13TH CANADIAN MASONRY SYMPOSIUM
HALIFAX, CANADA
JUNE 4TH – JUNE 7TH 2017

INITIAL DESIGN METHOD FOR THIN MASONRY VENEERS INDIVIDUALLY SECURED BY MORTAR ADHESION

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ABSTRACT

Thin masonry veneers individually secured by mortar adhesion have become increasingly popular in the North American construction industry. Some of the reasons include a reduction of the cladding weight and a resulting reduction in the size and cost of the supporting structure, as well as speed and ease of construction. As the height of the adhered masonry cladding increases, however, the reliance on mortar bond to attach the thin masonry cladding to the support structure also increases and the greater the risk of damage to property or injury if that bond fails. In the past the CSA-A371-04 limited the height of these types of claddings to 3 m (10') yet as these cladding have become more popular in commercial and multi-family residential construction veneer heights exceeding 3 m have become more common. The use of Type N and Type S in full bed masonry veneers are pre-dominantly relied upon in compression in the bed joint and to help mechanically anchor the veneer to the structural wall with ties. However, the use as the bonding mortar to adhere masonry places the mortar in both shear and tension. This paper explores a design method for adhered masonry veneer where the veneer heights exceed 3 m (10') above grade.

KEYWORDS: *adhered masonry veneer, polymer modified mortar, veneer structural design*

INTRODUCTION

Thin masonry veneers individually secured by mortar adhesion (Adhered thin masonry veneers) have become increasingly popular in the North American construction industry. However, the reliance on mortar bond to attach the thin masonry cladding to the support structure is greater than traditional masonry because the mortar bond is not acting in compression alone. In the past Annex A of the Canadian Standards Association CSA-A371-04 - *Masonry Construction for*

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Buildings [1] limited the height of these types of claddings to 3 m (10') above grade. However, as these cladding have gained popularity in commercial and multi-family residential construction, veneer heights exceeding 3 m (10') have become much more common. In the past, Type N and Type S mortars used in traditional full bed masonry veneers have been used to construct the scratch coat that embeds the metal lath, as well as the setting bed used to bond the adhered masonry unit to the scratch coat in adhered thin masonry veneers wall systems. Type N and Type S mortars in full bed masonry veneers pre-dominantly rely upon strength in compression in the bed joint and to aid in mechanical anchorage of the masonry veneer to the structural wall using metal brick ties. However, the use as the setting bed mortar to directly adhere thin masonry units to the substrate places the mortar in shear, flexure, and tension. According to CSA-A179-14- *Mortar and Grout for Unit Masonry* [2] the flexural bond strength of a full bed masonry unit to a Type N or Type S mortar is only 0.20 MPa (29 psi) while both the ASTM C1670-15 - *Specification for Adhered Manufactured Stone Masonry Veneer Units* [3] and the ASTM C1780-15a - *Standard Practice for Installation of Adhered Manufactured Stone Masonry Veneers* [4] both require a shear bond strength of 0.345MPa (50 psi) when adhered units are tested according to a modified ASTM C482-02 - *Standard Test Method for Bond Strength of Ceramic Tile to Portland Cement Paste* [5]. This paper explores a design method using shear and tensile bond strengths for Type S mortar and modified dry-set cement (thinset) mortars for veneer heights exceeding 3 m (10').

ADHERED MASONRY VENEER WALL SYSTEMS

Adhered Masonry Veneer Wall Systems (AMVWS) have common construction components which include the masonry veneer units, the setting bed mortar, and the substrate (typically metal lath encased in mortar which is scored to provide a "scratch coat") as illustrated in Figure 1. However, these systems have a large variability in both the materials used to construct them and type of assembly. The masonry veneer units can be natural stone, manufactured stone, thin clay brick, or thin concrete brick. The substrate to attach the adhered stone to the structural backing can be a mortar bed that embeds a self-furring lath and is typically scored to form the scratch coat or it can be an exterior grade cement board. The lath can be anchored with staples, roofing nails, or screws. The stone veneer may be "jointed" or "drystacked". The wall system may incorporate strapping or drainage medium materials for moisture management.

The components that affect the structural performance of AMVWS include the masonry units, the substrate used to attach the veneer to the structural backing, the type of mortar used as the setting bed mortar, the lath and the fasteners. With respect to the masonry units both the dimensions and density affect the weight of the cladding and whether the stone is natural or manufactured can affect the mortar bonding surfaces. The type of mortar used to bond both the setting bed to the scratch coat and the masonry unit to the setting bed and the use of "jointed" or "dry-stacked" can also affect the structural performance. Typically the self-furring diamond metal lath and fasteners used to anchor the lath to the structural wall are within their structural capacity when directly fastening the lath to the structural wall.

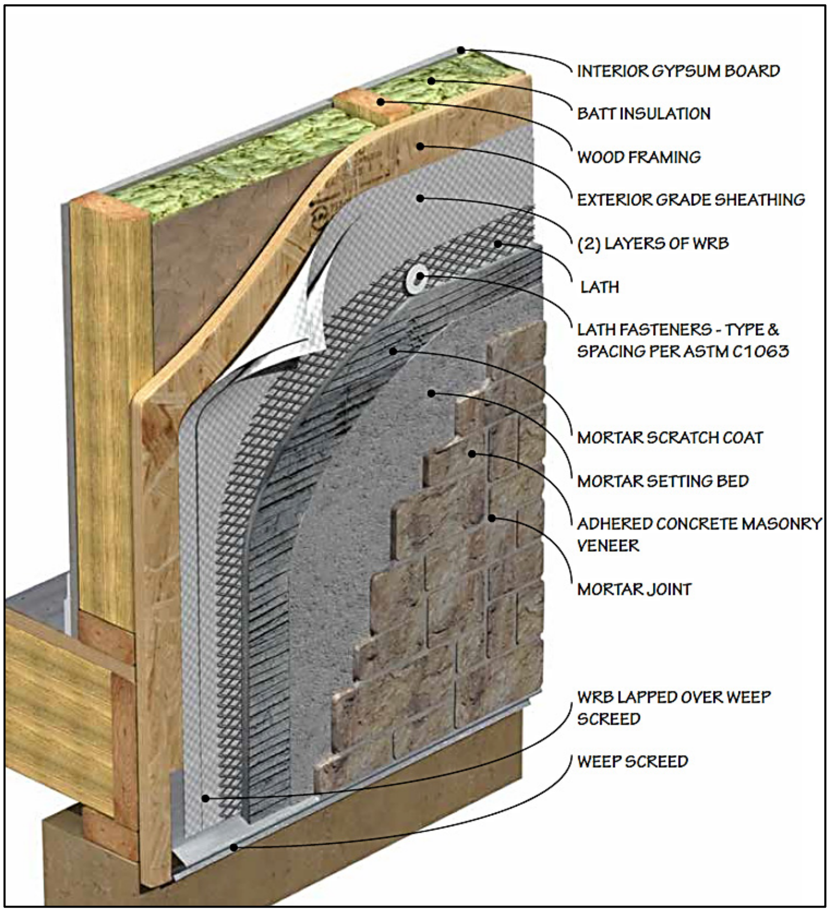

Figure 1: Isometric of a Jointed AMVWS on Wood Framing [6]

Masonry Units

The masonry veneer units can be natural stone, manufactured stone, or thin clay brick or concrete brick. When these systems utilize natural stone units, the units often have very smooth bonding surfaces akin to ceramic tile. Natural stone unit self-weights are highly variable and can be quite significant depending on the type of stone and thickness. Assuming a common thickness for adhered natural thin stone veneers of 38 mm (1½”) the self-weight of natural stone veneer for limestone, sandstone and granite would be approximately 0.96 kPa (20 psf) while a denser metamorphic stone like marble can be as heavy as 1.05 kPa (22 psf). Manufactured stone units are typically fabricated using light-weight concrete and are intentionally roughened on the bonding surface to increase bond strength. The ASTM C1670-15 [3] requires that the maximum saturated self-weight for manufactured stone not exceed 0.72 kPa (15 psf) though many of the products weigh less than 0.53 kPa (11 psf).

Setting Bed

The mortar used to bond units to the substrate (typically a scratch coat) is termed the setting bed in ASTM C1780-15a [4]. The setting bed is used to secure each individual masonry unit by mortar adhesion to the substrate which can be a mortar encasing lath that is scored to form the scratch coat or an exterior grade cement board. When a metal lath and scratch coat is used as the substrate, the mortar used to form the scratch coat can be Type N, Type S, a proprietary polymer modified stone veneer mortar, or American National Standards Institute (ANSI)-A118.4 compliant Modified Dry-set Cement mortars [7] or ANSI-A118.15 compliant Improved Modified Dry-set Cement [7] mortars for the setting bed. Modified Dry-set Cement mortars are typically referred to in industry as "thinset "mortars. It is important to note that polymer modified stone veneer mortar are not necessarily ANSI-118.4 [7] compliant mortars as the ASTM C1780-15a [4] only requires a shear bond strength to the veneer unit of 0.345MPa (50psi) while ANSI-A118.4 [7] requires a shear bond strength to the veneer unit of 2.07 MPa (300 psi).

Substrate

The substrate to attach the adhered stone to the structural backing can be a mortar bed that embeds a self-furring lath that is fastened to the structural backing and is typically scored to form the scratch coat. Alternatively, the substrate can be an exterior grade cement board that is fastened to the structural backing.

When a metal lath and scratch coat is used as the substrate, the mortar used to form the scratch coat can be Type N, Type S, or a proprietary polymer modified stone veneer mortar. The lath used to anchor the veneer system to the backup wall can be galvanized or stainless steel, glass-fiber, or plastic lath. Typically mill-galvanized self-furring diamond mesh metal (steel) lath is used to anchor the scratch coat and stone veneer to the structural wall (often wood-frame). The ASTM C1780 [4] requires the lath be attached with either corrosion resistant barbed roofing nails, staples or screws with a minimum fastener embedment of 19.1 mm ($^3/_4$") in to the stud.

An exterior grade cement board can also be used as the substrate. This product replaces the lath and scratch coat and should be a minimum 13 mm (½") thick and conform to requirements for cement boards in ASTM C1780 [4]. Cement board substrates require the use of ANSI-A118.4 or ANSI-A118.15 [7] compliant "thinset" mortar for the setting bed. Often a fluid applied, structural weather resistant barrier (WRB), is installed onto the surface of the cement board in contact with the setting bed mortar unit to provide additional protection against moisture ingress.

ADHERED MASONRY VENEER BOND FAILURES

Adhered stone veneer bond failures have been observed in the field to occur at the setting bed/ masonry unit interfaces, which have been classified Failure Mode I by the authors (Figure 2) or the setting bed/scratch coat interfaces, which have been classified as Failure Mode II by the authors (Figure 3). The former (Failure Mode I) has been most frequently observed in the field by the authors.

Figure 2: Failure Mode I - Bond Failure at the Setting Bed/Stone Unit interface (setting bed mortar visible) – photograph courtesy of Alberta Masonry Council.

Figure 3: Failure Mode II- Bond Failure at the Setting Bed Mortar/Scratch coat interface (scratch coat visible) – photograph courtesy of Alberta Masonry Council.

A combined Mode I and II Failure (Figure 4) has been observed in the laboratory by the authors but only very rarely in the field as one failure mode is typically governs over the other depending on the components used to construct the adhered stone assembly.

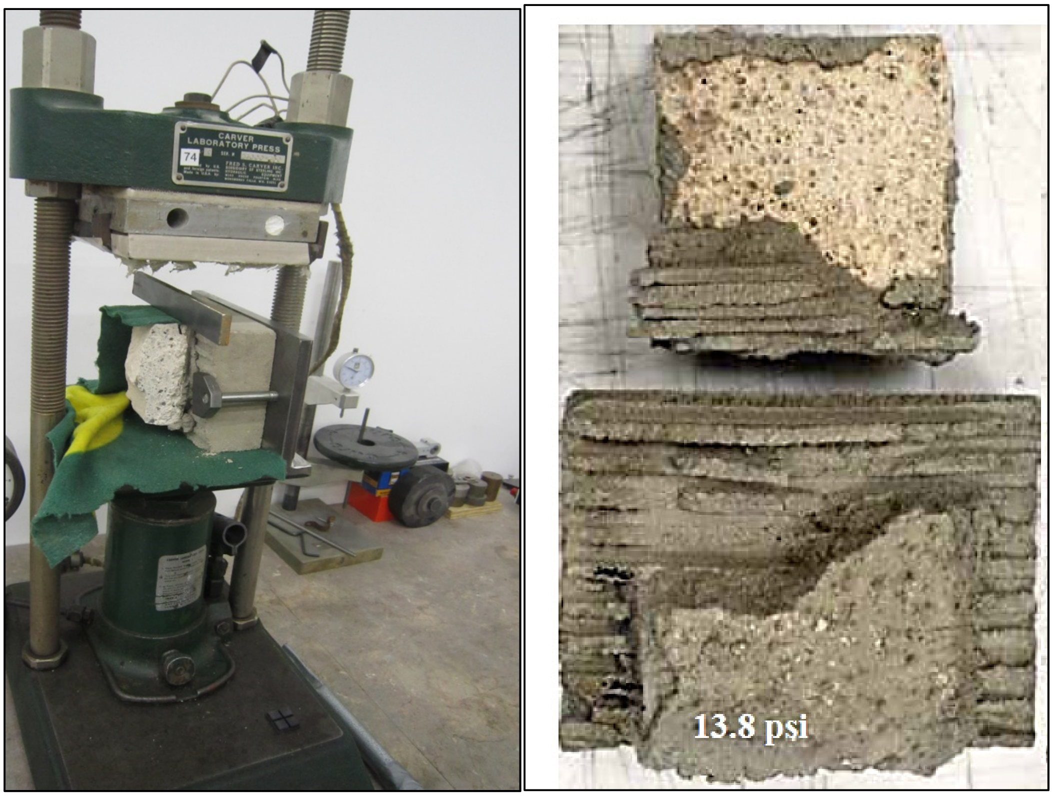

Figure 4: Combined Failure Mode I and Mode II post ASTM C482-02 [5] shear bond test-photograph courtesy of Adanac Global Laboratories.

DESIGN APPROACH

The limit states design approach was utilized for AMVWS. This approach is similar to that taken for homogenous materials such as structural steel design in the Canadian Codes. Factors increase the magnitude of loads acting on the element being designed and decrease the material capacity to account for variability in the workmanship, construction, and deviations between predicted strength from design equations and actual behaviour. Allowable stress design would also be possible with the equations developed in this approach, simply without the safety factors applied to the materials and loads.

Estimating the Forces Resisted by the Mortar

The tensile, shear, and bending forces exerted on wall system are used to estimate the forces resisted by the setting bed mortar. The tensile forces induced in the mortar are attributed to lateral loads such as wind or earthquake. Shear force is generated resisting the self-weight of the stone units in a given area (to account for units that may slip and transfer their self-weight to units lower on the wall). Bending forces are generated by the eccentricity between the bond surface and the centre of gravity through which the self-weight acts as illustrated in Figure 5. From these assumptions, and simple statics, the forces acting on the setting bed mortar can quickly be determined using Equation (1) to Equation (3):

$$T_f = \omega_f \cdot A_{bed} \tag{1}$$

$$V_f = P_f \tag{2}$$

$$M_f = P_f \cdot e \tag{3}$$

In Equation (1), T_f represents the factored tensile forces on the bedding mortar due to a uniform lateral load ω_f acting over the area A_{bed} of an adhered stone unit (considering the typical case of wind load governing in Alberta, Canada). In Equation (2) P_f is the factored axial dead load of the stone unit due to its self-weight and any other forces acting in direction of gravity that are estimated by the designer to act on the unit. This load is equated to the resulting shear force V_f acting on the mortar joint. In Equation (3), M_f is the factored bending moment on the mortar due to the eccentricity, e, of the axial load to the mortar joint. ASTM C1780-15a , requires a minimum scratch coat and bedding mortar thickness of 12.7 mm (½") each and a maximum of 19.1 mm ($^3/_4$") each. Depending on the thickness of the stone units which according to ASTM C1670-15 [3] can be a maximum 66.7 mm ($2^5/_8$") the eccentricity can be quite large as the self-weight acts through the centre of gravity for the material.

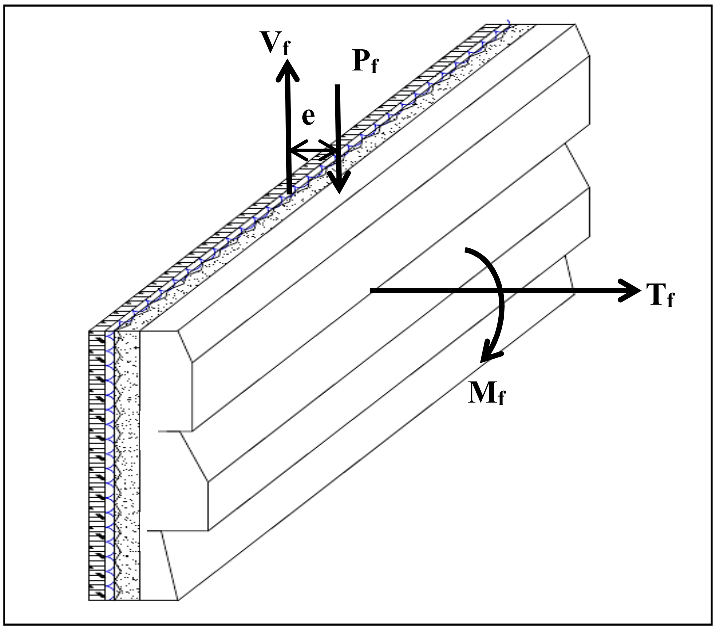

Figure 5: Forces acting on thin masonry unit individually secured by mortar adhesion – figure courtesy of Alberta Masonry Council.

Design Equations for the Mortar Capacity

The design equations for the mortar bond capacity were based on equations typically used for structural steel design [8]. This is based on the assumption that the mortar is behaving as a homogenous material, rather than considering the composite behaviour used in the design of reinforced concrete and masonry.

Equation (4) is used to determine the tensile capacity, T_r, of the setting bed mortar. The bond strength of the mortar, $f_{y,mortar}$, is obtained from testing via ASTM C952 – *Standard Test Methods for Measurement of Masonry Flexural Bond Strength* [9] or may be available from the manufacturer when using a proprietary polymer modified stone veneer mortar. Modified Dry-set Cement mortar manufacturers must meet ANSI-118.4 [7] minimum requirements and report tensile (flexural) bond strengths approximately 9 times the strength of traditional Type N and Type S flexural bond strengths [9].

A_{bed} represents area of setting bed mortar attaching the smallest masonry unit in the system and is calculated from the length, l_{unit}, and height, h_{unit}, the units contact area. The smallest unit dimensions are assumed as they generate the most conservative results. According to ASTM C1680 [2] the stone units are permitted to vary in length and height up to 914 mm (36") but with a combined maximum face area of 0.46 m^2 (713 in^2).

Modified Dry-set Cement mortars are pre-bagged products mixed with a specified amount of water per bag. Theoretically the bond capacity of these pre-bagged products should be more consistent than pre-bagged or field mixed, traditional Type S mortar. In the absence of an established reliability based factor, ϕ_{mortar} could be assumed to be 0.60 as is used for reinforced and unreinforced structural masonry design, ϕ_m in CSA-S304-14 - *Design of Masonry Structures* [10]. However, determination of a reliability based factor should be undertaken.

$$T_r = \phi_{mortar} \cdot F_{t,mortar} \cdot A_{bed} \tag{4}$$

$$A_{bed} = l_{unit} \cdot h_{unit} \tag{5}$$

Equation (6) is used to determine the shear bond capacity of the setting bed mortar. In this equation, $F_{t,mortar}$ is obtained from either testing via ASTM C482-02 [5] - shear bond test, or similar test. The value of $F_{v,mortar}$ is often available from the manufacturer [11] and the minimum shear bond between a manufactured stone veneer unit and the bedding mortar is required by ASTM C1670 and ASTM C1780 to be 0.345 MPa (50 psi). As with tensile (flexural) capacity, A_{bed} is the dimensions of the bedding mortar of the smallest masonry unit installed in the system. The reduction factor of 0.66 comes from beam theory where the shear stress can be determined for a rectangular cross-section on a cantilever beam as $^2/_3 \cdot F_V \cdot A_{web}$ [12].

$$V_r = 0.66 \cdot \phi_{mortar} \cdot F_{v,mortar} \cdot A_{bed} \tag{6}$$

Equation (7) is used to determine the bending moment resistance of the setting bed mortar. In this equation, ϕ_{mortar} and $F_{t,\ mortar}$ are the same parameters (values) as in Equation (4). The section modulus, S_x, is calculated using Equation (8) based on the dimensions of the smallest masonry unit installed in the system.

$$M_r = \phi_{mortar} \cdot F_{t,mortar} \cdot S_x \tag{7}$$

$$S_x = \frac{l_{unit} \cdot (h_{unit})^2}{6} \tag{8}$$

As with steel design [8], elements subjected to combined tension and bending and combined tension and shear should be bound by unity equations, such as the form taken in Equation (9) and Equation (10):

$$\frac{M_f}{M_r} + \frac{T_f}{T_r} \leq 1.0 \tag{9}$$

$$\left(\frac{V_f}{V_r}\right)^2 + \left(\frac{T_f}{T_r}\right)^2 \leq 1.0 \tag{10}$$

ANCHORED ADHERED MASONRY VENEERS

Jointed adhered masonry veneers can be installed using a grout bag to fill the joints after the units have set in a drystack configuration (Figure 6a) or "traditionally" where the mortar joints are installed as the stone units are installed by (Figure 6b).

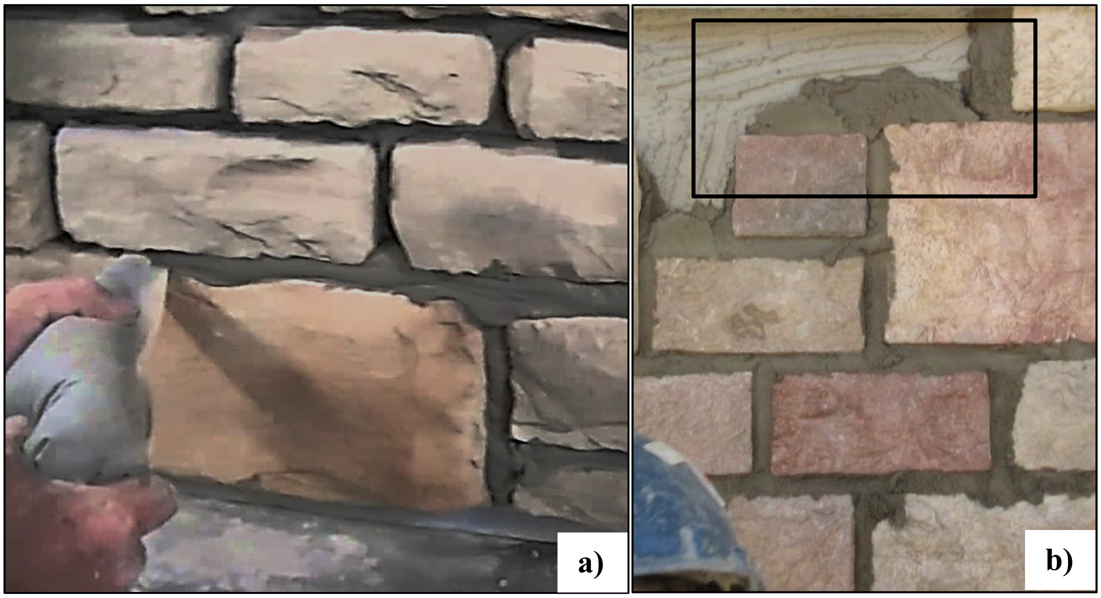

Figure 6: a) Grout bag joint installation of a jointed adhered masonry veneer b) "Traditionally" laid joint installation of a jointed adhered masonry veneer

Alternatively, a combination of an unmodified Type S mortar and mechanical anchorage may be used and *may* provide additional strength to the veneer system. Mechanical anchorage can be provided by brick ties, cut to fit midway in the stone thickness, or angle (L) plates from 2-part brick tie systems. These angle plates are often the correct length without modification (Figure 7). The strength gain attributed to mechanical anchorage is advantageous for adhered masonry veneer assemblies exceeding heights of 3 m. The depth of the thin masonry unit affects the depth of the mortar joint and the maximum embedment depth of the ties. This should be considered to ensure tie embedment can develop sufficient bond with the mortar and still provide sufficient mortar coverage for protection from corrosion of the embedded steel. However, in qualifying cases this method presents a very possible alternative using a modified dry-set cement mortar.

Figure 7: L-plate used as a brick tie

CONCLUSIONS

Bond failures can occur in the setting bed mortar that bonds a direct adhered masonry veneer unit to a substrate. The methods presented in this paper can be used to obtain the forces anticipated to act on the setting bed mortar in adhered masonry veneer systems and determine the shear and flexural resistance of the mortar bond based on the mortar's flexural and shear bond strengths. Using the methods presented here, the structural performance of a mortar relied on to secure a masonry unit by adhesion can be better estimated by a designer to provide a safe design. This is critical when the height of an adhered masonry veneer exceed 3 m (10') above grade. ANSI-A118.4 compliant Modified Dry-set Cement mortars typically achieve shear and tensile bond strengths 9 times greater than traditional Type N and Type S mortars. These mortars present an attractive solution to improve bond strengths for adhered veneers at height particularly in "dry-stack" installations. The design formulas presented are an initial effort and require calibration of the safety factors based on acceptable reliability methods. Other modification factors may also be necessary to address reductions to bond strength experienced in adhered masonry veneer systems.

For "jointed" installations laid traditionally (Figure 6a and 6b), an anchored adhered solution was presented. An anchored adhered masonry veneer could be achieved by providing additional mechanical anchorage using brick ties field cut to fit within the mortar joints in combination with un modified Type S mortar. This solution *may* be sufficient to use for jointed masonry veneers installations that exceed 3 m above grade and to avoid the use of more expensive modified dry-set cement mortars. Additional research is required to determine the strength increase provided by the mechanical ties, and appropriate embedment depth of the ties that account for development length and mortar coverage required for corrosion protection.

ACKNOWLEGEMENTS

The authors would like to thank MITACS, the University of Calgary, Adanac Global Laboratories and the Alberta Masonry Council for their support.

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