TEST REPORT:

REDI-ROCK BARRIER TESTING:
PHASE ONE Hollow Core Retaining Unit (R-41HC) Test Results

Tested By:
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1.0 Introduction
This report documents the performance and capacity of a barrier constructed from standard hollow core Redi-Rock system blocks. In this study four different block and reinforcement configurations were tested. Test wall samples consisted of a base block and a stem wall as shown in **Figure 1**. Walls were dry-stacked in different configurations, reinforced, and then the cores were filled with concrete to create a solid barrier wall. Construction and testing was performed by Aster Brands at its testing facility located in Charlevoix, Michigan throughout the months of February and March, 2020. Redi-Rock is an Aster Brands company.

This report documents half of the testing results from this test program, focusing on the walls with a base constructed from a single Redi-Rock 41-inch (1030 mm) Hollow Core retaining block (R-41HC). Results from testing that utilized Redi-Rock R-41PC blocks for the base are discussed in a separate report.

Figure 1 - Sample test wall from front and from back

2.0 Purpose
The objective of this test program was to verify the static load capacity and performance of a "unit" section of barrier wall. Secondary objectives included exploring possible failure mechanisms and providing data to calibrate mathematical models.

3.0 Materials

Typical barrier wall cross sections consist of a wall base moment slab connected to a wall stem. Barrier wall test samples for this test project were constructed from one full-sided Redi-Rock R-41HC retaining block at the base and the stem consisted of two courses of Redi-Rock Hollow Core Freestanding Blocks (F-HC).

Redi-Rock R-41HC blocks **(Figure 2)** are wet-cast concrete, precast modular block (PMB) units with a nominal width of 40½-inches (1029 mm), length of 46⅛-inches (1172 mm), and height of 18-inches (457 mm). These blocks are cast in a standard 41-inch (1029 mm) block form with inserts to create void areas in the block. Test blocks were cast with a low-profile, smooth-face face texture. No attempt has been made to account for any contribution from the extra concrete in a standard Redi-Rock face texture. Typical block weight (with Ledgestone texture) is about 1,620 lb (735 kg). Average test block weight was 1,465 lb (665 kg). Precast blocks did not contain reinforcing steel.

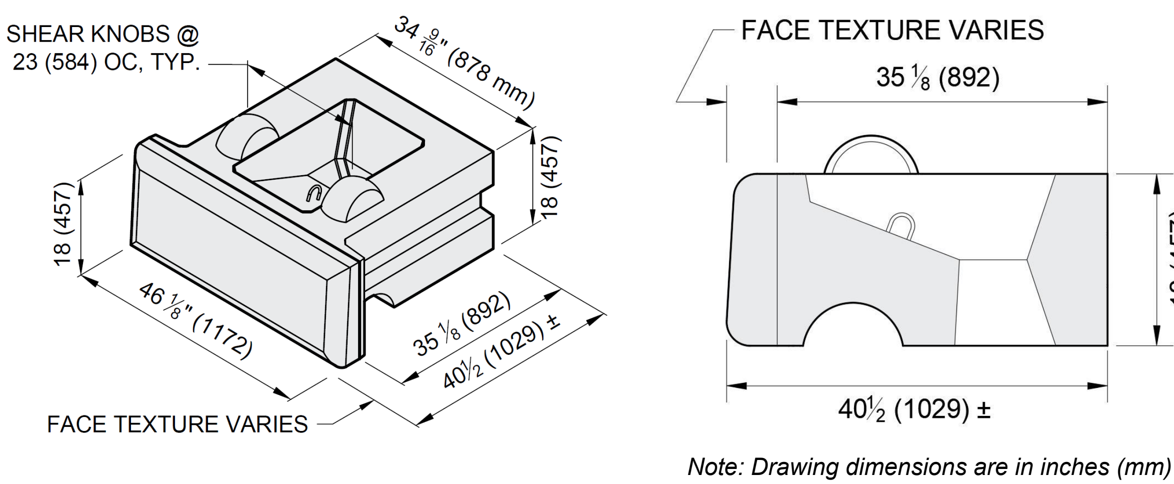

Figure 2 - R-41HC Block and Cross Sectional Depiction

Redi-Rock F-HC blocks **(Figure 3)** are wet-cast concrete, precast modular block (PMB) units with a nominal width of 24-inches (610 mm), length of 46⅛-inches (1172 mm), and height of 18-inches (457 mm). These blocks are cast in a standard freestanding block form with inserts to create cores through the block. Test blocks were cast with a low-profile, smooth-face face texture. No attempt has been made to account for any contribution from the extra concrete in a standard Redi-Rock face texture. Block weight (with Ledgestone texture) is about 770 lb (350 kg). Average test block weight was 440 lb (200 kg). Precast blocks do not contain reinforcing steel.

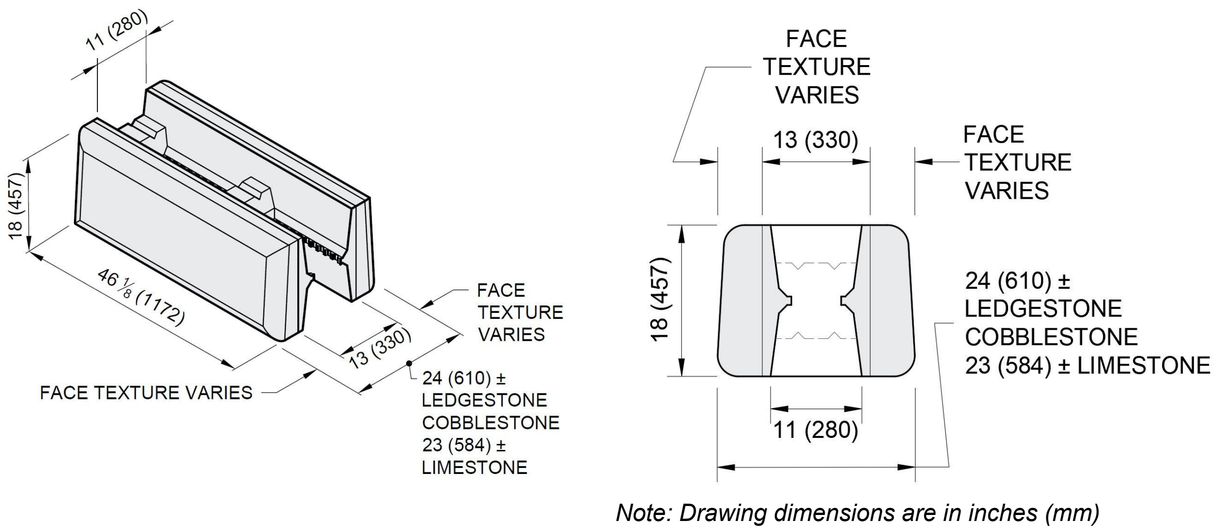

Figure 3 - F-HC Block and Cross Sectional Depiction

Concrete blocks used in this series of testing were produced by Aster Brands at its testing facility located in Charlevoix, Michigan. Blocks were cast from redi-mix concrete with a target compressive strength of 4,000 psi (27.6 MPa). The blocks were cast and cured inside a heated facility for a minimum 14 days before construction of the barrier walls began. All blocks were cured a minimum 28 days before the wall samples were tested. Compressive strength of the concrete used to produce the test blocks taken at the actual test date ranged from 3,000 psi (20.7 MPa) to 4,500 psi (31.0 MPa), as determined by ASTM C39 on 4-inch by 8-inch (102 mm by 203 mm) field-cured concrete cylinder specimens. Block strengths for each test wall are shown in **Figure 4**.

Concrete infill used to fill the cores of the wall samples was a pumpable concrete mix with a target compressive strength of 4,000 psi (27.6 MPa). Wall cores were filled on 2/26/2020 and allowed to cure a minimum 14 days before barrier wall testing began. It was determined, from compressive strength data, that the infill concrete was sufficiently cured to begin testing before 28 days (actual 15 - 20 days). The concrete infill compressive strength at the actual test dates ranged from 4,500 psi (31.0 MPa) to 4,700 psi (32.4 MPa), as determined by ASTM C39 on 4-inch by 8-inch (102 mm by 203 mm) field-cured concrete cylinder specimens. Concrete infill strengths for each test wall are shown in **Figure 4**.

Reinforcing steel used in the construction of the test walls was specified as ASTM A615 - Grade 60, uncoated bars. Structural reinforcement was specified as #6 (19.1 mm) bar. Hooks and stirrups were fabricated from #3 (9.5 mm) or #4 (12.7 mm) bar. Reinforcement was cut and bent per specified drawings by Striker Concrete Supply located in Traverse City, Michigan. None of the rebar was field cut or bent.

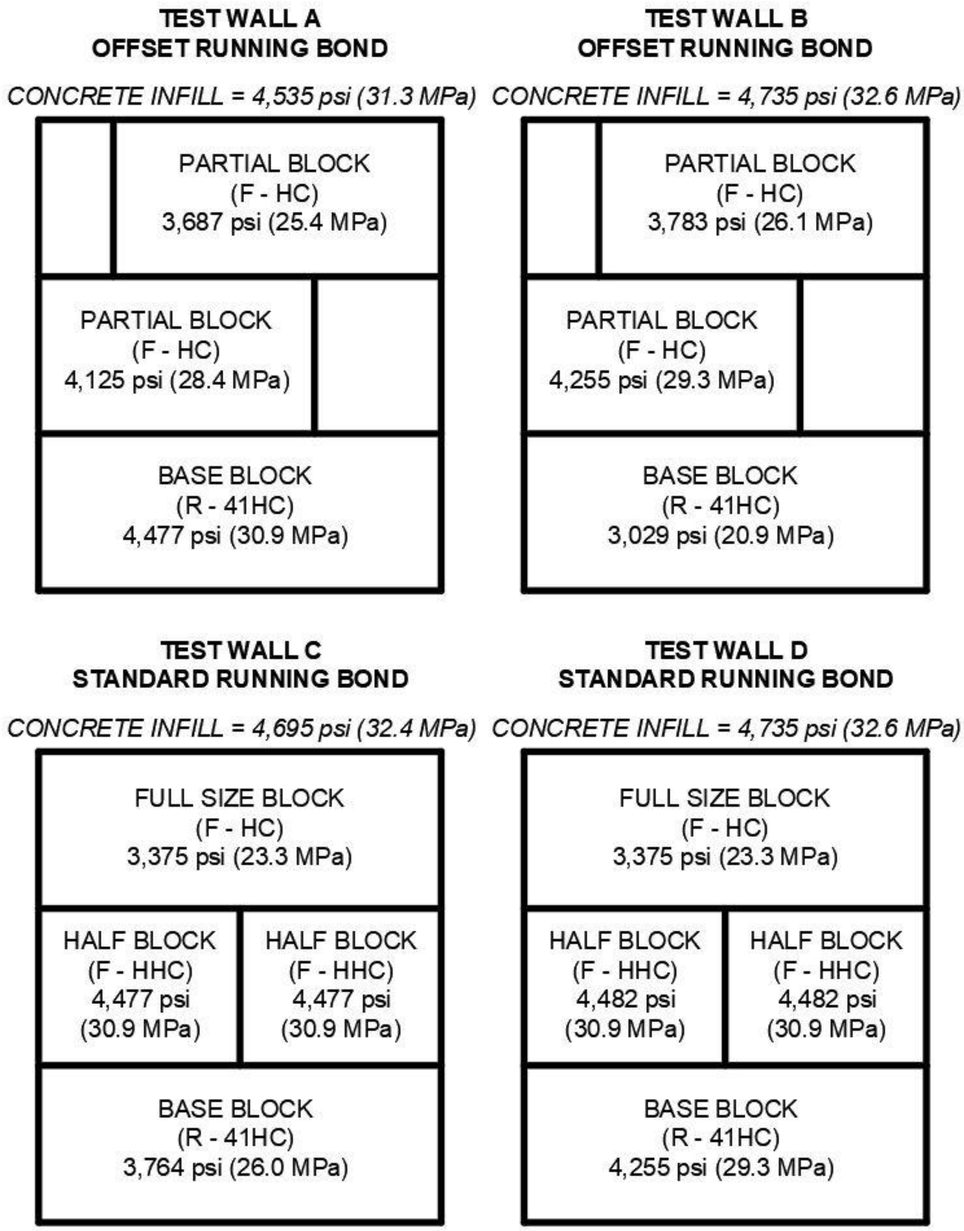

Figure 4 - Concrete Compressive Strengths (looking from the front of the wall sample)

4.0 Barrier Wall Design

A total of four test walls were constructed for this portion of the test. Two different wall bond and reinforcement configurations were considered and two samples of each configuration were constructed. The primary difference between the configurations was the lateral location of the block joints (bond pattern) and the quantity of reinforcing steel extending between the wall stem and base. See **Figures 5 through 9** for bond patterns, reinforcement layouts and actual dimensions of wall samples constructed.

Test Walls A and B were designed to maximize the amount of reinforcing steel that could be placed in the core of the F-HC blocks. Offsetting the bond from a standard running bond allows for a uniform “core” pattern between the blocks which allows for an easier and more consistent rebar placement. This configuration was reinforced with four #6 (19.1 mm) bars vertically between the wall stem and base.

Test Walls C and D had a standard running bond with the joint in the middle of the test. The cores in this configuration are not as well aligned and do not allow for as much reinforcement between the stem and base as in Test Walls A and B. Test Walls C and D were reinforced with three #6 (19.1 mm) bars vertically between the wall stem and base.

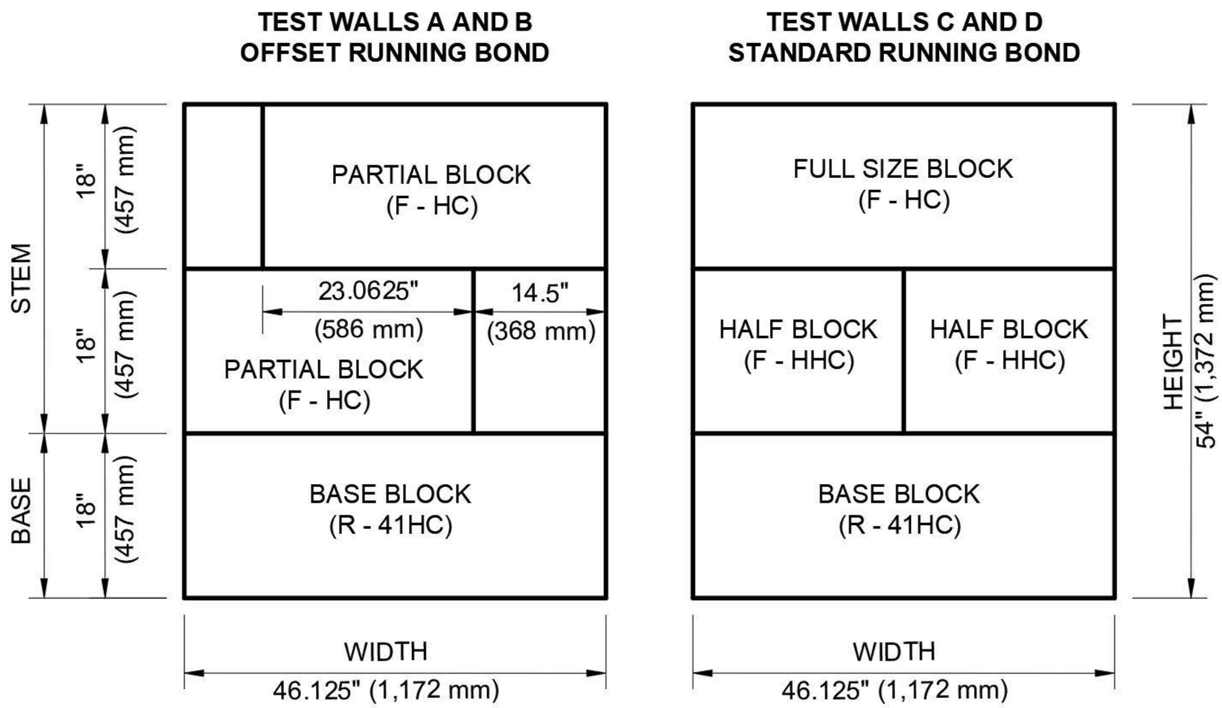

Figure 5 - Test Block Layout (looking from the front of the wall sample)

All of the wall stems were reinforced with #6 (19.1 mm) reinforcement. Two bars were placed horizontally in the horizontal cores of the F-HC blocks. This reinforcement helps to spread load laterally along the wall. There were also (8) #6 vertical bars spaced in four pairs across the width of the wall. These bars were extended into the base block below, where possible, to help connect the stem to the base. Where not, the rebar ended at the bottom of the stem. Four, #4 (12.7 mm) U-shaped stirrups finish the top of the wall and are placed 1” clear from the top.

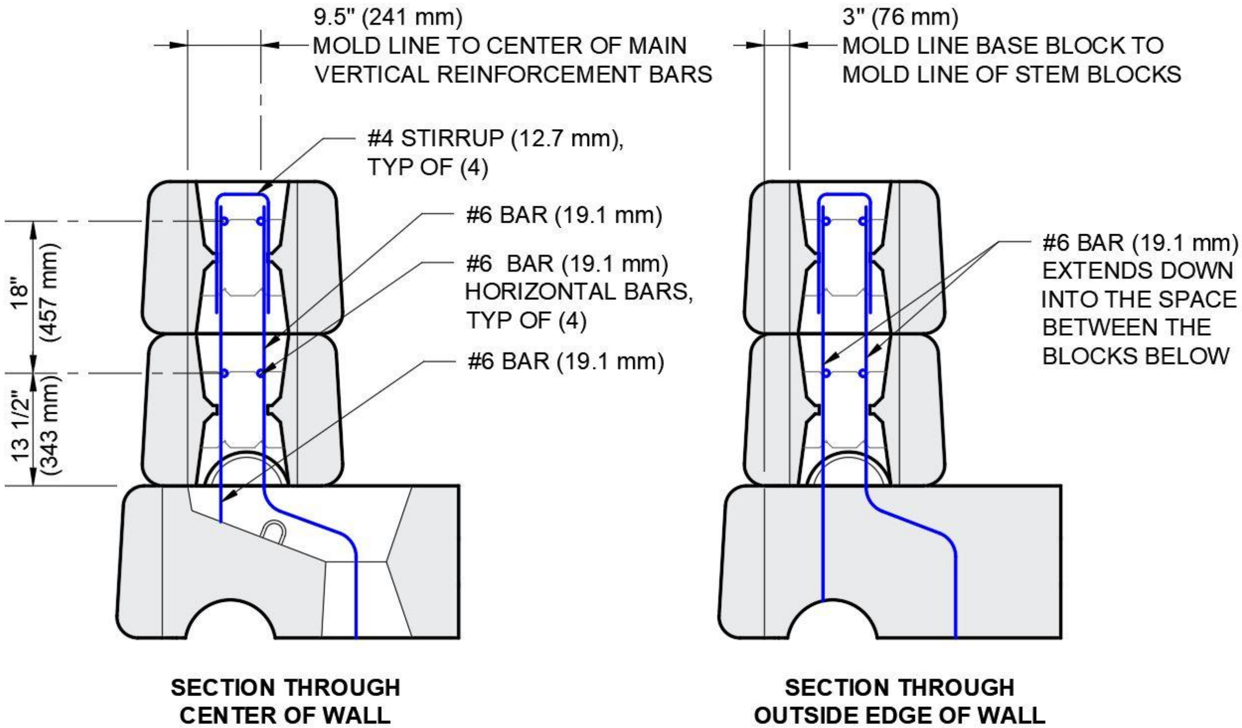

Figure 6 - Wall Cross Sections

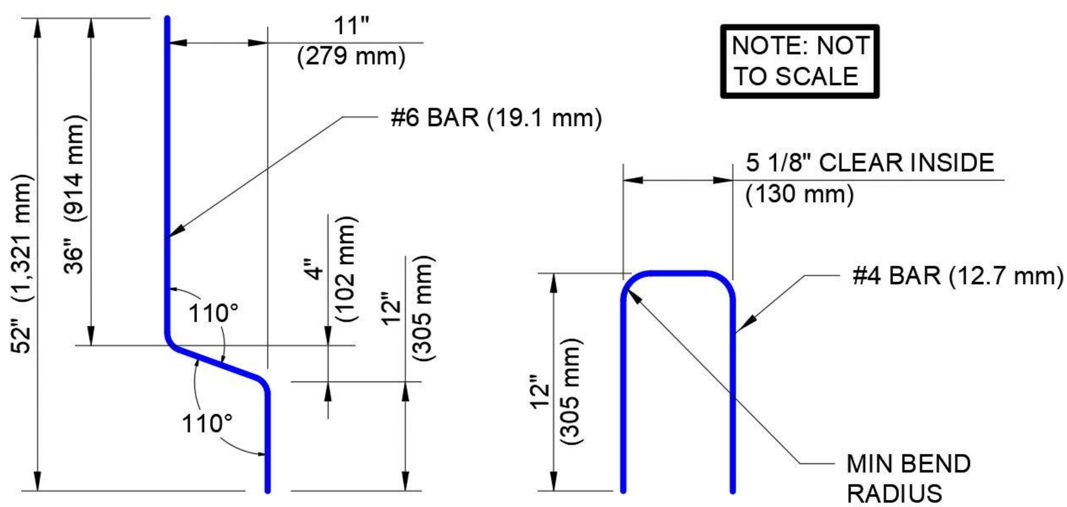

Figure 7 - Rebar Details. Bent Reinforcement Bars and U-Shaped stirrups.

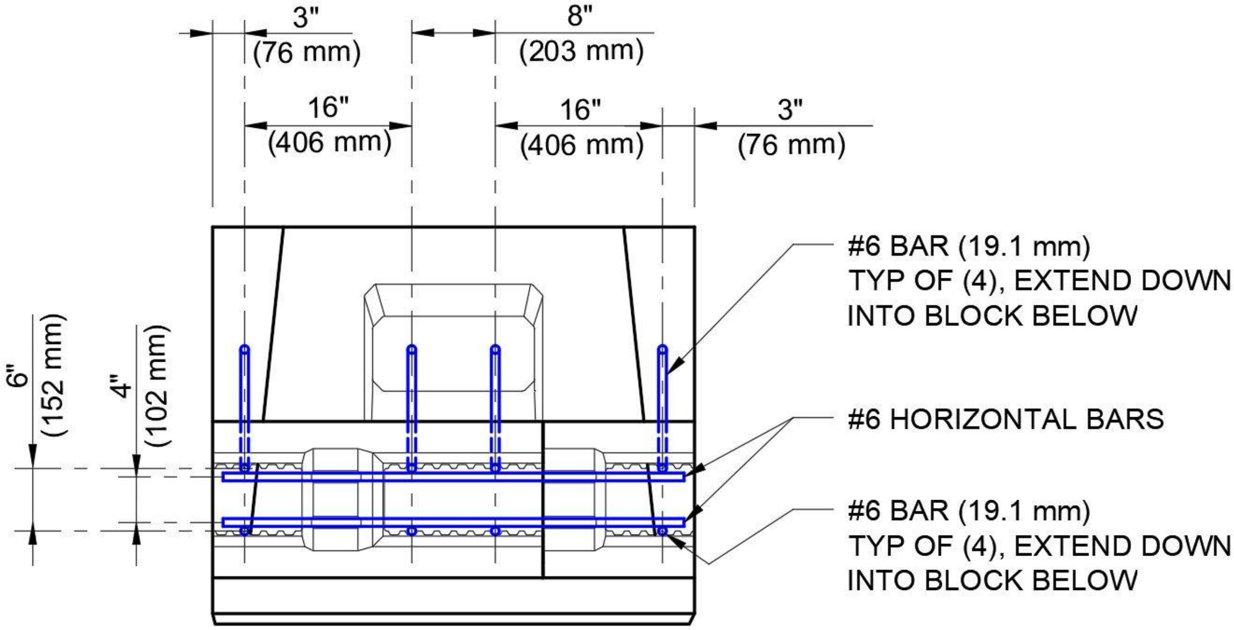

Figure 8 - Top View of Walls A and B (Offset Bond)

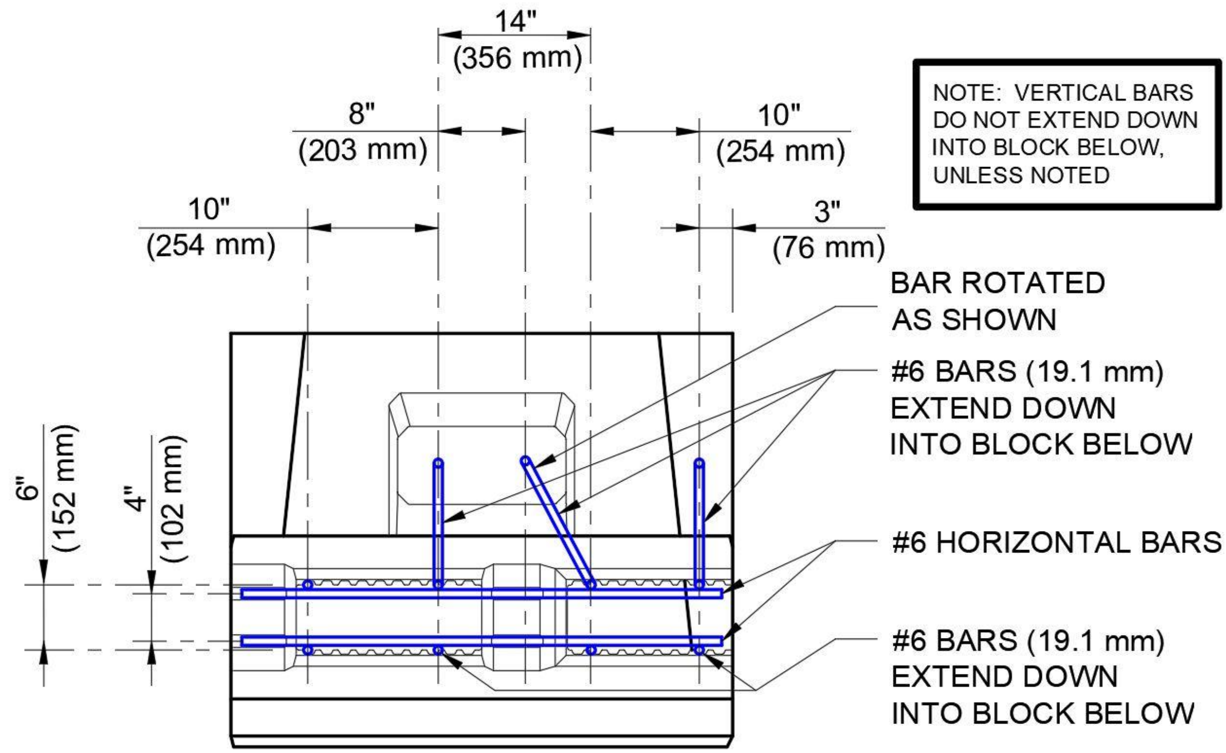

Figure 9 - Top View of Walls C and D (Running Bond)

4.0 Barrier Wall Construction

Barrier wall sections were constructed directly adjacent to the testing frame in the Aster Brands testing facility. Size of the wall specimens was such that they could be moved into and out of the testing frame by an overhead crane. Walls were constructed by first placing the R-41HC retaining block on a leveled plywood platform topped with a ⅛-inch (3 mm) plastic sheet. Two courses of F-HC hollow core freestanding blocks were then stacked on top of this retaining block to form the barrier section. After the walls were dry stacked, rebar was placed in the cores and tied in place with standard, uncoated wire ties. The outside edges of the walls were then formed and braced with plywood formwork. Joints were lightly tuck pointed on the outside with non-shrink grout to seal all joints before filling the cores with infill concrete.

Once all of the wall test specimens were constructed, they were infilled from a single pour of concrete. Concrete infill was placed by pump and the walls were vibrated while filling to ensure all of the voids were filled. Lifting anchors were cast into the tops of the walls to facilitate moving test wall sections into and out of the testing frame. Forms were stripped the next day and wall samples were left undisturbed for a minimum of (14) days before moving or testing. See **Figure 10** for photos taken during construction.

Figure 10 - Construction Photos of Barrier Walls

4.0 Testing Methodology

The intent of the test procedure was to verify the failure modes and structural capacity of the joint between the stem and the base of the wall for a “unit” section of barrier wall. The base block of the wall sample was secured and prevented from sliding and overturning. Test samples were restrained from overturning by a 12-inch (305 mm) wide steel beam tied down to the test frame’s reaction floor. The outside edge of this beam was aligned with the back of the base block. A shear reaction plate was bolted to the test floor to react against the inside edge of the groove on the bottom of the base block to restrain the wall from sliding horizontally. A horizontal load was then applied to the wall stem to force a structural failure of the wall. The test set-up is illustrated in **Figure 11**.

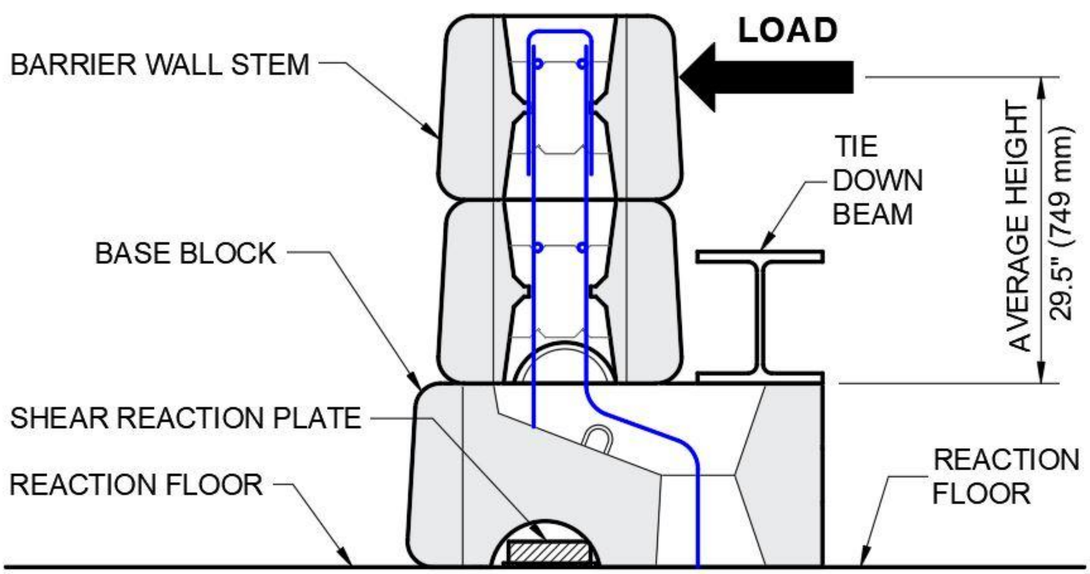

Figure 11 - Test Set-up

Load was applied to the wall stem using the horizontal hydraulic actuator mounted in Aster Brands’ structural test frame. Two 100 kip (445 kN) capacity load cells were installed in series at the end of the hydraulic actuator. A hardened, spherical load button was attached to the load cells and pushed against a set of hardened, graphited plates which allowed for rotation and lateral movement at the point of application of the load. Load was spread laterally across the wall sample with an 8-inch (203 mm) wide steel beam backed by a 1-inch (25 mm) thick polyurethane bearing pad. Load was applied 29 ½” (749mm) (**Figure 11**) above the top of the base block and laterally in the center of the wall. Horizontal displacements of the wall were measured at three locations. Displacement at the point of load was measured with an LDT displacement gauge mounted inside the hydraulic cylinder. Horizontal displacements of the upper corners of the blocks were measured with two string potentiometer displacement gauges.

A preload of approximately 1,000 lbs (4.4kN) was applied to each wall sample to seat the wall in the test frame before recording displacements. The preload was held for approximately one minute before loading of the wall commenced. Displacement measurements were zeroed at the end of the preload period. Walls were then pushed until failure with a slowly increasing, pseudo-static, load-controlled rate of approximately 4,600 lb per minute (20.5 kN per minute), which correlates to an approximate 0.1-inch per minute (2.5 mm per minute) displacement rate of the actuator. This load rate was maintained until the wall failed and load dropped off significantly (approximately at 0.5-inch (12.7 mm) of actuator displacement). After significant load drop, the test was switched to a displacement-control rate of approximately 0.4-inch (10 mm) per minute. Walls were then pushed to a final actuator displacement of anywhere from 2.5-inch (64 mm) to 4-inch (102 mm) depending on the test. Final actuator displacement values were determined during the test to ensure that the joint between the wall stem and base was failed completely and that the test sample would be able to be removed from the test frame.

Test data was recorded at 1-second intervals with a National Instruments brand data acquisition system and Labview DAQ software. Both load cells, horizontal hydraulic cylinder displacement, string potentiometer wall displacement, pump speed, horizontal cylinder velocity, and time were recorded. In addition to this data, video was taken from multiple angles to evaluate failure modes of the wall assembly.

5.0 Results

Results from this test program can be seen in **Table 1** and graphs shown in **Figure 13**. All of the walls failed in two steps. First there was a noticeable bond failure at the joint between the wall stem and base. This failure can be seen as the “first peak” value in the graphs shown in **Figures 13 - 15** After this point, the reinforcing steel was engaged and the base block of the walls failed vertically between the back of the stem and the groove located at the bottom of the block (**Figure 12**). This corresponds to the “second peak” value in the graphs shown in **Figures 13 - 15.** Values of the first and second peaks are shown in **Table 1**

Test data for Walls A and B can be seen in **Figure 14** and for Walls C and D and be seen in **Figure 15**. It is interesting to note that all four wall samples failed in a similar way and the loads and deflections were fairly similar. Walls with less steel reinforcement failed at a slightly less peak load, but not proportionally less compared to the amount of rebar contained in the sample.

Figure 12 - Typical Failure Mode (taken from Test Wall A)

Table 1 - Results

Test Wall	Wall Bond Type	Load at First Peak lb (kN)	Load at Second Peak lb (kN)	Deflection at First Peak inch (mm)	Deflection at Second Peak inch (mm)	Notes
A	Offset	19,426 (86.4)	19,591 (87.1)	0.28 (7)	0.43 (11)	Final failure mode: vertical crack through shear groove.
B	Offset	18,467 (82.1)	18,373 (81.7)	0.23 (6)	0.42 (11)	Final failure mode: vertical crack through shear groove.
C	Standard	18,574 (82.6)	18,931 (84.2)	0.24 (6)	0.36 (9)	Final failure mode: vertical crack through shear groove.
D	Standard	17,978 (80.0)	16,312 (72.6)	0.31 (8)	0.55 (14)	Final failure mode: vertical crack through shear groove.

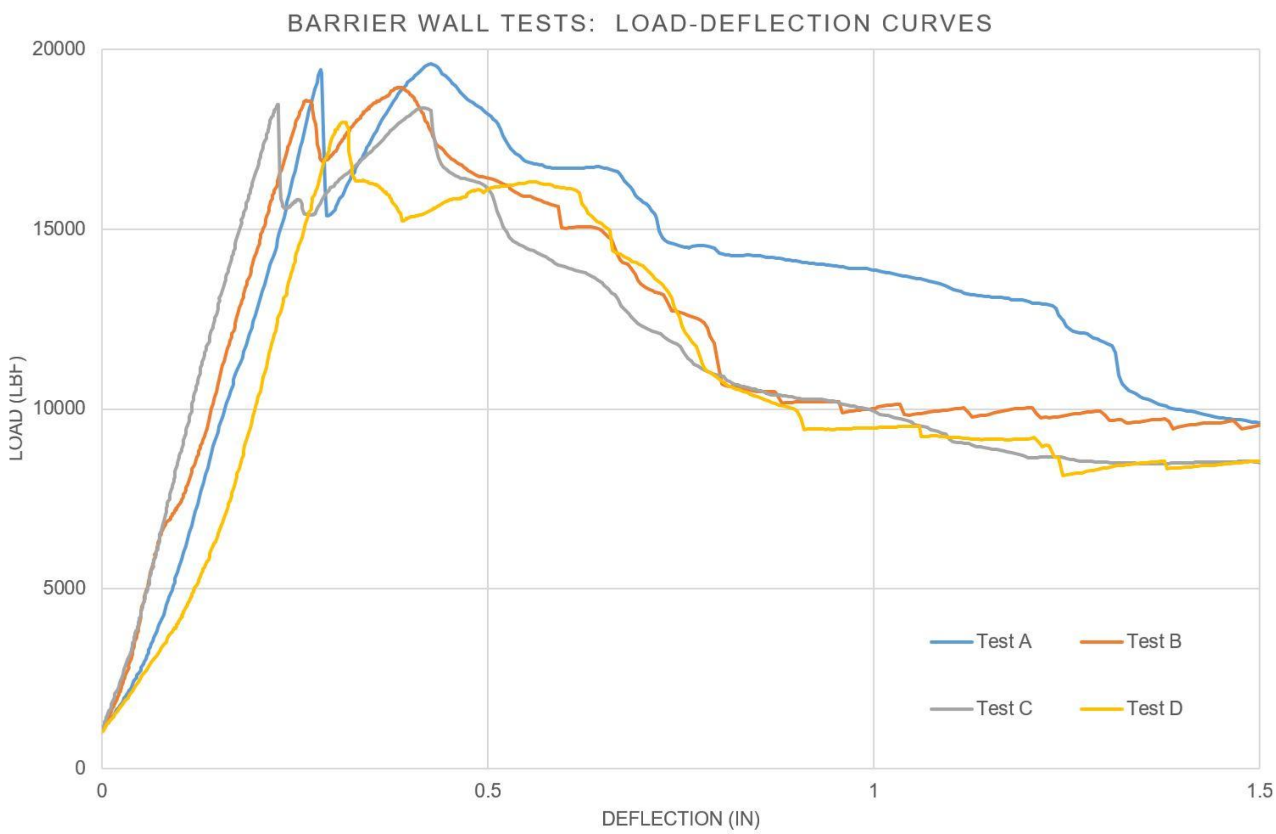

Figure 13 - Test Results (All four tests)

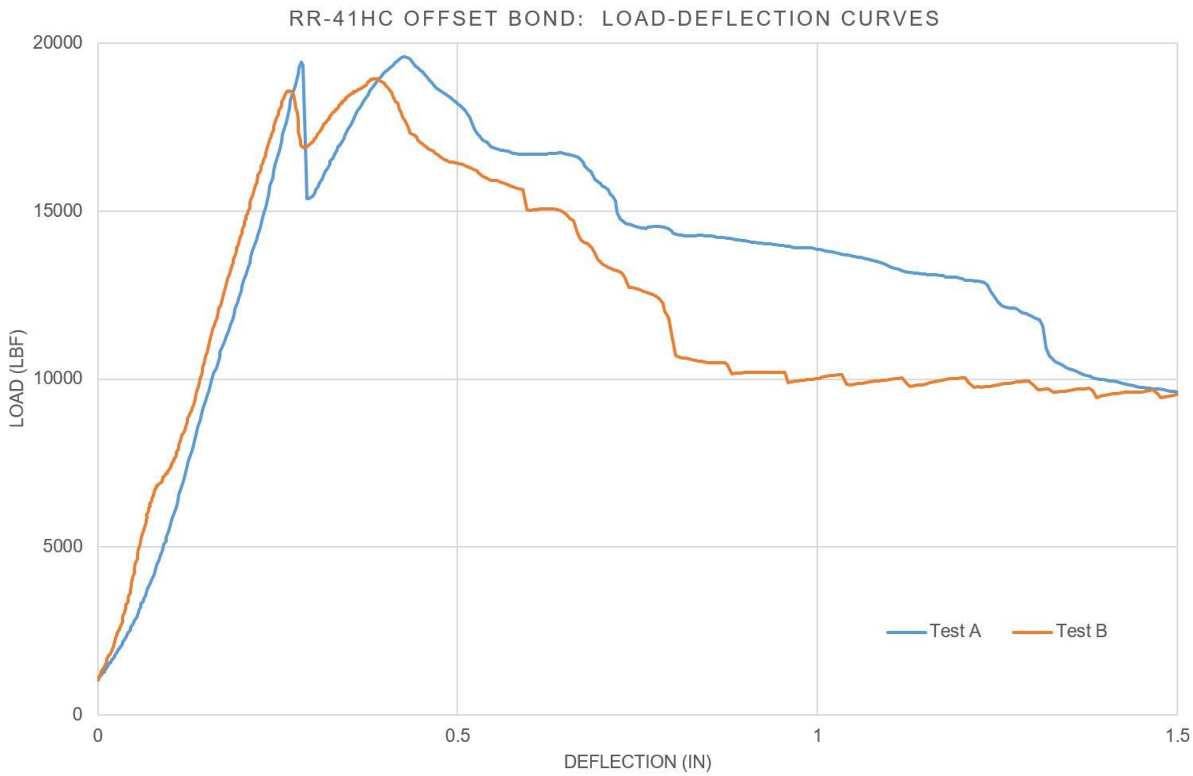

Figure 14 - Test Results by Wall Type (Tests A and B)

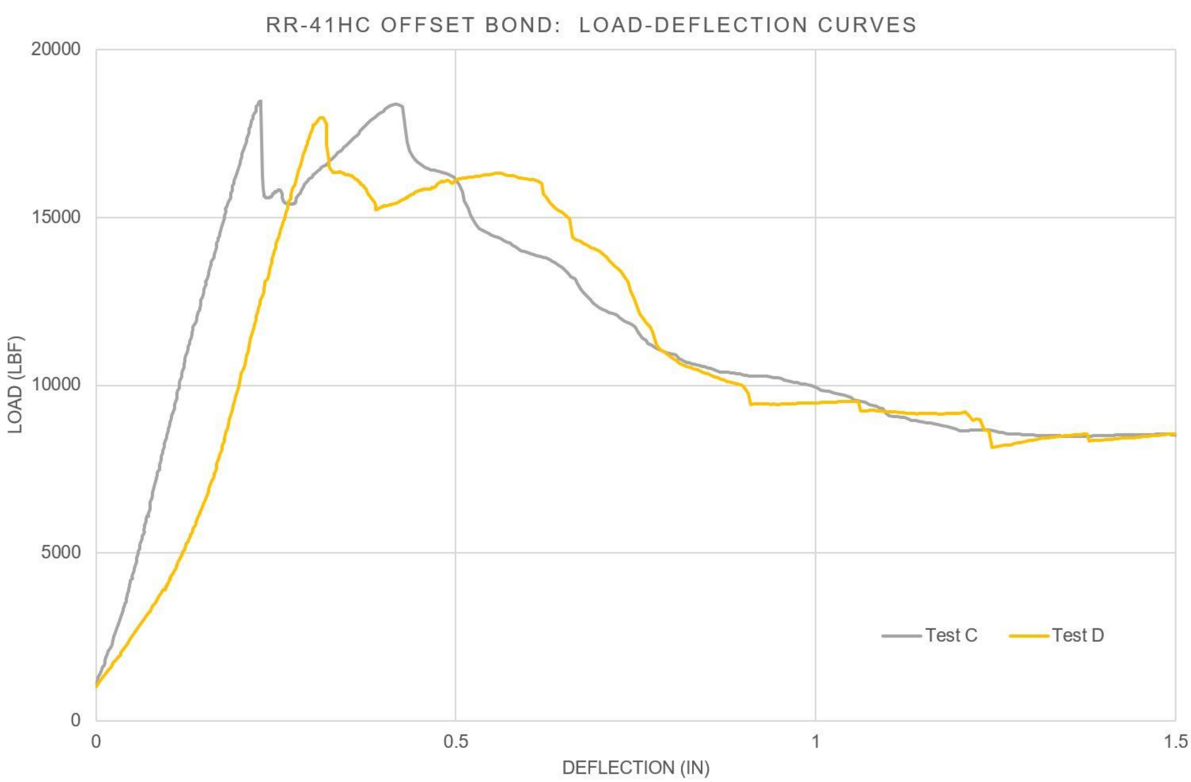

Figure 15 - Test Results by Wall Type (Tests C and D)

6.0 Closure

This data and conclusions should be used with care. The user should verify that project conditions are equivalent to laboratory conditions and account for variations.

This test data is accurate to the best of our knowledge. It is the responsibility of the user to determine suitability for the intended use.

ASTER BRANDS

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