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# ADAPTING ASTM C1823 FOR TESTING ADHERED MASONRY VENEER

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## ABSTRACT

Adhered Masonry Veneer (AMV) has increased in popularity in recent years and is becoming commonplace both in residential and commercial construction as an alternative to more conventional anchored veneer systems. However, unlike anchored veneer, AMV material characteristics and installation methods vary considerably based on aesthetic considerations, manufacturer's installation requirements, and local installer means and methods. This variability, coupled with detailing and integration challenges on the part of designers and specifiers, has led to an increase in AMV adhesion failures and durability problems.

Loss of veneer adhesion has been observed to be one of the principal causes of AMV failure. For over two decades, the TMS 402 prescriptive provisions have included requirements for the bond between the units and backing to develop a minimum shear strength of 50 psi. However, until recently there was no standardized test method for verifying the shear bond strength of installed AMV assemblies in the field.

ASTM International recently published a new standard, ASTM C1823, for testing the in-situ shear bond strength of adhered dimension stone. This paper presents a discussion regarding the unique aspects of AMV testing that are not addressed in ASTM C1823 and provides recommendations for those seeking to adapt the methodology of ASTM C1823 for testing adhered masonry veneer.

**KEYWORDS:** *adhered masonry veneer, ASTM C1823, field testing, quality control, shear bond testing*

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## INTRODUCTION

ASTM International has recently published a new standard, ASTM C1823 [1], for testing dimension stone adherence to a substrate in a laboratory or in the field. While this standard was specifically written for use with dimension stone, the methodology in ASTM C1823 could be easily adapted for testing adhered masonry veneer (AMV) assemblies. Using this methodology would add two major items lacking in ASTM C482 [2], the testing standard that is currently referenced in TMS 402 [3]: in-field testing and testing of bond adherence to the substrate.

ASTM C1823 is a destructive test method developed as a quantitative means of determining the shear bond strength of AMV units to their substrate. The test is performed by applying a uniform load to one of the edges of a test specimen to produce shear stress in the setting bed. The load is applied parallel to the substrate by means of a specially fabricated testing apparatus that mounts to the face of the wall. The apparatus pushes on the edge of the specimen unit through a plate that extends into the mortar joint. The specimen is loaded using a hydraulic ram inside the apparatus at a specified rate until a shear failure occurs. After the apparatus is removed from the wall, the specimen and substrate are observed to verify the failure mode, evaluate the condition and quality of the setting bed installation, and measure the net adhesive contact area. The reader is referred to ASTM C1823 for a more in-depth description of the test procedure.

This paper is the second in a two-paper series about the application of in-field direct shear bond strength testing of AMV assemblies. The first paper [4] presents a case study of investigations at an AMV installation prior to the initial publication of ASTM C1823 but using a methodology similar to that in the published standard. Since the publication of ASTM C1823 in 2020, the content of the new standard has been reviewed and compared with the experiences and lessons learned during the previous in-field AMV testing. This paper presents a discussion regarding the unique aspects of AMV testing that are not addressed in ASTM C1823 and provides recommendations for those seeking to adapt the methodology of ASTM C1823 for testing adhered masonry veneer.

## TEST PREPARATION

A detailed explanation of all the steps required for preparing the specimens for testing is outside of the scope of the ASTM C1823 standard. The following commentary provides several considerations that should be accounted for when planning and performing specimen preparation for bond shear testing AMV units.

Prior to testing, the bed and head joints must be removed around the specimens to be tested (Figure 1a). Depending on the size of the AMV units, they may also need to be cut into smaller specimens for testing (Figure 1b). A practice that seemed effective was to label specimens to be tested and to lay out, plumb and level, and mark the locations of all cuts within each test area prior to cutting. For AMV assemblies with varying unit lengths, cut locations must be coordinated with the unit dimensions so that the specimens are not wider than the bearing plate and the corner of the bearing plate does not contact either of the adjacent units during the test.

For AMV systems with varying unit heights, it is important to select test specimens which provide a representative sample of the various unit sizes. When testing a veneer assembly with multiple unit sizes, the investigator may be tempted to select only the smaller units because they do not need to be divided into multiple specimens for testing and require less preparation. However, it is critical to include a representative proportion of larger units in the test sample. Larger units are more prone to containing voids or other deficiencies in the setting bed because of the greater force required to press them into the backup during installation.


(a) Mortar joint removal around perimeter

(b) Cut through unit

**Figure 1: Specimen Preparation**

ASTM C1823 notes that cuts must be made all the way through the unit and that cutting should not extend into the substrate, but it does not clearly direct whether the cuts should extend into the setting bed or not. Figure 2 of ASTM C1823 does not show the cut extending into the mortar joint (Figure 2). Based on the observations during field testing [4], adhesive failure between the setting bed and backup is a critical failure mode that must be evaluated. Therefore, the cuts should extend as far into the setting bed as possible without damaging the substrate so that the adhesion of the setting bed to the backup can be evaluated during the test.

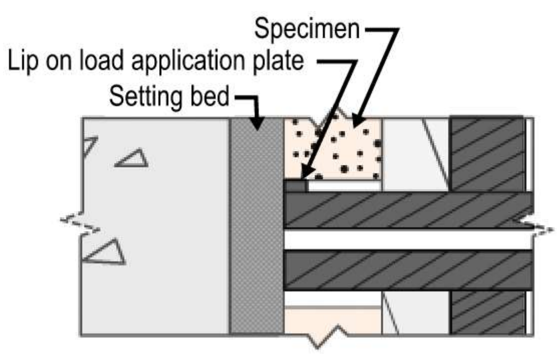



**Figure 2: Section at Loading Plate (Adapted from Figure 2 of ASTM C1823 [1])**

Cuts in the unit and joints were performed efficiently using an angle grinder fitted with a diamond-tipped cutting wheel (Figure 3), but in different circumstances other tools may be more appropriate. For example, at unit thicknesses approaching the maximum thickness permitted in TMS 402, a handheld masonry saw may need to be employed. In cases where poorly bonded units may be present, the risk of dislodging a unit during cutting may be reduced if the cut through the unit is made prior to removing the mortar joints around the perimeter. Depending on the joint size and the size and configuration of the testing apparatus, the joint may need to be enlarged at the loaded edge so that the loading plate may fit into the joint. Cutting will require personal protective equipment and containment for the silica dust generated.

**Figure 3: Mortar Joint Removal Using a Diamond-Tipped Cutting Wheel**

Care must be exercised to produce cuts that are straight and square, particularly along the edge of the specimen that will be loaded. Cuts should generally be made using multiple passes to reduce the amount of material removed in each pass and improve control of the cutting wheel. Mortar fragments should be carefully removed using hand tools, such as composite fiber brushes. Straight and square cuts require extra skill and time on units with textured surface profiles, such as simulated hewn stone.

Due to the level of skill, time, equipment, and safety procedures required to perform many of the required steps in specimen preparation, the authors generally recommend engaging a masonry contractor to help with preparing the specimens for testing. When tests are to be performed at multiple areas, test preparation time can be improved by having the contractor perform the cuts at one area while the investigator proceeds to lay out the cuts at the next area. For larger investigations, a separate team of investigators may be employed to follow behind the contractor to perform the tests at each area to reduce the overall time on site.

When performing tests at large veneer assemblies, access will need to be coordinated so that representative testing can be performed at different heights along the veneer. During investigations at existing construction and other cases where scaffolding is not in place, the overall scope and impact of the investigation should be evaluated to determine if multiple aerial lifts should be used. Specimen preparation and testing generally require more time to perform on an aerial lift compared to the same tasks performed on grade, not including the added time required for moving and positioning the lift.

## SPECIMEN SIZE

ASTM C1823 limits the tests to a maximum specimen size of 150×150 mm (6×6 inches). The reasons listed for the size limitations are "to establish a practical specimen size, limit maximum breaking load, and prevent out-of-plane stress." Based on structural analysis, it appears the specimen size limit was likely established primarily on the load capacity of the prototype test apparatus. It is not clear how limiting the specimen size is intended to prevent out-of-plane stress because increasing the specimen size in the direction of the applied load should result in a decrease in out-of-plane stress. The specimen size limit in C1823 may be practical for testing adhered dimension stone tiles, but it appears unnecessarily restrictive for use with testing some AMV units. Arguments in favor of testing larger units include results that are more representative of actual performance and improved test productivity.

Based on the loading rate in ASTM C1823, the specimen loading should require less than a minute to perform. By comparison, preparing the specimens for testing requires significantly more time and is the most time intensive part of the test procedure. Reducing the amount of cutting that needs to be performed improves productivity. Smaller test specimens require a greater amount of cutting relative to the test area than larger units. For a total given testing area, more cutting will be required for testing smaller specimens compared to performing the testing on a larger specimen.

Many AMV unit sizes are based on multiples of the standard nominal modular dimension of 200 mm (8 inches), but multiples of 225 and 300 mm (9 and 12 inches) are also frequently used. If the specimen widths were limited to 150 mm (6 inches), then many additional cuts would need to be made through the units to comply with the limit. Considering that cutting through the units is generally more difficult than cutting through the mortar joints, unnecessary cuts in the units add unnecessary time and expense to the testing. In the case of in-situ testing or in-place mockups, the partial unit fragments remaining from cutting test specimens from a larger unit would still need to be removed to install replacement units. In addition, completely cutting through a unit requires extending the cuts into the adjacent units (Figure 1b), which would also have to be removed and replaced. In these cases, eliminating unnecessary cutting results in even greater reductions in time and expense from the testing.

During field testing, the larger test specimens were observed to generally have a larger shear bond strength than the smaller specimens [4]. Based on these observations, it appears that testing unnecessarily small units may yield unrepresentatively low bond strengths. It is likely that smaller specimens are more susceptible than larger units to small defects in the setting bed or accidental torsion during testing. Another possible cause for reduced strength is that the process of sawing a unit into smaller specimens may unintentionally induce vibrations into the unit that weaken the adhesion of the setting bed to the unit or backup.

During the previous investigation [4], the quality of the setting bed and bond to the backup were generally observed to be better at the center of the unit than near the edges. When cutting and testing only a portion of a unit at a time, there is a greater risk of accidental torsion on the specimen because the voids near the edges shift the setting bed's center of rigidity away from the center of the specimen. Where possible, it is recommended to align the apparatus loading with the center of the unit to reduce the risk of torsion in the setting bed. Whole units should be tested, where feasible, because they are more representative of actual bond conditions than testing smaller portions.

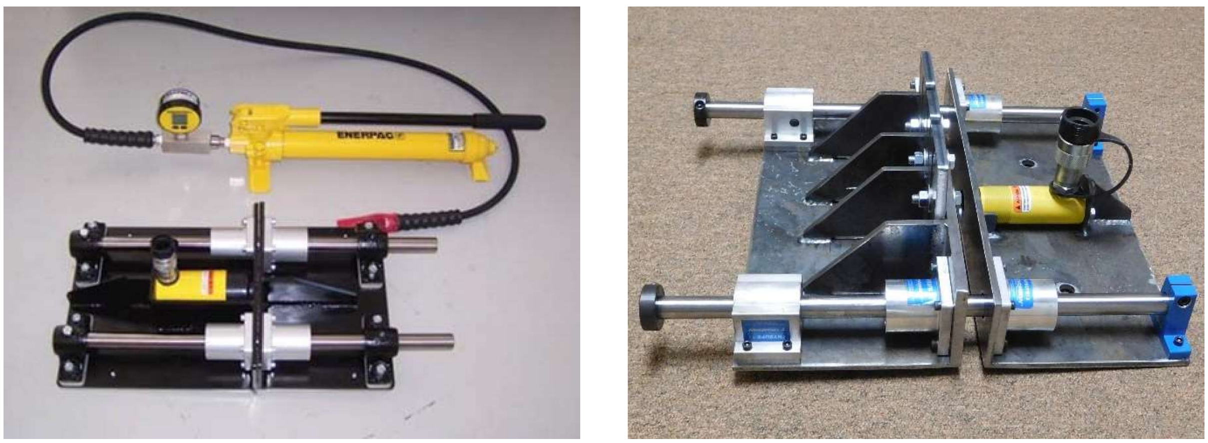
During field testing, test specimens up to 877 $cm^2$ (136 $in^2$) were safely tested using a test apparatus specially designed and fabricated for AMV units. The testing of larger specimens appears to be possible with an apparatus that is adequately large, strong, and rigid for the anticipated loads. Based on the weight of the apparatus used during field testing, approximately 20 kg (45 lbs), it appears the maximum practical specimen size may be limited based on the apparatus weight that can be safely and comfortably handled by those performing the testing.

**APPARATUS**

The example testing apparatus shown in ASTM C1823 was based on a prototype apparatus designed for testing adhered dimension stone tiles, which are typically ¾ inch or less in thickness and generally have a flat surface profile. While the diagram of the apparatus in ASTM C1823 does not include dimensions, the approximate member dimensions were estimated based on photographs. The prototype apparatus includes two plates that protrude approximately ¾ inch from the bottom, one plate to load the test specimen and another to react against the edge of an adjacent unit. The thickness of both plates appears to be 3/16 inch, which allows for testing 6-inch×6-inch specimens up to ¾ inches thick and permit both plates to fit into a standard joint when the apparatus is in its closed position. Variations in unit thickness are accommodated using shims inserted between the apparatus and the face of the veneer.

Adhered masonry veneer units typically range from ¾ to 1½ inches thick depending on the style and manufacturer, but based on TMS 402 requirements, AMV units up to 2⅝ inches in thickness are permitted. In addition, many available AMV units have a textured surface profile designed to imitate the appearance of hewn stone. The example apparatus shown in ASTM C1823 would be capable of testing only a small portion of AMV units on the market today, those with thicknesses of ¾ inch or less and with flat surfaces. To adapt the methodology of ASTM C1823 for use with AMV units, the testing apparatus must be designed and fabricated for thicker units, uneven surface profiles, and higher stresses.

ASTM C1823 does not require a specific apparatus configuration to be used but only requires that the apparatus be capable of uniformly loading the full width of the specimen and that it reacts against an intact restraining surface. The test apparatus used during the field testing [4] was modeled after the prototype apparatus in the draft standard (Figure 4a) but was modified and improved for testing AMV units (Figure 4b). The new design was developed around a hydraulic ram with a load capacity of 10,000 pounds to accommodate larger AMV units with less cutting. The innovative design incorporated interchangeable loading plates with two difference widths—150 and 200 mm (6 and 8 inches)—to facilitate testing of different AMV unit dimensions. Both plates were fabricated from ⅜-inch thick, ASTM A572 Grade 50 steel to provide a higher yield strength. The loading plate attachment was designed to permit the loading plate to slide up and down to adjust the penetration depth to account for differences in specimen thickness (Figure 5).




(a) Prototype Shear Test Apparatus [1] (b) Modified Shear Test Apparatus for AMV Testing

**Figure 4: Side-by-Side Comparison of Prototype and Modified Shear Test Apparatuses**

(a) Loading Plate Retracted (b) Loading Plate Extended

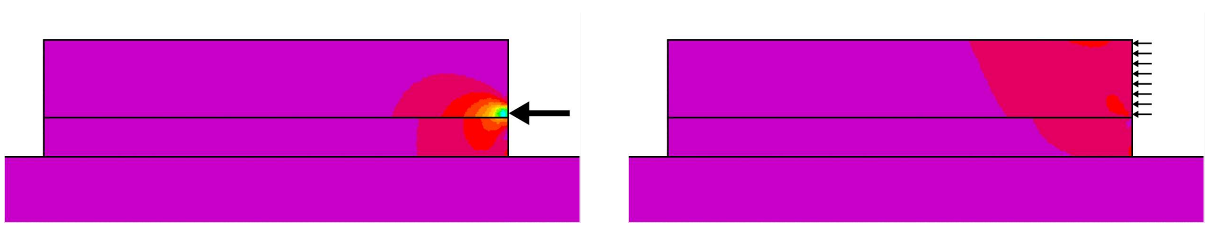
**Figure 5: Loading Plate Depth Adjustment on Modified Apparatus**

For the modified apparatus to accommodate the thicker ⅜-inch loading plate in a standard ⅜-inch mortar joint, the apparatus was designed to react against a pair of large-diameter concrete anchors installed through holes in the apparatus into intact material on the face of the veneer. The concrete anchors provide a secondary benefit of holding the apparatus onto the wall so that the user does not have to hold the apparatus during the test. Fastening the apparatus to the wall is safer for the user, particularly when the built-up stresses in the apparatus are released at bond failure, and is necessary when testing larger units. Fastening also helps hold the failed unit against the wall until it can be retrieved, reducing the risk of the unit falling to the ground, which provides additional safety when performing tests at elevated locations.

Many AMV systems are manufactured with uneven faces to meet a certain aesthetic. To account for the uneven surface profile of the veneer, shims should be installed between the perimeter of the apparatus and face of the veneer to level and plumb the apparatus prior to anchoring the apparatus and beginning the test. It should be noted that direct anchoring to the wall may not be feasible for all AMV assemblies and that other methods of restraint may need to be developed. It is still recommended to provide means to anchor or support the apparatus during testing.

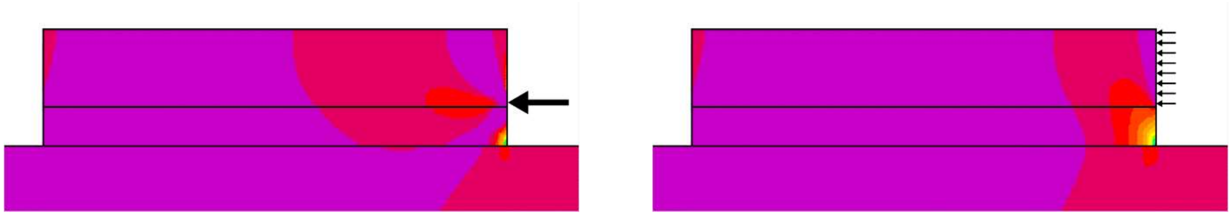
The example apparatus in ASTM C1823 includes a lip near the bottom edge of the loading plate that is to be positioned near the base of the specimen (Figure 2). The intent of the lip is to load the specimen close to the setting bed to reduce eccentricity and out-of-plane loading on the setting bed. Unfortunately, concentrating the load onto such a narrow area appears to have the opposite effect due to the diverging stress fields created withing the unit and mortar.

A simple finite element analysis (FEA) shows that concentrating the load at the base of the unit produces extremely high shear stresses adjacent to the point of loading (Figure 6a), which can cause premature failure and yield lower failure strength. The FEA shows distributing the loading over the depth of the unit results in lower peak shear stresses in the setting bed (Figure 6b), which is particularly important when testing larger units with higher loads. Even though the resultant of the distributed loading is further from the backup, the analysis shows no increase in the peak out-of-plane (OOP) tension stress (Figure 7). The distributed loading also results in lower OOP tensile stresses along the interface between the unit and the setting bed (Figure 7). Distributing the load along the depth of the of unit also aligns the resultant of the loading more closely with the unit's center of mass.



(a) Concentrated Loading (b) Distributed Loading

**Figure 6: Comparison of Maximum Shear Stresses**



(a) Concentrated Loading (b) Distributed Loading

**Figure 7: Comparison of Maximum Out-of-Plane Tensile Stresses**

It is important to note that the shear bond testing apparatus is not perfectly rigid and will deflect under the stresses imposed on it during testing. Since there is an eccentricity between the hydraulic ram and the loading on the edge of the specimen, a moment force is induced into the linear bearing rods that will cause the loading plate to deflect outward slightly under loading. If a lip is included on the loading plate, the top edge of the lip may catch the unit and restrain the deflection of the apparatus, causing the apparatus to pry the specimen off the backup (Figure 8), leading to a reduced failure load. Omitting the lip permits the apparatus deflection to be accommodated through sliding between the plate and the specimen. For AMV testing, the loading plate should bear uniformly along the edge of the specimen and no lip should be included on the loading plate.

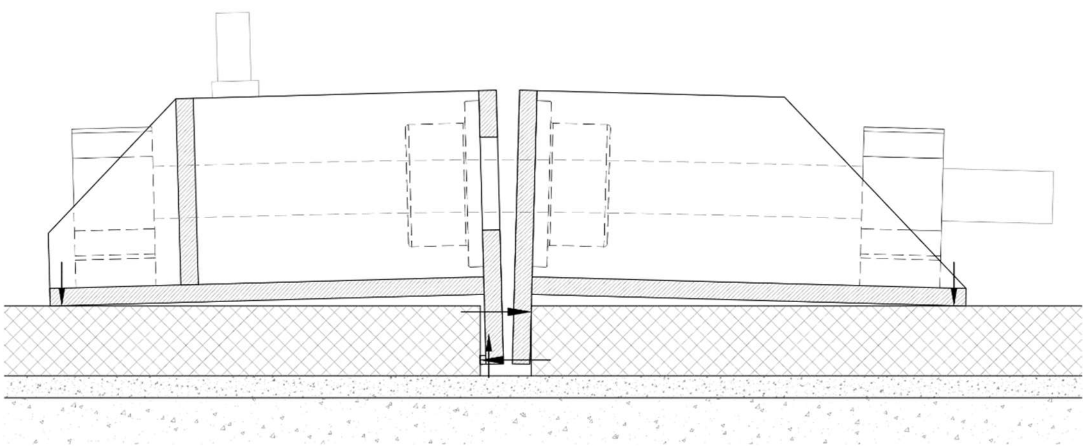


**Figure 8: Potential Prying Load on Specimen from Restrained Apparatus Deflection**

## STRENGTH CALCULATIONS

ASTM C1823 requires that both the gross and net shear bond strengths be calculated for each specimen. The net shear bond strength $B_n$ is calculated by

$$B_n = P/A_n \tag{1}$$

where $P$ is the load at specimen failure and $A_n$ is the net adhesive contact area. The net adhesive contact area is the difference between the gross area of the unit and the total area of the voids in the setting bed. ASTM C1823 presents an approach for estimating the net adhesive contact area by using a 150×150 mm (6×6 inch) grid with gridlines spaced at 6.25 mm (¼ inch) and by shading squares corresponding to areas where adhesive bond was observed. The shaded squares are counted and multiplied by the area of an individual square.

A more effective and precise way of estimating the area is to take a photograph of the adhesive area on the back of the specimen or face of the backup. Taking a photograph of both is recommended because it will allow the two areas to be compared with each other. The photograph should be taken with the camera lens centered and square with the center of the area. The photograph is imported and scaled in a CAD program and the outline of the contact area and voids are traced (Figure 9). The CAD program is then used to calculate the area of the outlined region.

Based on observations during testing, voids in the adhesive coverage will shift the centroid of the coverage area so that it does not align with the center of applied force from the test. The resulting eccentricity produces an additional torsional loading that increases the net shear stresses at some areas of the coverage area compared to what is calculated using Equation 1. The maximum shear stress can be calculated using the properties of the adhesive contact area. If a photograph of the adhesive area is imported and outlined in a CAD program, the area, centroid, and moments of inertia may be obtained directly from the program. For example, in AutoCAD, the parameters may be obtained by created a Region over the adhesive area and by using the MASSPROP command. To correctly obtain the moments of inertia, the user coordinate system (UCS) must be moved to the centroid of the Region.

Once the area properties are obtained, the shear bond stress at any location may be obtained by using elastic method:

$$B_{ny} = \frac{P}{A_n} + \frac{P \cdot e \cdot c_x}{I_p} \tag{3}$$

$$B_{nx} = \frac{P \cdot e \cdot c_y}{I_p} \tag{4}$$

$$B_n = \sqrt{B_{nx}^2 + B_{ny}^2} \tag{5}$$

where $I_p = I_x + I_y$ is the polar moment of inertia, $e$ is the load eccentricity, and $c_x$ and $c_y$ are the components perpendicular and parallel to the direction of loading, respectively, as shown in Figure 9. The maximum shear bond stress will be located at the point with greatest radial distance from the centroid of the adhesive contact area. While net shear bond strength is beneficial for understanding the ultimate shear stress in of the setting bed at failure, criteria for acceptance of AMV should be based on gross shear bond strength.

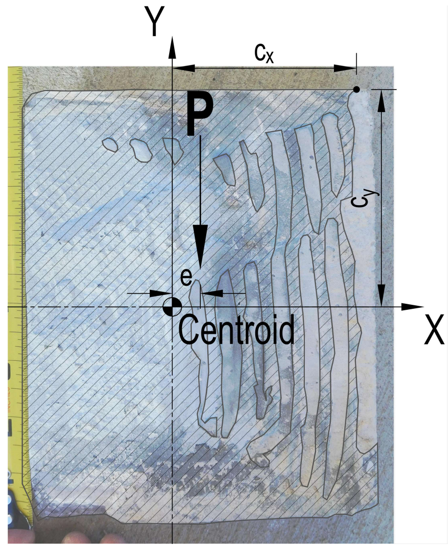



**Figure 9: Net Adhesive Contact Area (Hatched) and Elastic Method Parameters**

**SUMMARY**

Previous work has shown that shear bond strength testing of adhered masonry veneer assemblies can be effectively performed in the field [4]. The recently published test methodology in ASTM C1823 for testing adhered dimension stone provides a good starting point for developing a test methodology for testing AMV assemblies in the field. The following practices are recommended for adapting the methodology of ASTM C1823 to testing AMV assemblies.

- A masonry contractor should be engaged to help with preparing the specimens for testing.
- All cuts and specimens at each test area should be laid out and marked before beginning to cut the specimens.
- Test specimens must be selected to provide a representative sample of the various unit sizes within the AMV assembly.
- Cuts should extend all the way through the unit and as far into the setting bed as possible without damaging the substrate so that adhesion to the backup can be tested.
- Cuts through a unit should be made prior to removing the mortar joints.
- The maximum specimen size in ASTM C1823 is unnecessarily restrictive for testing many types of AMV and should not be used.
- Cuts through units should be reduced or eliminated, if possible, by testing whole units.
- When testing specimens cut from larger units, orient the apparatus so the load is applied through the center of the unit.
- There is no standard design for test apparatuses for performing ASTM C1823 testing. The test apparatus to be used in testing should be designed for the intended range of AMV types to be tested. Innovations can be incorporated into the design to improve apparatus utility and versatility.
- Apparatuses for testing AMV will generally be larger than that shown in ASTM C1823, but should be limited in size to what can safely and comfortably handled by the users.
- If possible, the test apparatus should be anchored to the wall during testing to improve test safety, particularly at larger specimen sizes and loads.

- The loading plate should bear uniformly along the edge of the specimen; no lip should be included on the loading plate.
- Calculation of the net adhesive contact area can be performed easily using a CAD program.
- Due to the accidental torsion caused by voids in the adhesive contact area, the peak net shear bond strength should be calculated using the elastic method.

## REFERENCES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