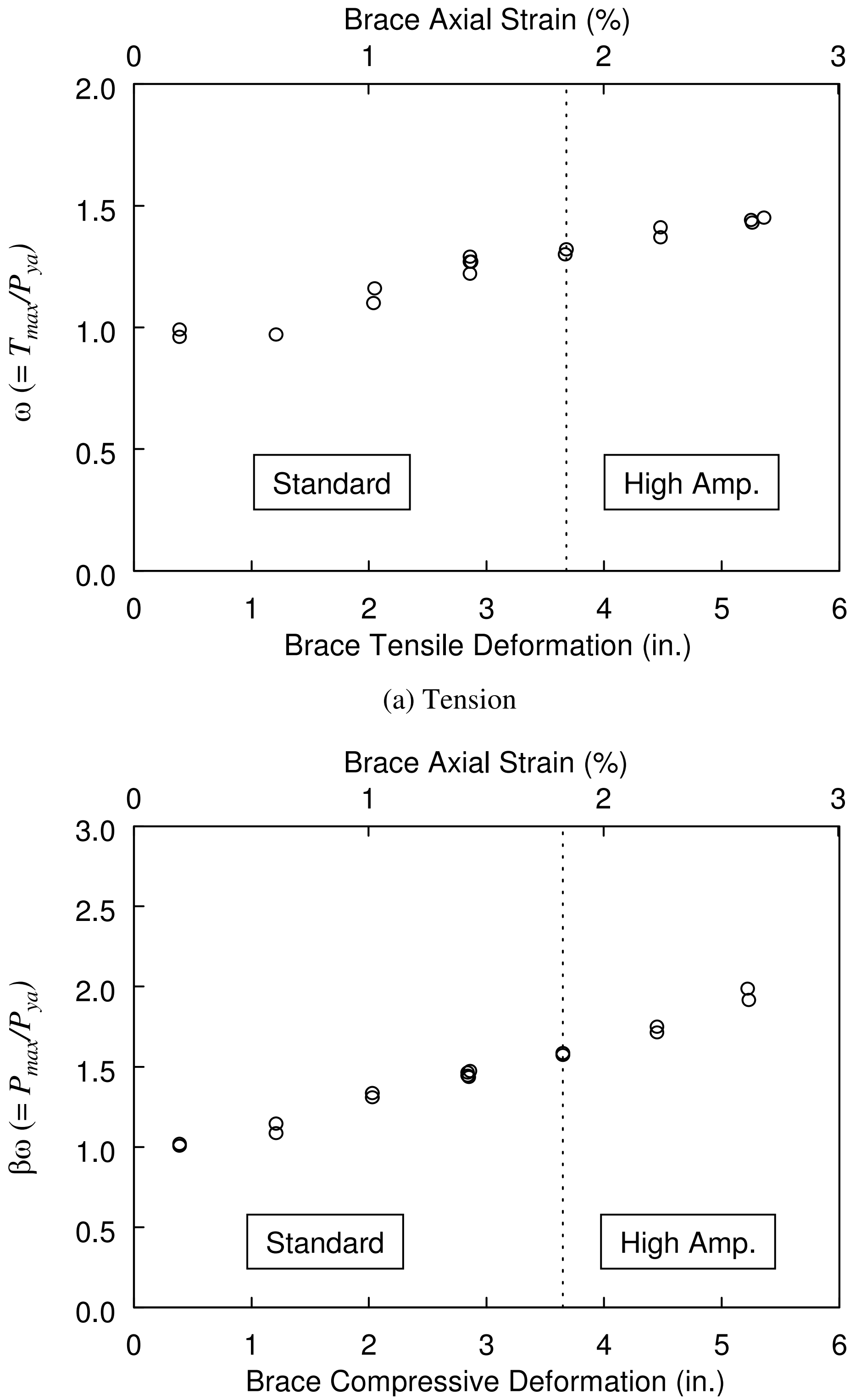


Figure 3.14 Specimen 2P: β vs. Axial Deformation Level



(a) Tension

(b) Compression

Figure 3.15 Specimen 2P: ω and βω vs. Axial Deformation Level

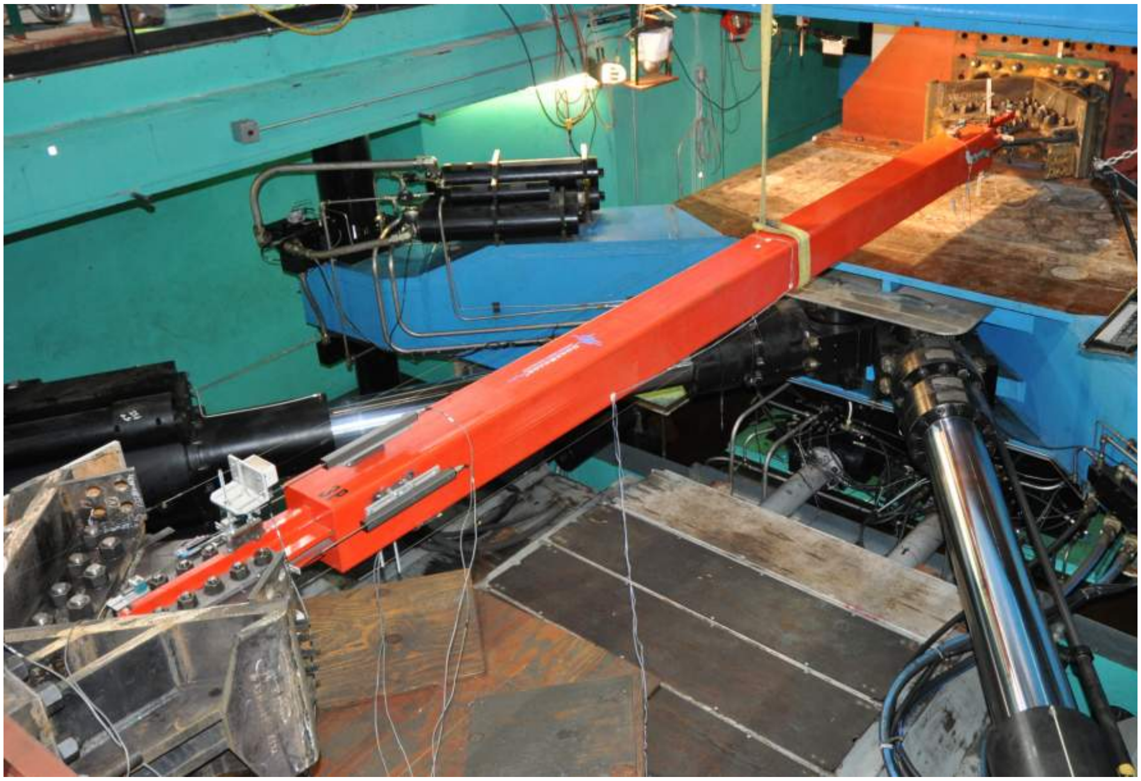


Figure 3.16 Specimen 3P: Test Setup

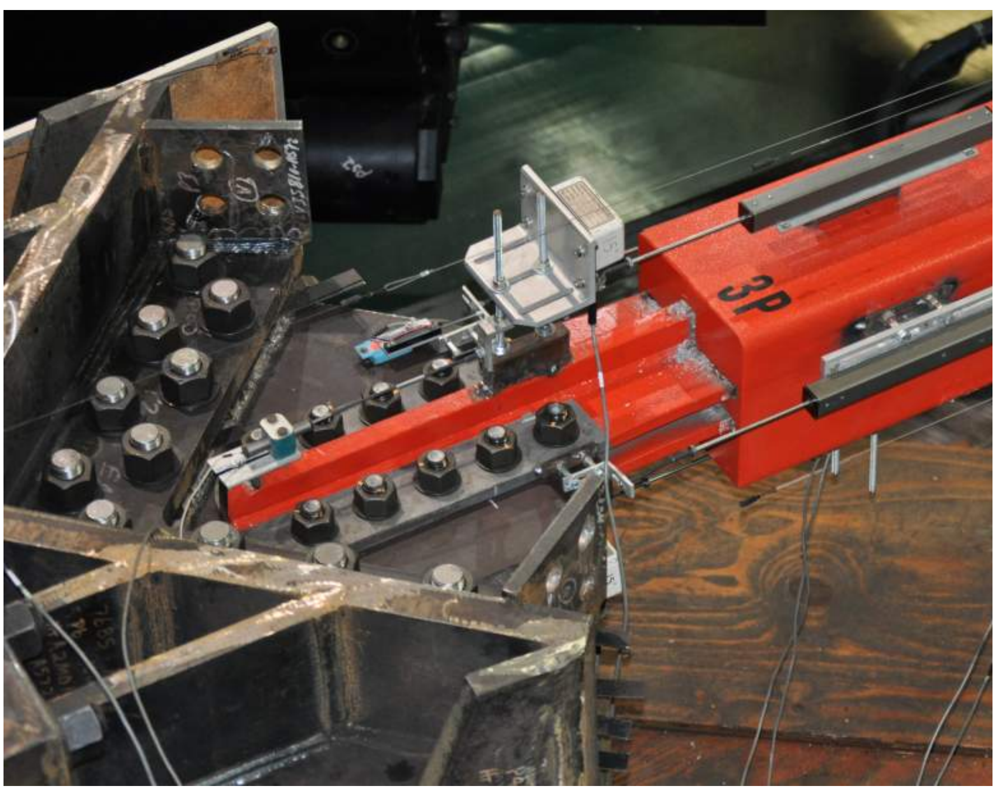
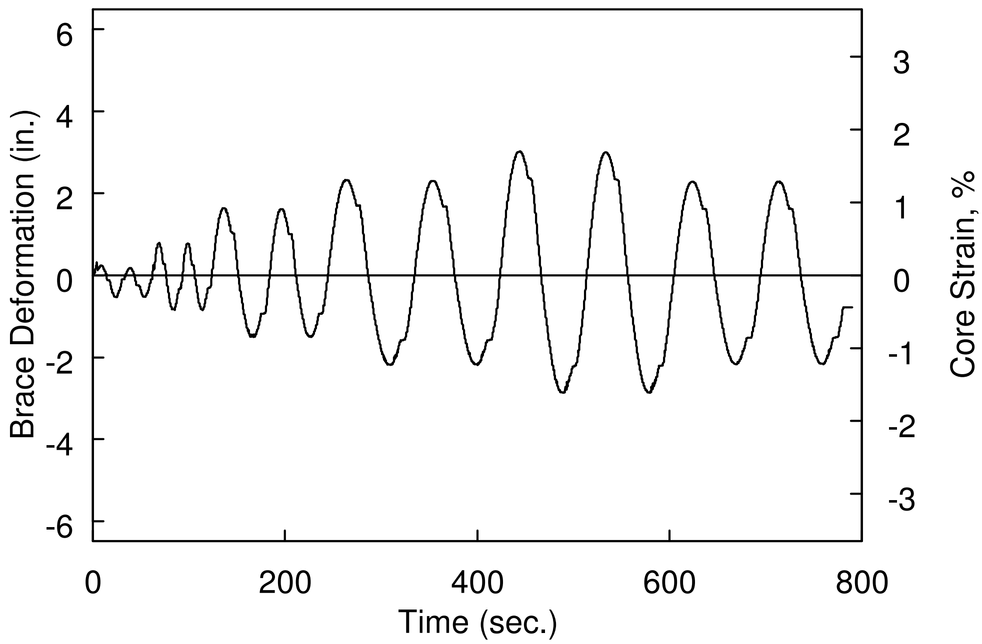
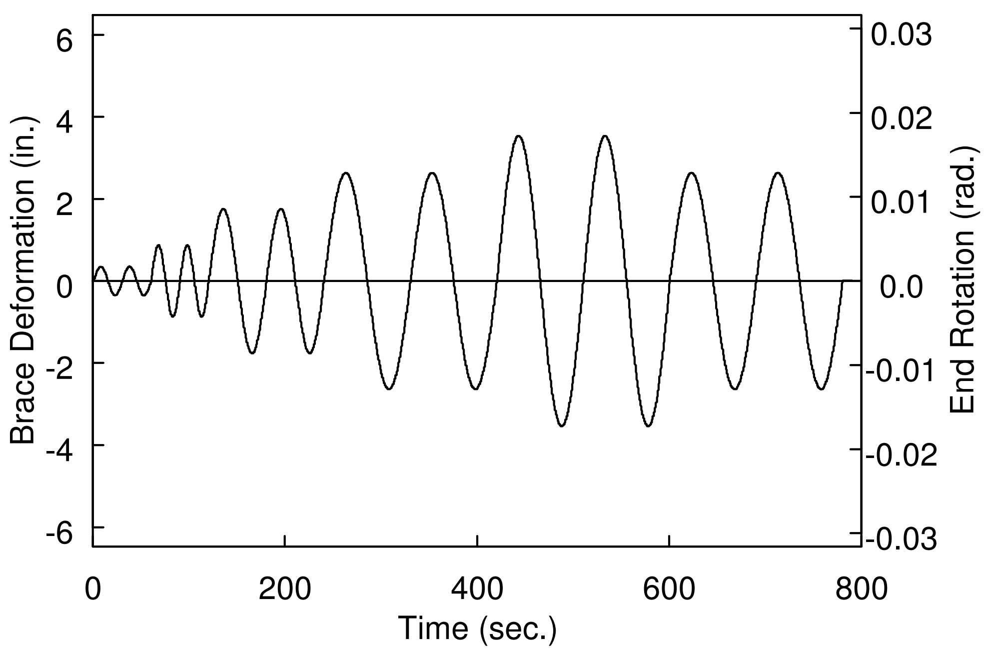


Figure 3.17 Specimen 3P End Connection During Testing



(a) Longitudinal Direction



(b) Transverse Direction

Figure 3.18 Specimen 3P: Brace Deformation Time Histories (Standard Protocol)

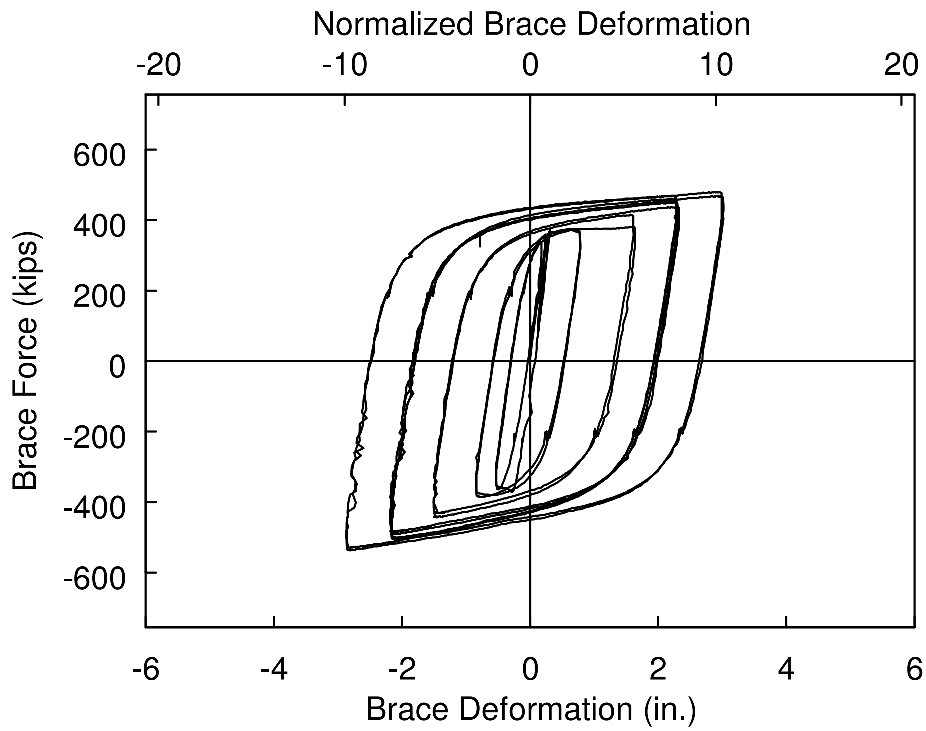


Figure 3.19 Specimen 3P: Brace Force vs. Axial Deformation (Standard Protocol)

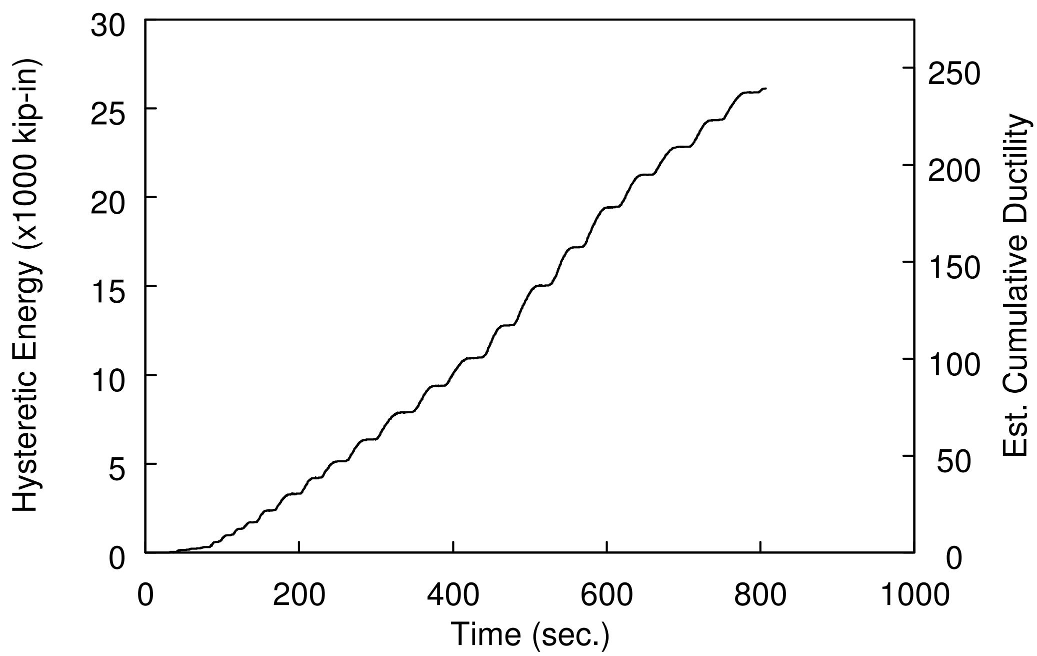
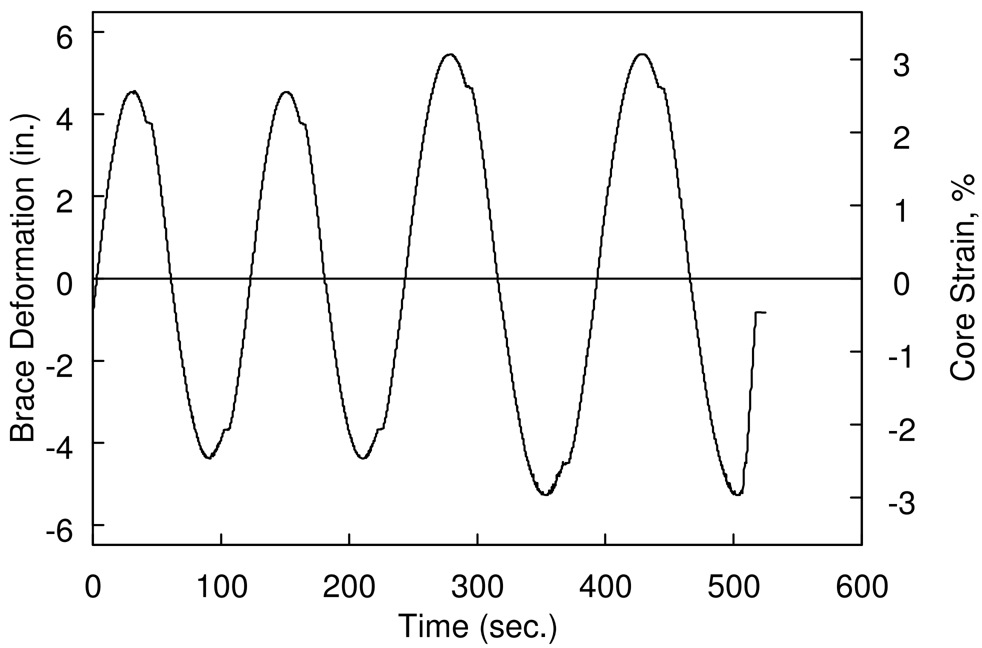
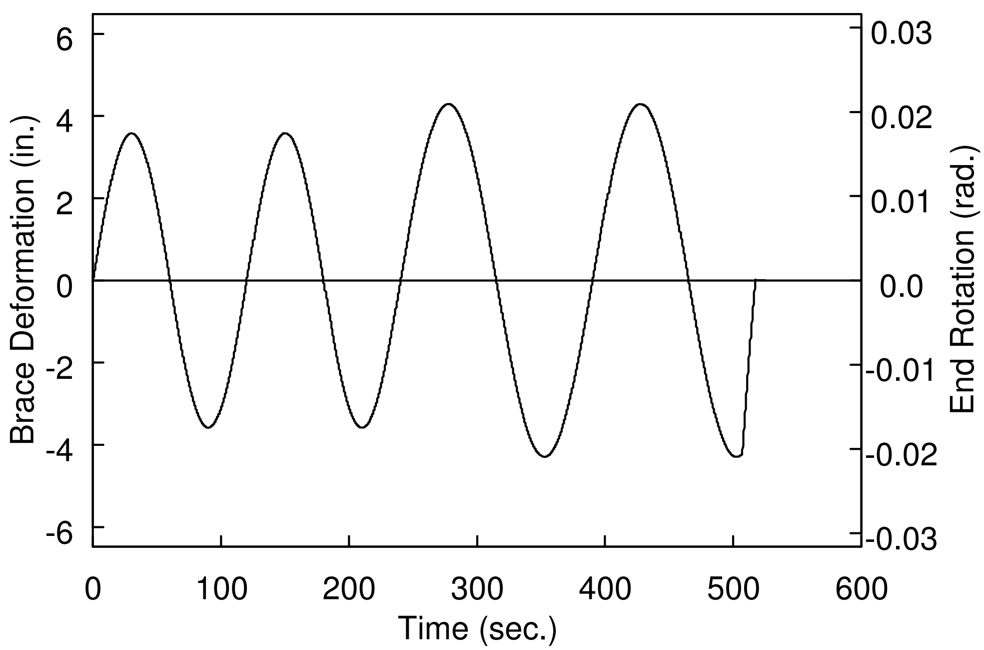


Figure 3.20 Specimen 3P: Hysteretic Energy Time History (Standard Protocol)



(a) Longitudinal Direction



(b) Transverse Direction

Figure 3.21 Specimen 3P: Brace Deformation Time Histories (High-Amplitude Protocol)

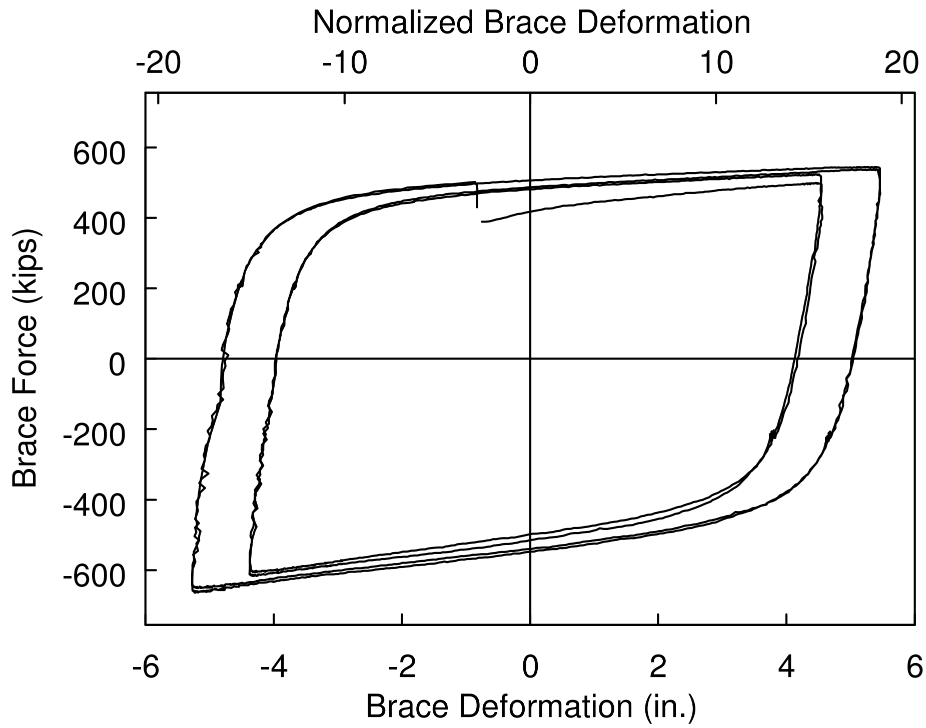


Figure 3.22 Specimen 3P: Brace Force vs. Axial Deformation (High-Amplitude Protocol)

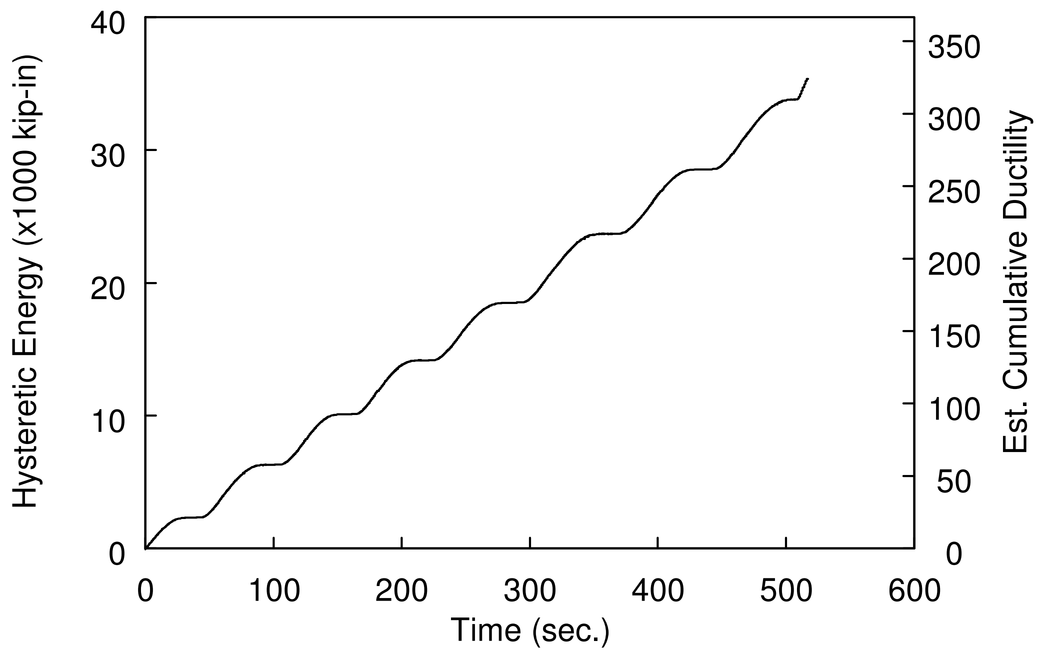
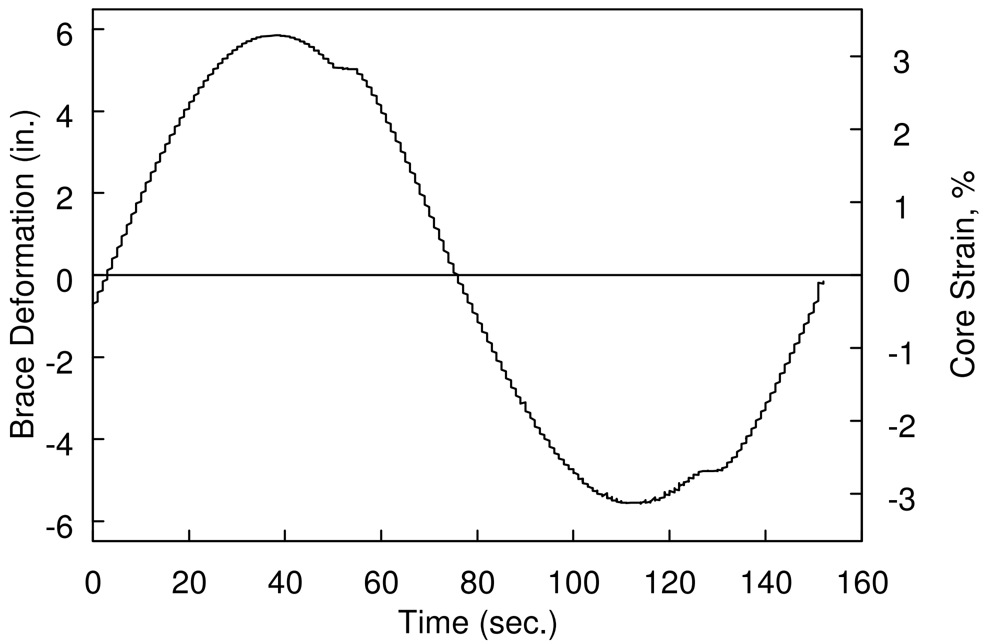
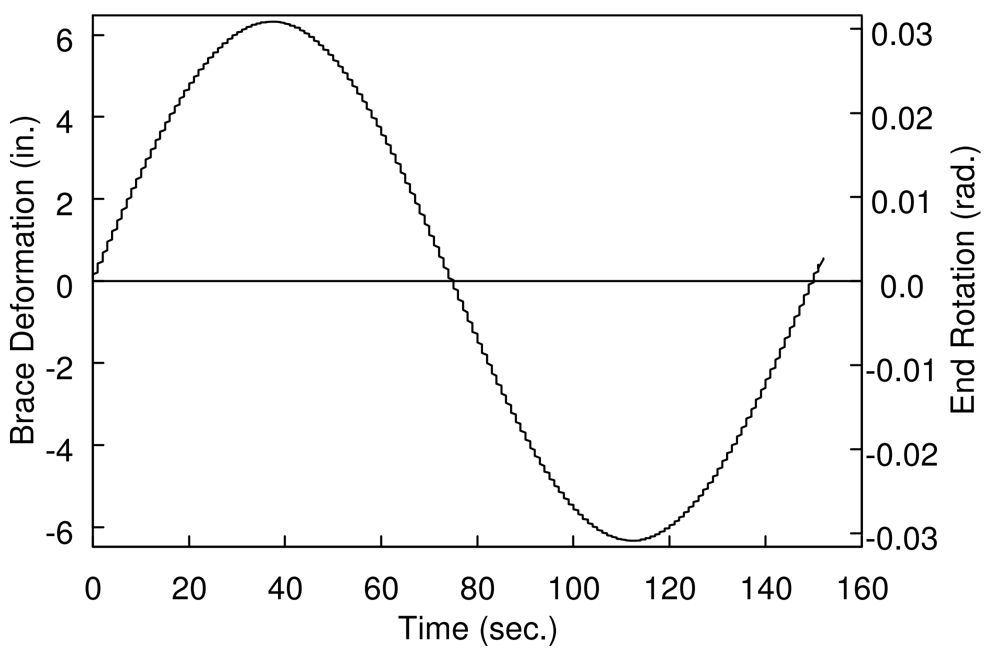


Figure 3.23 Specimen 3P: Hysteretic Energy Time History (High-Amplitude Protocol)



(a) Longitudinal Direction



(b) Transverse Direction

Figure 3.24 Specimen 3P: Brace Deformation Time Histories (Fracture Protocol)

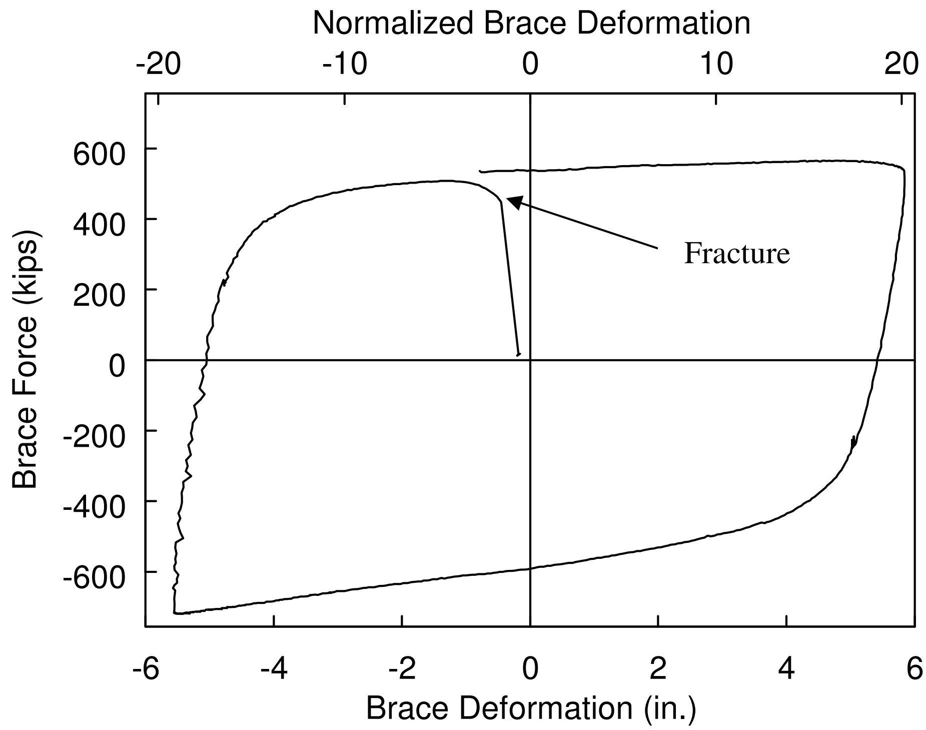


Figure 3.25 Specimen 3P: Brace Force vs. Axial Deformation (Fracture Protocol)

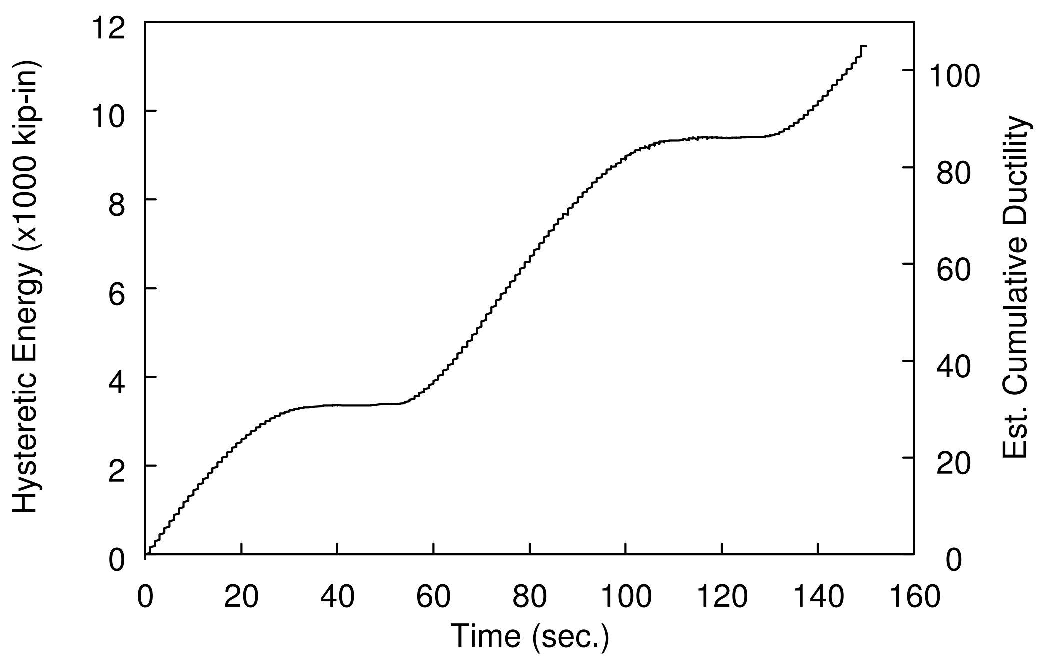
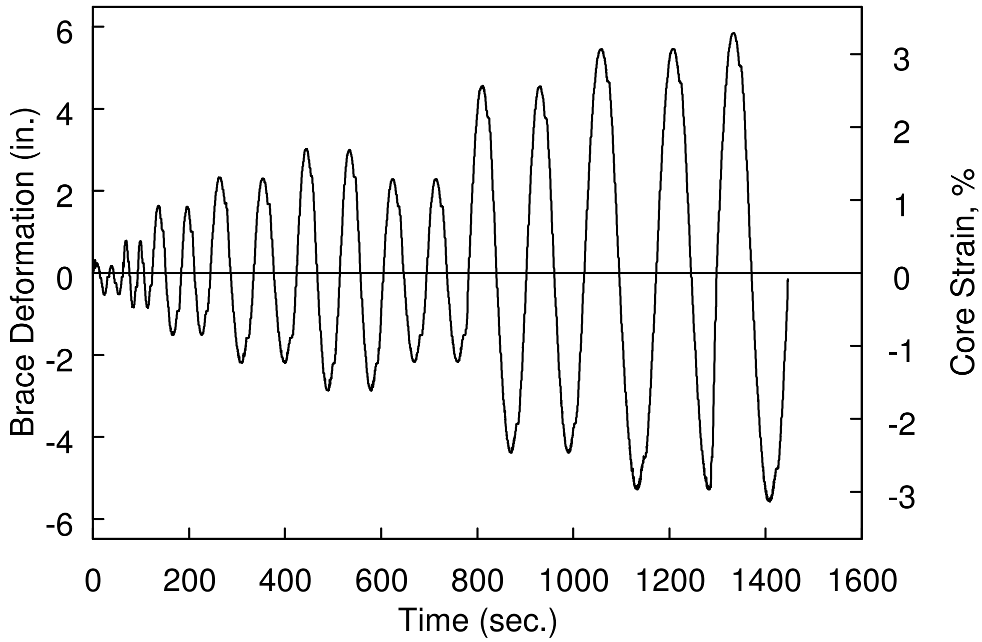
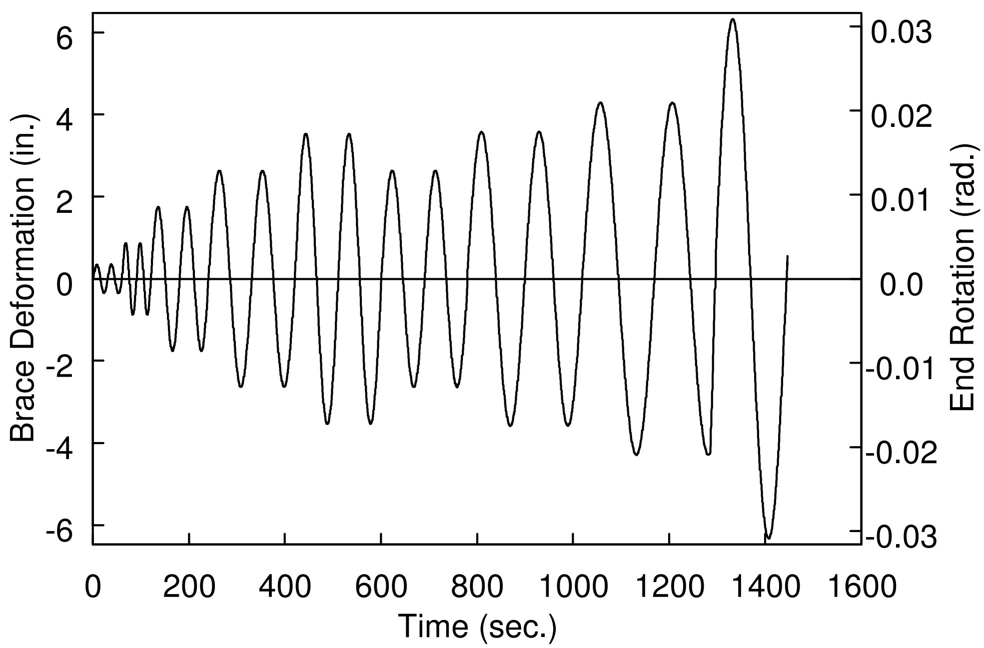


Figure 3.26 Specimen 3P: Hysteretic Energy Time History (Fracture Protocol)



(a) Longitudinal Direction



(b) Transverse Direction

Figure 3.27 Specimen 3P: Brace Deformation Time Histories (All Cycles)

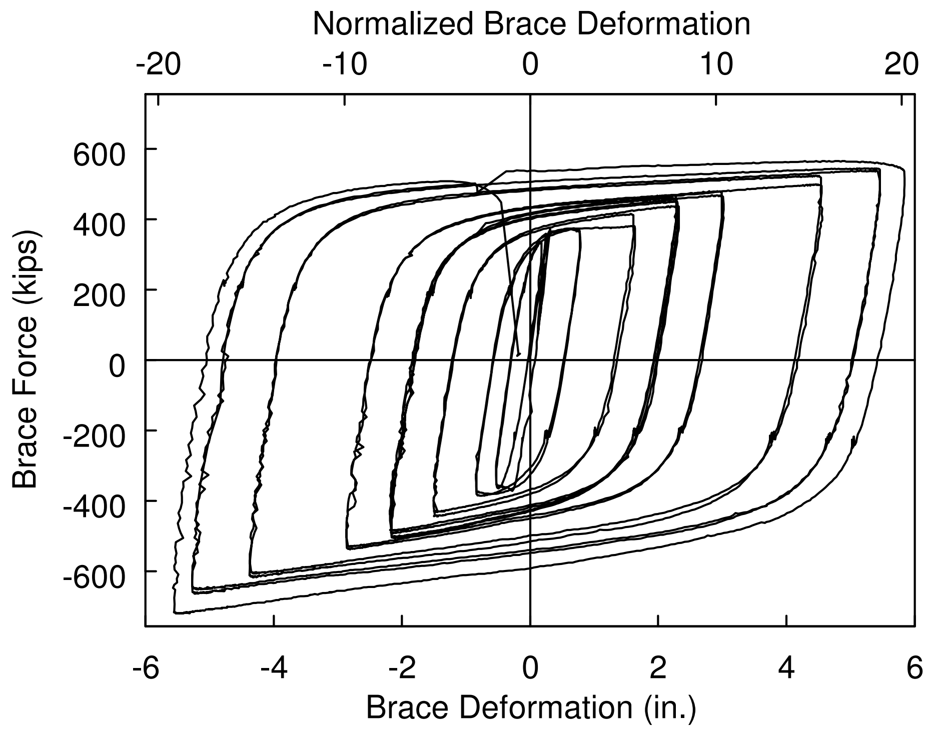


Figure 3.28 Specimen 3P: Brace Force vs. Axial Deformation (All Cycles)

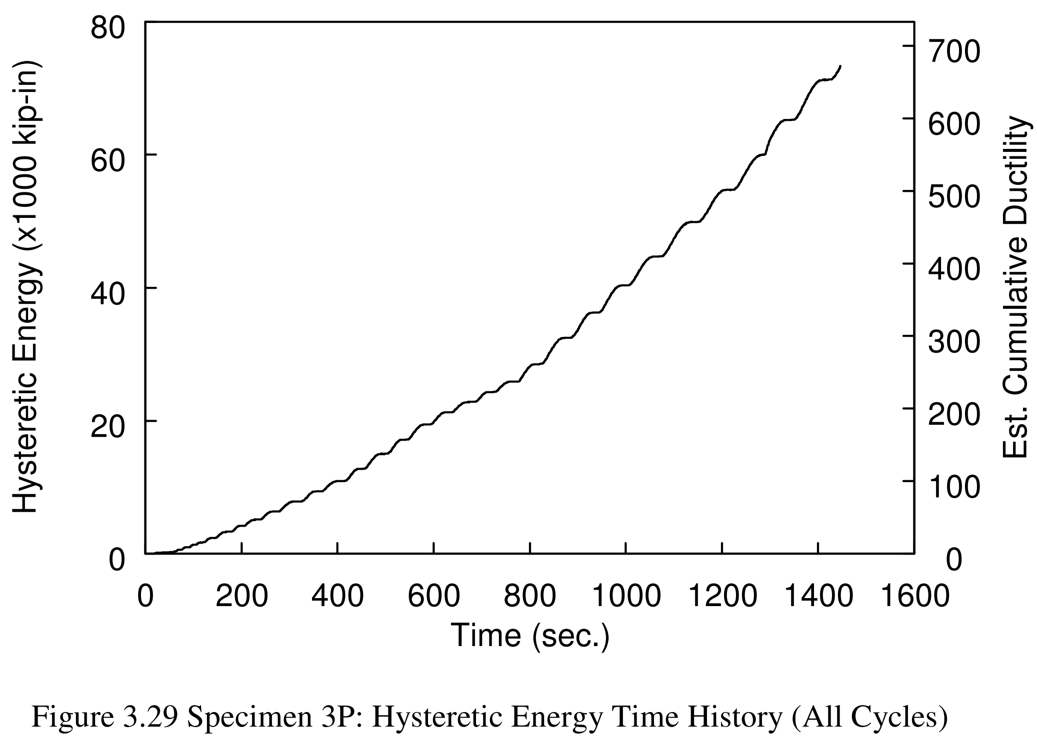


Figure 3.29 Specimen 3P: Hysteretic Energy Time History (All Cycles)

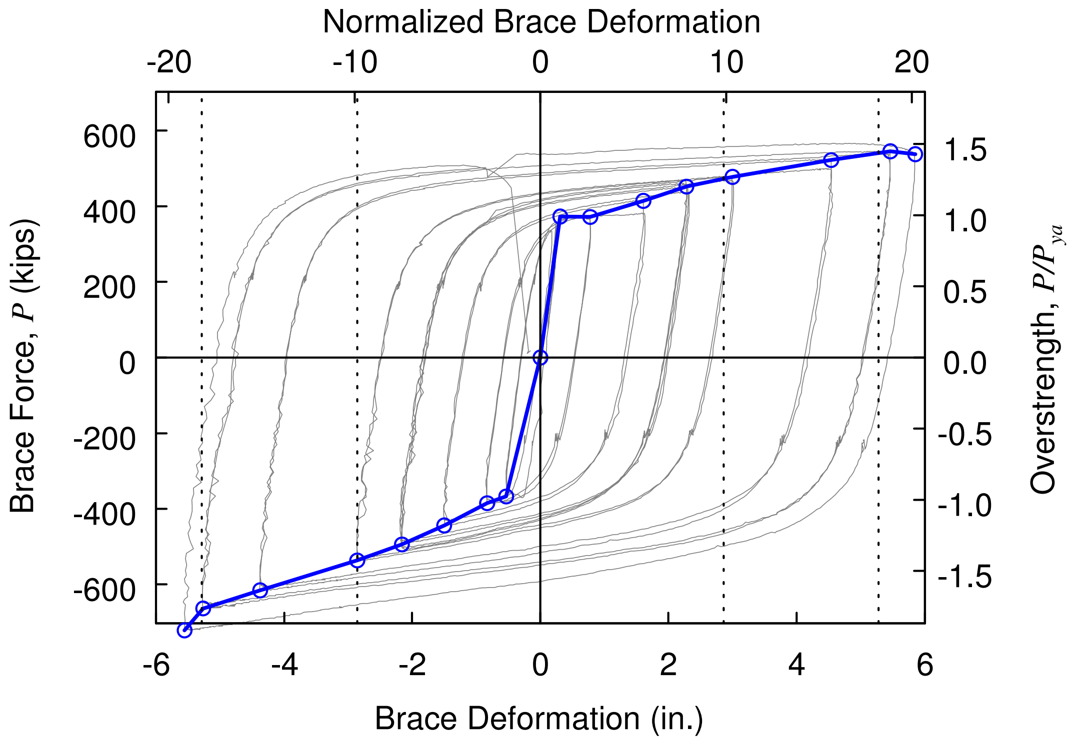


Figure 3.30 Specimen 3P: Brace Response Envelope

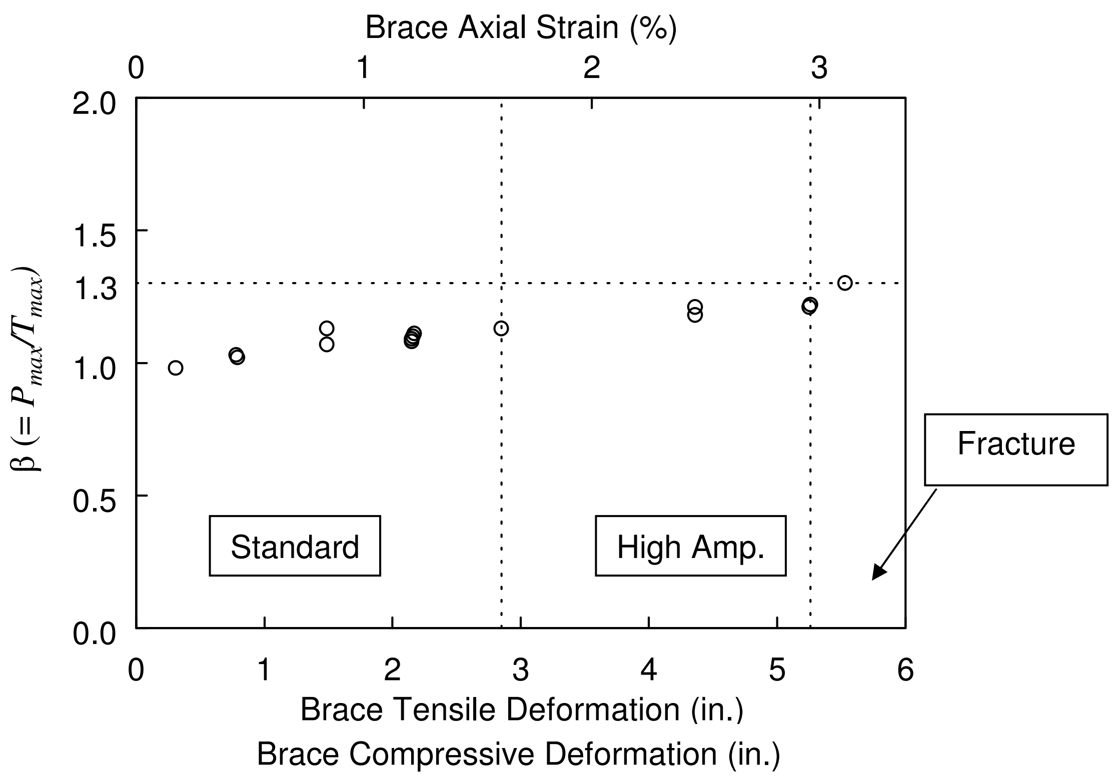
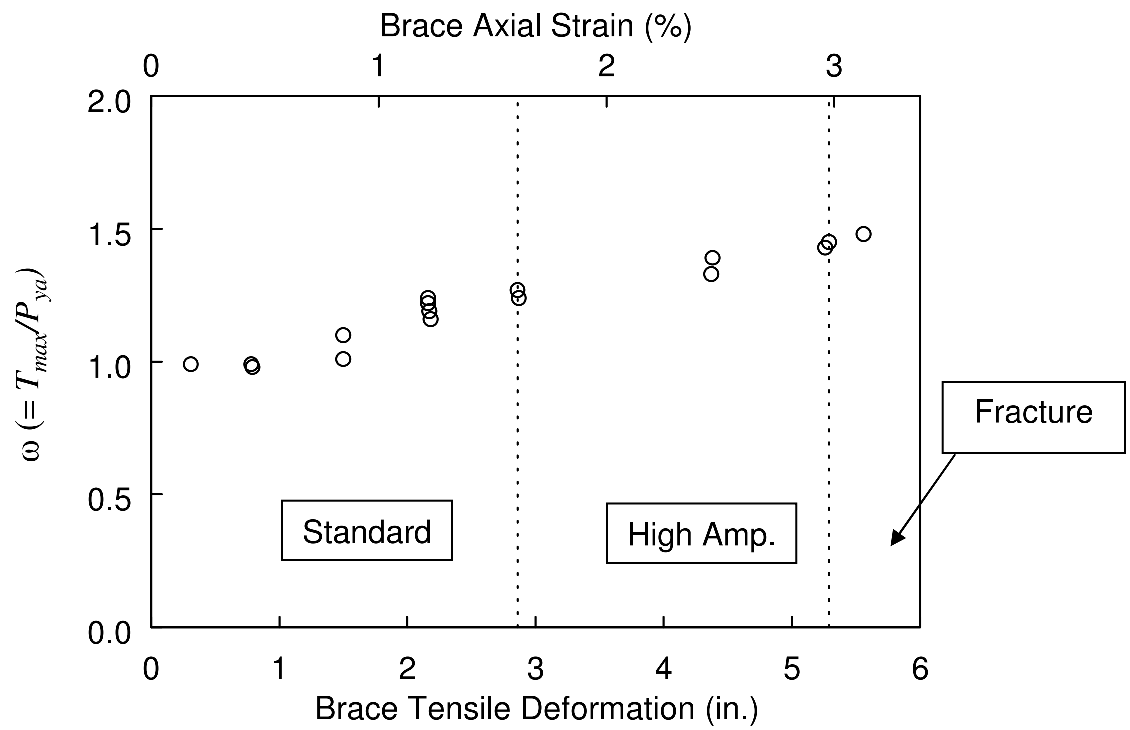
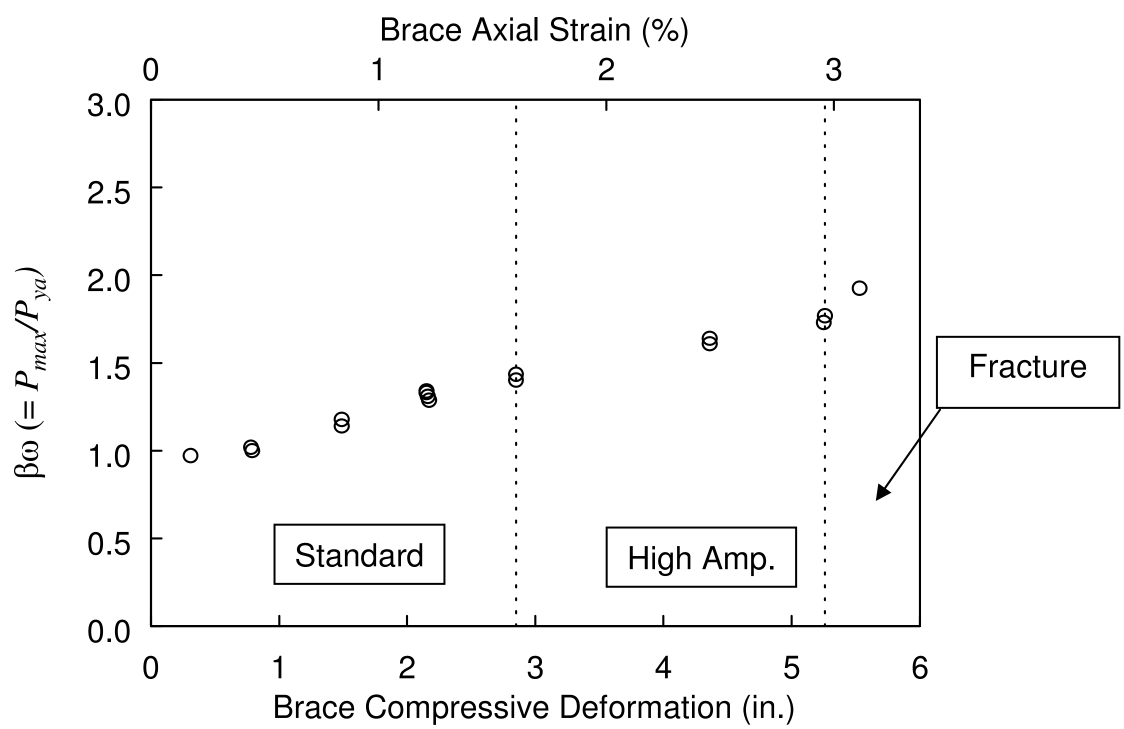


Figure 3.31 Specimen 3P: β vs. Axial Deformation Level



(a) Tension



(b) Compression

Figure 3.32 Specimen 3P: ω and βω vs. Axial Deformation Level

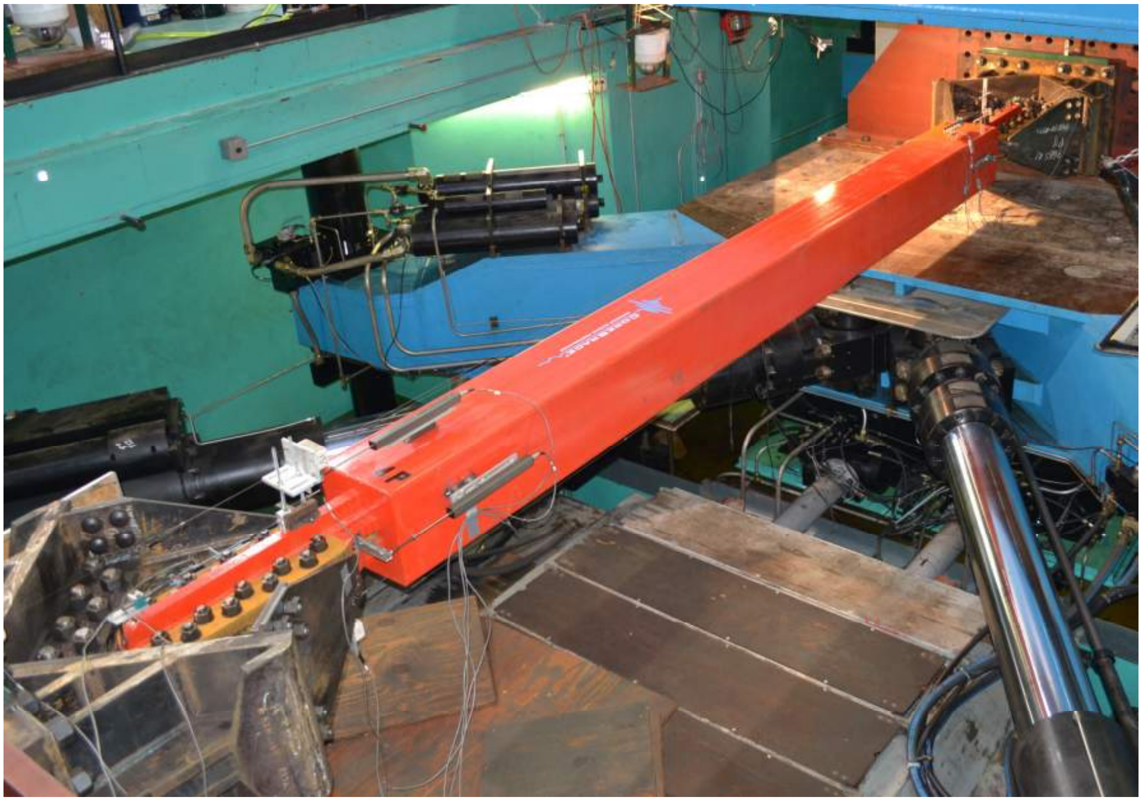


Figure 3.33 Specimen 4P: Test Setup

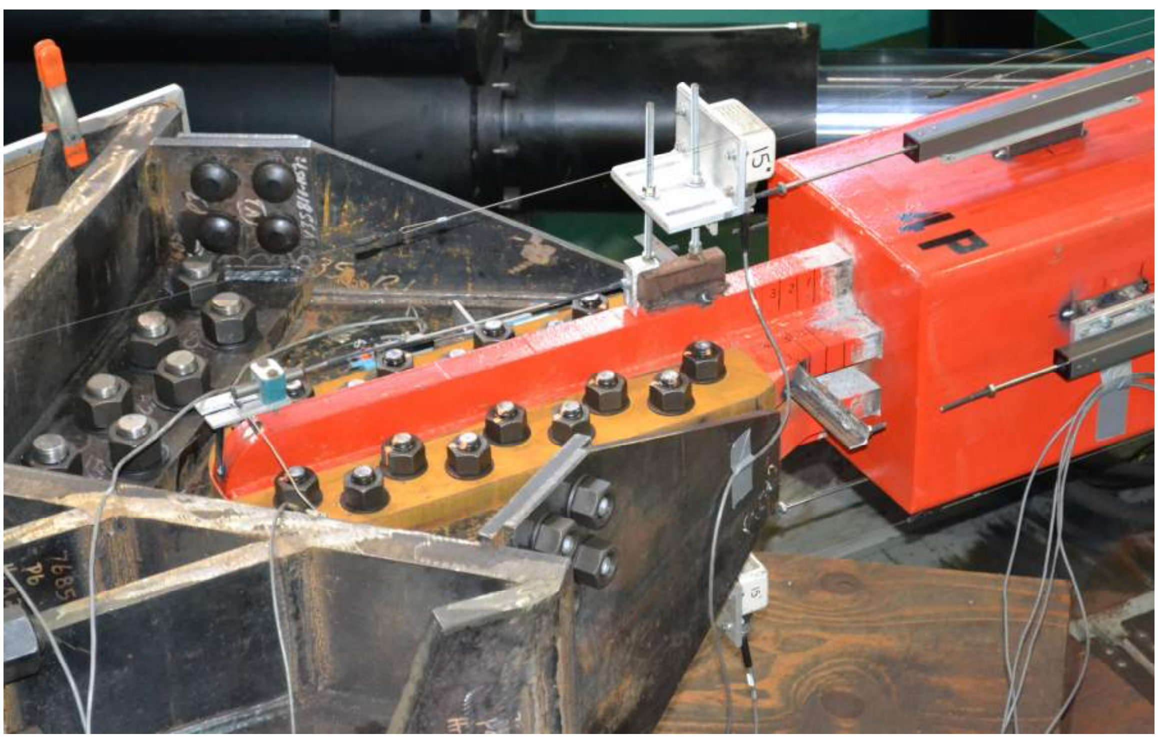
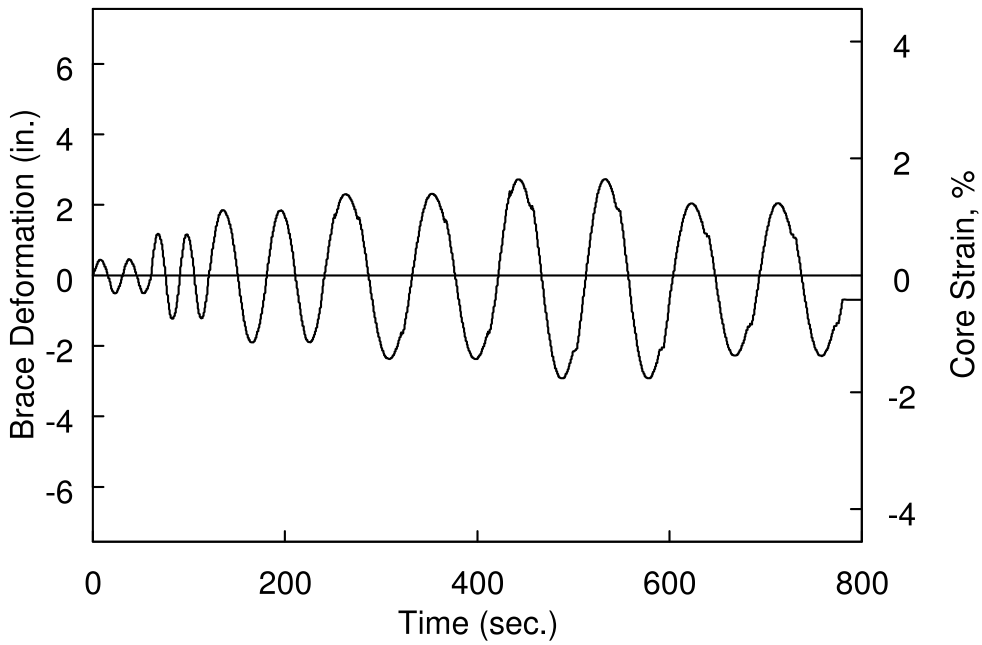
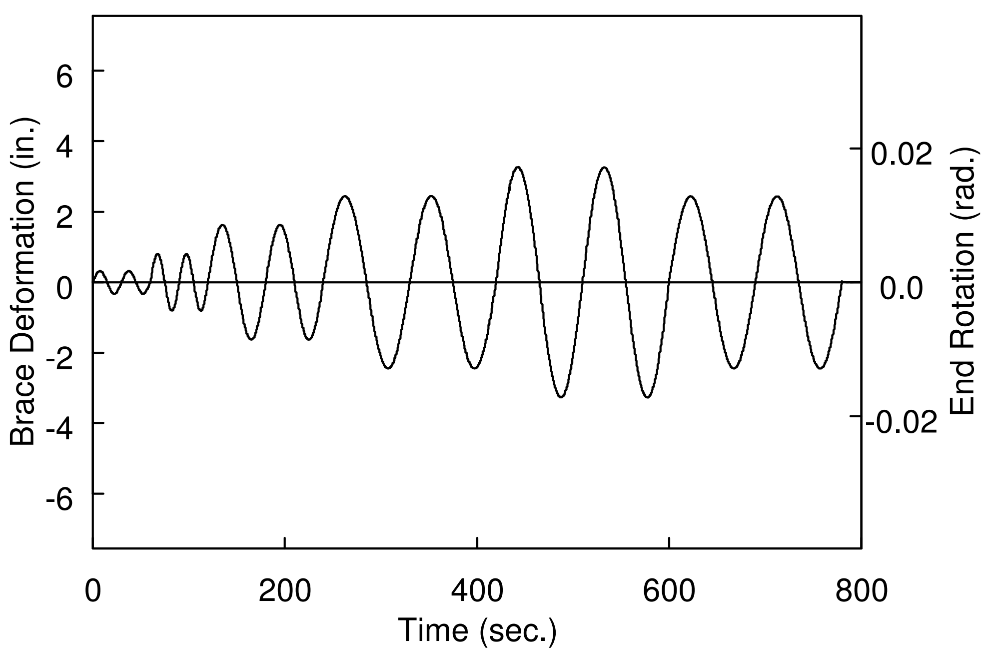


Figure 3.34 Specimen 4P End Connection During Testing



(a) Longitudinal Direction



(b) Transverse Direction

Figure 3.35 Specimen 4P: Brace Deformation Time Histories (Standard Protocol)

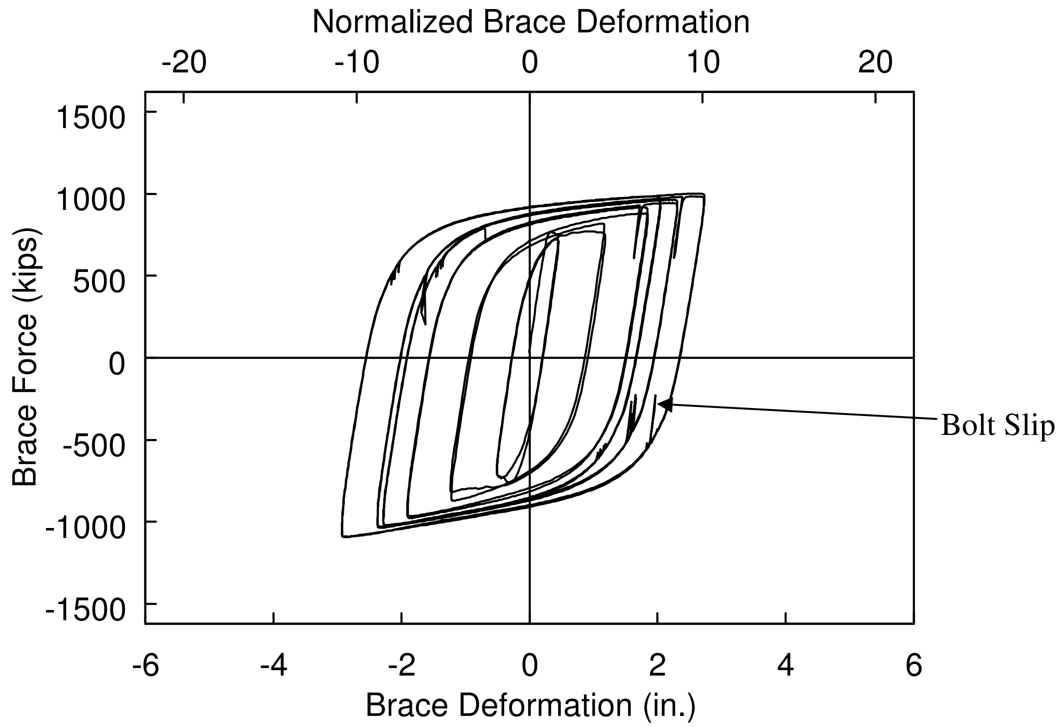


Figure 3.36 Specimen 4P: Brace Force vs. Axial Deformation (Standard Protocol)

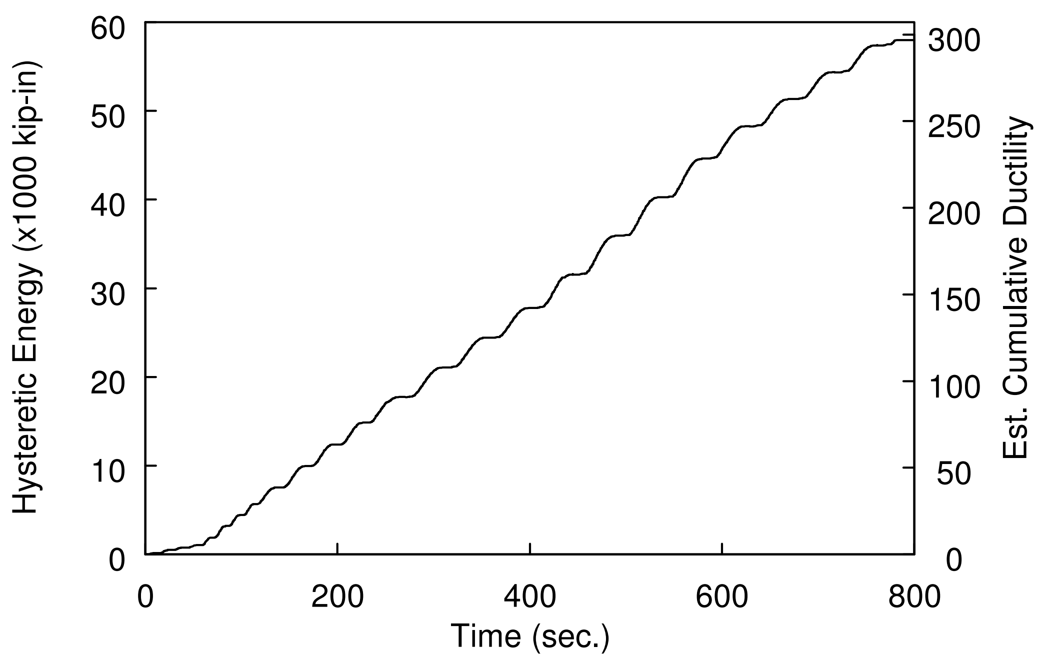
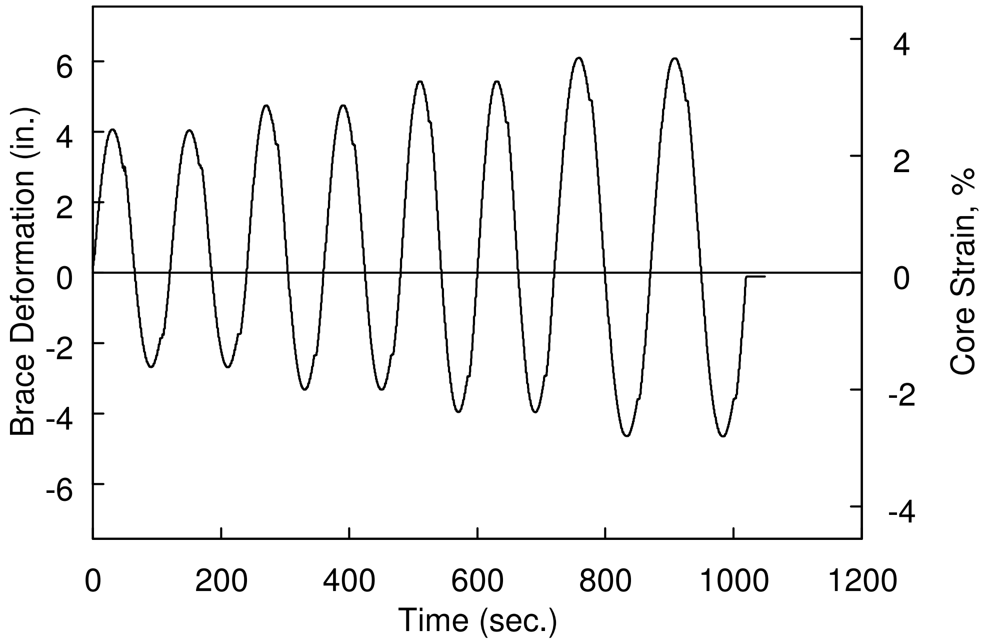
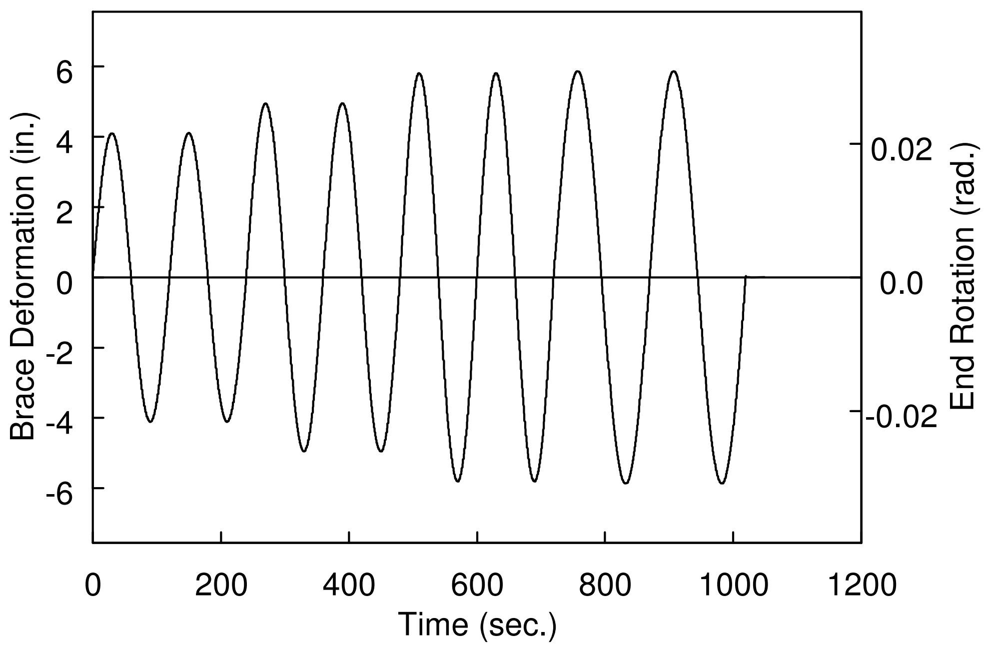


Figure 3.37 Specimen 4P: Hysteretic Energy Time History (Standard Protocol)



(a) Longitudinal Direction



(b) Transverse Direction

Figure 3.38 Specimen 4P: Brace Deformation Time Histories (High-Amplitude Protocol)

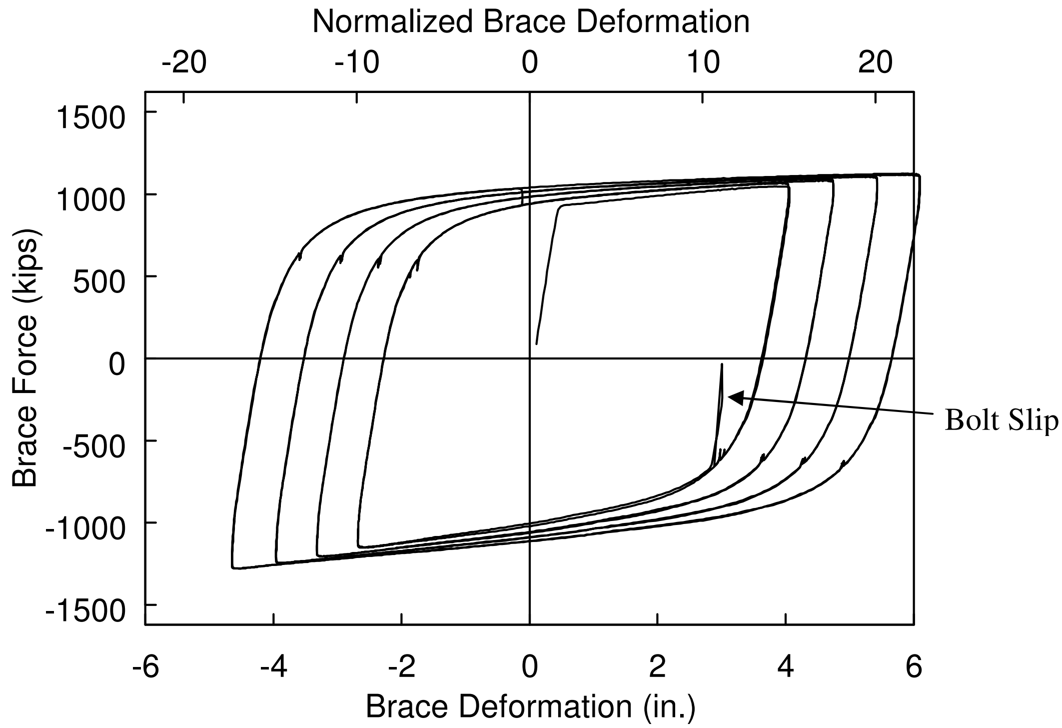


Figure 3.39 Specimen 4P: Brace Force vs. Axial Deformation (High-Amplitude Protocol)

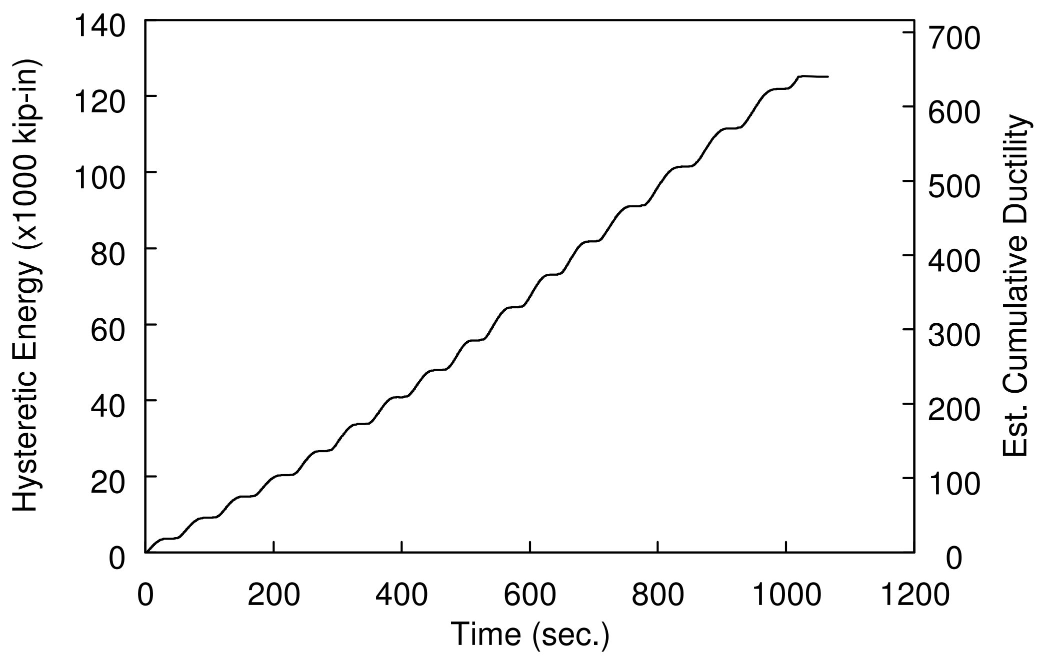
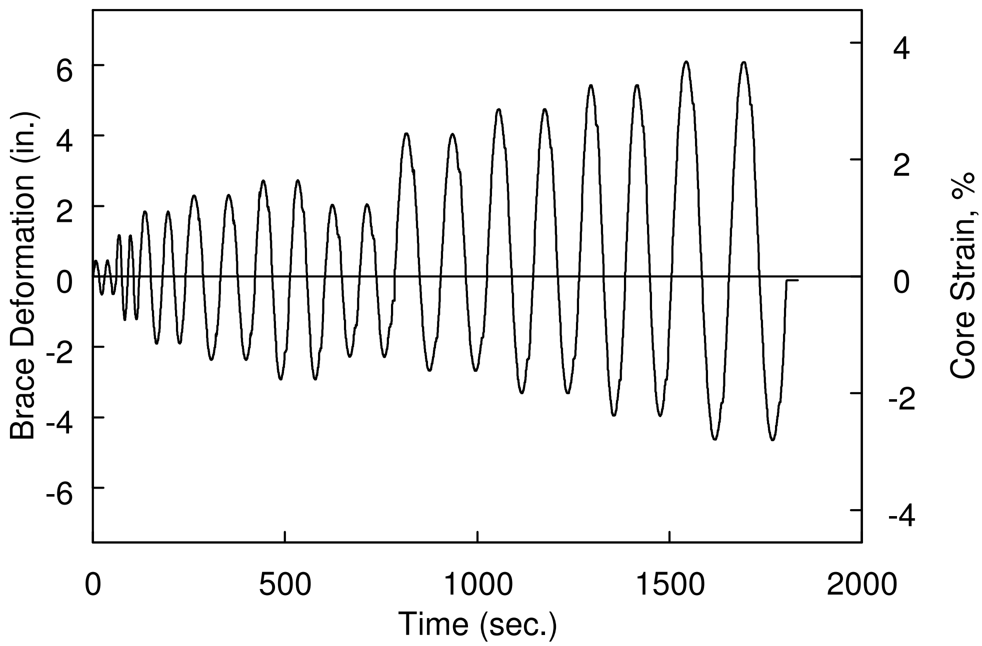
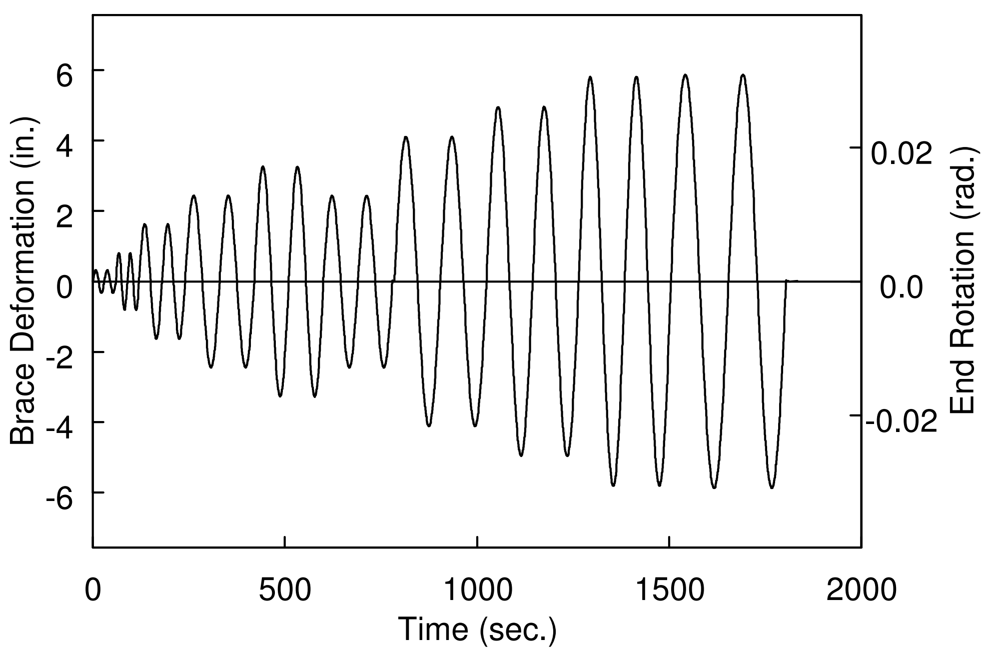


Figure 3.40 Specimen 4P: Hysteretic Energy Time History (High-Amplitude Protocol)



(a) Longitudinal Direction



(b) Transverse Direction

Figure 3.41 Specimen 4P: Brace Deformation Time Histories (All Cycles)

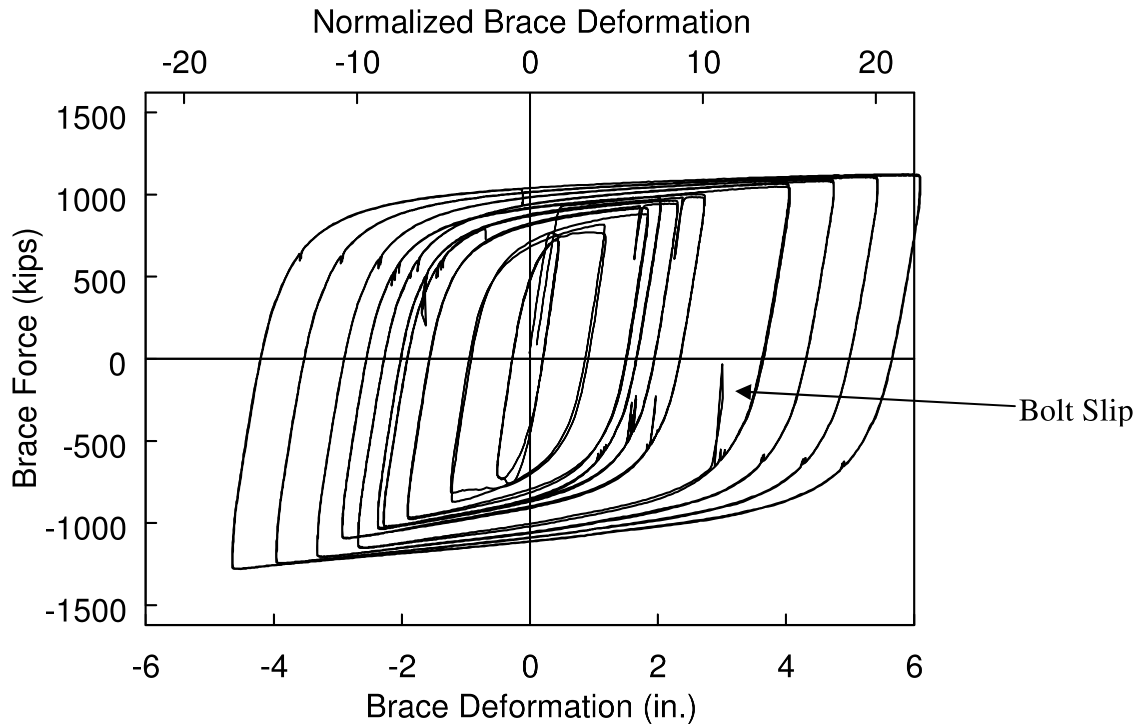


Figure 3.42 Specimen 4P: Brace Force vs. Axial Deformation (All Cycles)

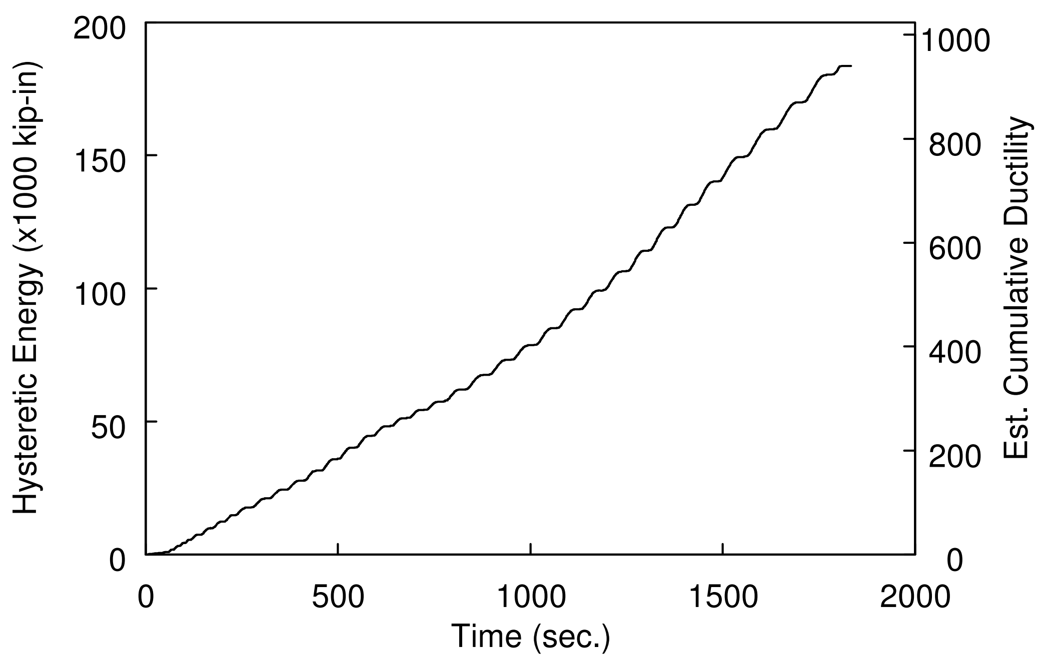


Figure 3.43 Specimen 4P: Hysteretic Energy Time History (All Cycles)

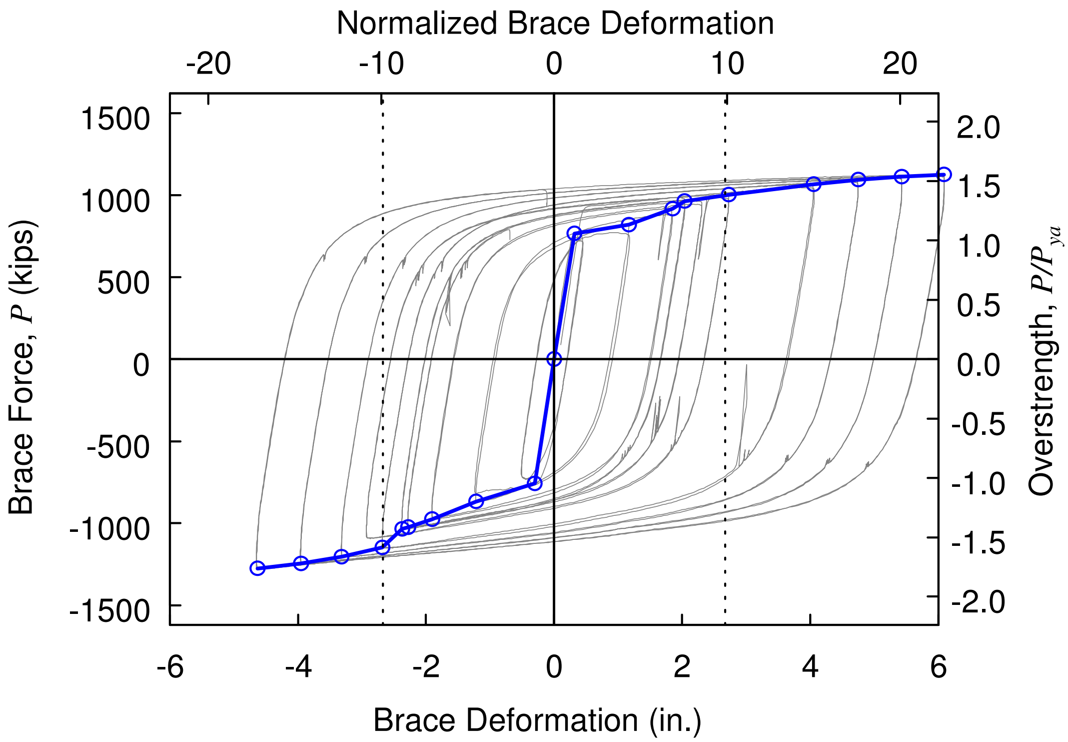


Figure 3.44 Specimen 4P: Brace Response Envelope

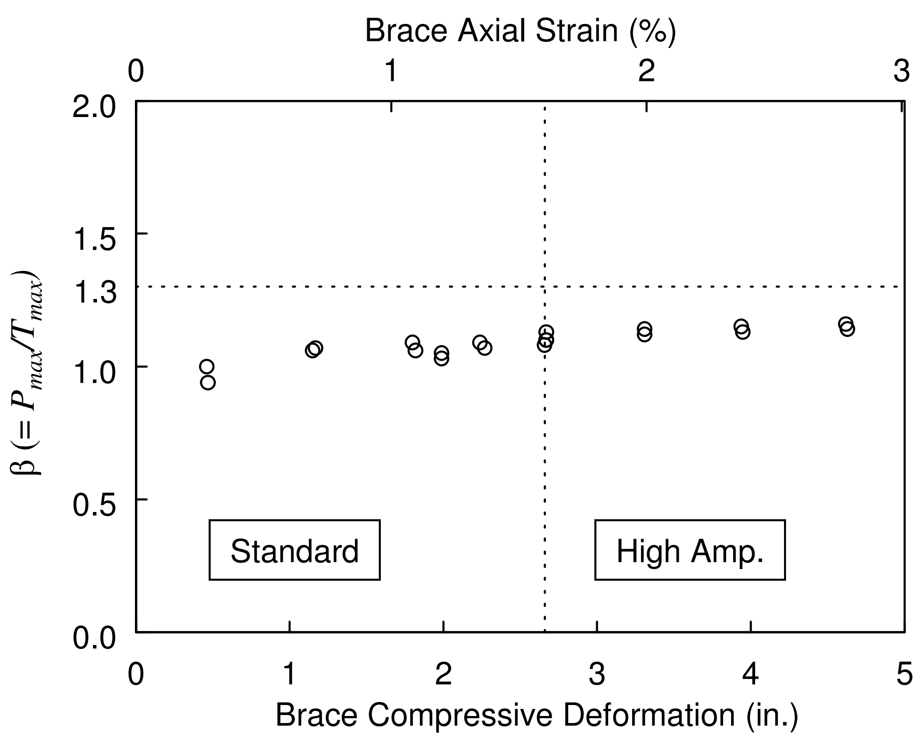
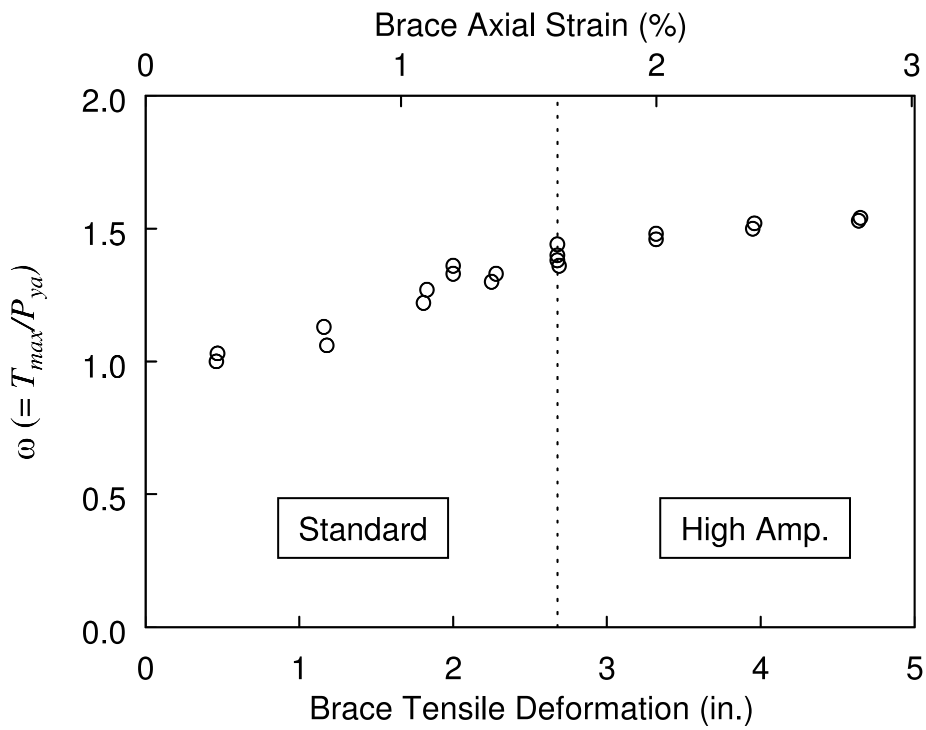
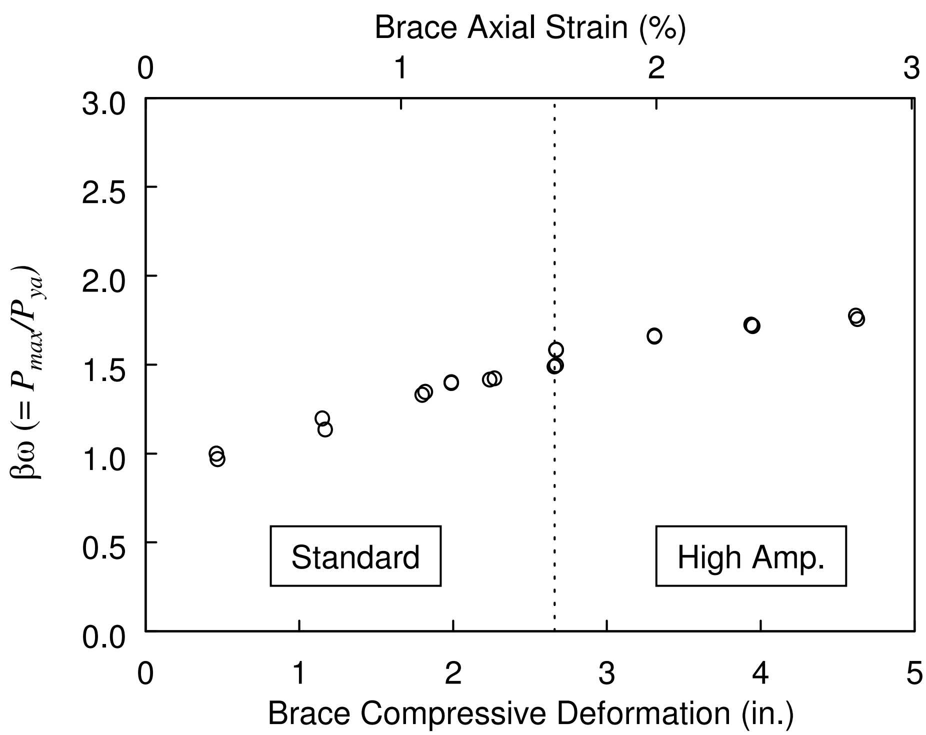


Figure 3.45 Specimen 4P: β vs. Axial Deformation Level



(a) Tension



(b) Compression

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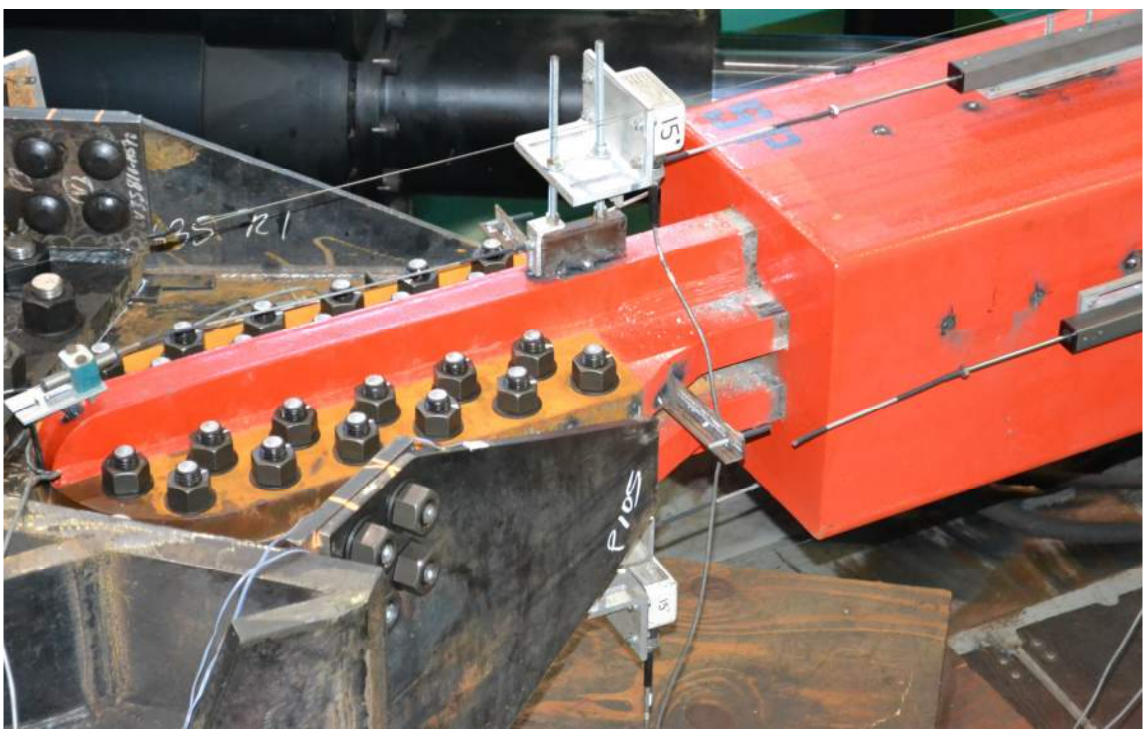
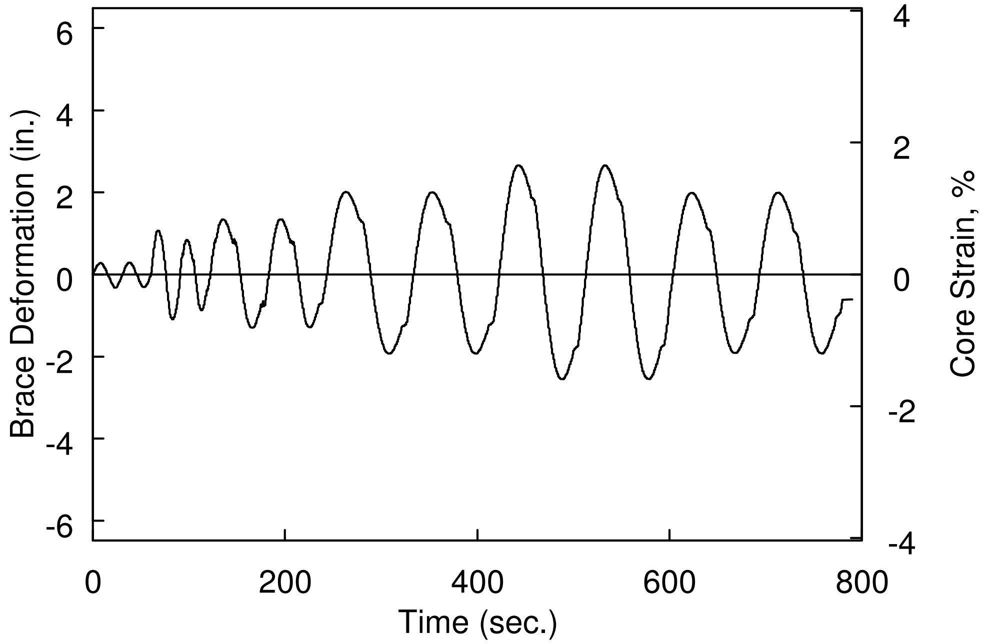


Figure 3.48 Specimen 5P End Connection During Testing



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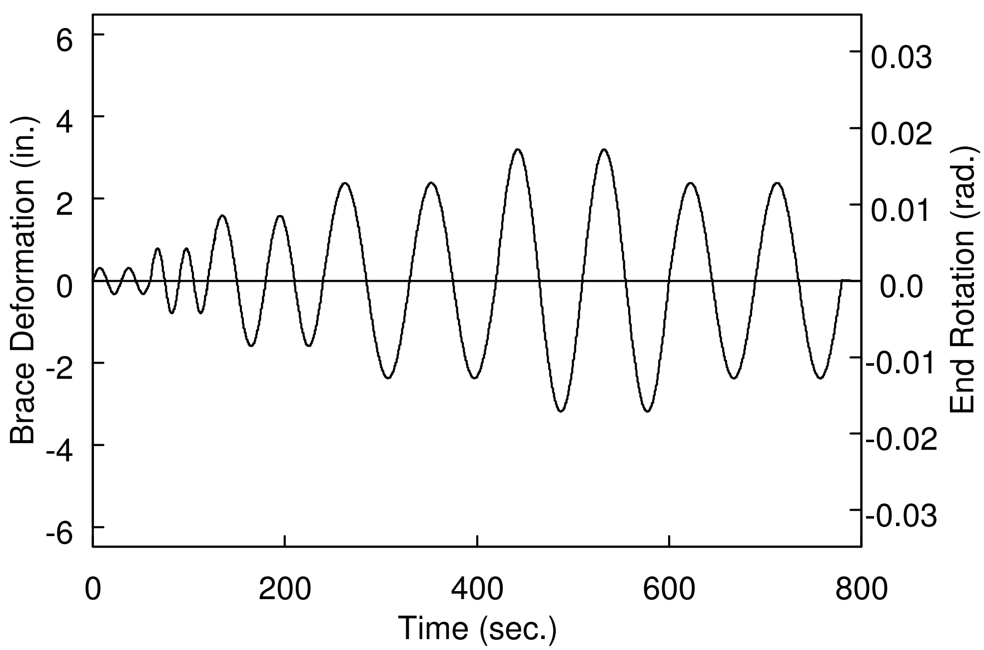


(b) Transverse Direction

Figure 3.49 Specimen 5P: Brace Deformation Time Histories (Standard Protocol)

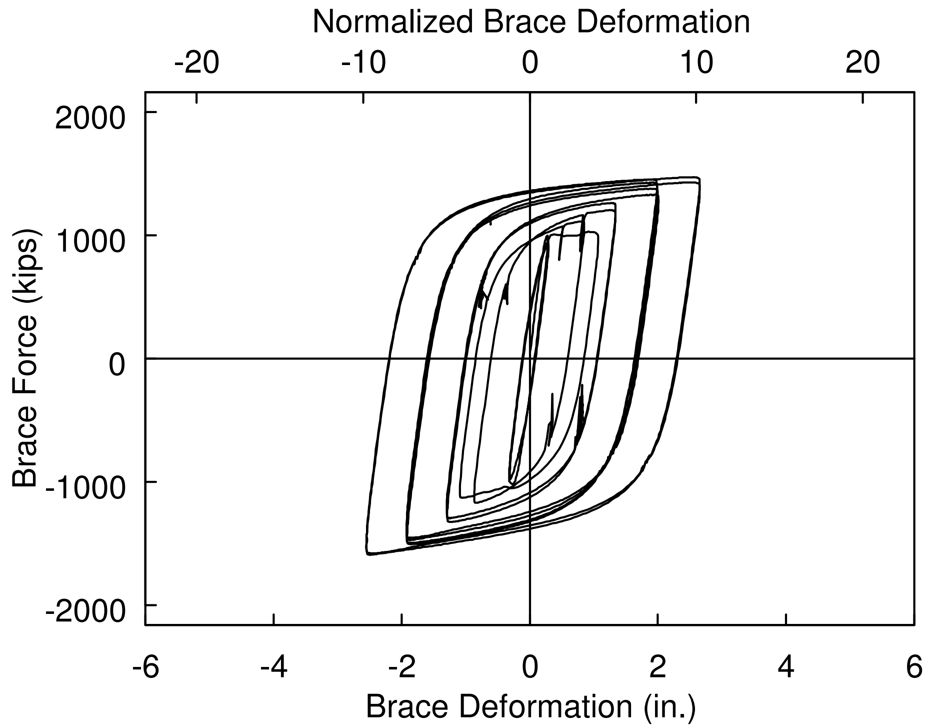


Figure 3.50 Specimen 5P: Brace Force vs. Axial Deformation (Standard Protocol)

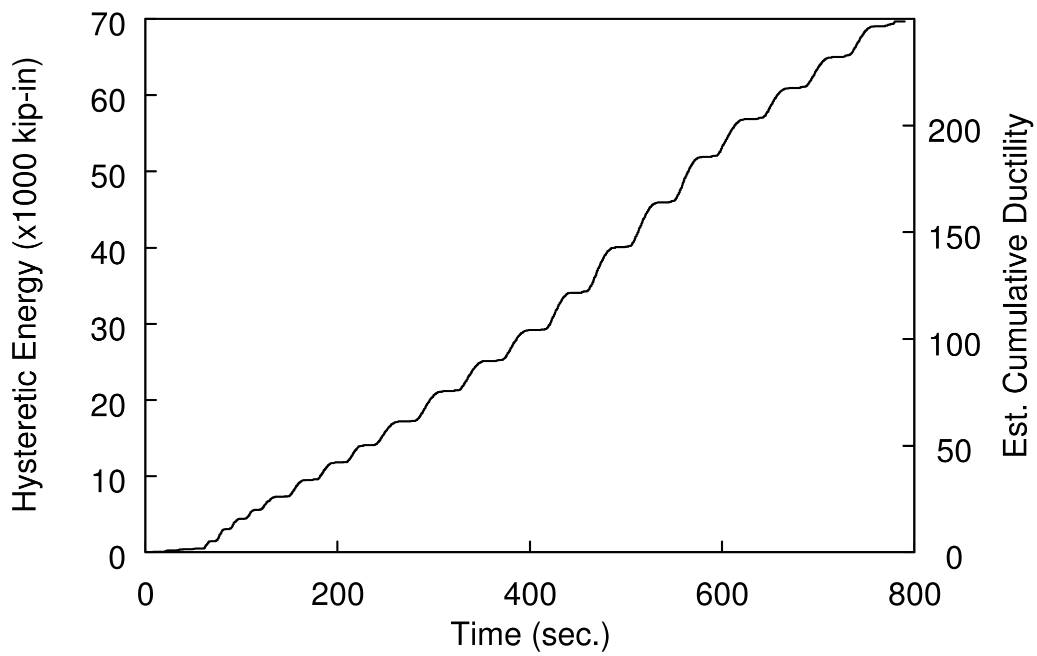
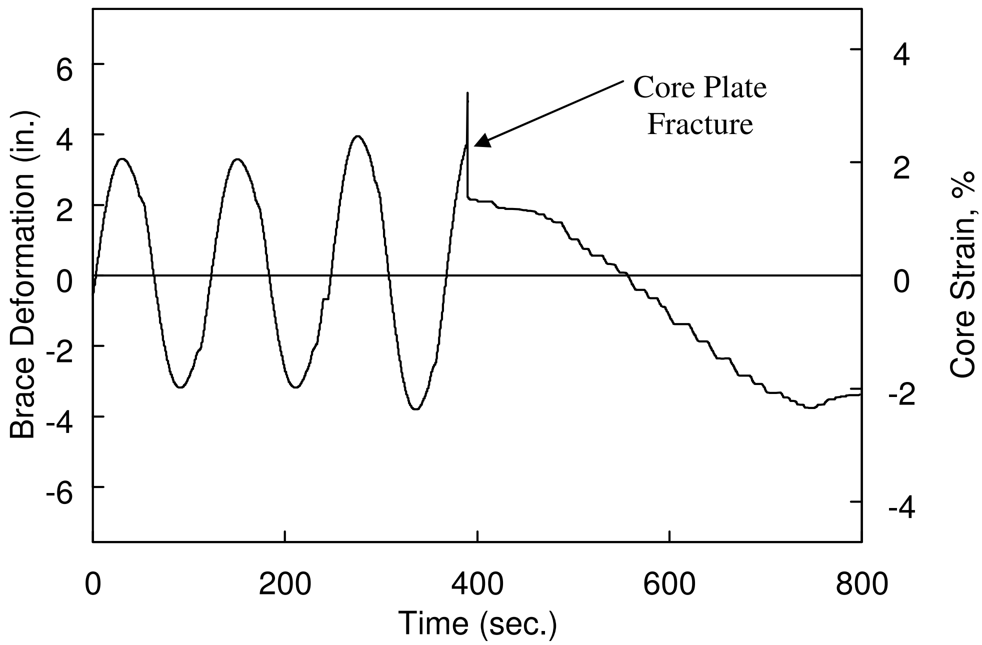
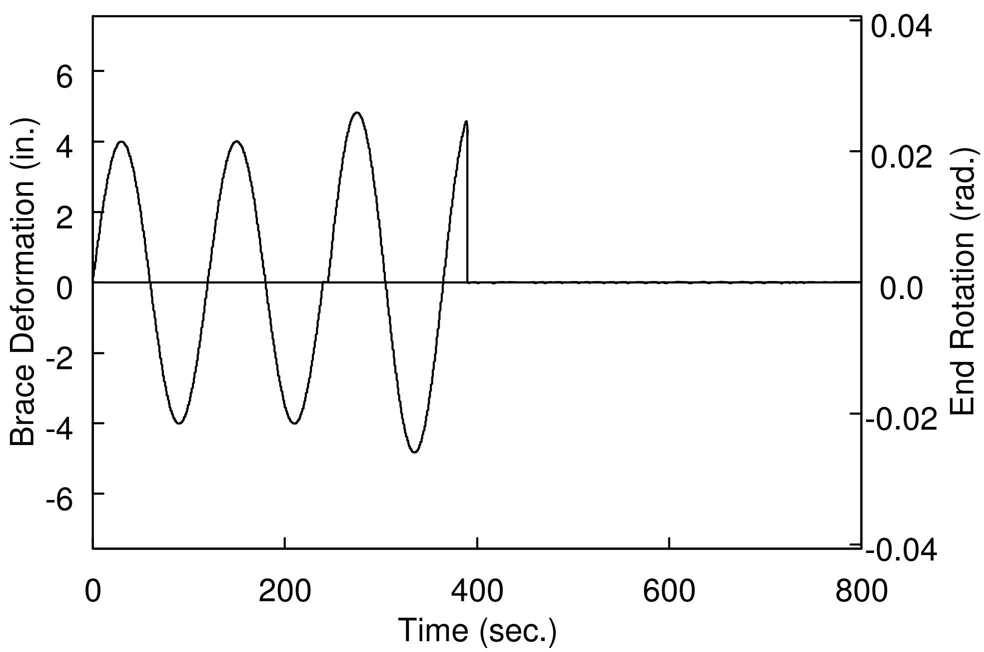


Figure 3.51 Specimen 5P: Hysteretic Energy Time History (Standard Protocol)



(a) Longitudinal Direction



(b) Transverse Direction

Figure 3.52 Specimen 5P: Brace Deformation Time Histories (High-Amplitude Protocol)

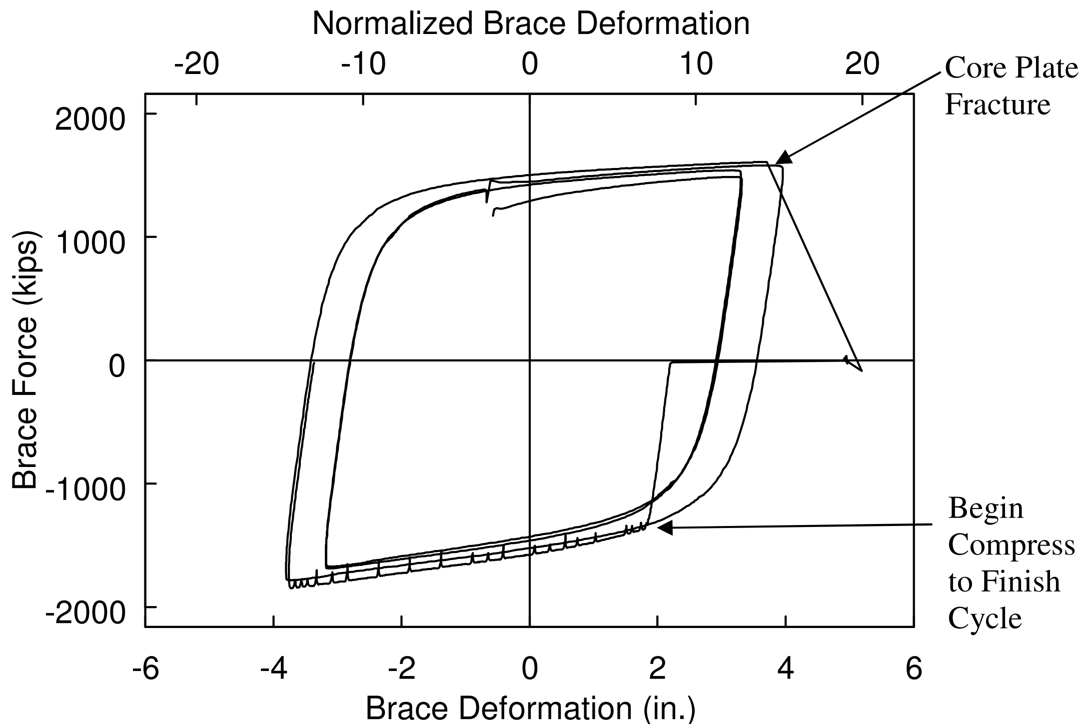


Figure 3.53 Specimen 5P: Brace Force vs. Axial Deformation (High-Amplitude Protocol)

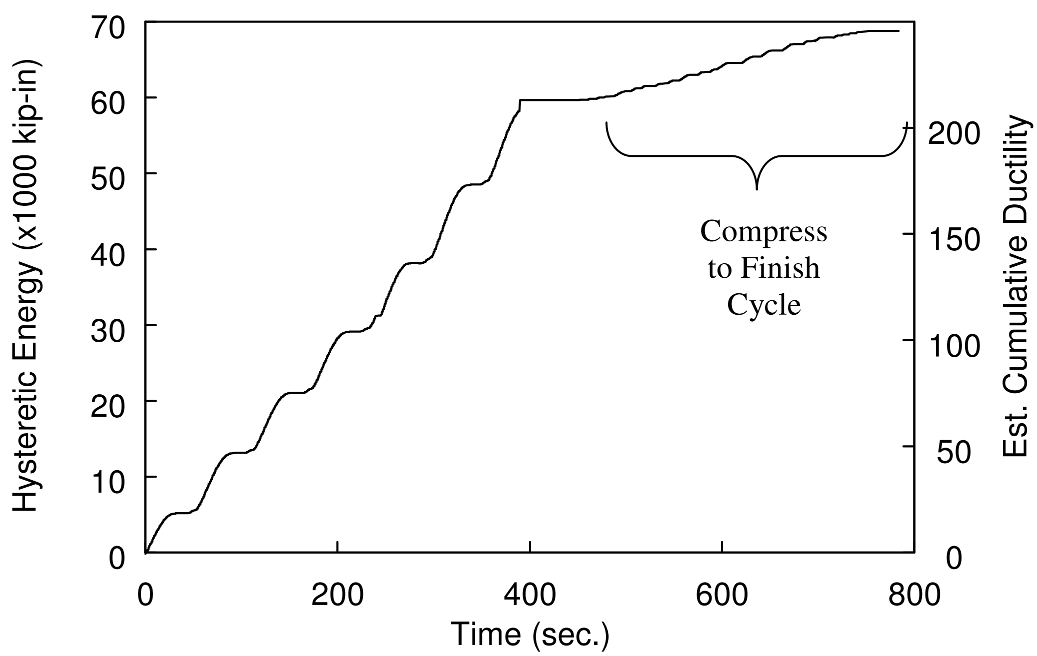
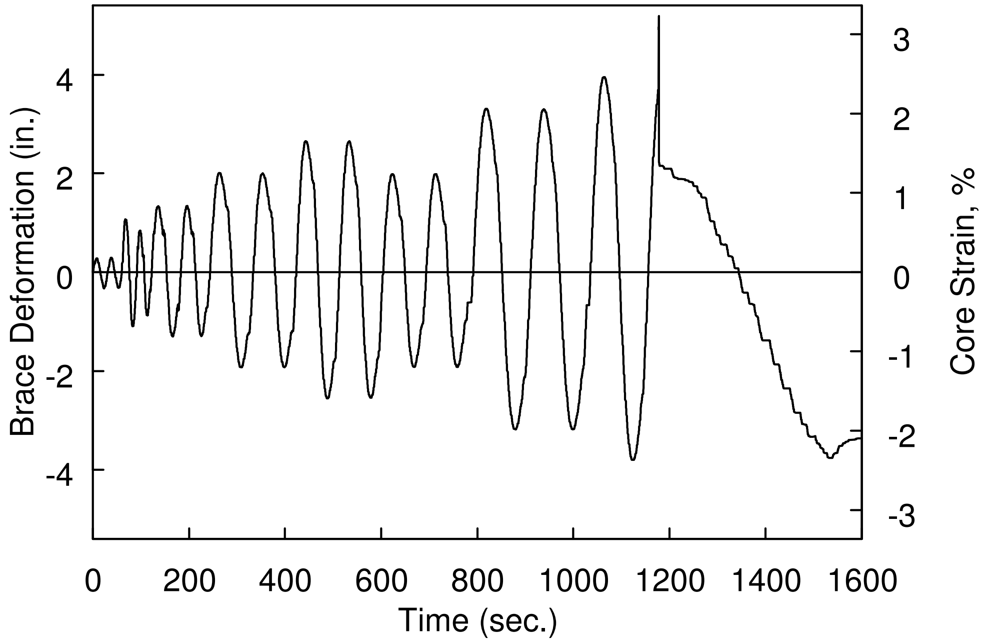
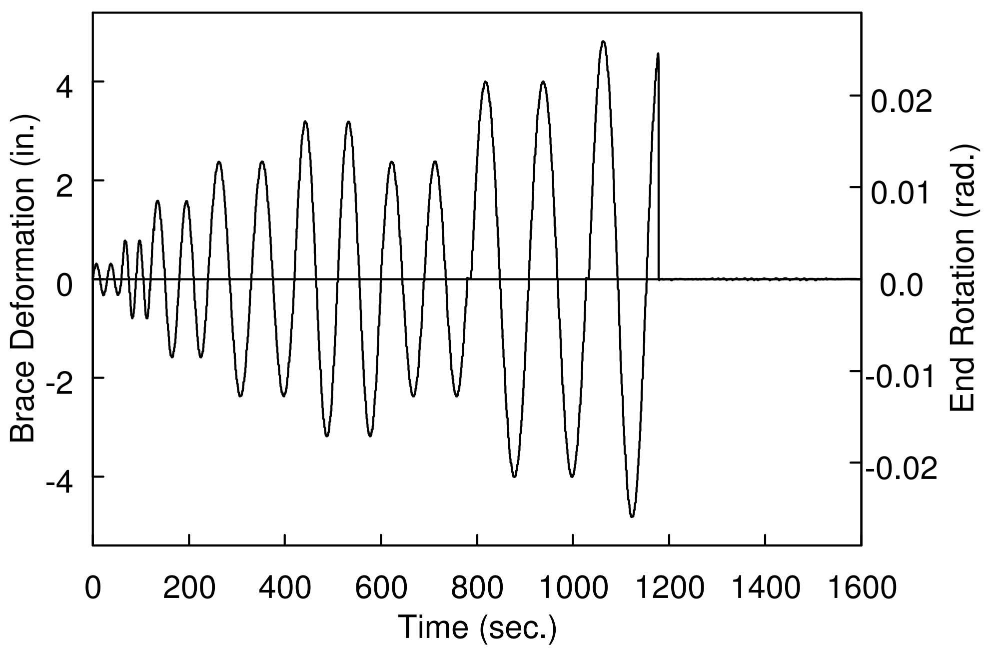


Figure 3.54 Specimen 5P: Hysteretic Energy Time History (High-Amplitude Protocol)



(a) Longitudinal Direction



(b) Transverse Direction

Figure 3.55 Specimen 5P: Brace Deformation Time Histories (All Cycles)

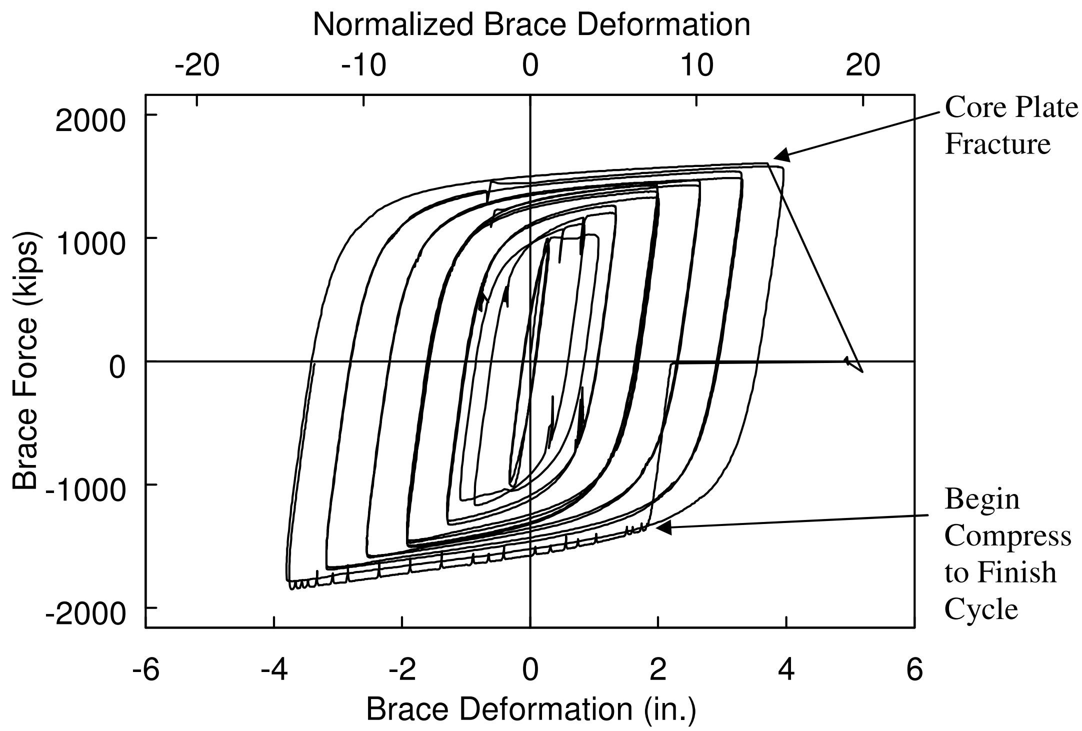


Figure 3.56 Specimen 5P: Brace Force vs. Axial Deformation (All Cycles)

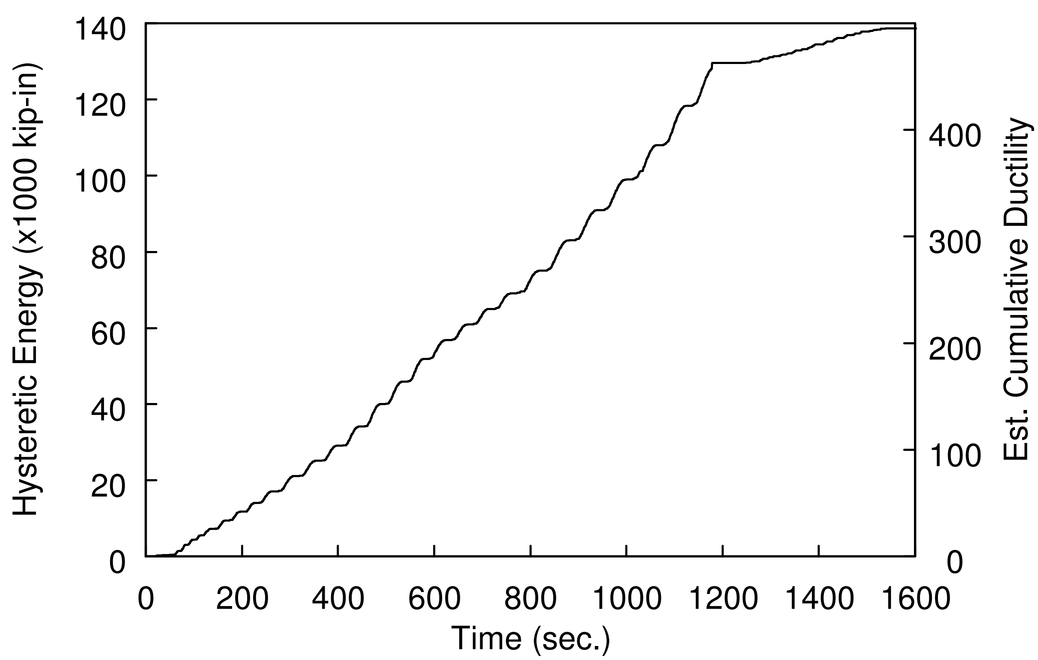


Figure 3.57 Specimen 5P: Hysteretic Energy Time History (All Cycles)

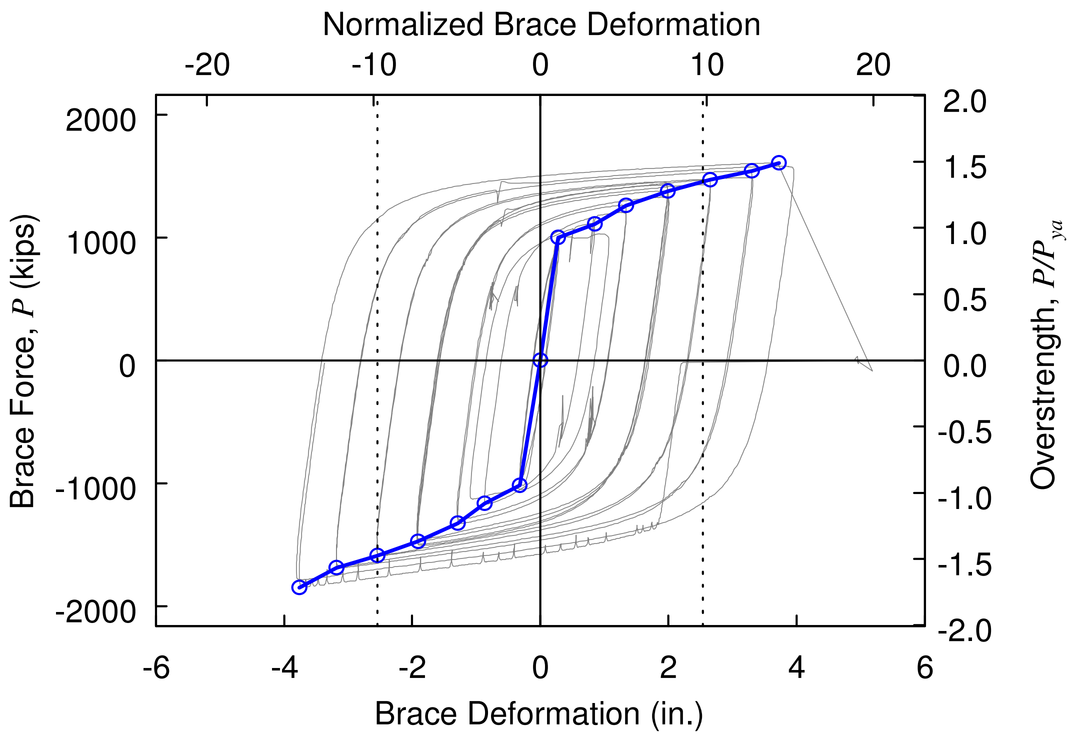


Figure 3.58 Specimen 5P: Brace Response Envelope

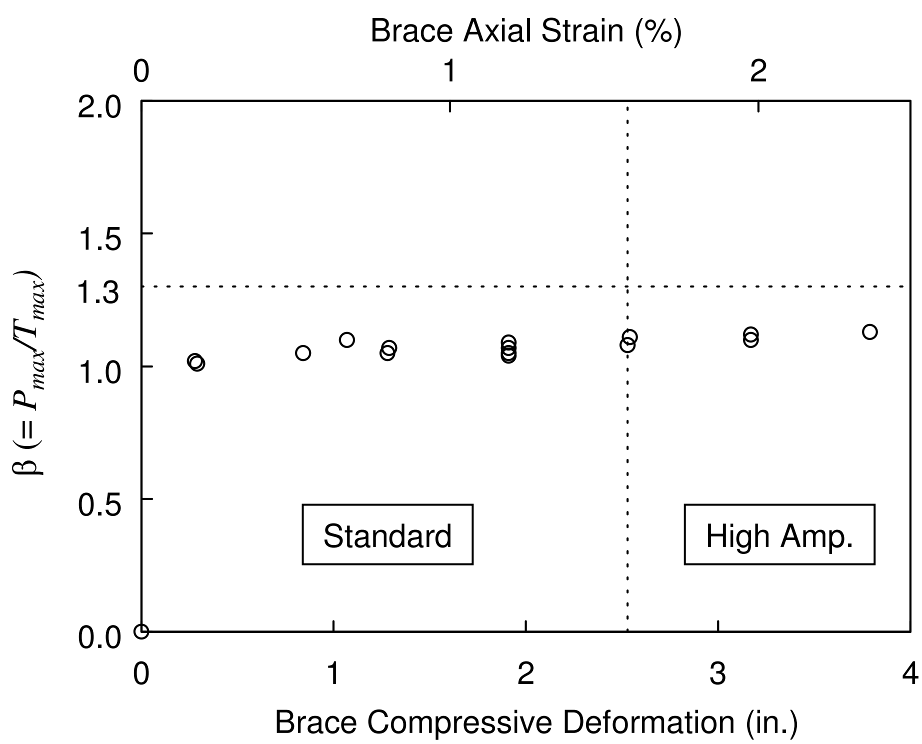
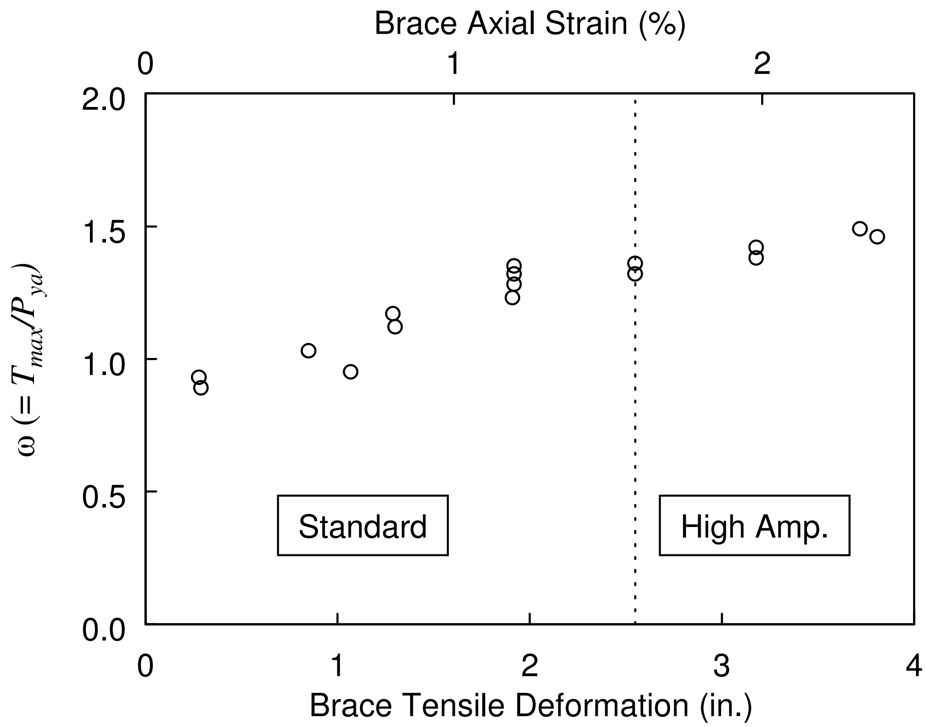
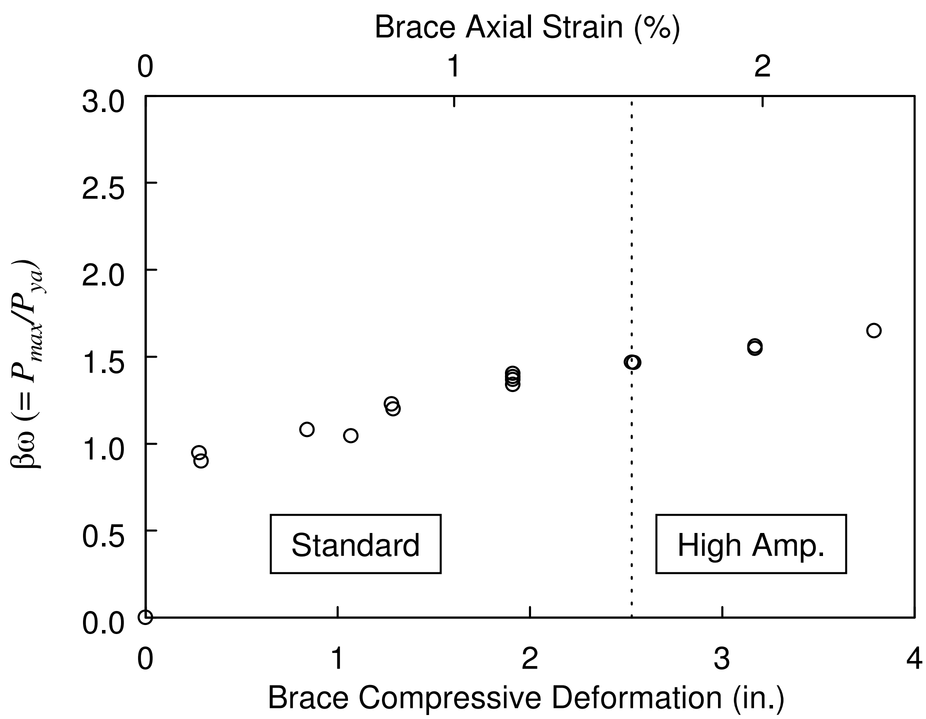


Figure 3.59 Specimen 5P: β vs. Axial Deformation Level



(a) Tension



(b) Compression

Figure 3.60 Specimen 5P: β and βω vs. Axial Deformation Level

4. COMPARISON OF TEST RESULTS

4.1 Overall Performance

All specimens performed well in the Standard Loading Protocol test. Figure 4.1 shows the brace force versus axial deformation, and Figure 4.2 shows the brace response envelopes for all specimens. The brace response envelopes show the similar pattern of response for all specimens. Table 4.1(a) provides peak response quantities for the Standard Loading Protocol, and Table 4.1(b) provides these quantities for all cycles.

4.2 Hysteretic Energy, E_h, and Cumulative Inelastic Deformation, η

The total hysteretic energy and cumulative inelastic deformation achieved by each specimen is summarized in Table 4.1(c). Note that Specimens 2P, 3P, and 5P were tested up to core plate fracture. The cumulative inelastic axial deformation achieved by all specimens was significantly greater than the $200\Delta_{by}$ required by the AISC *Seismic Provisions* for uniaxial brace test specimens.

4.3 AISC Acceptance Criteria

Section K3.8 of the AISC *Seismic Provisions* provides the following four acceptance criteria for buckling-restrained brace testing:

(1) *The plot showing the applied load versus displacement history shall exhibit stable, repeatable behavior with positive incremental stiffness*.

All specimens exhibited stable repeatable behavior with positive incremental stiffness.

(2) *There shall be no fracture, brace instability or brace end connection failure*.

None of the specimens fractured during the Standard Loading Protocol test. No brace instability or brace connection failures were observed during the Standard Loading Protocol test.

(3) *For brace tests, each cycle to a deformation greater than* Δ_{by} *the maximum tension and compression forces shall not be less than* $1.0P_{yn}$.

This criterion was met for all specimens (see Table 3.1 to Table 3.8).

(4) *For brace tests, each cycle to a deformation greater than* Δ_{by} *the ratio of the maximum compression force to the maximum tension force shall not exceed* 1.3.

The maximum value of the ratio, β, of maximum compression force to maximum tension force for each specimen is summarized in Table 4.1(a) and (b). Maximum β values were less than 1.3 in the Standard Loading Protocol test for all specimens

Table 4.1 Summary of Specimen Performance

(a) Maximum Response Quantities (Standard Loading Protocol)

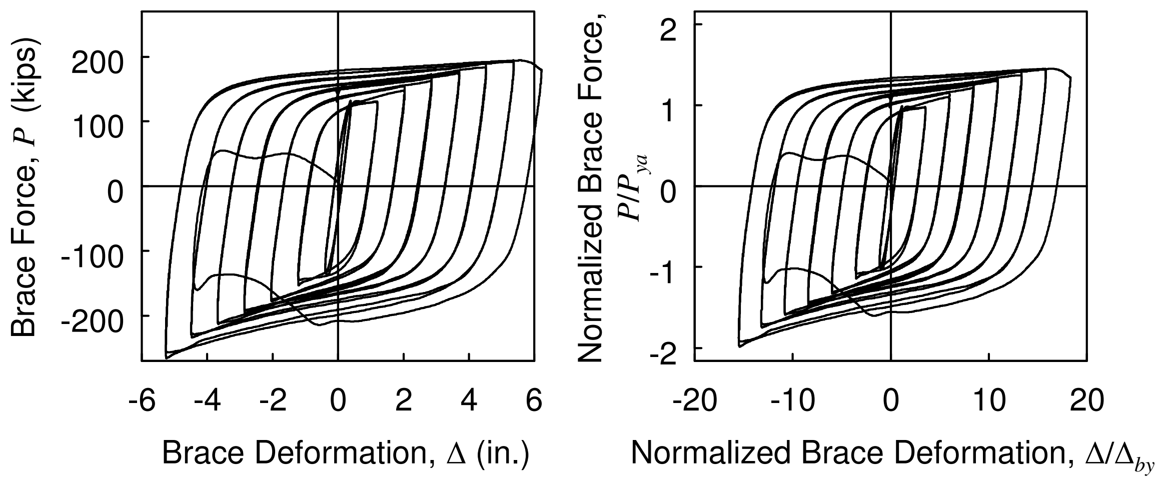
Specimen	β	ω	$\beta\omega$	Brace Strain (%)		End Rotation (rad.)
				Tension	Compression	
2P	1.20	1.33	1.58	1.86	-1.84	0.018
3P	1.13	1.27	1.43	1.70	-1.61	0.017
4P	1.10	1.38	1.50	1.62	-1.65	0.017
5P	1.11	1.36	1.47	1.65	-1.59	0.017

(b) Maximum Response Quantities (All Cycles)

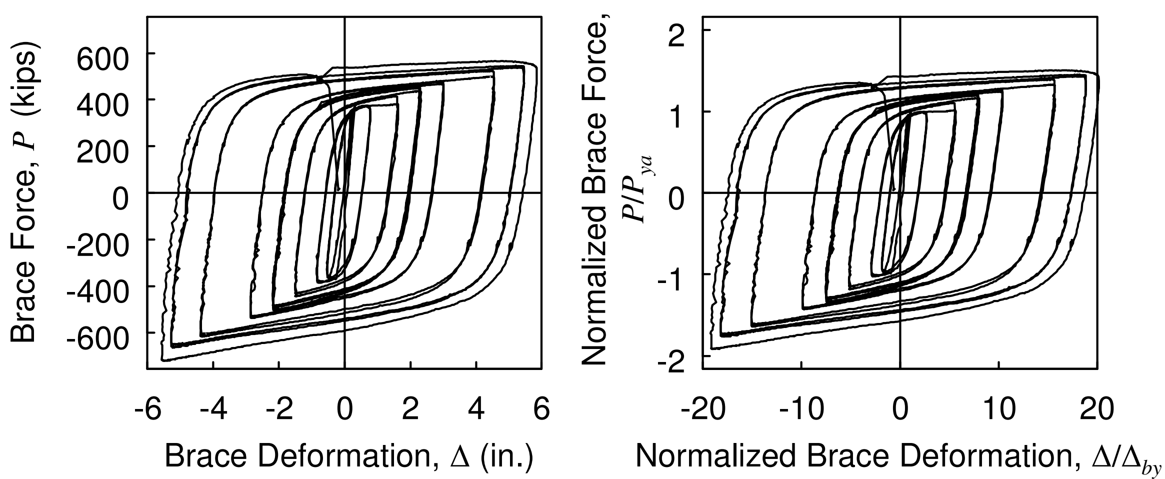
Specimen	β	ω	$\beta\omega$	Brace Strain (%)		End Rotation (rad.)
				Tension	Compression	
2P	1.37	1.45	1.99	3.12	-2.63	0.031
3P	1.34	1.45	1.92	3.29	-3.12	0.021
4P	1.16	1.54	1.76	3.67	-2.79	0.031
5P	1.13	1.49	1.65	2.46	-2.37	0.026

(c) Hysteretic Energy and Cumulative Inelastic Deformation

Specimen	Cumulative Inelastic Deformation, η_D	Hysteretic Energy, E_h (kip-in)
2P	$532\Delta_{by}$	28,457
3P	$561\Delta_{by}$	73,336
4P	$659\Delta_{by}$	183,586
5P	$403\Delta_{by}$	138,635

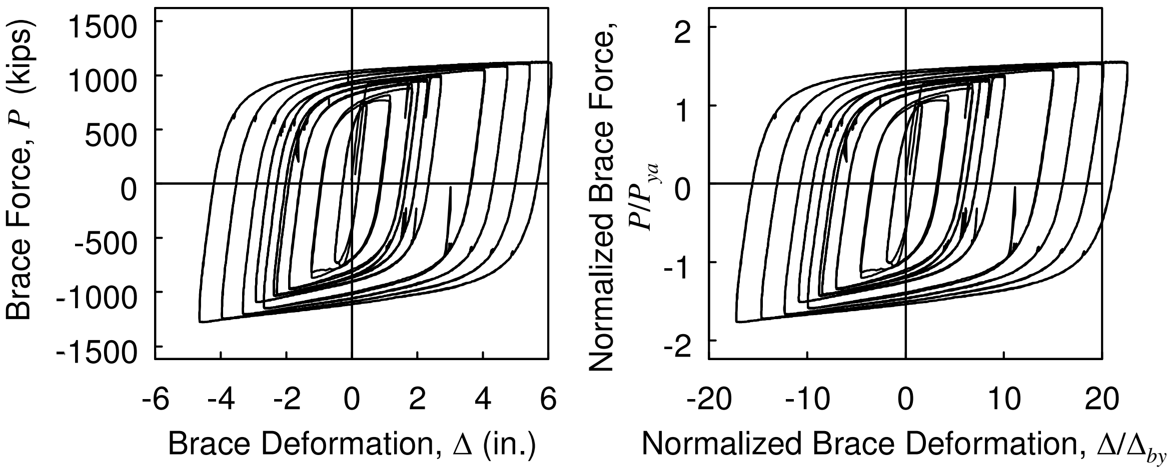


(a) Specimen 2P

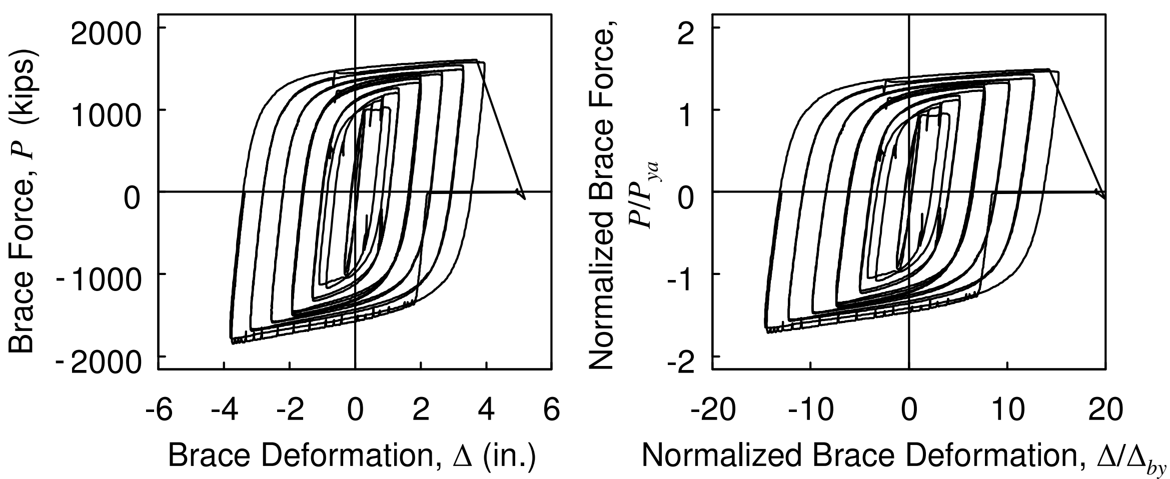


(b) Specimen 3P

Figure 4.1 All Specimens Brace Force vs. Axial Deformation Comparison

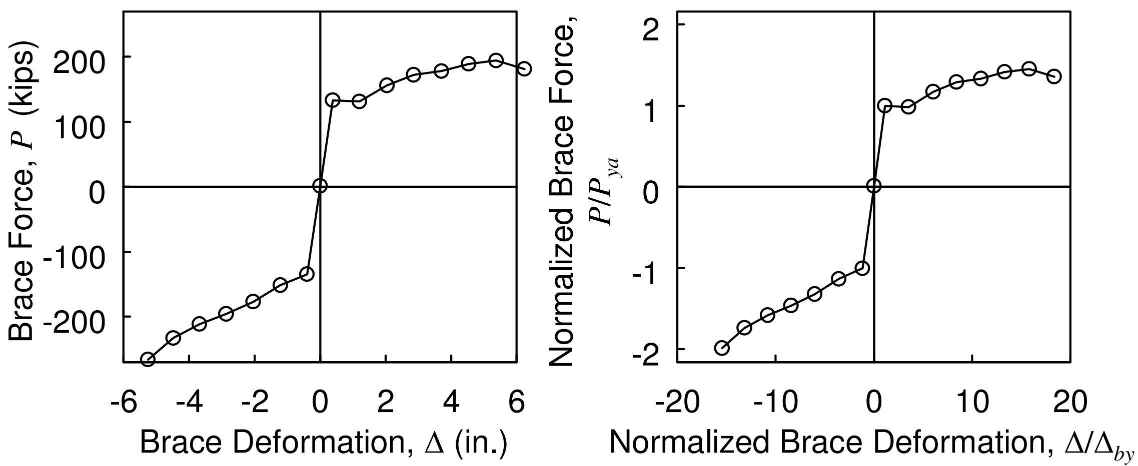


(c) Specimen 4P

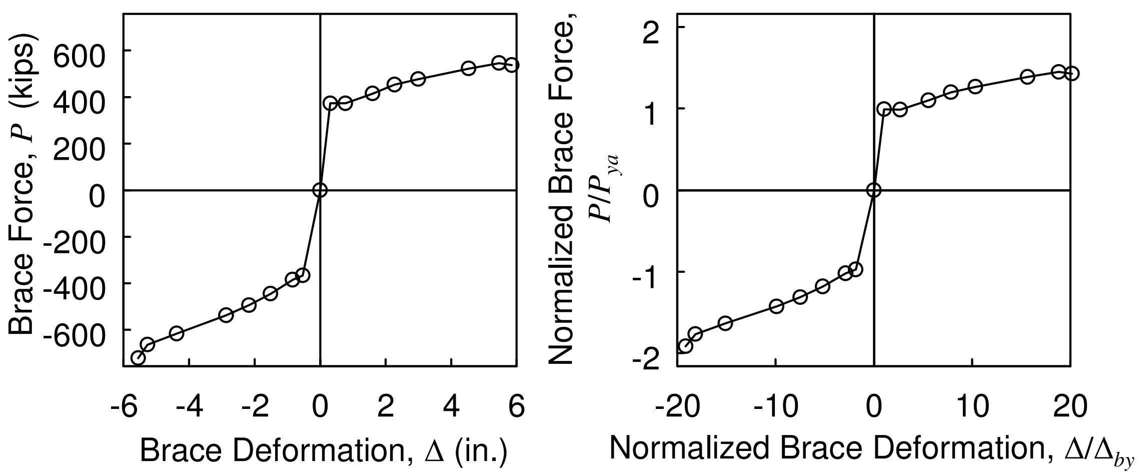


(d) Specimen 5P

Figure 4.1 All Specimens Brace Force vs. Axial Deformation (continued)

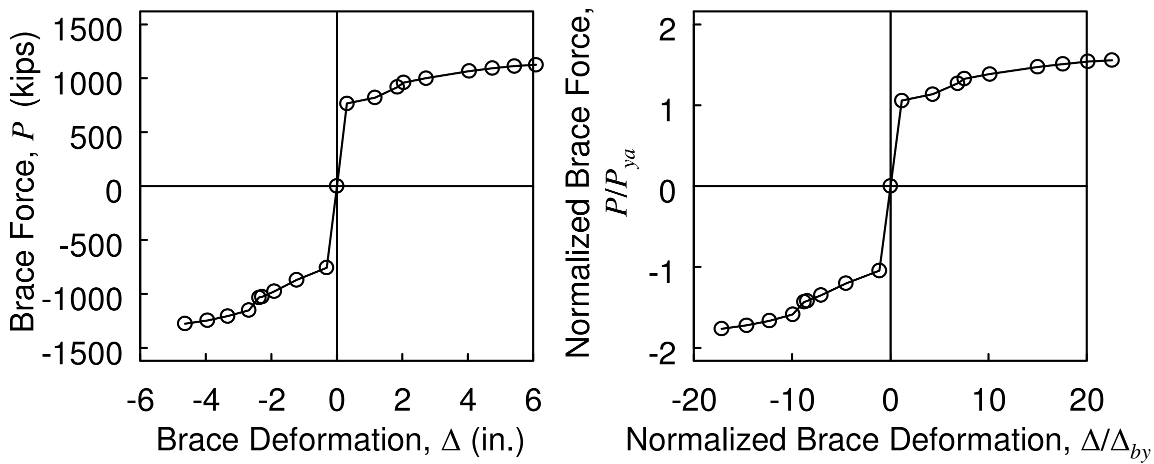


(a) Specimen 2P

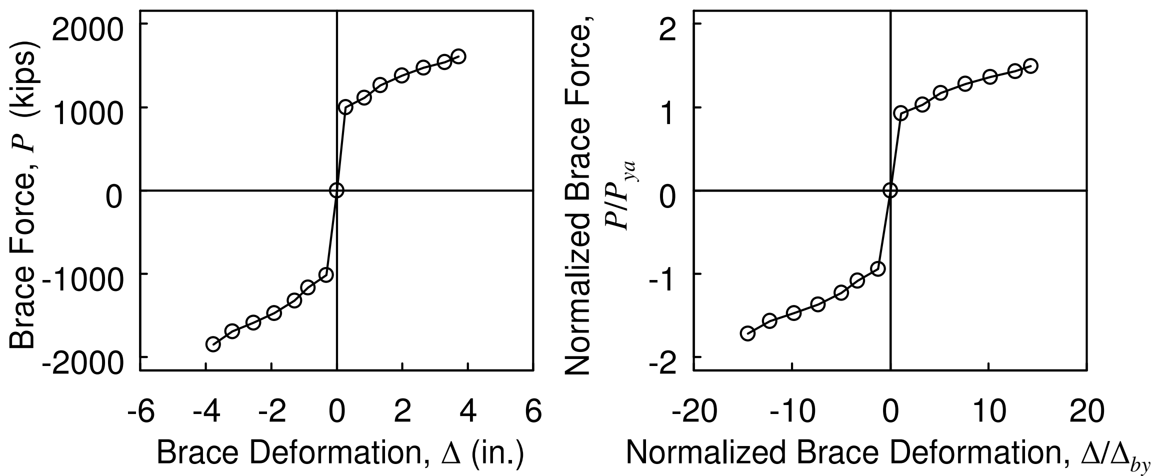


(b Specimen 3P

Figure 4.2 All Specimens Response Envelope Comparison

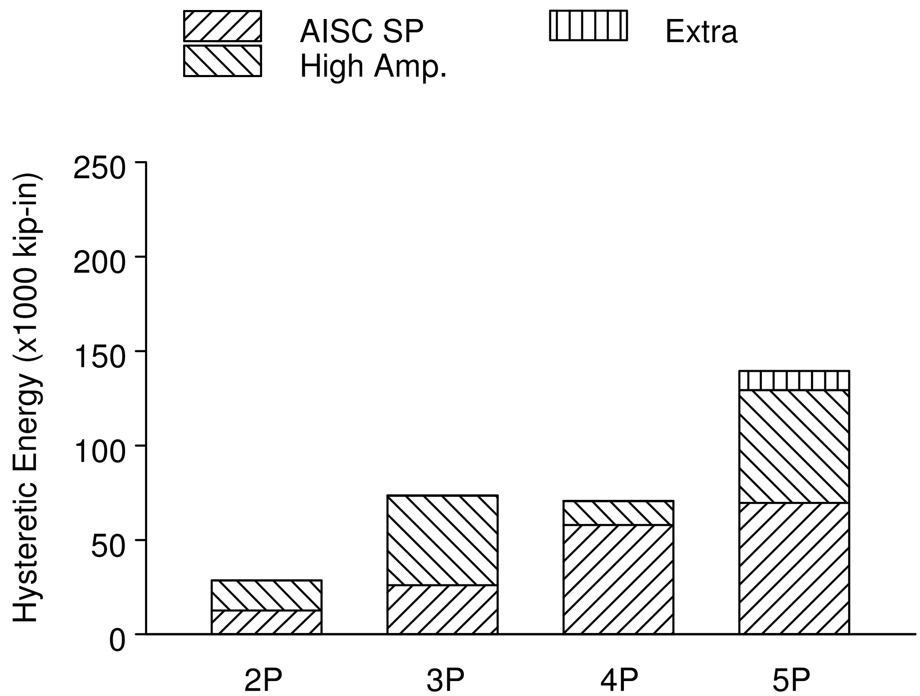


(c) Specimen 4P

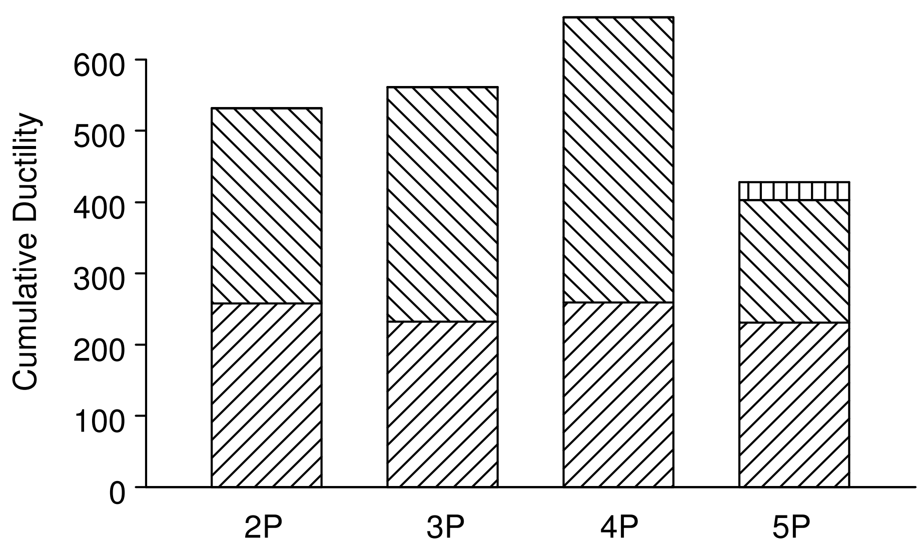


(d) Specimen 5P

Figure 4.2 All Specimens Response Envelope Comparison (continued)



(a) Hysteretic Energy



(b) Cumulative Ductility, η_E

Figure 4.3 Accumulated Response Comparison

5. SUMMARY AND CONCLUSIONS

5.1 Summary

Four BRB specimens were tested in a subassemblage configuration for CoreBrace, while one was tested for uniaxial deformation only. Each specimen was composed of a steel core plate, which was encased in a grout-filled HSS casing. All core plates were specified to be fabricated from A36 steel. Each brace was bolt-connected through a pair of end gusset plates. The bracket on one end of the brace was attached to a strong-wall and the other end to a shake table platen. Specimens were cyclically tested by imposing both axial and transverse displacements to the end of the brace attached to the shake table.

All specimens were subjected to a Standard Loading Protocol test, followed by a High-Amplitude Loading Protocol test. The Standard Loading Protocol was developed in accordance with the 2010 AISC Seismic Provisions for Structural Steel Buildings. An additional High-Amplitude Loading Protocol was developed to impose greater deformation demand to the BRB specimens. Transverse displacements applied to test specimens were calculated from the prescribed axial displacements using the brace plastic-hinge-to-plastic-hinge length and an assumed brace angle of about 50° from horizontal with peak rotations limited to 0.03 radians. Axial and transverse displacements were in phase to simulate the realistic frame action effects at the gusset connection.

All specimens performed well during the Standard Loading Protocol, and also provided stable hysteretic response under the High-Amplitude Loading Protocol. Specimens 2P, 3P, and 5P were tested to core plate rupture during the High-Amplitude Loading Protocol test; while Specimen 4P was not.

5.2 Conclusions

Based on the test results, the following conclusions and observations can be made.

(1) All specimens performed well under the Standard Loading Protocol; no fracture, brace instability or brace end connection failures were observed.

(2) Plots showing the applied load versus brace deformation showed stable, repeatable behavior with positive incremental stiffness.

(3) For all cycles to an axial deformation greater than the yield deformation, Δ_{by}, the maximum tension and compression forces were not less than 1.0 times the nominal brace yield force, P_{yn}.

(4) For all cycles to an axial deformation greater than the yield deformation, Δ_{by}, during the Standard Loading Protocol test, the ratio of the maximum compression force to the maximum tension force did not exceed 1.3.

(5) The cumulative inelastic axial deformation achieved by all specimens was significantly greater than $200\Delta_{by}$ required by the AISC *Seismic Provisions for Structural Steel Buildings* for uniaxial brace test specimens.

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STRUCTURAL SYSTEMS
RESEARCH PROJECT

Report No.
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Final Report

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by

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Final Report Submitted to CoreBrace, LLC.

April 2021

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University of California, San Diego
La Jolla, California 92093-0085

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Chia-Ming Uang
Professor of Structural Engineering

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La Jolla, California 92093-0085

ABSTRACT

Three buckling-restrained braces (BRBs) of different design strengths were tested in the SRMD Test Facility at the University of California, San Diego. Specimens 8P and 9P were tested in July 2019, while Specimen 10P was tested in April 2020. All specimens consisted of A36 steel core plates encased in grout-filled A500 Gr. B square HSS casings. Bolted end connections were implemented on both ends of the brace to connect each brace end to a bracket with a gusset plate in this P Series. Specimens 8P, 9P, and 10P were connected to gusset plates with a thickness of 1-in., 1¼-in., and 1-in., respectively. The west end of the brace was fastened to the strong wall and the east end was fastened to the SRMD shake table platen.

The cyclic loading protocol used for this test program was composed of three stages. The first stage loading was the same as that specified in the AISC *Seismic Provisions*. The second stage loading was developed to impose greater deformation demands then a code-prescribed requirement. The third stage loading had larger numbers of low-cycle inelastic deformation until core failure. Axial and transverse displacements were imposed to the specimens to simulate the in-plane frame action effect at the gusset connection.

All three specimens performed well during the AISC loading protocol (Stage 1) and Stage 2 loading, fracturing during Stage 3 testing. The braces achieved capacity parameters within the AISC *Seismic Provisions* requirements. For all specimens, the maximum values of compression strength adjustment factor, β, were less than the AISC limiting value of 1.5. The computed cumulative inelastic deformation for all specimens were greater than $200\Delta_{by}$. Note that Specimen 9P had been dropped form a height of multiple stories during construction before it was shipped back for testing, the brace performed well throughout the testing protocol and did not show any degradation in strength. The steel core of Specimen 10P was intentionally made from a plate with a low CVN toughness. This was lower than the New Zealand code requirement but above the AISC requirement. Tests results showed that this low-toughness BRB still exhibited a satisfactory cyclic performance.

ACKNOWLEDGMENTS

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A_{sc}	Area of yielding element
C_{max}	Maximum brace compressive force at peak cyclic deformation
E_h	Total hysteretic energy dissipated by brace
E_{hi}	Total hysteretic energy dissipated by brace for the i^{th} cycle
E_s	Young's modulus of elasticity of steel
E_{si}	Elastic strain energy for the i^{th} cycle
F_{ya}	Actual or measured yield strength of steel core (average of coupon tests)
F_{yn}	Nominal yield strength of steel core
L_b	Total length of brace
L_y	Length of yielding element
P_{ya}	Actual brace yield force, $F_{ya}A_{sc}$
P_{yn}	Nominal brace yield force, $F_{yn}A_{sc}$
P	Axial brace force
R_y	Material overstrength factor, F_{ya}/F_{yn}
T_{max}	Maximum brace tensile force at peak cyclic displacement
β	Compression strength adjustment factor, C_{max}/T_{max}
Δ	Axial brace deformation
Δ_b	Deformation quantity used to control loading of test specimen
Δ_{bm}	Value of deformation quantity, Δ_b, corresponding to the design story drift
Δ_{by}	Value of deformation quantity, Δ_b, at first significant yield of test specimen
Δ^+	Maximum tensile axial deformation for the i^{th} cycle

Δ^{-}	Absolute value of the maximum compressive axial deformation for the i[th] cycle
ε	Axial brace strain
η_D	Cumulative inelastic axial deformation (CID), based on cyclic deformation
η_E	Cumulative inelastic axial deformation (CID), based on hysteretic energy
μ_i	Inelastic axial deformation of the i[th] cycle
ω	Strain hardening adjustment factor, T_{max}/P_{ya}

1 INTRODUCTION

1.1 General

Three buckling-restrained braces (BRBs) of different design strengths were tested to evaluate their cyclic performance. Bolted (P series) end connections were implemented on both ends of the brace. Provisions for the design and qualifying cyclic testing of BRBs are included in the AISC 341-16 *Seismic Provisions for Structural Steel Buildings* (AISC 2016). The AISC provisions require subassemblage testing to be conducted to verify the performance of BRBs, which demonstrates the BRB's ability to accommodate combined axial and rotational deformation demands imposed during a seismic event. Specimens 8P and 9P were tested in July 2019 (Mansing *et al*. 2019). Specimen 10P was tested in April 2020. This report includes test results of all three specimens.

1.2 Scope and Objectives

All the specimens were designed and fabricated by CoreBrace, LLC and tested at the University of California, San Diego. The testing was performed at the Caltrans Seismic Response Modification Device (SRMD) Testing Facility. The objective of the testing was to evaluate the cyclic performance and the capacity parameters of these BRBs based on the acceptance criteria of the AISC Seismic Provisions.

2 TESTING PROGRAM

2.1 Test Specimens

All specimens consisted of A36 steel core plates encased in grout-filled square HSS casing. Specimens 8P, 9P, and 10P had a core cross-sectional area of 7 in.^{2}, 8 in.^{2}, and 2.25 in.^{2} and of an outer casing made from HSS 10×10×1/4, 10×10×3/16, and 8×8×1/4, respectively. Bolted end connections were implemented on both ends of the brace to connect each brace end to a bracket with a gusset plate. Table 2.1 and Table 2.2 provide detailed brace information, and Figure 2.1 shows the overall brace geometry. Specimen 9P was dropped at the construction site from a height of multiple stories prior to testing, landing on one end of the BRB on a set of precast concrete stairs. As a result, there was damage to the connection lugs and outer casing. This damage included a bend to the lugs at one end (closing the gap from the specified 1-7/16" to approximately 11/16"), gouges to the casing, and a shift in the casing of approximately 5/16" (see Figure 2.14). Additionally, the damaged brace was left out in the elements for 2-3 months at the jobsite in a tropical climate and then for nearly 2 years after its return to CoreBrace while awaiting testing, and as such, noticeable rusting had occurred. Only the bend in the lugs was repaired (as required to fit over the gusset), which employed typical heat flare methods available to site erection crews. The relevant dates and associated events for Specimen 9P are listed in Table 2.3.

2.2 Material Properties

The steel cores and HSS casings were manufactured with ASTM A36 plate and A500 Gr. B steel, respectively. Measured steel properties from the mill reports and tensile coupon tests of the steel core plate materials are summarized in Table 2.5. Based on measured yield stress, F_{ya}, the material overstrength factor, R_y, and brace deformation at first significant yield, Δ_{by}, are listed in Table 2.6. Table 2.7 lists the measured Charpy V-notch (CVN) toughness of the core plate for Specimen 10P and the associated code-prescribed requirements from the United States (AISC 2016) and New Zealand (Standards New Zealand 2009). Specimen 10P was intentionally made from a core plate with a CVN toughness lower than the New Zealand requirement in order to investigate the cyclic behavior of low-toughness BRBs.

2.3 Test Setup

The SRMD facility, which has a shake table platen capable of imposing displacement in six degrees of freedom, is shown in Figure 2.5. Figure 2.6 shows a BRB specimen installed between the platen and strong wall. Either end uses nearly rigid steel fixtures between the strong wall and table platen to fasten the gusset plates, where the BRB end plates are ultimately affixed. Horizontal motion was applied to all specimens in displacement-control mode, resulting in axial and transverse deformations in the brace.

2.4 End Connections

The BRB end connections used for the test program consisted of a pair of connection plates, or lugs. Specimens 8P, 9P, and 10P were connected to gusset plates with a thickness of 1-in., 1¼-in., and 1-in., respectively. For all specimens, the lugs were connected to the gusset plate with 1-1/8 in. diameter ASTM F3148 TNA bolts. Figure 2.7 shows the strong wall end after the TNA bolts were fully tensioned. Bolt holes in the lug plates were standard size, while those in the gusset plates were oversized. The bolted connections were designed to resist slip at the yield strength of the brace.

2.5 Instrumentation

Two string potentiometers, labeled as L1 and L2 in Figure 2.8, were used to measure the axial deformation of the braces. Figure 2.12 shows a comparison between the SRMD input motion and the measured deformation by the string potentiometers for Specimen 9P. Similar comparison of all testing protocol can be found in Appendix. An additional string potentiometer, L3, provided displacement information between BRB end brackets. Brace forces were measured by the load cell in each of the four actuators that drove the shake table and were recorded by the system. Synchronized data was collected in a triggered mode for pseudo-static tests.

2.6 Loading Protocol

According to the AISC Seismic Provisions, the design of BRBs shall be based upon results from qualifying cyclic tests. The loading requirements in such cyclic tests are based on the effects of far-field ground motions on building frames. These motions are usually symmetric, with consistent relatively small amplitude cycles with low to moderate strain rates. According to Section K3.4c of the AISC Seismic Provisions, the test must be conducted by controlling the level of axial or rotational deformation, Δ_b, imposed on the test specimen.

Loads shall be applied to the test specimen to produce the following deformations, where the deformation is the steel core axial deformation of the test specimen:

(1) 2 cycles of loading at the deformation corresponding to Δ_b = 1.0Δ_{by},

(2) 2 cycles of loading at the deformation corresponding to Δ_b = 0.5Δ_{bm},

(3) 2 cycles of loading at the deformation corresponding to Δ_b = 1.0Δ_{bm},

(4) 2 cycles of loading at the deformation corresponding to Δ_b = 1.5Δ_{bm},

(5) 2 cycles of loading at the deformation corresponding to Δ_b = 2.0Δ_{bm}, and

(6) additional complete cycles of loading at the deformation corresponding to Δ_b = 1.5Δ_{bm} as required for the brace test specimen to achieve a cumulative inelastic axial deformation of at least 200 times the deformation at first yield.

The deformation at first yield, Δ_{by}, is computed using the actual yield strength of the material, F_{ya}, and the core yielding length, L_y. The deformation corresponding to the frame drift, Δ_{bm}, would typically be derived based on a structural model of a building. For the purposes of establishing a boundary for the AISC loading protocol used in this testing program, Δ_{bm} is taken as 7.5Δ_{by}, 6Δ_{by}, and 7Δ_{by} for Specimens 8P, 9P, and 10P, respectively. This loading protocol is usually applied to BRBs pseudo-statically in recognition of the increased costs of applying the loads dynamically (AISC 341, 2016). In this testing program, the entire loading protocol consisted of three stages. The first stage loading was the same as that specified in the AISC *Seismic Provisions*, while the second stage loading imposed a greater deformation demand to the BRB specimens. Stage 3 loading corresponds to larger numbers of low cycle deformation until core fracture.

Using the calculated Δ_{by} value for each specimen (see Table 2.6), the total shake table input displacement was established by adding additional components to account for the following:

(1) deformation of the gusset plates,

(2) deformation due to the flexibility of the end supports and reaction wall at the SRMD testing facility based on a known total system flexibility (1/6800 in./kip), and

(3) deformation of bolt slippage.

Transverse displacements corresponding to the prescribed axial displacement were calculated based on the plastic-hinge-to-plastic-hinge length, which was approximately equal to the length L_b shown in Figure 2.1, and it represents the length between the effective centers of lateral rotation at each end of the brace. Since the loading system was very rigid in the transverse direction, no additional transverse displacement was added to establish the shake table input transverse displacements.

2.7 Data Reduction

Brace Axial Deformation, Δ_b

In the following chapter, the brace specimen deformation, Δ_b, corresponding to the average of those measured by displacement transducers (L1 and L2) is reported. The brace axial strain was calculated per Eq. 2.1.

$$\varepsilon = \frac{\Delta_b}{L_y} \tag{2.1}$$

where L_y equals the length of the steel core plate in the yielding zone. The brace axial deformation is also normalized by the yield deformation. Note that Δ_b includes some minor elastic deformation outside the yielding length, L_y.

Brace Force, P

The brace force was determined by the resultant force along the brace length in the deformed position, which was calculated by combining the force components along the brace from the measured longitudinal and transverse forces.

Platen Friction

The SRMD shake table is a steel platen which rests on hydrostatic bearings that vertically support it and the specimen. This system has an inherent friction force that must be overcome by the machine to move the platen and deform the brace specimen. The friction forces are relatively small compared to the forces experienced by the BRBs, hence it was neglected in computing the brace forces.

Tension and Compression Strength Adjustment Factors, ω, β

Two parameters, ω and β, are defined in the AISC Seismic Provisions (AISC, 2016). The first parameter, ω, is the strain hardening adjustment factor relating the maximum tension force in the brace to the actual brace yield force (see Eq. 2.2). The second parameter, β, is the compression strength adjustment factor which compares the maximum compression force to the maximum tension force of each cycle in the brace (see Eq. 2.3). Therefore, the maximum compression is related to brace yield force by the multiplication of ω and β (see Eq. 2.4).

$$\omega = \frac{T_{max}}{P_{ya}} = \frac{T_{max}}{F_{ya}A_{sc}} \tag{2.2}$$

$$\beta = \frac{C_{max}}{T_{max}} = \frac{\omega\beta}{\omega} \tag{2.3}$$

$$\omega\beta = \frac{C_{max}}{P_{ya}} \tag{2.4}$$

where F_{ya} is the measured yield stress, and A_{sc} is the area of the yielding core. The AISC Seismic Provisions limit the value of β to 1.5 for the cycles of deformation that exceed the yielding deformation.

Hysteretic Energy, E_h

The area enclosed by the P versus Δ_b response curve represents the dissipated hysteretic energy (see Eq. 2.5).

$$E_h = \int P d\Delta \tag{2.5}$$

Cumulative Inelastic Axial Deformation, η_D and η_E

The normalized total inelastic axial deformation for a cycle with a deformation level greater than the yield deformation is given by:

$$\mu_i = \frac{2|\Delta_i^+ - \Delta_i^-|}{\Delta_{by}} - 4 \tag{2.6}$$

where Δ_i^+ and Δ_i^- are the absolute values of the maximum and minimum deformations for the ith cycle, respectively, and Δ_{by} is the deformation corresponding to yielding of the brace. The deformation-based cumulative inelastic axial deformation, η_D, is calculated as the summation of the normalized inelastic axial deformation for each cycle:

$$\eta_D = \sum \mu_i \tag{2.7}$$

For uniaxial testing of BRBs, the AISC Seismic Provisions require that the cumulative normalized inelastic deformation reach a value of at least 200.

Alternatively, the cumulative inelastic deformation (CID) is also calculated as a normalized cumulative dissipated energy as per Eq. 2.8. The value of η_E is also reported in this study.

$$\eta_E = \frac{E_h}{P_{ya}\Delta_{by}} \tag{2.8}$$

Table 2.1 Specimen Dimensions: Core Plate and Casing Size

	W_L (in.)	W_1 (in.)	t_L (in.)	W_2 (in.)	t_{sc} (in.)	Core Plate	HSS Casing Size
8P	8-7/8	8-1/4	3/4	5-5/8	1-1/4	Flat	10×10×1/4
9P	8-7/8	7-13/16	3/4	6-3/8	1-1/4	Flat	10×10×3/16
10P	7-1/2	3-11/16	1/2	3	3/4	Flat	8×8×1/4

Table 2.2 Specimen Dimensions: Lengths

	L_b (in.)	L_c (in.)	L_y (in.)	L_L (in.)	a (in.)	L_T (in.)
8P	236-5/8	192-1/2	165-1/16	14-9/16	4	17-1/4
9P	214-9/16	169-3/8	144	15-5/16	4	16
10P	239-5/8	206-5/16	174-1/4	9-3/8	4	11-7/16

Table 2.3 Relevant Dates for Specimen 9P

Date	Event
2016-06-22	Fabrication Completed
2016-07-15 thru 08-08	Shipping: CB Facility to Jobsite Port
2017-02-25	Damaged During Erection
2017-05-14 thru 06-19	Return Shipping: Jobsite Port to CB Facility
2019-05-17	Repair: Lugs Flared to Fit Gusset
2019-06-07	Test

Table 2.4 Specimen Dimensions: Connection Layout

	Lug PL Hole Dia. (in.)	Gusset PL Hole Dia. (in.)	Rows of Bolts	s (in.)	g_i (in.)	g_o (in.)
8P	1-1/4	1-7/16	4	3-1/4	2-13/16	–
9P	1-1/4	1-7/16	4	3-1/2	2-13/16	–
10P	1-1/4	1-7/16	2	5	2-1/8	–

Table 2.5 Mechanical Properties of Core Plates

	Mill Test Report Average					Tensile Coupon Average				
	Heat No.	F_{ya} (ksi)	F_{ua} (ksi)	F_{ua}/F_{ya}	Elong.[a] (%)	Plate No.	F_{ya} (ksi)	F_{ua} (ksi)	F_{ua}/F_{ya}	Elong.[a] (%)
8P	N18901	41.6	62.5	1.50	35 (8")	4687	41.7	63.6	1.52	36.5 (2")
9P	N05872	40.8	62.5	1.53	34 (8")	1777	44.4	66.6	1.50	34.5 (2")
10P	A9M0361	41.9	59.9	1.43	40 (2")	3597	38.1	57.4	1.50	34 (2")

a) Value in parenthesis indicates gage length of sample

Table 2.6 Yield Stress and Deformation

	A_{sc} (in.^{2})	F_{yn} (ksi)	P_{yn}[a] (kip)	P_{ya}[b] (kip)	R_y[c]	Δ_{by} (in.)
8P	7.00	36	252	292	1.16	0.24
9P	8.00	36	288	355	1.23	0.22
10P	2.25	36	81	86	1.06	0.23

a) $P_{yn} = A_{sc}F_{yn}$
b) $P_{ya} = A_{sc}F_{ya}$
c) $R_y = F_{ya}/F_{yn}$, where F_{yn} is the nominal yield stress of the specified steel.

Table 2.7 CVN Toughness of Core Plate for Specimen 10P

CVN Test Results				Code Requirements
CVN Toughness @ 32°F (0°C) [ft-lb (J)]				NZS 3404.1: 2009: For plate thickness > 12 mm, 51.6 ft-lb (70J) @ 32°F (0°C) – Average of three tests 36.9 ft-lb (50J) @ 32°F (0°C) – Individual test
Sample 1	Sample 2	Sample 3	Average	
13 (17.6)	15 (20.3)	10 (13.6)	12.7 (17.2)	
CVN Toughness @ 70°F (21°C) [ft-lb (J)]				AISC 341-16: For plate thickness ≥ 2 in., 20 ft-lb (27 J) @ 70°F (21°C)
Sample 1	Sample 2	Sample 3	Average	
32 (43.4)	43 (58.3)	29 (39.3)	34.7 (47.0)	

Table 2.8 Target BRB Deformations

(a) Axial Deformation (in.)

	Standard Protocol					Extended Protocol			
	Stage 1					Stage 2			Stage 3
No. of Cycles	2	2	2	2	2	2	2	2	10 (until Fracture)
8P	0.24 ($1\Delta_{by}$)	0.89 ($3.75\Delta_{by}$)	1.78 ($7.5\Delta_{by}$)	2.67 ($11.25\Delta_{by}$)	3.56 ($15\Delta_{by}$)	4.27 ($18\Delta_{by}$)	4.98 ($21\Delta_{by}$)	–	2.67 ($11.25\Delta_{by}$)
9P	0.22 ($1\Delta_{by}$)	0.66 ($3\Delta_{by}$)	1.32 ($6\Delta_{by}$)	1.98 ($9\Delta_{by}$)	2.65 ($12\Delta_{by}$)	3.31 ($15\Delta_{by}$)	3.97 ($18\Delta_{by}$)	2.65 ($12\Delta_{by}$)	2.65 ($12\Delta_{by}$)
10P	0.23 ($1\Delta_{by}$)	0.80 ($3.5\Delta_{by}$)	1.60 ($7\Delta_{by}$)	2.41 ($10.5\Delta_{by}$)	3.21 ($14\Delta_{by}$)	4.24 ($18.5\Delta_{by}$)	5.27 ($23\Delta_{by}$)	–	3.21 ($14\Delta_{by}$)

(b) Transverse Deformation (in.)

	Standard Protocol					Extended Protocol			
	Stage 1					Stage 2			Stage 3
No. of Cycles	2	2	2	2	2	2	2	2	10 (until Fracture)
8P	0.24	0.89	1.80	2.71	3.64	4.39	5.14	–	2.71
9P	0.22	0.66	1.34	2.01	2.69	3.38	4.08	2.69	2.69
10P	0.23	0.81	1.62	2.44	3.27	4.35	5.45	–	3.27

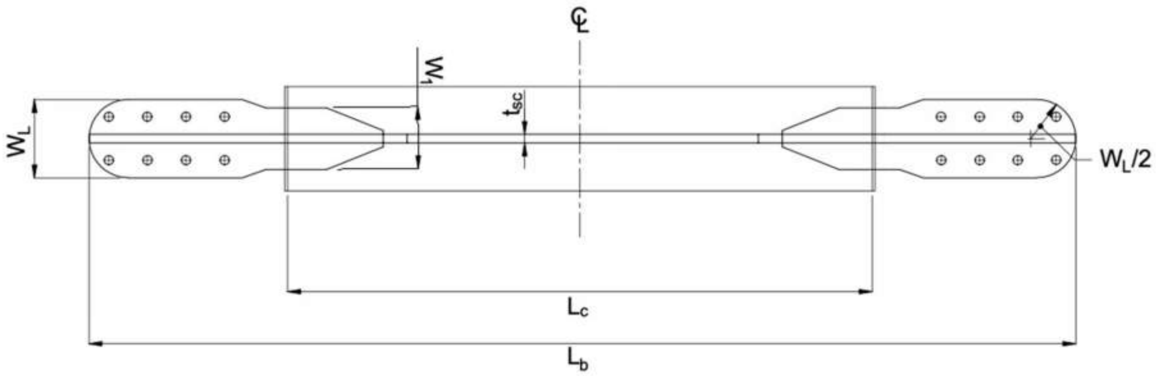
Table 2.9 Shake Table Input Displacements

(a) Axial Deformation (in.)

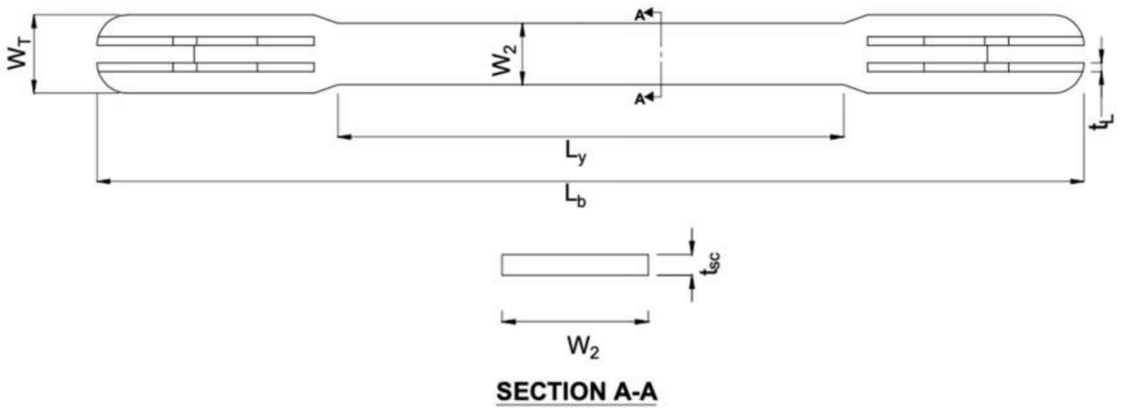
	Standard Protocol					Extended Protocol			
	Stage 1					Stage 2			Stage 3
No. of Cycles	2	2	2	2	2	2	2	2	10 (until Fracture)
8P	0.32/ –0.32	0.98/ –0.99	1.88/ –1.89	3.01/ –3.02	3.90/ –3.92	4.60/ –4.63	5.31/ –5.34	–	3.01/ –3.02
9P	0.32/ –0.33	0.77/ –0.78	1.67/ –1.70	2.34/ –2.39	3.01/ –3.07	3.67/ –3.75	4.36/ –4.47	3.01/ –3.07	3.01/ –3.07
10P	0.28/ –0.28	0.86/ –0.86	1.66/ –1.67	2.47/ –2.47	3.55/ –3.55	4.57/ –4.57	5.58/ –5.59	–	3.55/ –3.55

(b) Transverse Deformation (in.)

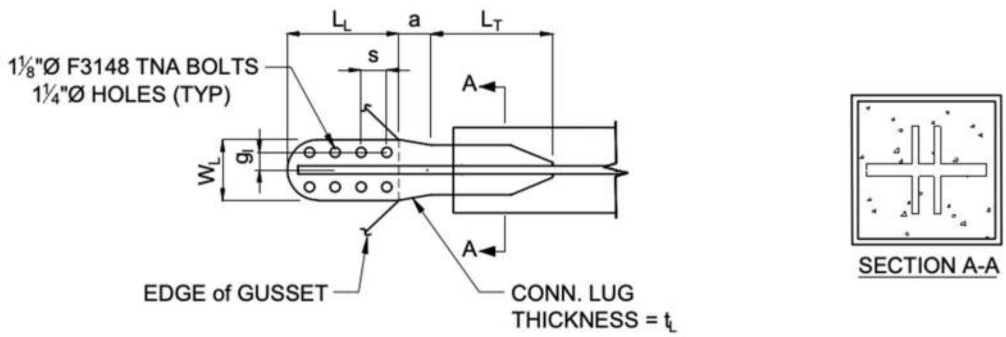
	Standard Protocol					Extended Protocol			
	Stage 1					Stage 2			Stage 3
No. of Cycles	2	2	2	2	2	2	2	2	10 (until Fracture)
8P	0.24	0.89	1.80	2.71	3.64	4.39	5.14	–	2.71
9P	0.22	0.66	1.34	2.01	2.69	3.38	4.08	2.69	2.69
10P	0.23	0.81	1.62	2.44	3.27	4.35	5.45	–	3.27



(a) Elevation View



(b) Plan View



(c) End Detail and Cross Section

Figure 2.1 Overall Brace Geometry

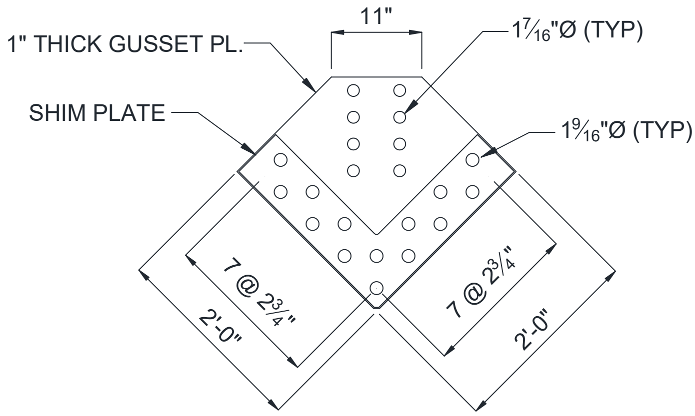


Figure 2.2 Specimen 8P: Detail of Gussets

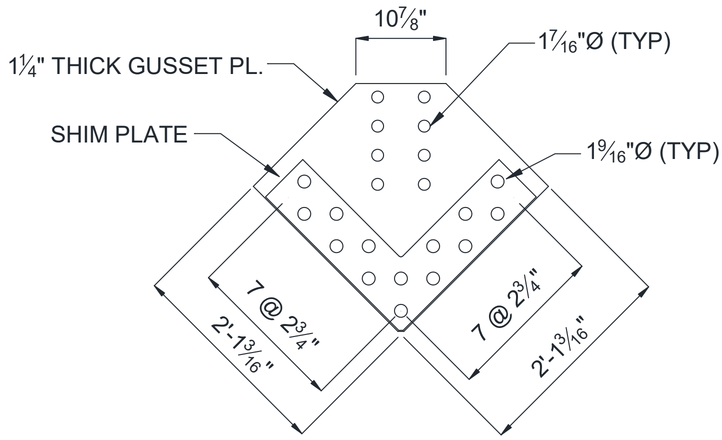


Figure 2.3 Specimen 9P: Detail of Gussets

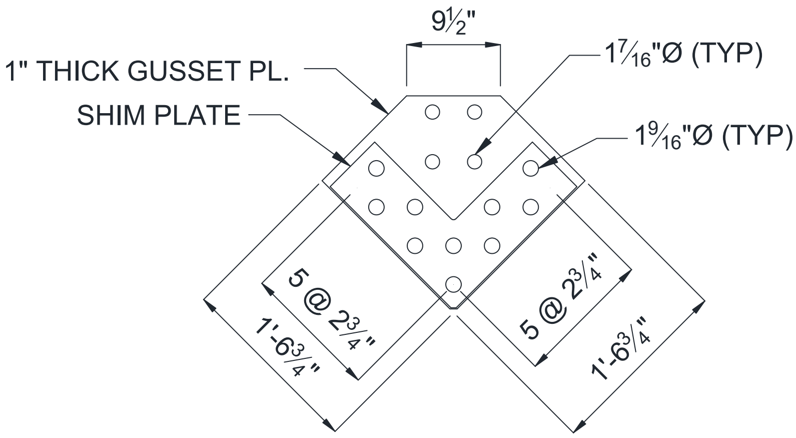


Figure 2.4 Specimen 10P: Detail of Gussets

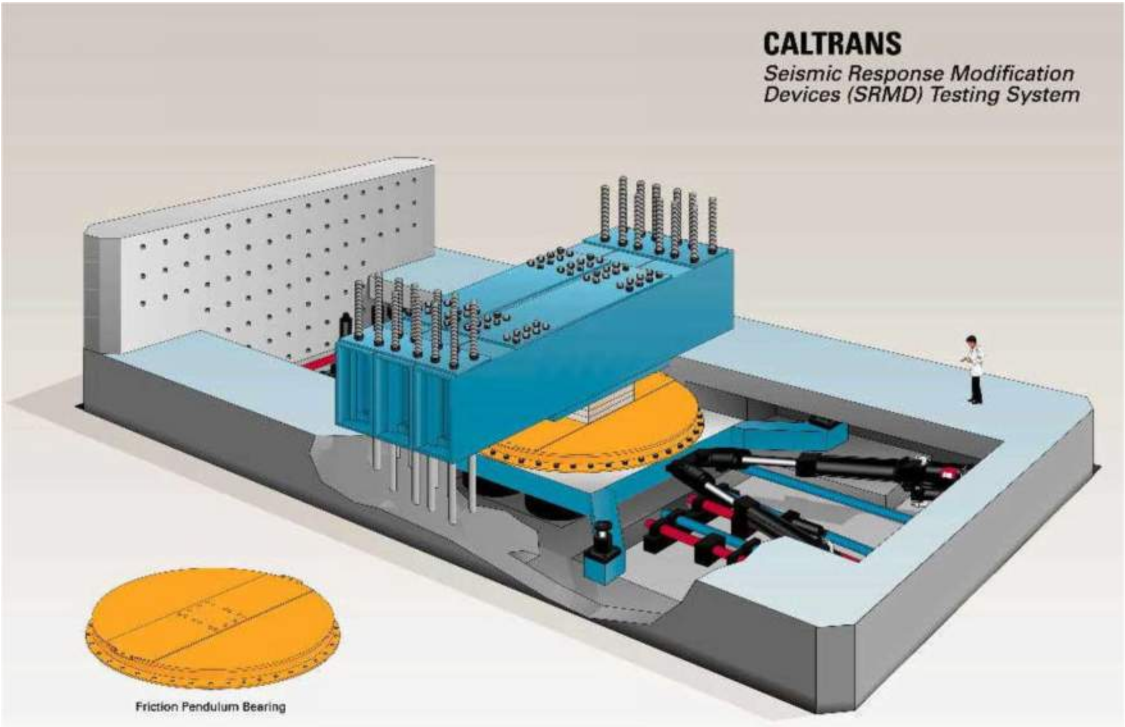


Figure 2.5 SRMD Test Facility

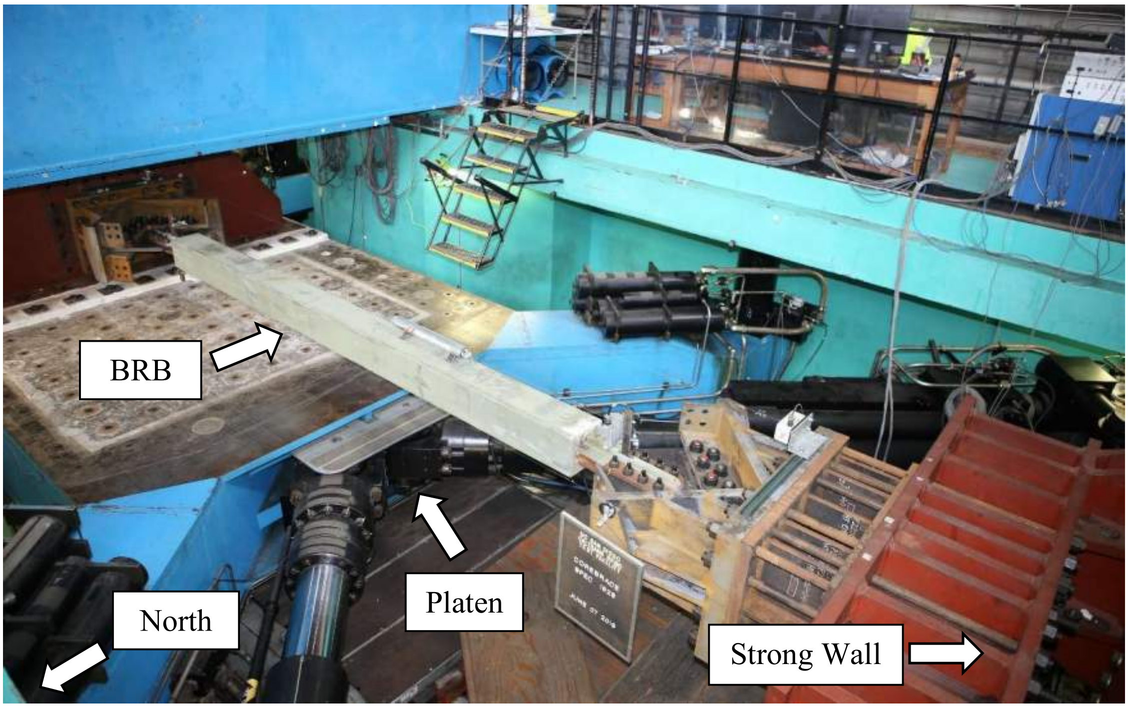
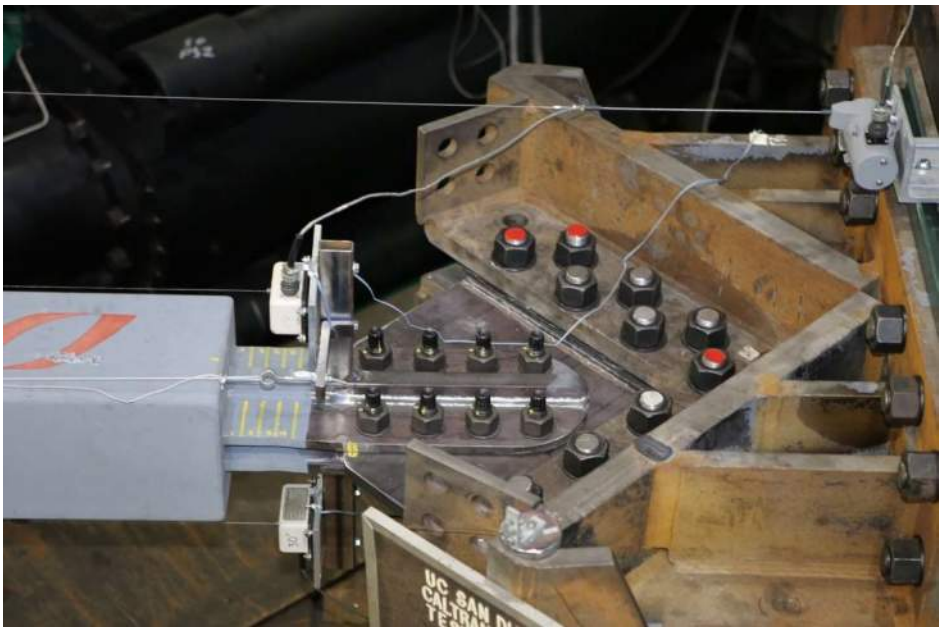
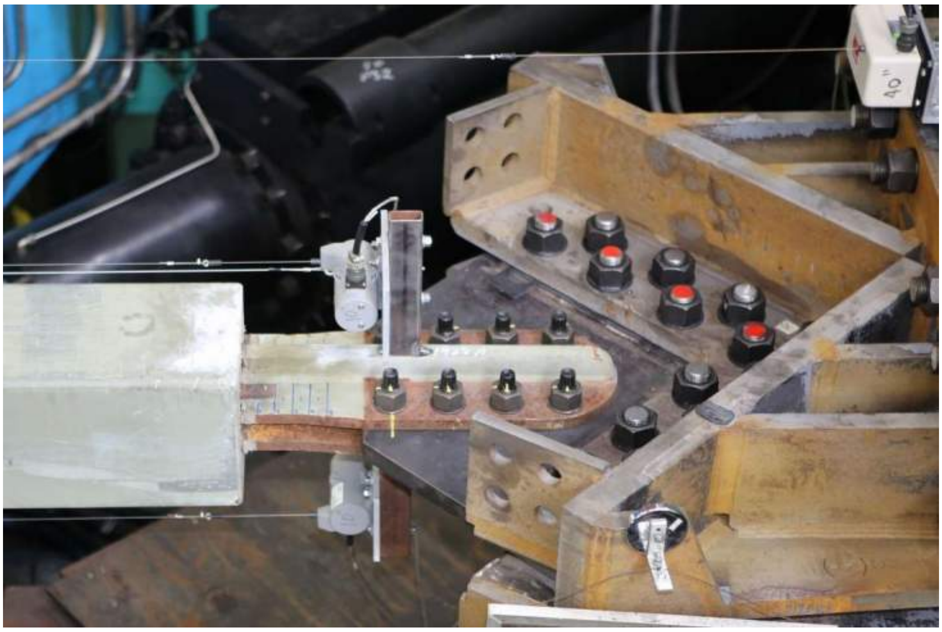


Figure 2.6 Typical Overall View of SRMD (Looking South)



(a) Specimen 8P (West End)

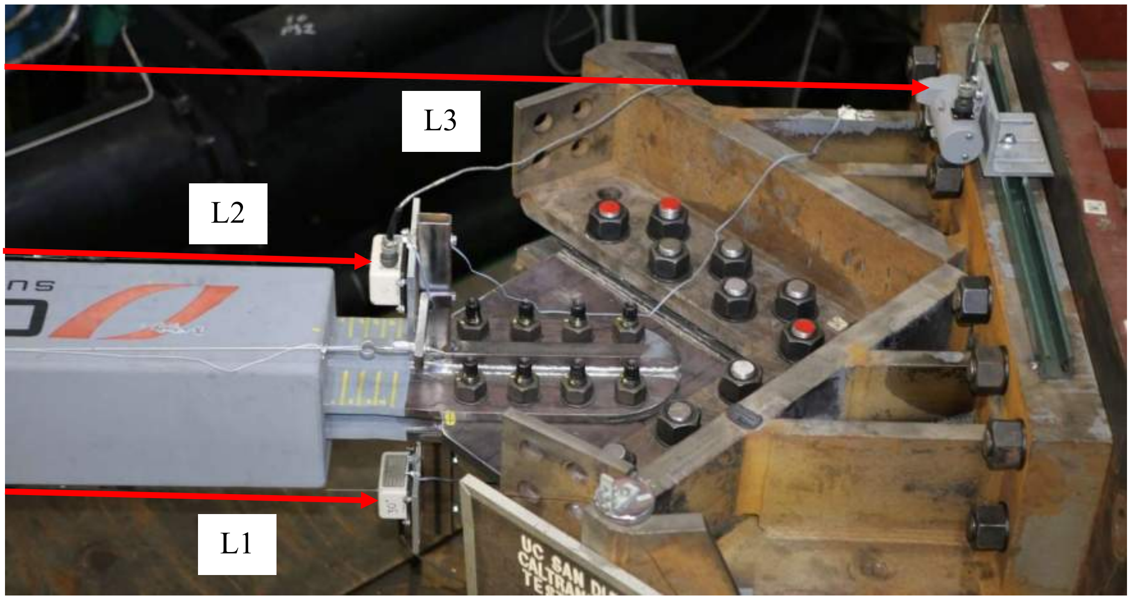


(b) Specimen 9P (West End)

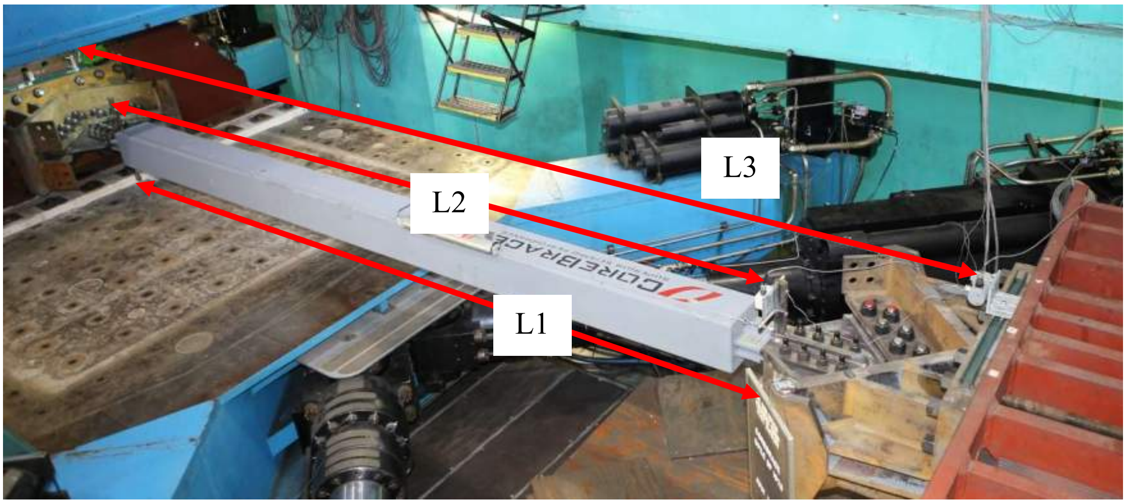
Figure 2.7 BRB End Connection

(c) Specimen 10P (West End)

Figure 2.7 BRB End Connection (continued)

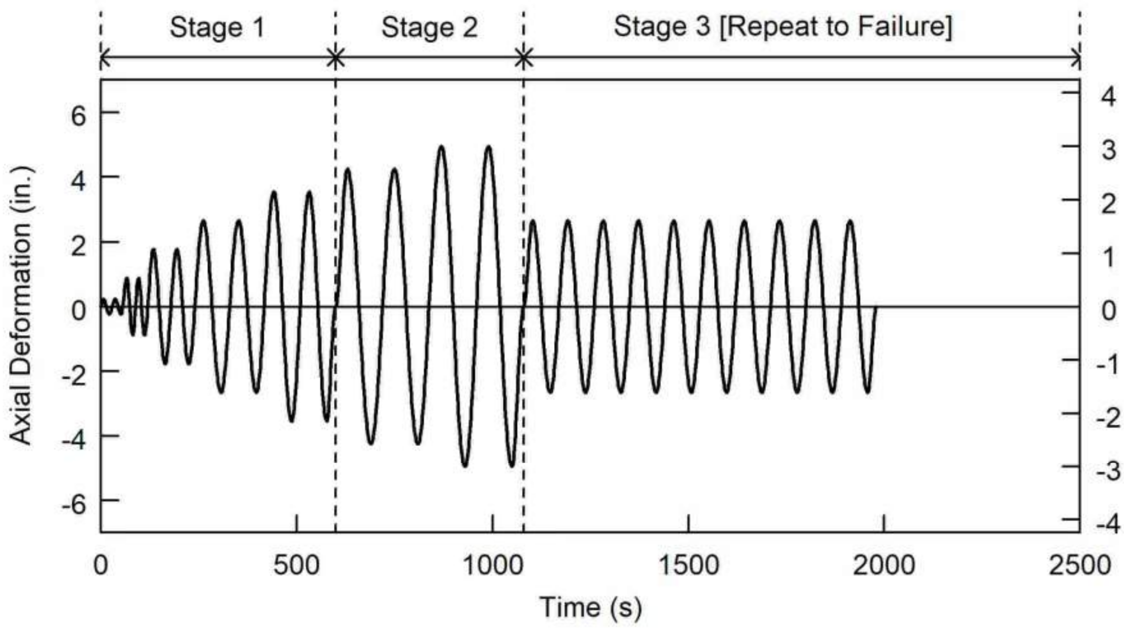


(a) West End

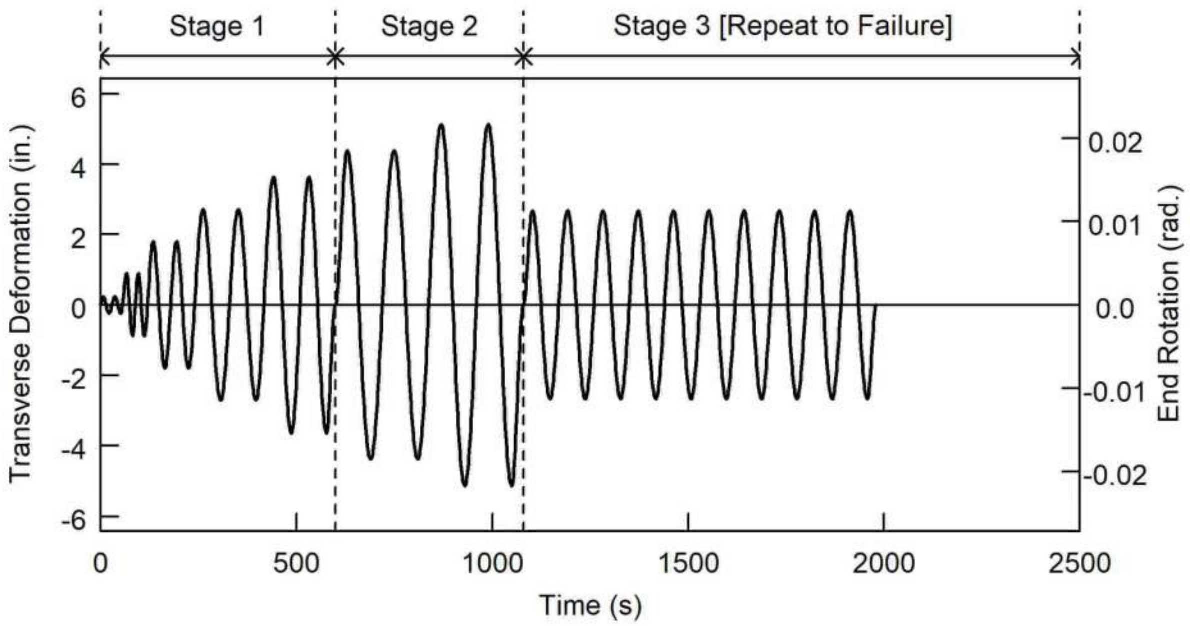


(b) Overall View

Figure 2.8 Typical Brace Instrumentation



(a) Longitudinal Direction



(b) Transverse Direction

Figure 2.9 Specimen 8P: Loading Protocol

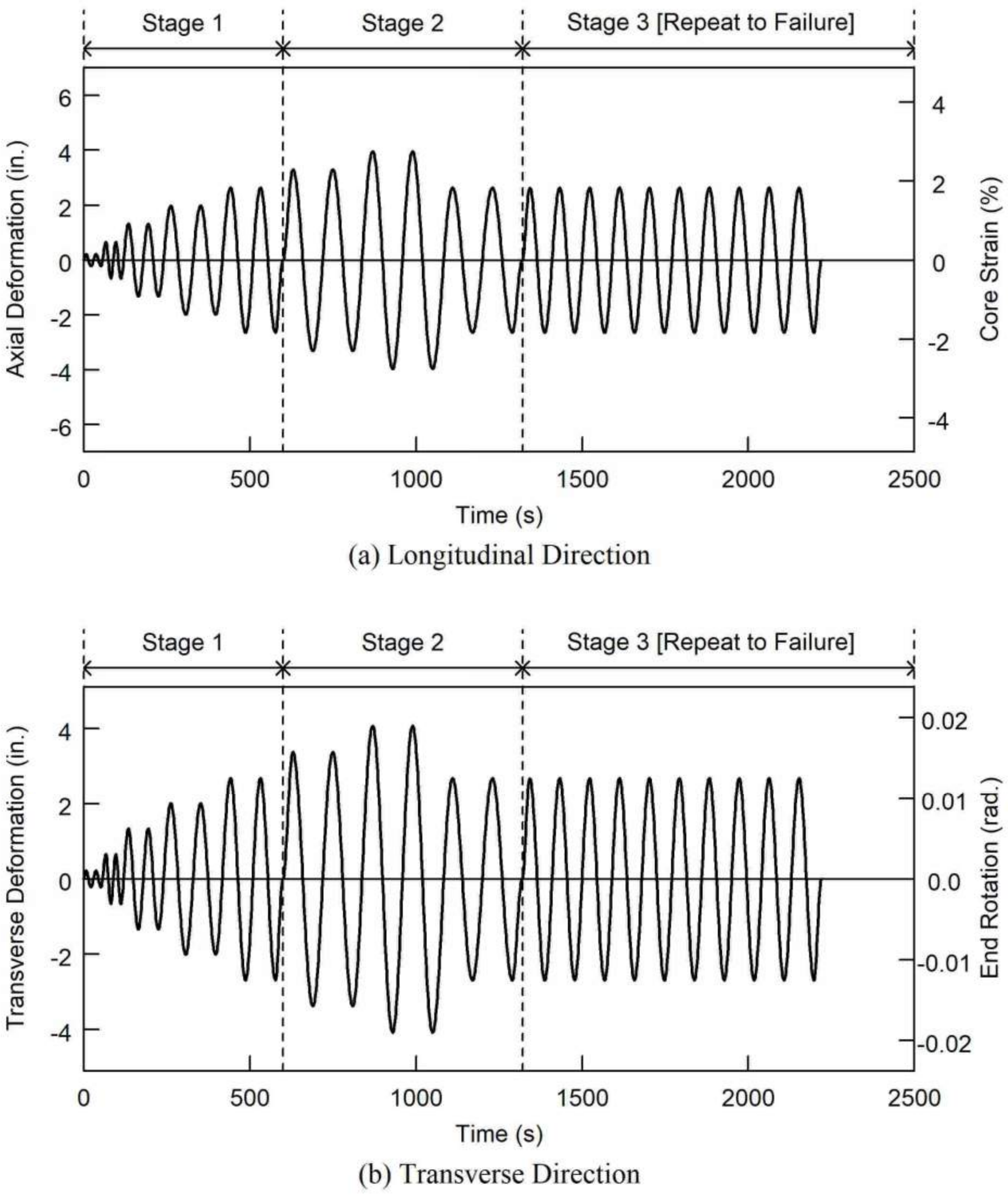
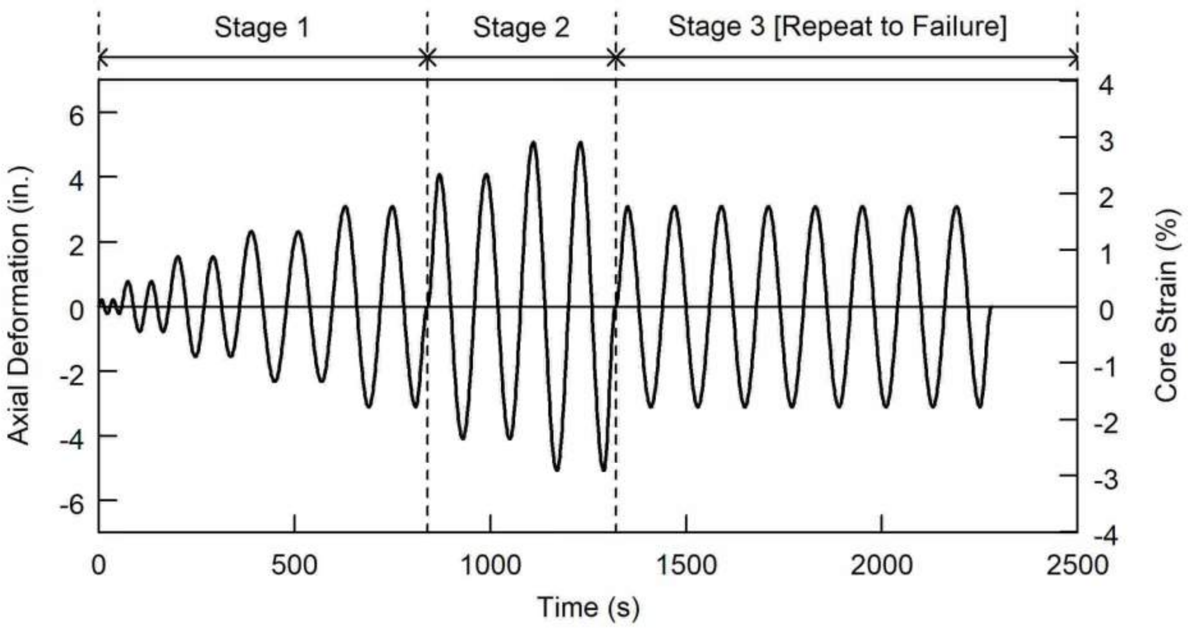
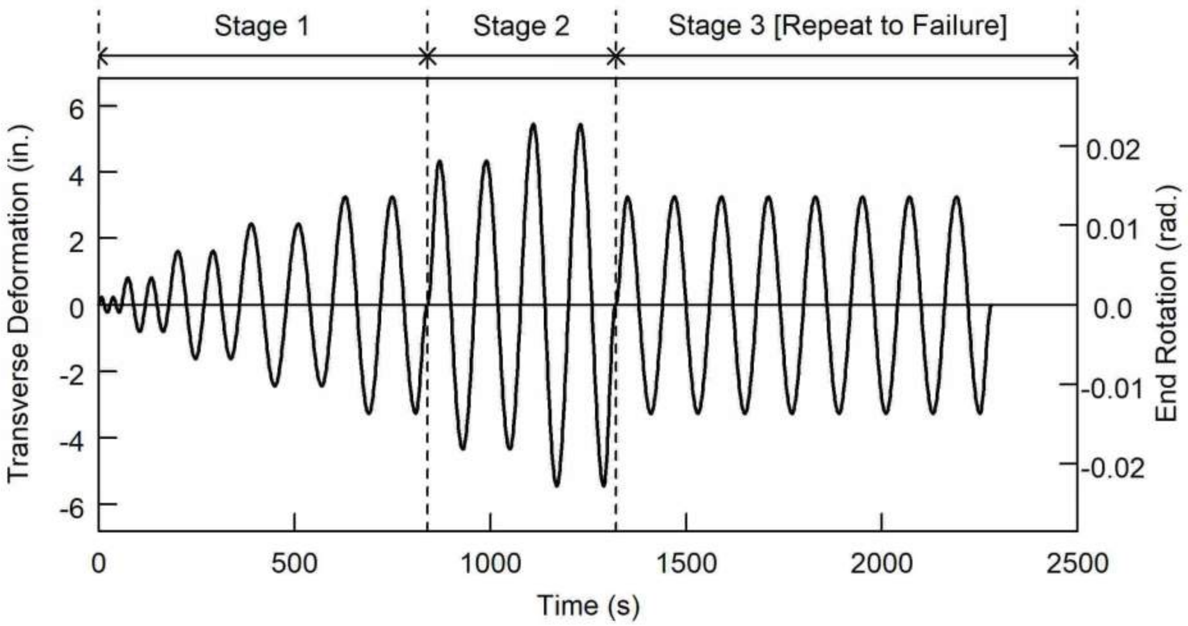


Figure 2.10 Specimen 9P: Loading Protocol



(a) Longitudinal Direction



(b) Transverse Direction

Figure 2.11 Specimen 10P: Loading Protocol

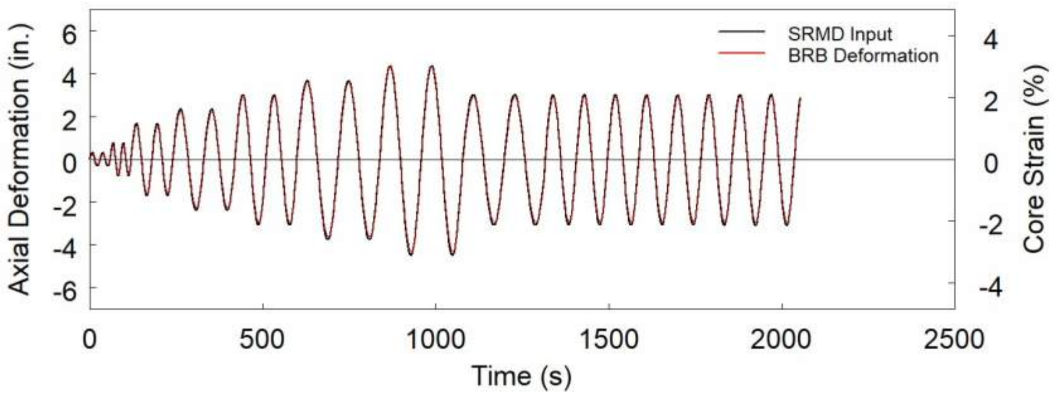


Figure 2.12 Specimen 9P: Comparison of SRMD Input Motion Compared and Measured BRB Axial Deformation

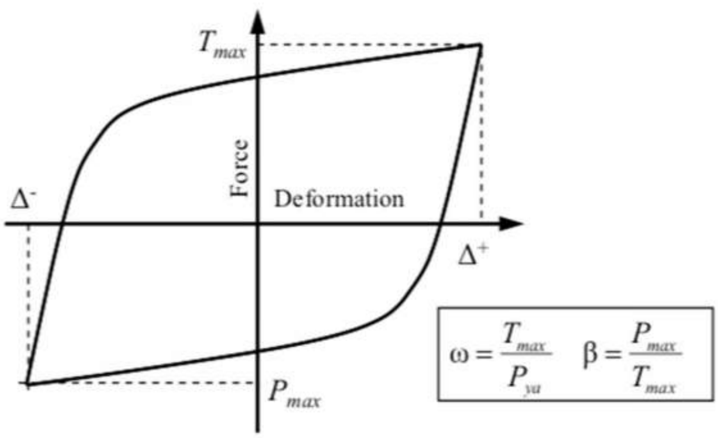


Figure 2.13 Definition of Strength Adjustment Factors for the i-th Cycle

(a) Casing Shift (Approx. 5/16")

(b) Casing Gouge (Approx. 1/8" Deep)

(c) Lug Bend: Overall View

(d) Heat Flare on Bent Lug

(e) Lug Measurement before Repair

(f) Lug Measurement after Repair

Figure 2.14 Specimen 9P: Damage due to Fall and Repaired Condition

3 TEST RESULTS

3.1 General

For each specimen, a table summarizing the brace forces, corresponding strength adjustment factors and cumulative inelastic axial deformation for each cycle of test run, as described in Section 2.7, is provided (see Table 3.1 through Table 3.3). The table also reports the axial deformation in terms of core axial strain (Eq. 2.1), deformation-based (Eqs. 2.6 to 2.7), and dissipated energy-based (Eq. 2.8) cumulative inelastic deformation. In addition, the following results are presented.

(1) Measured brace displacement time histories in the longitudinal and transverse directions. These displacements represent the actual deformations and end rotations experienced by the brace.

(2) Brace force versus deformation hysteretic responses in the longitudinal and transverse directions.

(3) Cumulative hysteretic energy, E_h, computed in accordance with Eq. 2.5 and the normalized cumulative dissipated energy, η_E, computed in accordance with Eq. 2.8 at the instance of core fracture.

(4) Axial brace response envelope, or backbone curve.

(5) Strength adjustment factors (ω, β, and βω) versus brace axial deformation (see Figure 3.5 through Figure 3.15). ω, β, and βω, were computed in accordance with Eqs. 2.2, 2.3, and 2.4, respectively.

3.2 Specimen 8P

Specimen 8P was tested on July 2nd, 2019. The specimen fractured during the first cycle of Stage 3 of the loading protocol. The failure occurred in the beginning of the cycle as it was approaching the peak tensile force which occurred at $22\Delta_{by}$. An initial peak force jump was observed at the start of Stage 3 of the loading protocol, right before the core fractured, as shown in Figure 3.2(a).

A maximum tension (ω) and compression (β) overstrength factor of 1.49 and 1.24 were achieved, respectively, during the loading protocol (see Table 3.1). The maximum tension force during the loading protocol was 435 kips at a displacement of 5.29 in., which corresponded to a core strain of 3.21%. The maximum compression force during the loading protocol was 538 kips at a displacement of −5.18 in., which corresponded to a core strain of −3.14%.

Figure 3.4 shows the computed hysteretic energy and cumulative dissipated energy for the loading protocol. A total of 53,180 kip-in. of hysteretic energy was absorbed, which corresponds to a cumulative ductility of $772\Delta_{by}$. About 55% energy came from Stage 2 of the loading protocol, as shown in Figure 4.1.

3.3 Specimen 9P

Specimen 9P was tested on June 7th, 2019. The specimen fractured during the 9th cycle of Stage 3 of the loading protocol. The failure occurred in the beginning of the cycle as it was approaching the peak tensile force which occurred at $12\Delta_{by}$ (after completing $20\Delta_{by}$ cycles in Stage 2).

A maximum tension (ω) and compression (β) overstrength factor of 1.37 and 1.27 were achieved, respectively, during the loading protocol (see Table 3.2). The maximum tension force during the loading protocol was 488 kips at a displacement of 4.32 in., which corresponded to a core strain of 3.00%. The maximum compression force during the loading protocol was 610 kips at a displacement of −4.29 in., which corresponded to a core strain of −2.98%.

Figure 3.9 shows the computed hysteretic energy and cumulative dissipated energy for the loading protocol. A total of 91,710 kip-in. of hysteretic energy was absorbed, which corresponds to a cumulative ductility of $1,173\Delta_{by}$. The energy from Stages 2 and 3 of the loading protocols were very similar, but larger than from Stage 1 of the loading protocol, as shown in Figure 4.1.

3.4 Specimen 10P

Specimen 10P was tested on April 14th, 2020. The specimen completed Stages 1 and 2 loadings and fractured during the 2nd cycle of Stage 3 loading. The failure occurred just before the brace reached the peak tensile force which occurred at $14\Delta_{by}$ in that cycle (after completing $24\Delta_{by}$ cycles in Stage 2).

A maximum tension (ω) and compression (β) overstrength factor of 1.52 and 1.48 were achieved, respectively, during the loading protocol (see Table 3.3). The β values for Specimen 10P was higher than those for Specimens 8P and 9P. This could be due to the nature of small core BRB for Specimen 10P. The maximum tension force during the loading protocol was 130 kips at a displacement of 5.60 in., which corresponds to a core strain of 3.21%. The maximum compression force during the loading protocol was 193 kips at a displacement of -5.52 in., which corresponds to a core strain of -3.17%.

Figure 3.9 shows the computed hysteretic energy and cumulative dissipated energy for the loading protocol. A total of 16,730 kip-in. of hysteretic energy was absorbed, which corresponds to a cumulative ductility of $851\Delta_{by}$. About 54% energy came from Stage 2 of the loading protocol, as shown Figure 4.1.

Table 3.1 Specimen 8P: Response Quantities

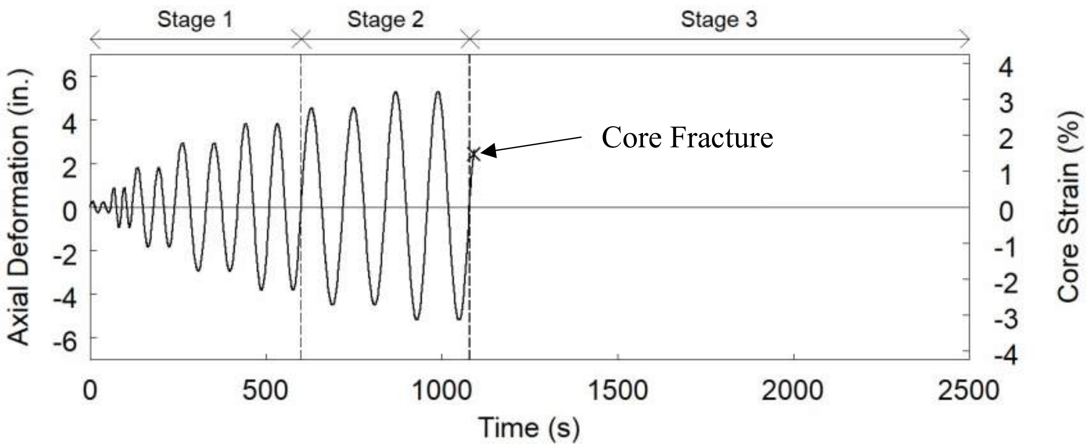
Test	Cycle No.	T_{max} (kips)	C_{max} (kips)	ω	β	βω	Brace Deformation: Axial Positive (in.)	Axial Positive (Δ_{by})	Axial Positive (%)	Axial Negative (in.)	Axial Negative (Δ_{by})	Axial Negative (%)	Transverse (in.)	Transverse (rad)	μ_i	η_D	η_E
Loading Protocol – Stage 1 (AISC)	1	287	297	0.98	1.04	1.02	0.26	1.08	0.15	0.26	1.08	0.15	0.23	0.001	0.32	0	1
	2	278	284	0.95	1.02	0.97	0.24	1.03	0.15	0.25	1.06	0.15	0.23	0.001	0.19	1	1
	3	296	305	1.02	1.03	1.05	0.89	3.78	0.54	0.94	3.97	0.57	0.88	0.004	11.51	12	10
	4	302	313	1.04	1.04	1.07	0.89	3.76	0.54	0.94	3.97	0.57	0.87	0.004	11.46	23	21
	5	326	369	1.12	1.13	1.27	1.81	7.67	1.10	1.83	7.77	1.11	1.79	0.008	26.89	50	44
	6	349	376	1.20	1.08	1.29	1.80	7.62	1.09	1.84	7.78	1.11	1.78	0.008	26.80	77	71
	7	368	422	1.26	1.15	1.45	2.93	12.43	1.78	2.93	12.43	1.78	2.70	0.011	45.73	123	117
	8	384	430	1.32	1.12	1.47	2.93	12.42	1.78	2.93	12.42	1.78	2.69	0.011	45.69	169	170
	9	397	465	1.36	1.17	1.59	3.83	16.21	2.32	3.80	16.12	2.31	3.61	0.015	60.66	229	240
	10	408	474	1.40	1.16	1.62	3.83	16.22	2.32	3.80	16.09	2.30	3.61	0.015	60.62	290	315
Loading Protocol – Stage 2	11	419	508	1.44	1.21	1.74	4.55	19.28	2.76	4.50	19.06	2.73	4.38	0.019	72.68	363	407
	12	428	513	1.47	1.20	1.76	4.55	19.27	2.76	4.50	19.06	2.73	4.38	0.019	72.67	435	503
	13	433	533	1.48	1.23	1.83	5.29	22.41	3.21	5.18	21.93	3.14	5.12	0.022	84.69	520	615
	14	435	538	1.49	1.24	1.84	5.29	22.43	3.21	5.18	21.93	3.14	5.11	0.022	84.71	605	733

Table 3.2 Specimen 9P: Response Quantities

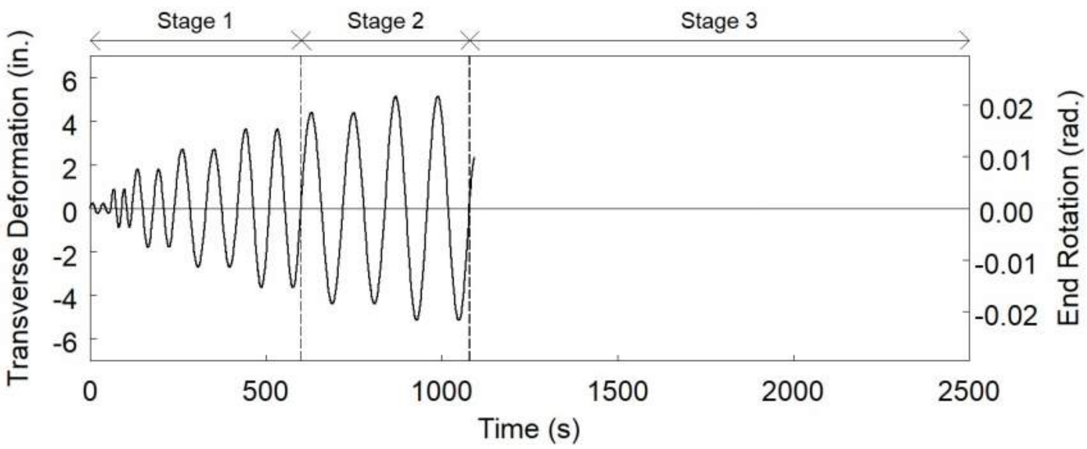
Test		Cycle No.	T_{max} (kips)	C_{max} (kips)	ω	β	βω	Brace Deformation								μ_i	η_D	η_E
								Axial						Transverse				
								Positive			Negative							
								(in.)	(Δ_{by})	(%)	(in.)	(Δ_{by})	(%)	(in.)	(rad)			
Loading Protocol	Stage 1 (AISC)	1	329	350	0.93	1.06	0.98	0.23	1.06	0.16	0.24	1.07	0.16	0.21	0.001	0.26	0	1
		2	326	337	0.92	1.04	0.95	0.23	1.04	0.16	0.24	1.08	0.17	0.20	0.001	0.24	0	2
		3	335	353	0.94	1.05	0.99	0.67	3.07	0.47	0.69	3.13	0.48	0.65	0.003	8.39	9	8
		4	332	354	0.94	1.07	1.00	0.68	3.07	0.47	0.68	3.11	0.48	0.64	0.003	8.36	17	16
		5	355	423	1.00	1.19	1.19	1.57	7.16	1.09	1.59	7.22	1.10	1.34	0.006	24.75	42	35
		6	390	437	1.10	1.12	1.23	1.56	7.08	1.08	1.59	7.21	1.10	1.34	0.006	24.58	67	59
		7	408	484	1.15	1.19	1.36	2.24	10.17	1.55	2.25	10.25	1.57	2.01	0.009	36.83	103	94
		8	422	490	1.19	1.16	1.38	2.23	10.12	1.55	2.26	10.25	1.57	2.00	0.009	36.74	140	133
		9	437	529	1.23	1.21	1.49	2.91	13.24	2.02	2.92	13.28	2.03	2.68	0.013	49.03	189	184
		10	448	535	1.26	1.19	1.51	2.91	13.21	2.02	2.92	13.27	2.03	2.68	0.012	48.96	238	239
	Stage 2	11	466	578	1.31	1.24	1.63	3.60	16.36	2.50	3.59	16.33	2.50	3.37	0.016	61.37	300	309
		12	474	582	1.34	1.23	1.64	3.60	16.35	2.50	3.59	16.30	2.49	3.36	0.016	61.30	361	384
		13	482	610	1.36	1.27	1.72	4.32	19.65	3.00	4.29	19.51	2.98	4.07	0.019	74.31	435	474
		14	488	610	1.37	1.25	1.72	4.32	19.65	3.00	4.29	19.48	2.98	4.06	0.019	74.26	509	569
		15	479	555	1.35	1.16	1.56	2.91	13.23	2.02	2.91	13.22	2.02	2.68	0.012	48.91	558	636
		16	469	552	1.32	1.18	1.56	2.91	13.24	2.02	2.91	13.23	2.02	2.68	0.012	48.95	607	693
	Stage 3	17	473	557	1.33	1.18	1.57	2.91	13.23	2.02	2.91	13.20	2.02	2.68	0.012	48.87	656	751
		18	467	556	1.31	1.19	1.57	2.91	13.21	2.02	2.91	13.24	2.02	2.68	0.012	48.88	705	808
		19	463	554	1.30	1.20	1.56	2.91	13.21	2.02	2.91	13.21	2.02	2.67	0.012	48.83	754	865
		20	461	553	1.30	1.20	1.56	2.91	13.22	2.02	2.90	13.18	2.01	2.68	0.013	48.80	803	922
		21	459	554	1.29	1.21	1.56	2.91	13.21	2.02	2.91	13.22	2.02	2.69	0.013	48.86	851	978
		22	458	555	1.29	1.21	1.56	2.92	13.25	2.03	2.91	13.24	2.02	2.67	0.012	48.99	900	1035
		23	455	550	1.28	1.21	1.55	2.92	13.27	2.03	2.91	13.25	2.02	2.67	0.012	49.03	949	1091
		24	454	560	1.28	1.23	1.58	2.92	13.27	2.03	2.93	13.31	2.03	2.67	0.012	49.16	999	1148

Table 3.3 Specimen 10P: Response Quantities

Test		Cycle No.	T_{max} (kips)	C_{max} (kips)	ω	β	βω	Brace Deformation								μ_i	η_D	η_E
								Axial						Transverse				
								Positive			Negative							
								(in.)	(Δ_{by})	(%)	(in.)	(Δ_{by})	(%)	(in.)	(rad)			
Loading Protocol	Stage 1 (AISC)	1	76	78	0.88	1.03	0.91	0.26	1.12	0.15	0.27	1.17	0.15	0.22	0.001	0.56	1	1
		2	76	76	0.89	1.00	0.89	0.26	1.12	0.15	0.26	1.12	0.15	0.21	0.001	0.47	1	2
		3	98	102	1.14	1.04	1.19	0.85	3.71	0.49	0.85	3.69	0.49	0.80	0.003	10.80	12	10
		4	100	99	1.16	1.00	1.16	0.85	3.71	0.49	0.85	3.70	0.49	0.80	0.003	10.82	23	19
		5	103	114	1.20	1.11	1.33	1.64	7.18	0.94	1.63	7.13	0.94	1.61	0.007	24.63	47	41
		6	107	115	1.24	1.08	1.34	1.65	7.19	0.94	1.63	7.13	0.94	1.61	0.007	24.62	72	66
		7	110	126	1.28	1.14	1.46	2.47	10.77	1.42	2.44	10.65	1.40	2.43	0.010	38.84	111	105
		8	112	125	1.31	1.11	1.46	2.47	10.78	1.42	2.44	10.65	1.40	2.44	0.010	38.86	150	148
		9	115	139	1.34	1.21	1.62	3.53	15.42	2.03	3.50	15.26	2.01	3.27	0.014	57.36	207	210
		10	118	140	1.38	1.19	1.64	3.52	15.38	2.02	3.50	15.27	2.01	3.27	0.014	57.29	264	280
	Stage 2	11	122	156	1.42	1.28	1.82	4.57	19.95	2.62	4.49	19.59	2.57	4.36	0.018	75.08	339	371
		12	125	161	1.45	1.29	1.88	4.56	19.93	2.62	4.49	19.62	2.58	4.36	0.018	75.09	414	470
		13	128	182	1.49	1.43	2.13	5.60	24.45	3.21	5.52	24.09	3.17	5.45	0.023	93.09	508	595
		14	130	193	1.52	1.48	2.24	5.59	24.43	3.21	5.52	24.12	3.17	5.46	0.023	93.10	601	729
	Stage 3	15	130	163	1.51	1.26	1.90	3.51	15.33	2.01	3.53	15.39	2.02	3.28	0.014	57.45	658	818

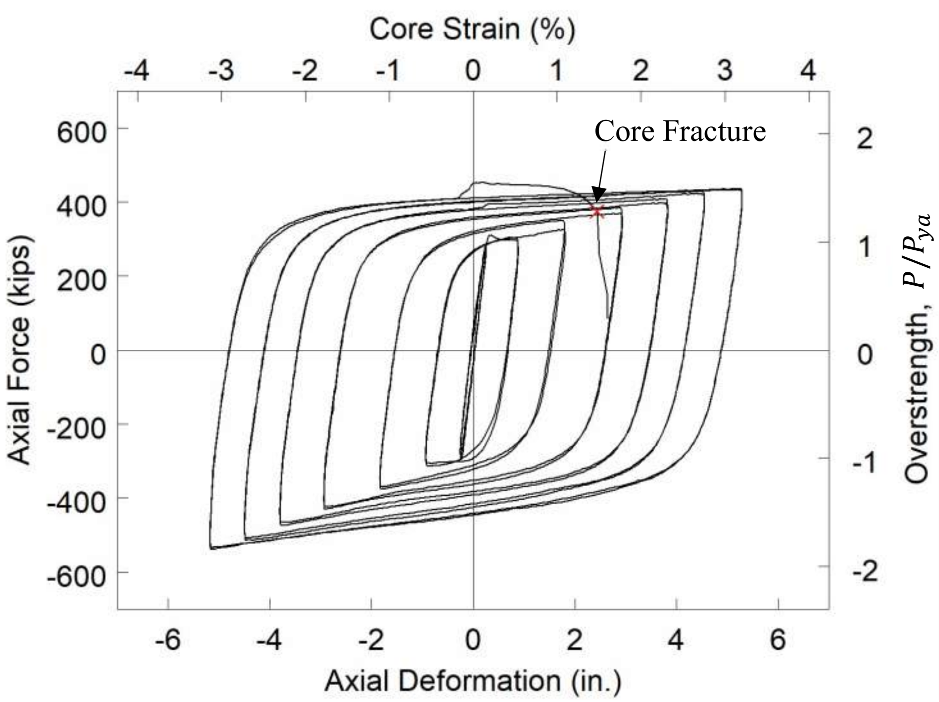


(a) Longitudinal Direction

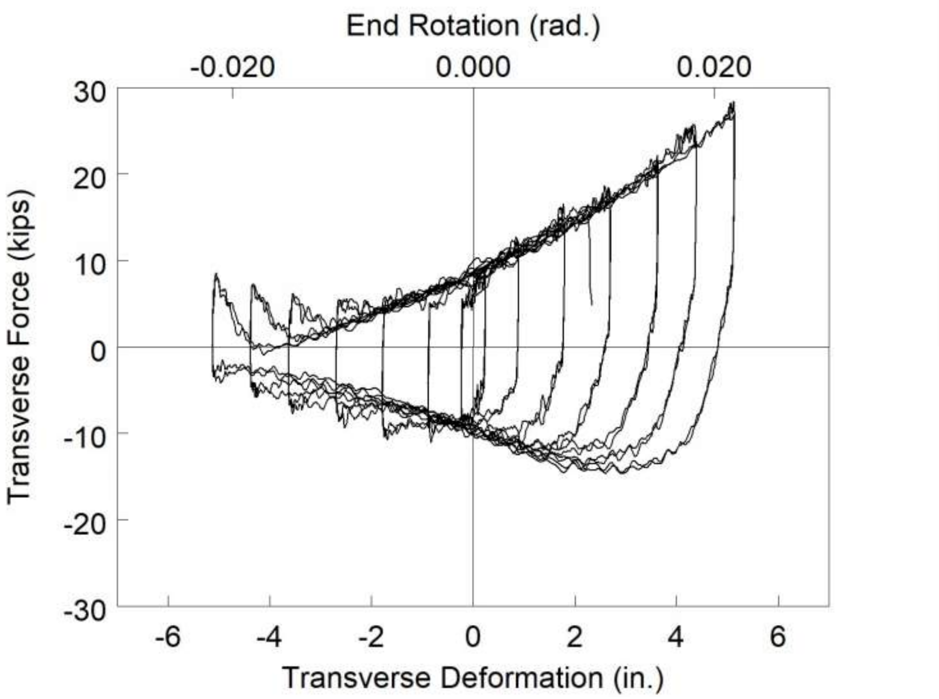


(b) Transverse Direction

Figure 3.1 Specimen 8P: Brace Deformation Time Histories



(a) Axial Force vs. Axial Deformation



(b) Transverse Force vs. Transverse Deformation

Figure 3.2 Specimen 8P: Hysteretic Response

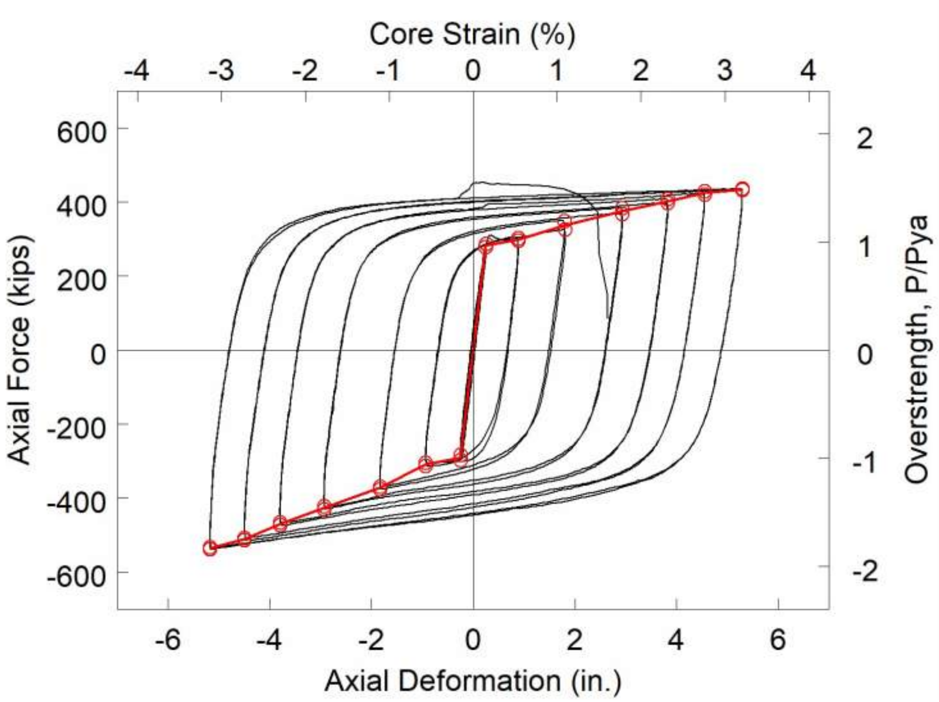


Figure 3.3 Specimen 8P: Hysteretic Response Envelope

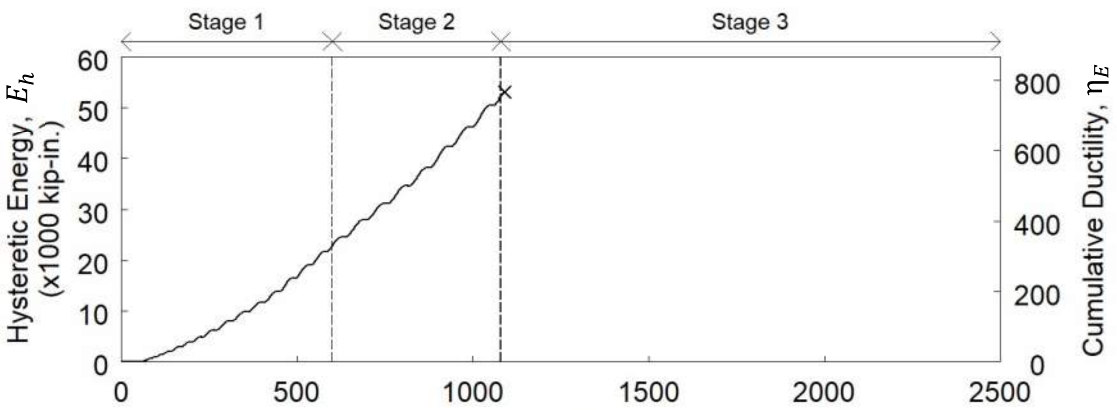
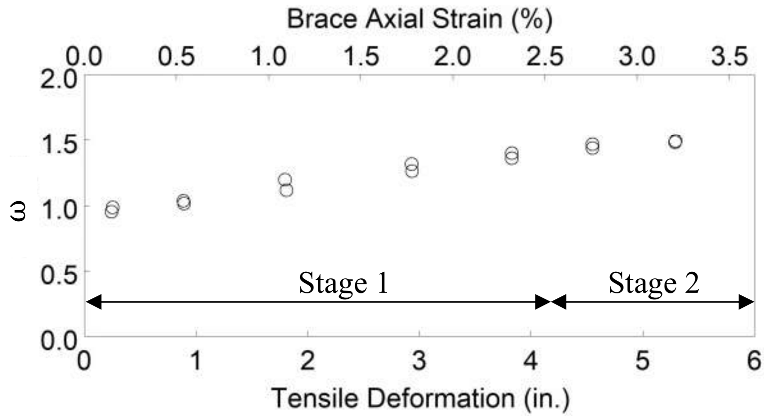
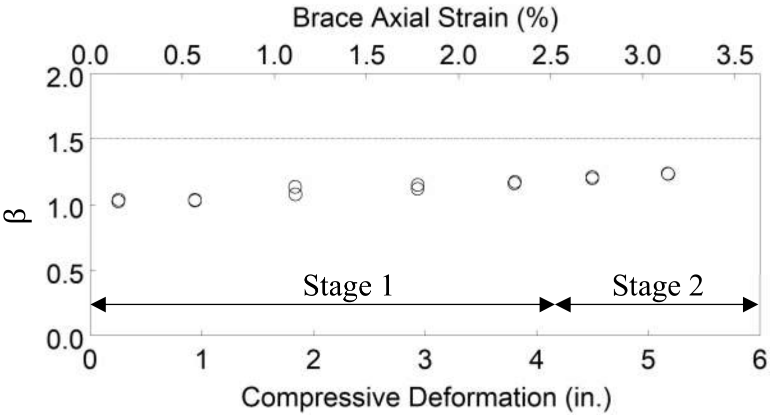


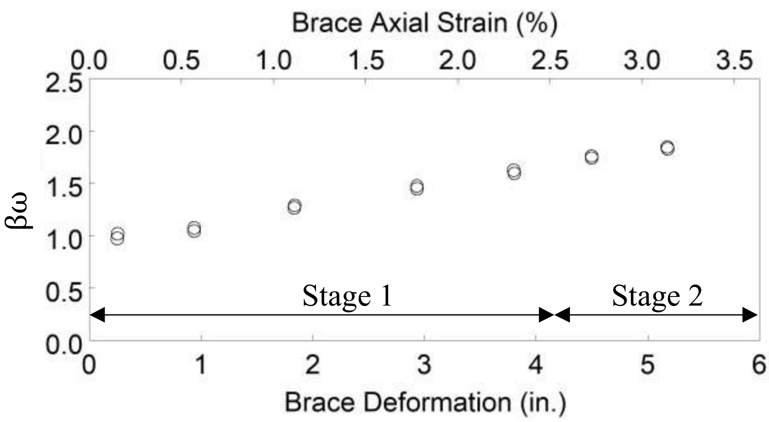
Figure 3.4 Specimen 8P: Cumulative Hysteretic Energy



(a) ω vs. Axial Deformation

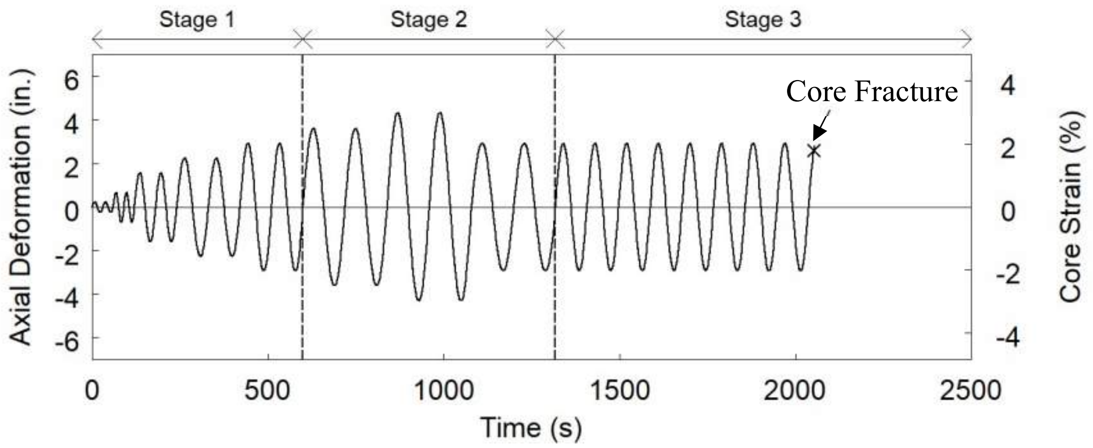


(b) β vs. Axial Deformation

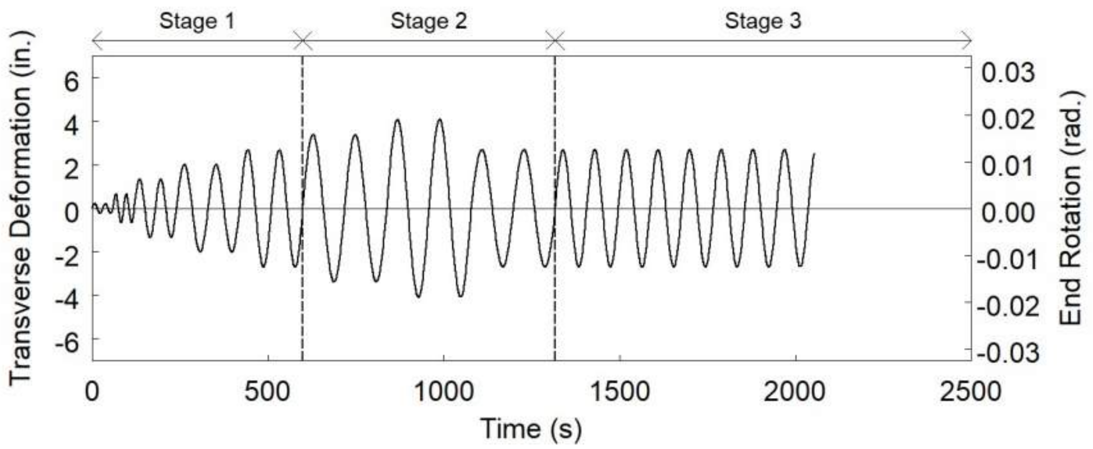


(c) βω vs. Axial Deformation

Figure 3.5 Specimen 8P: Strength Adjustment Factors

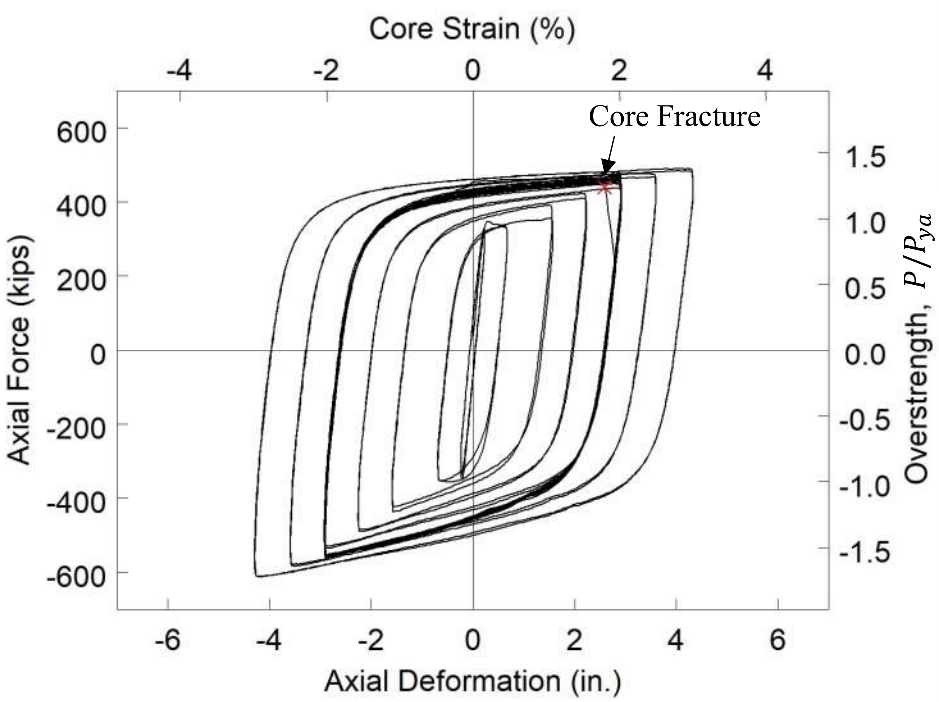


(a) Longitudinal Direction

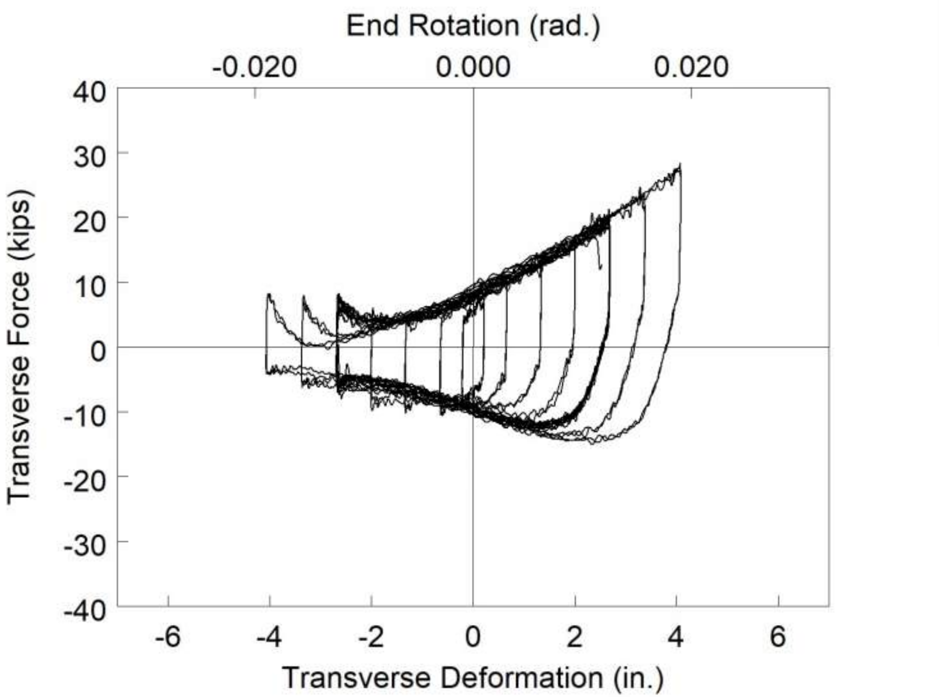


(b) Transverse Direction

Figure 3.6 Specimen 9P: Brace Deformation Time Histories



(a) Axial Force vs. Axial Deformation



(b) Transverse Force vs. Transverse Deformation

Figure 3.7 Specimen 9P: Hysteretic Response

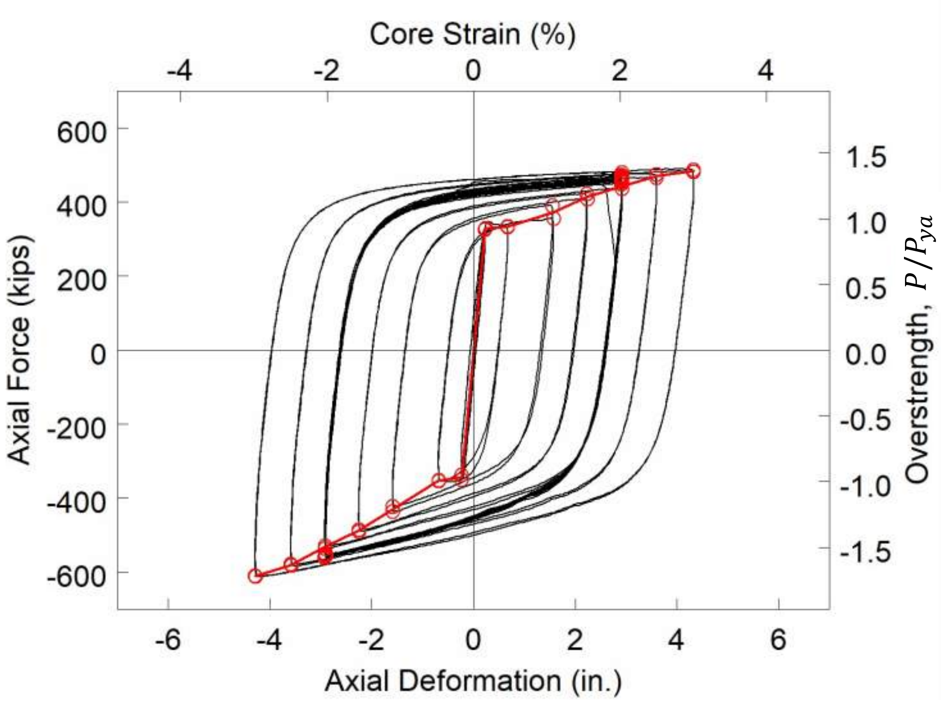


Figure 3.8 Specimen 9P: Hysteretic Response Envelope

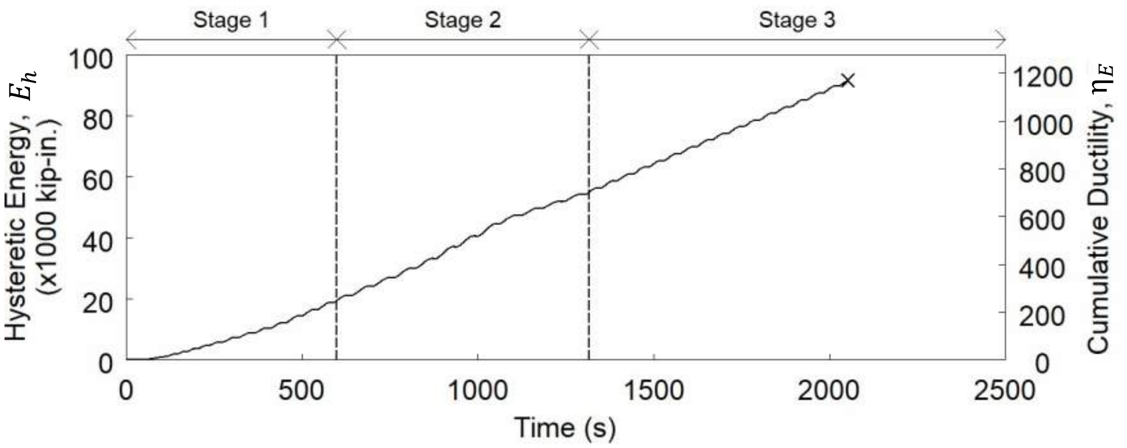
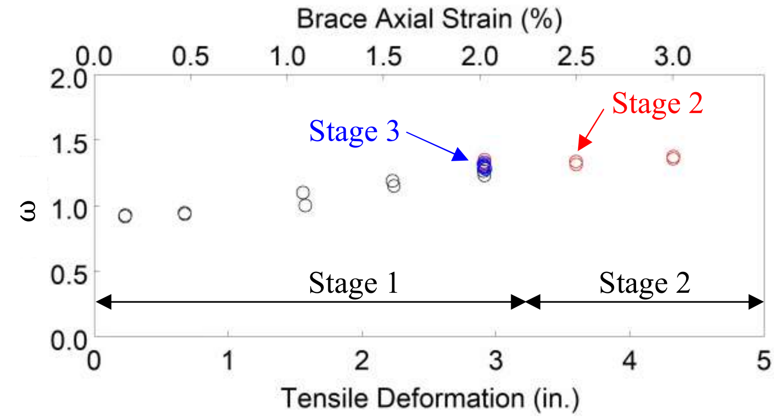
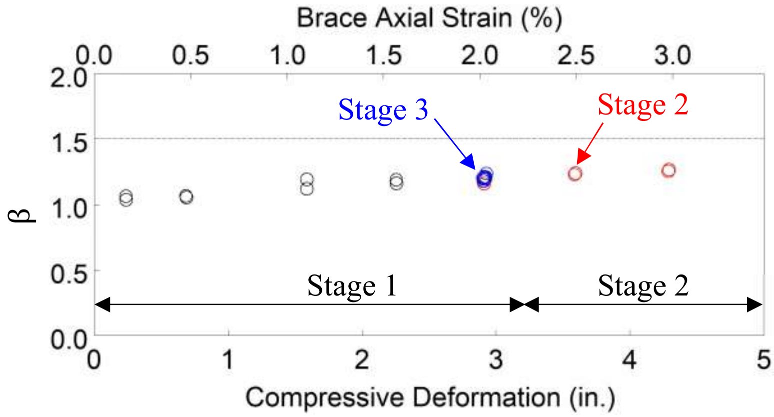


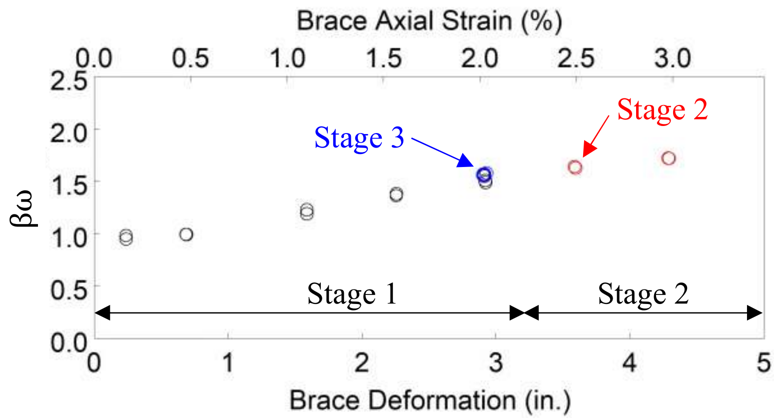
Figure 3.9 Specimen 9P: Cumulative Hysteretic Energy



(a) ω vs. Axial Deformation

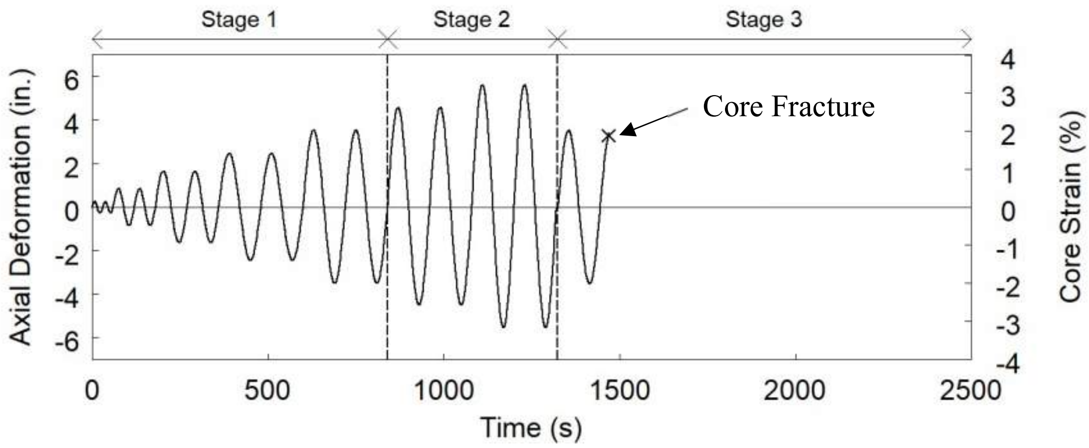


(b) β vs. Axial Deformation

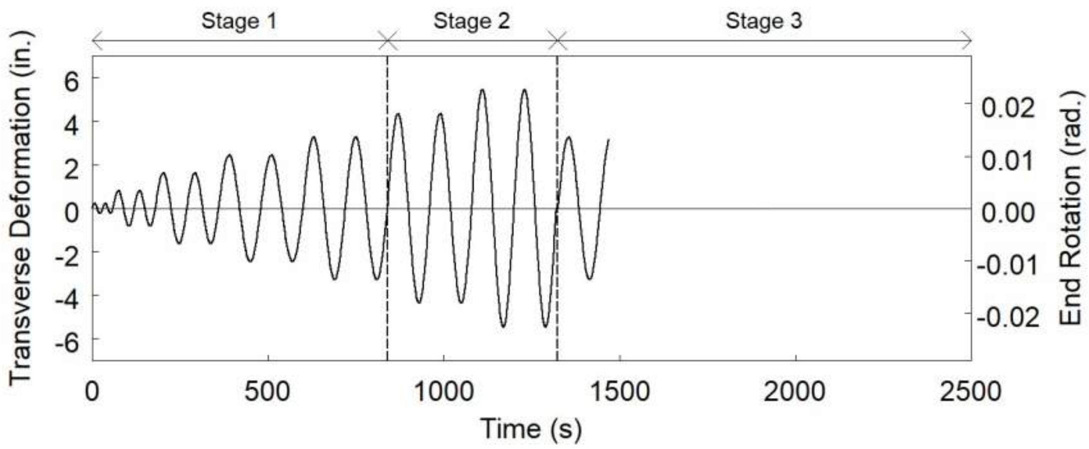


(c) βω vs. Axial Deformation

Figure 3.10 Specimen 9P: Strength Adjustment Factors

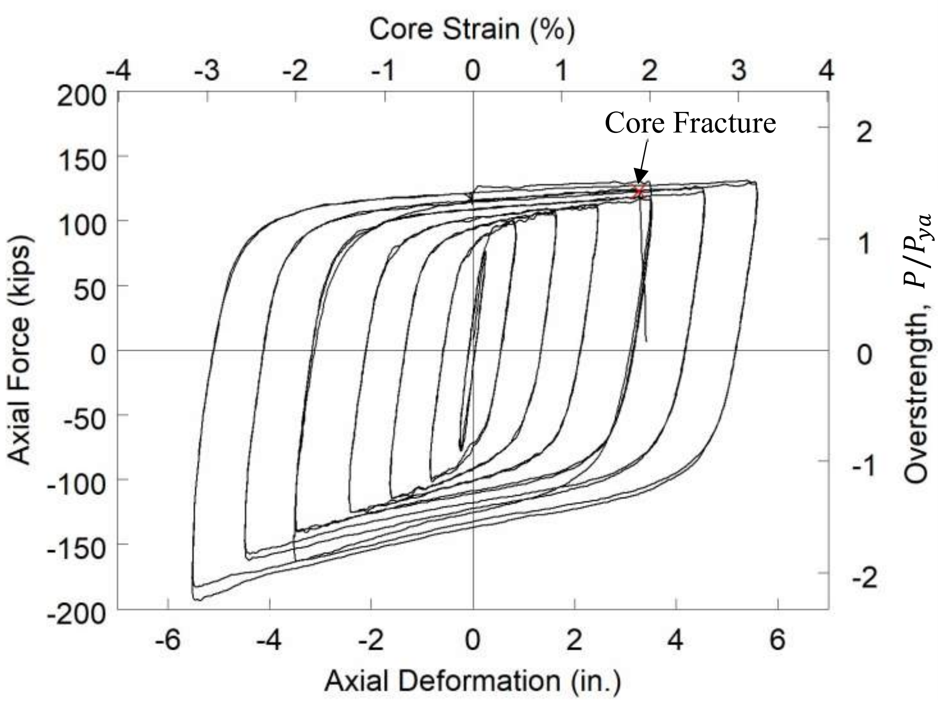


(c) Longitudinal Direction

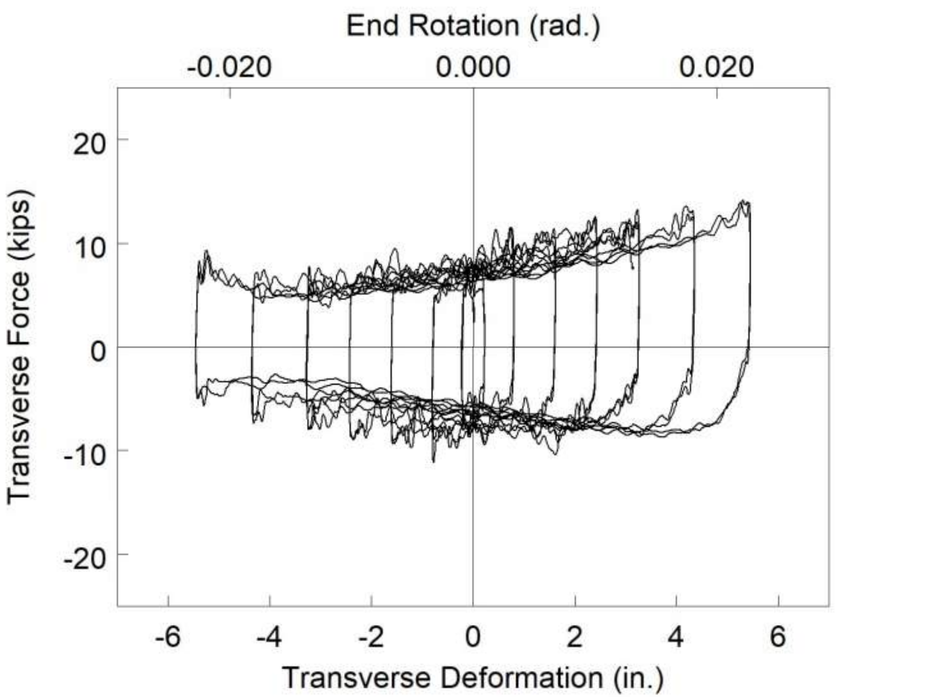


(d) Transverse Direction

Figure 3.11 Specimen 10P: Brace Deformation Time Histories



(c) Axial Force vs. Axial Deformation



(d) Transverse Force vs. Transverse Deformation

Figure 3.12 Specimen 10P: Hysteretic Response

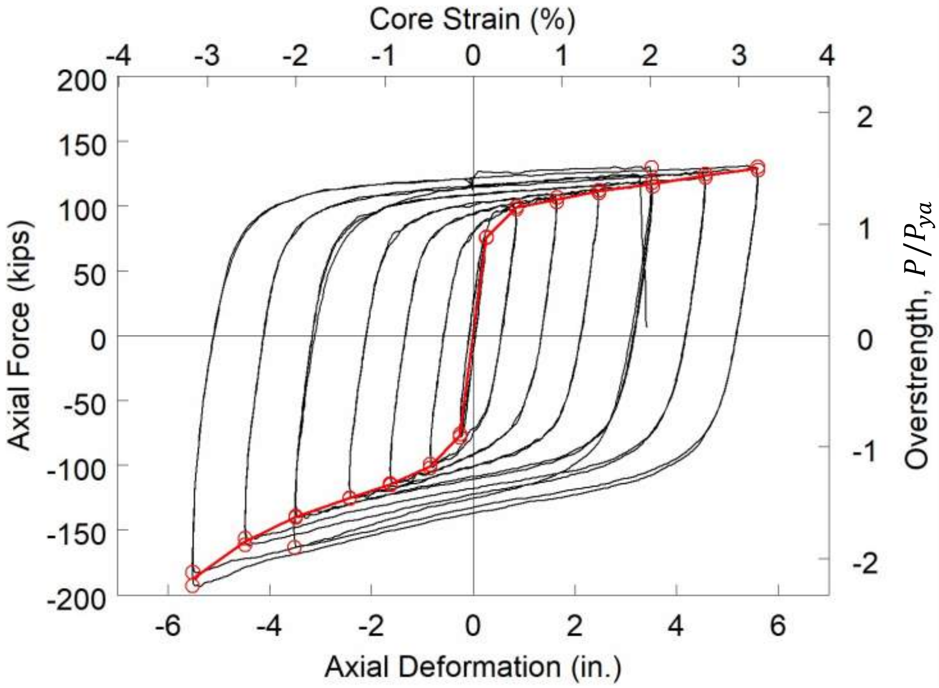


Figure 3.13 Specimen 10P: Hysteretic Response Envelope

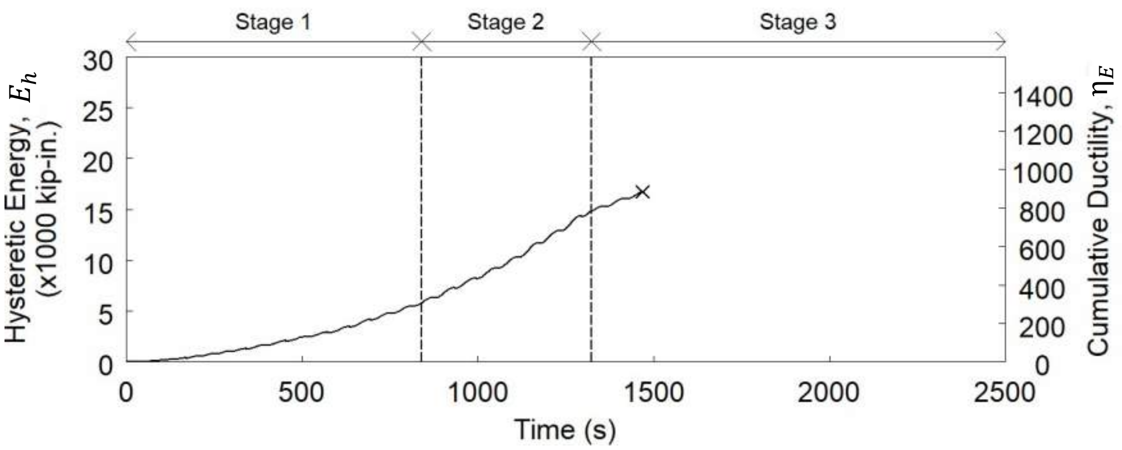
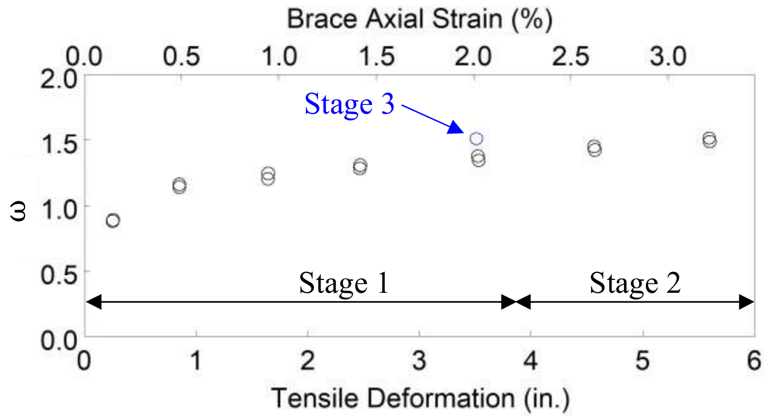
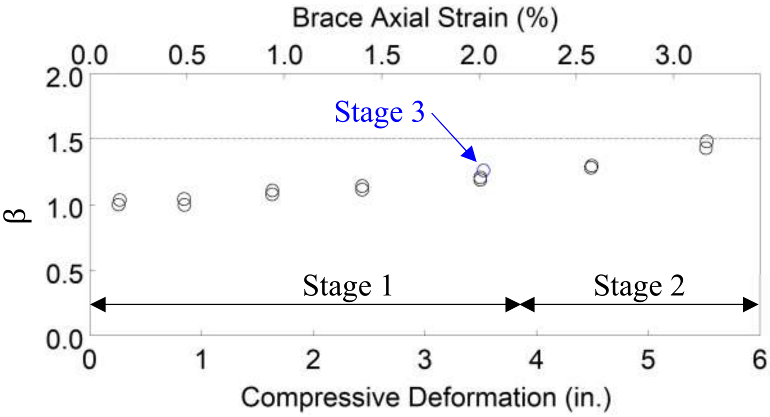


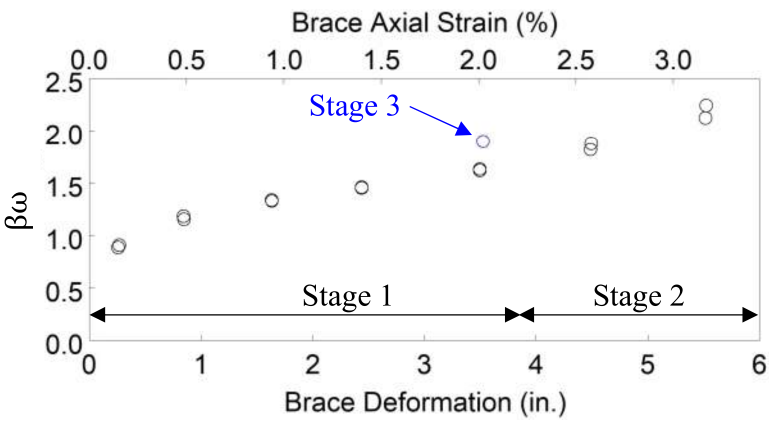
Figure 3.14 Specimen 10P: Cumulative Hysteretic Energy



(d) ω vs. Axial Deformation



(e) β vs. Axial Deformation



(f) βω vs. Axial Deformation

Figure 3.15 Specimen 10P: Strength Adjustment Factors

4 COMPARISON OF TEST RESULTS

4.1 Overall Performance

All three specimens were subjected to the pseudo-static loading protocol, they all performed well during the AISC loading protocol. Specimen 8P fractured in the beginning of the 1st cycle of Stage 3 loading, following the peak compressive force which occurred at $-21\Delta_{by}$. Specimen 9P complete Stages 1 and 2 loadings. After the brace reached the peak deformations of $\pm 20\Delta_{by}$ in Stage 2 loading, it fractured in the beginning of the 9th cycle of Stage 3 loading protocol as it was approaching the peak tensile force which occurred at $12\Delta_{by}$. Specimen 10P brace completed Stages 1 and 2 loadings. After the brace achieved the peak deformations of $\pm 23\Delta_{by}$ in Stage 2 loading, it fractured during the 2nd cycle of Stage 3 loading. The failure occurred just before the brace reached the peak tensile force which occurred at $14\Delta_{by}$. Table 4.1(a) provides key peak response quantities based on all loading protocols. All compression strength adjustment factors are below the AISC limiting value of 1.5.

4.2 Hysteretic Energy, E_h, and Cumulative Inelastic Deformation, η

The hysteretic energy and cumulative inelastic deformation achieved by each specimen are summarized in Figure 4.1 and Table 4.1(b). The cumulative inelastic axial deformations achieved by all specimens were significantly greater than $200\Delta_{by}$, an AISC acceptance criterion for BRBs. Table 4.1(b) shows the cumulative hysteretic energy achieved during each stage of loading protocol and the corresponding cumulative ductility at the end of testing altogether. All specimens exhibited larger cumulative inelastic deformation derived from the normalized cumulative dissipated energy, η_E, than that derived from the summation of the normalized inelastic axial deformation, η_D.

4.3 Acceptance Criteria

Section K3.8 of the 2016 AISC Seismic Provisions provides the following four acceptance criteria for buckling-restrained brace testing:

(1) *The plot showing the applied load versus displacement history shall exhibit stable, repeated behavior with positive incremental stiffness.*

Test results (see Figure 3.3 through Figure 3.13) show that all the specimens exhibit stable repeatable behavior with positive incremental stiffness.

(2) *There shall be no fracture, brace instability, or brace end connection failure.*

None of the specimens fractured during stage 1 of the loading protocols. All the specimens eventually failed during Stage 3 of the loading protocol, after the required cumulative inelastic ductility of 200 was achieved.

(3) *For brace tests, each cycle to a deformation greater than Δ_{by}, the maximum tension and compression forces shall not be less than the nominal strength of the core.*

Test results (see Figure 3.3 through Figure 3.13) show that no specimens experienced a degradation in resisting force.

(4) *For brace tests, each cycle to a deformation greater than Δ_{by}, the ratio of the maximum compression force to the maximum tension force shall not exceed 1.5.*

The maximum β values reported in Table 4.1 were less than 1.5 for all the specimens.

4.4 Cyclic Behavior of Low-Toughness BRB

Note that the core plate of Specimen 10P was intentionally selected to have a CVN toughness lower than the New Zealand code requirement (see Table 2.7). The ambient temperature in the SRMD laboratory during the testing for Specimen 10P was 63.7ºF. Test results showed that this low-toughness BRB still performed satisfactorily. The hysteretic responses of Specimen 8P [Figure 3.2(a)] and 9P [Figure 3.7(a)] show that the second cycle usually achieved a higher tensile force than the first cycle at each deformation level. By contrast, the increase in tensile force from the first to second cycles at each deformation level for Specimen 10P [see Figure 3.12(a)] was usually smaller than those in the other two specimens. Figure 4.2 shows the tensile peak force increment ratio versus core strain relationships for all specimens. Note that the tensile peak force increment ratio from the first to second cycles is defined as $\Delta T_{max}/T_{max1}$, where $\Delta T_{max} =$

$T_{max2} - T_{max1}$. Also, T_{max1} and T_{max2} are the forces at the tensile displacement peaks of the first and second cycles, respectively. It is observed that the tensile peak force increment ratio for Specimen 10P remained around 2% across all deformation levels. By contrast, the tensile peak force increment ratio varied with the core strain for Specimens 8P and 9P. For these two specimens, at a core strain of about 0.5%, the tensile peak force increment ratio did not exceed 2%. As the core strain reached about 1%, the increment ratio increased to 7% to 10%. After that, the increment ratio decreased with the core strain and approached 2% after the core strain reached 2.5%. It is apparent that, within a core strain range from 1% to 2.5%, the tensile peak force increment for Specimen 10P was noticeably smaller than those in the other two specimens. This suggests that the hysteretic responses of low-toughness Specimen 10P exhibited a smaller isotropic hardening than the other two specimens in that core strain range.

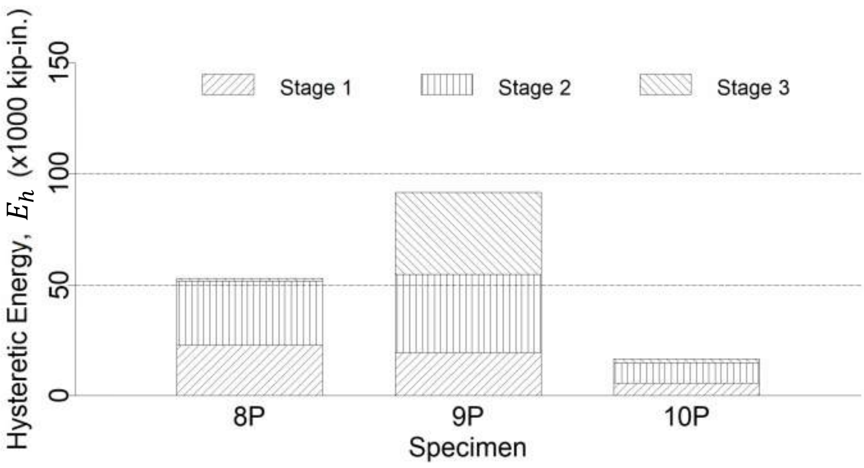
Table 4.1 Summary of Specimen Performances

(a) Maximum Response Quantities

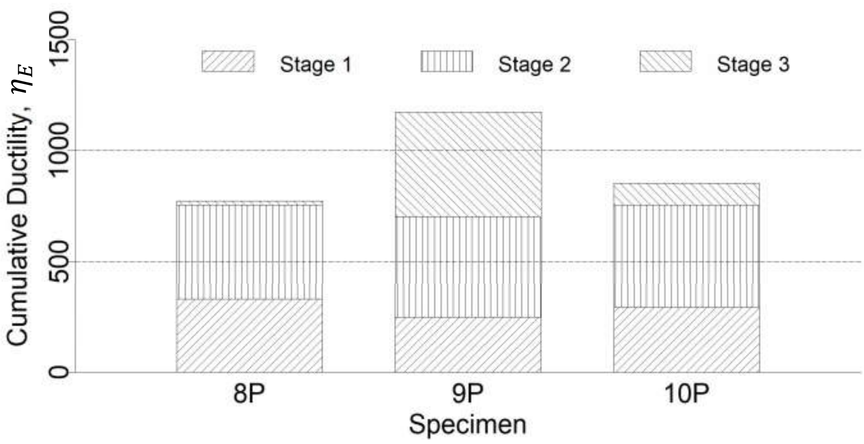
Specimen	ω	β	βω	Max. Core Strain (%)	Min. Core Strain (%)
8P	1.49	1.24	1.84	3.21	−3.14
9P	1.37	1.27	1.72	3.00	−2.98
10P	1.52	1.48	2.24	3.21	−3.17

(b) Hysteric Energy and Cumulative Inelastic Deformation

Specimen	E_h (×1000 kip-in.)				η_D	η_E
	Stage 1	Stage 2	Stage 3	Total		
8P	22.72	29.25	1.21	53.18	605	772
9P	19.40	35.47	36.84	91.71	999	1173
10P	5.77	9.07	1.90	16.73	658	851



(a) Hysteretic Energy



(b) Cumulative Ductility

Figure 4.1 Comparison of Hysteretic Energy and Cumulative Ductility

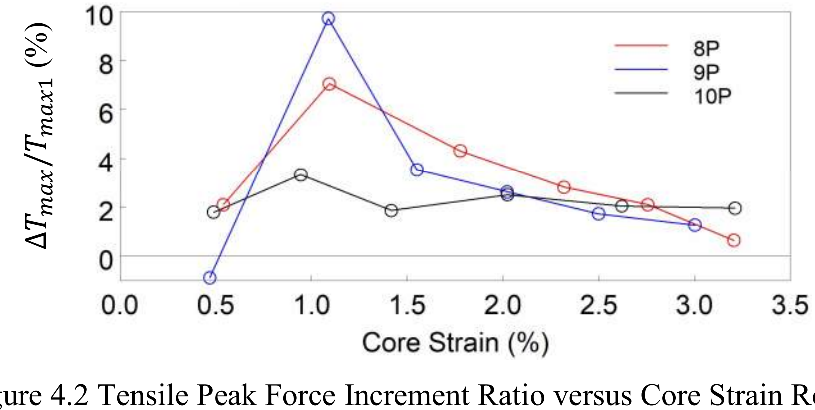


Figure 4.2 Tensile Peak Force Increment Ratio versus Core Strain Relationship

5 SUMMARY AND CONCLUSIONS

5.1 Summary

Three buckling-restrained braces (BRBs) of different design strengths were tested in the SRMD Test Facility at the University of California, San Diego. Specimens 8P and 9P were tested in July 2019, while Specimen 10P was tested in April 2020. All specimens consisted of A36 steel core plates encased in grout-filled A500 Gr. B square HSS casings. Bolted end connections were implemented on both ends of the brace in this P Series to connect each brace end to a bracket with a gusset plate. Specimens 8P, 9P, and 10P were connected to gusset plates with a thickness of 1-in., 1¼-in., and 1-in., respectively. The west end of the brace was fastened to the strong wall and the east end was fastened to the SRMD shake table platen.

The cyclic loading protocol used for this test program was composed of three stages. The first stage loading was the same as that specified in the AISC *Seismic Provisions*. The second stage loading was developed to impose a greater deformation demand to the brace to demonstrate that each specimen could achieve a cumulative inelastic axial deformation of at least $200\Delta_{by}$. The third stage loading had larger numbers of low-cycle inelastic deformation until core failure. Axial and transverse displacements were imposed to the specimens in the horizontal plane to simulate the in-plane frame action effect at the gusset connection.

All three specimens performed well during the AISC loading protocol (Stage 1), fracturing during Stage 3 testing. For all specimens, the maximum values of compression strength adjustment factor, β, were less than the AISC limiting value of 1.5. The computed cumulative inelastic deformation for all specimens were greater than $200\Delta_{by}$. Note that Specimen 9P dropped during construction before it was shipped back for testing, the brace performed well throughout the testing protocol and did not show any degradation in strength. In addition, steel core of Specimen 10P was intentionally made from a plate with a low CVN toughness. This was lower than the New Zealand code requirement but above the AISC requirement. Test results showed that this low-toughness BRB still exhibited a satisfactory cyclic performance.

5.2 Conclusions

Based on the test results, the following conclusions can be made.

(1) All three specimens performed well during the AISC loading protocol; no brace instability or brace end connection failures were observed. The braces fractured during Stage 3 loading protocol, whereby it incorporated greater deformation demands.

(2) The brace axial force versus deformation response showed stable and repeatable behavior with positive incremental stiffness.

(3) For all the cycles with an axial deformation greater than the yield deformation, Δ_{by}, the ratio of the maximum compression force to the maximum tension force, β, was under 1.5 for all stages of the loading protocol.

(4) For all the cycles with an axial deformation greater than the yield deformation, Δ_{by}, the maximum compression and tension forces were not less than 1.0 times the nominal brace yield force for all stages of the loading protocol.

(5) The cumulative inelastic deformation achieved by all the specimens were significantly greater than the minimum $200\Delta_{by}$ that is required by AISC *Seismic Provisions* for uniaxial brace test specimens.

(6) Specimen 9P had been dropped from a height of multiple stories during construction before it was shipped back for testing, the brace performed well throughout the testing protocol and did not show any degradation in strength.

(7) Specimen 10P was made from a core plate with a CVN toughness lower than the New Zealand code requirement. Tests results showed that this low-toughness BRB still exhibited satisfactory cyclic performance.

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Standards New Zealand (2009). "Steel structures Standard Part 1: Materials, fabrication and construction." *NZS 3404.1:2009*, Standards New Zealand, Wellington, New Zealand.

APPENDIX SRMD Command Signal Input

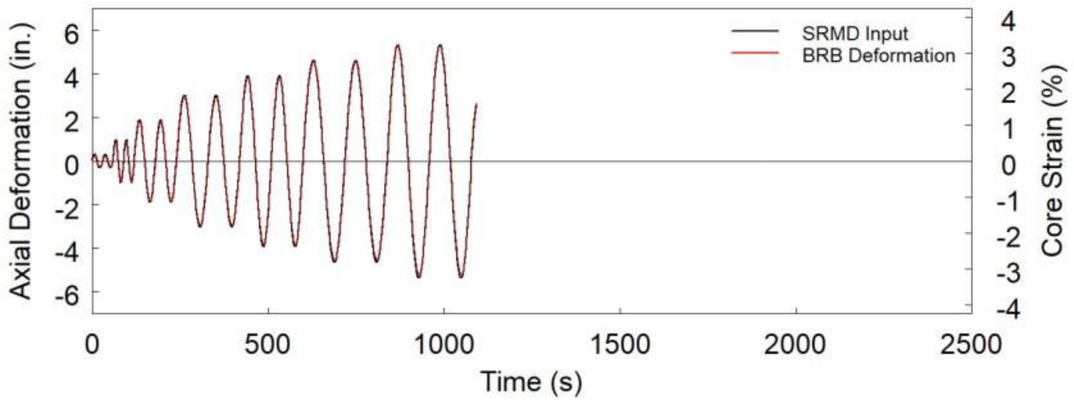

Figure A.1 Specimen 8P

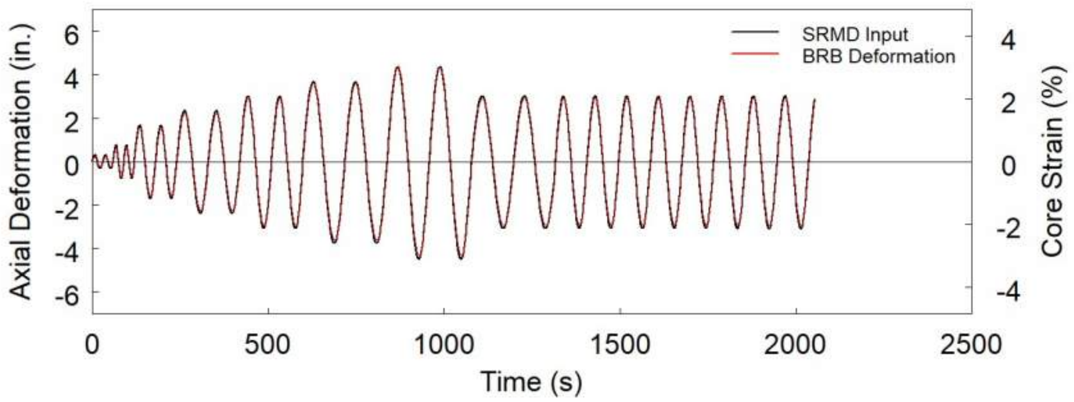

Figure A.2 Specimen 9P

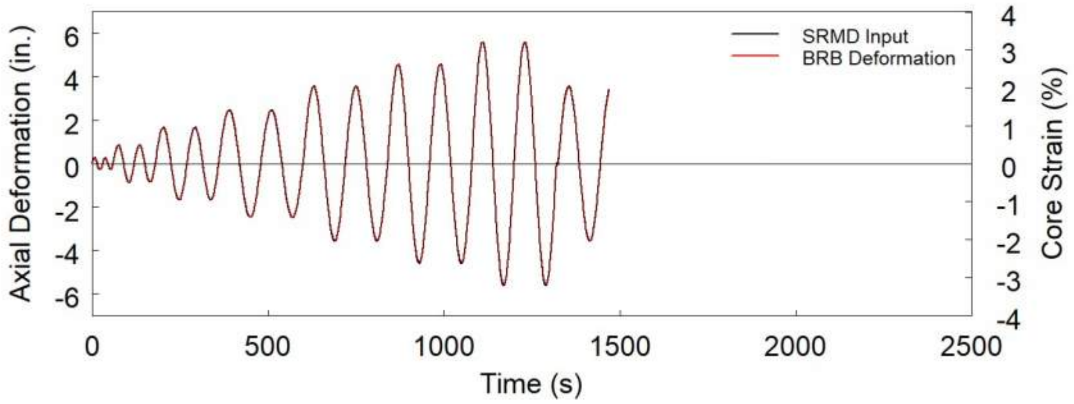

Figure A.3 Specimen 10P