Assessing the Impact of Thickness on the Performance of Stucco Cladding

William C. Brown, P.Eng.
Member ASHRAE

Mike Dietrich, P.Eng.

Mark Latimer

ABSTRACT

Stucco, or portland cement plaster, is a traditional cladding material, and the requirements for stucco cladding in building codes are generally prescriptive in nature. The National Building Code of Canada *(NBC), which is a model building code, requires that stucco cladding be installed in three coats with a total thickness of 21 mm. The* Alberta Building Code *(ABC), which is the legislated building code in Alberta, is based on the NBC but also permits two-coat stucco with a total thickness of not less than 19 mm.*

Homebuilders in Alberta had requested that the minimum thickness required by the ABC for two-coat stucco be reduced to 15 mm because that thickness would be easier to install in a two-coat application and also because, in their opinion, the performance of stucco at that thickness would meet the intent of the building code. In response, the Alberta Housing Industry Technical Committee (AHITC), the technical committee of the homebuilders association, undertook to obtain clear evidence that 15 mm stucco would provide water management and serviceability performance equivalent to that of code-compliant stucco.

AHITC retained a firm to conduct laboratory and field studies to assess the impact of stucco thickness on water management and serviceability performance. The project had two phases:

Laboratory study: *Select an appropriate set of properties and a suitable set of laboratory test methods to measure water management and serviceability performance and conduct laboratory testing of two- and three-coat stucco to evaluate water management and serviceability performance.*

Field study: *Develop a field survey protocol and conduct a field investigation to assess the effect of thickness on in-service water management and serviceability performance of stucco cladding.*

The laboratory study showed that water management performance of code-compliant stucco cladding was inadequate for many situations but provided limited information on serviceability performance. Consequently, the field study was executed to develop a better understanding of serviceability performance. However, the field study unexpectedly identified quality control concerns with the installation of stucco cladding, concerns that had an impact on both water management and serviceability performance.

This paper discusses the approach, investigation, and conclusions of the project phases and summarizes the positive response of the homebuilders to the quality control concerns identified in the field study.

INTRODUCTION

Stucco is a cladding material for which design and regulation have evolved from traditional practice. A historic perspective on stucco is provided by the following quotation, which is paraphrased from a book published in 1851 (Downing).

> Outside plastering or stuccoing is generally so little understood in this country, and has been so badly prac-

William C. Brown is director of building science, Morrison Hershfield Limited, Ottawa, Ontario, Canada. **Mike Dietrich** is a building science specialist, Morrison Hershfield Limited, Calgary, Alberta, Canada. **Mark Latimer** is a building science technologist, Morrison Hershfield Limited, Edmonton, Alberta, Canada.

ticed by many masons, that there is an unjust prejudice against it.

Nothing but attention to a few simple rules is necessary to insure success.

1) The first rule is not to use stucco except upon buildings with projecting roofs, in order to prevent the possibility of the wall getting saturated.

2) The second is never to use sand which has not been washed until it is perfectly clean and no longer discolors the water that is poured upon it.

3) The third is never to use "cement" or hydraulic lime the character of which for tenacity has not been fully tested on outside walls for ten years at least.

The requirements for stucco in Canadian building codes are reflective of the traditional nature of stucco and are primarily prescriptive. All Canadian building codes are based on the *National Building Code of Canada* (NBC), which is a model building code. The section on stucco requires that it be installed in three coats of portland cement plaster with a total thickness of 21 mm. A number of code-compliant plaster mixtures are listed in the code. An early building code perspective is contained in the following excerpt from the 1941 edition of the *National Building Code of Canada*:

3.8.5. Stucco Walls

3.8.5.1. General Requirements. — Stucco …shall be applied in three coats…

The minimum thickness of stucco from the face of the base shall be not less than 3/4 inch at every point…

Non-corrodible flashing or other expedients that will prevent penetration of moisture behind the stucco shall be used when necessary.

The Alberta Building Code (ABC), which is the legislated building code in the province of Alberta, is based on the NBC and includes the NBC requirements for three-coat stucco. In addition, it permits two-coat stucco with a total thickness of not less than 19 mm. Homebuilders in Alberta had requested that the total thickness required by the ABC for two-coat stucco be reduced to 15 mm because, in their opinion, that thickness would be easier to install in a two-coat application and as well, in their opinion, the performance of stucco at that thickness would meet the intent of the building code. In response, the homebuilders association, through the Alberta Housing Industry Technical Committee (AHITC), undertook to obtain clear evidence that 15 mm stucco would provide water management and serviceability performance equivalent to that of code-compliant stucco. (AHITC is made up of representatives from local homebuilders associations, the provincial home warranty program, and several related government agencies, and their goal is to investigate and develop solutions for technical issues that have an impact on the residential construction industry in Alberta.)

The authors' firm was retained to execute the project. The project consisted of a laboratory study and a field study. In the laboratory study, we identified relevant properties of stucco cladding that relate to water management and serviceability performance, recommended standard measurement procedures, constructed two- and three-coat stucco specimens and measured the water management and serviceability properties of the specimens. In the field study, we developed a survey instrument with a set of observable conditions and a five-point rating scale and conducted a visual survey to assess the impact of thickness on water management and serviceability performance.

LABORATORY STUDY

The objective of the laboratory study was to evaluate, through material properties, the effect of stucco thickness on water management and serviceability performance. Our approach was to identify relevant water management and serviceability properties, determine appropriate test methods to measure these properties, and assess the effect of stucco thickness on water management and serviceability performance by measuring the relevant properties using the appropriate test methods.

Literature Review

We conducted a literature review to determine code requirements and industry standards for stucco in order to identify relevant properties of stucco cladding. In accordance with the project parameters, we identified material properties, as opposed to system properties, and included those that could be measured by either standard or nonstandard test methods.

Building Codes. The *National Building Code of Canada* (NBC) and the *Alberta Building Code* (ABC) were the prime reference documents for this project. The NBC sets out requirements for the composition and application of three-coat stucco. The ABC sets out the same requirements for three-coat stucco and, in addition, sets out an alternative method for application of two–coat stucco. The codes do not provide standards to evaluate stucco performance. However, it is understood that stucco manufactured to the prescriptive requirements in the codes provides a "standard of performance" that noncompliant stucco mixtures must provide.

Portland Cement Association. The *Portland Cement Plaster (Stucco) Manual,* published by the Portland Cement Association (PCA 1996), is "intended as an authoritative reference manual for architects, specifiers, building officials, inspectors, contractors, plasterers, and apprentices." The manual provides a comprehensive discussion of tools, components, mixtures, accessories, and applications. It notes that two of the three model building codes in the USA require that stucco comply with ASTM C926 and ASTM C1063. According to the manual, water management in stucco is addressed on both the material and assembly levels in the material "by using properly cured Portland cement plaster that has been adequately densified during application" and in the backup assembly with building paper and flashing. Serviceability is addressed through appropriate mixtures and proper application. Twenty-one ASTM standards and a "Guide Specification" are listed in appendices.

ASTM Standards. ASTM publishes an extensive list of standard specifications and test methods that relate to cement, cementitious materials, building envelope materials and assemblies, and related topics. Most of the prescriptive requirements for stucco in the codes are contained in ASTM C926 and ASTM C1063, while some code requirements are covered by specific standards. For example, ASTM C897 addresses the code requirements for aggregates, and ASTM C979 addresses the code requirements for pigments. Stucco properties can be determined from stucco that meets ASTM C926 and ASTM C1063, and ASTM C1185 provides test methods that can be used to measure many of these properties. Summaries of C926, C1063, and C1185 are included in the appendix.

ICBO Evaluation. *ICBO Evaluation Service AC90* (ICBO 1993) provides water management and serviceability criteria for cement panels that are intended for use as exterior siding. The document includes a required set of physical property tests for the material that are selected from ASTM C1185, as well as a number of water management and serviceability tests for assemblies. These criteria provide guidance on the development of criteria for stucco.

Impact Resistance Documents. We reviewed research reports and standards to develop a position on impact resistance. Thorogood (1978, 1981) provides an excellent discussion of the basis for impact resistance tests. He notes that security, safety, and serviceability are the reasons for testing, and that the damage generated is a function of the size, hardness, and energy of the impacting body. ISO 7892 (ISO 1988) prescribes a test method to be used but directs the user to performance standards for building elements for test specimen and pass/fail criteria. The *UEAtc Directive* (1987) provides a test method, guidance on a test specimen, and a pass/fail criterion. A summary of the document is included in the appendix.

Relevant Properties

Water Management. From a material perspective, water management with stucco is a balance between the rate of water penetration through the exterior surface and the rate of drying from the surface. Stucco is a porous material and should not be considered "waterproof." Rates of water penetration and of drying are dependent on material properties, and material properties are dependent on composition.

Water penetration is related to the rate at which liquid water will be absorbed into and diffuse through stucco when the surface is in contact with water, e.g., rainwater on the exterior face.

- *Water absorption coefficient* is a measure of the rate of water absorption through a surface in contact with water. Rainwater penetration of stucco cladding is directly related to this property.
- *Moisture diffusivity* is a measure of the rate of moisture passage through a porous material after being absorbed at the surface. Moisture diffusivity is not a constant but rather is a function of the amount of water in the material. The time it takes stucco to become saturated is related to this property.

Drying ability is primarily related to the rate at which water vapor will dissipate from a material.

- *Water vapor permeability* is a measure of the rate of water vapor flow through a material. Vapor diffusion through the entire wall system is influenced by this material property.
- *Sorption/desorption/suction isotherms* are a measure of the moisture retention capacity of a material during the wetting/drying process. The equilibrium moisture content of a material, which is a function of the relative humidity of the surrounding environment, and the drying potential/ability are greatly influenced by these isotherms.

Composition is primarily related to chemical content, although the type of lath, e.g., welded wire, expanded metal, would also be expected to have an impact on water management. The codes prescribe a number of acceptable mixtures while a broader set is tabulated in ASTM C926. The codes recognize pigments and do not recognize admixtures.

From a system perspective, water management is also a function of climate, and the balance between wetting (by rainwater) and drying (by evaporation) is time dependent, e.g., how frequently does it rain, how dry are the periods between rainfall. Simulation tools may help reduce the complexity of the real situation to a few simpler parameters that can be used to predict performance.

System issues with water management were beyond the scope of this project. The standards say that water that enters behind stucco cladding is expected to drain, and the codes require that flashing and caulking be installed. We are uncertain how drainage is traditionally achieved since no details were provided for draining stucco cladding. It is possible that some drainage capability exists because the lath is required to be furred "not less than 6 mm away from the backing." ASTM C926 requires that flashing be provided at openings, etc., to minimize water entry. Because stucco is porous, a capillary break, such as a drainage cavity, should be installed on the inner surface to prevent water from being drawn through the stucco to the interior of the wall. Architectural features, such as roof overhangs and cornices, have traditionally been used to shade stucco cladding from rainfall. For the traditional approach, we are reminded of the first simple rule of Mr. Downing (Downing 1851), "not to use stucco except upon buildings with projecting roofs, in order to prevent the possibility of the wall getting saturated."

Serviceability. Serviceability of stucco, namely, impact resistance, resistance to cracking, and load and movement stress, is a function of the inherent strength of the cladding in combination with the supporting frame wall. Stucco is essentially a reinforced cementitious panel, i.e., Portland cement paste with lath reinforcing. The codes prescribe acceptable lath and means of attachment and require that the lath be fully embedded in the first coat of plaster. ASTM C926 and ASTM C1063 prescribe similar requirements.

Impact resistance is related to the ability of the cladding to provide security, safety, or serviceability after being hit. Security was beyond the scope of this project; safety and serviceability concerns arise from impacts ranging from those of high energy, small hard bodies, e.g., a thrown rock, to those of low energy, large soft bodies, e.g., a tripping human body.

- *Small hard body* impacts tend to expend most energy on the cladding while transmitting some energy to the support structure.
- *Large soft body* impacts tend to expend some energy on the cladding while transmitting a significant amount to the support structure.

Resistance to cracking is a function of "flexural strength." However, it must also be noted that, based on the literature review, resistance to cracking is also a function of workmanship, a factor that is assumed to be independent of thickness.

Load and movement stress is related to "modulus of elasticity." When combined with the moment of inertia, it provides a measure of the resistance of a material to racking (stiffness).

From a system perspective, there are a number of issues that could affect the serviceability of stucco. The structural sufficiency of stucco depends on the attachment of the lath to the substrate, and the codes prescribe suitable lath and attachment. It is unlikely that the strength of the attachment will be affected by the thickness of the stucco, although it is possible that the integrity of the cladding will be affected. The toughness of the stucco could be affected by the support provided to the stucco by the backing. However, the expectation of drainage suggests that the backing will not provide continuous support. In any event, the codes do not require that sheathing be installed behind stucco when the lath meets prescribed provisions.

Full-Scale Test Specimens

We constructed two full-scale stucco specimens in order to construct two-coat and three-coat material specimens. The client supplied raw materials for the stucco test specimens, including pit-run sand, Spanish trowel sand, Portland and white cement, lime, 50 mm (2 in.) welded-wire lath, and metal J-trim. We obtained 30-minute sheathing paper and expanded metal lath (29 in. × 8 ft) from local building suppliers. All materials used to construct the specimens met the applicable code requirements. For example, we conducted a sieve analysis of the pit-run sand and determined that it met code requirements for particle size distribution.

We constructed two wood-frame test panels to serve as substrates for the full-scale specimens. The panels, 1200 mm wide × 2400 mm high (4 ft × 8 ft), were mounted vertically in order to simulate a typical substrate for stucco installation. Each test specimen was constructed of the following layers (see Table 1 for details):

- 38 mm × 140 mm (2 in. × 6 in.) wood studs at 400 mm (16 in.) on center
- 12 mm (0.5 in.) OSB sheathing, 1200 mm × 2400 mm (4 ft × 8 ft)
- 30-minute sheathing paper
- stucco lath and J-trim
- stucco cladding

A professional plasterer was hired to fabricate the stucco test specimens on the test panels (Table 1). The fabrication proceeded as follows:

1. On Friday, materials arrived and were stored in our laboratory for conditioning.
2. On Monday, the plasterer stapled 30-minute sheathing paper to the OSB sheathing on the test panels and installed 50 mm (2 in.) wire lath and J-trim. He prepared a stucco paste using a plaster mixer, with a code-compliant mix of nominally 1 part portland cement, 0.25 part lime, and 3.25 parts sand; warm water was used in the preparation, and a scratch coat was applied to Specimens 1 and 2 with a nominal thickness of 12 mm (1/2 in.). In addition, we cast six 150 mm (6 in.) diameter specimens and one 300 mm × 900 mm (12 in. × 36 in.) specimen from the paste for characterization purposes. All specimens were nominally 25 mm (1 in.) thick. The stucco test specimens were left exposed to the laboratory environment overnight.
3. On Tuesday, we observed drying cracks (checking) in the scratch coats of the specimens. The plasterer expressed the

Table 1. Characteristics of Full-Scale Stucco Test Specimens

Specimen Number	Sheathing Paper	Stucco Lath	J-Trim Thickness	Number of Coats	Nominal Thickness
1	30-minute 1 layer	50 mm (2 in.) welded wire	19 mm (3/4 in.)	3	21 mm (7/8 in.)
2	30-minute 1 layer	50 mm (2 in.) welded wire	15 mm (5/8 in.)	2	15 mm (5/8 in.)

opinion that the amount of checking was not excessive in his experience. We measured conditions in the laboratory to be 20°C and 30% relative humidity. The plasterer prepared brown coat stucco paste for Specimen 1 using the plaster mixer, with a code-compliant mix of nominally 1 part portland cement, 0.25 part lime, and 3.25 parts sand; warm water was used in the preparation, and a brown coat was applied to Specimen 1 with a nominal thickness of 6 mm (1/4 in.). Following application of the brown coat, we tented the specimens under polyethylene sheets to shield them from air currents and installed a small humidifier to maintain a higher relative humidity around the specimens, in an attempt to minimize checking of the specimens.

4. On Friday, the tenting was removed.
5. On Monday, we observed no checking in the brown coat on Specimen 1. The plasterer prepared finish coat stucco paste using a plaster mixer, with a mix of nominally 1 part white cement, 1 part lime, and 6 parts Spanish trowel sand; warm water was used in the preparation, and a finish coat was applied to Specimens 1 and 2 to a nominal thickness of 3 mm (1/8 in.). In addition, we cast six 150 mm (6 in.) diameter specimens and one 300 mm × 900 mm (12 in. × 36 in.) specimen of the paste for characterization purposes. All specimens were nominally 25 mm (1 in.) thick.

The stucco test specimens remained in our laboratory for two months to cure. No checking was observed in the finish coat of either specimen.

Testing

Laboratories with recognized expertise were engaged to measure water management properties and serviceability properties respectively.

Water Management. ***Test Methods.*** Water vapor permeability was determined according to ASTM E96 Procedure B —Water Method. The test specimens were sealed to the face of a container that had a quantity of water, and the container was placed in a cabinet with temperature controlled at 23°C and relative humidity controlled at 72.5%. The mass of the container with specimen was measured at regular intervals and the decrease in mass because of vapor diffusion was recorded as a function of time. Water vapor permeability was determined from the rate of change in mass and the thickness of the specimen.

Water absorption coefficient was determined from a partial immersion test according to draft CEN Standard 89 N 370. In this procedure, a major surface of a test specimen was placed in contact with liquid water. The mass of the specimen was measured at regular intervals and the increase in mass because of moisture absorption was recorded as a function of time. During the initial part of the absorption process, the mass increase is a linear function of the square root of time. Water absorption coefficient was calculated by dividing the slope of the mass increase by the surface area in contact with the water.

Liquid diffusivity is a measure of the capacity of liquid water to diffuse within a material. However, there is no standard test procedure to determine liquid diffusivity. Liquid diffusivity was derived from the water absorption coefficient using the relationship $D_w \approx (A/w_c)^2$, where A = water absorption coefficient of the material in kg/(m^2 s$^{1/2}$), and w_c = the volumetric moisture content of the material at saturation in kg/m^3.

Test Specimens. Two stucco material specimens, 600 mm × 600 mm (24 in. × 24 in.), were cut from each of the full-scale specimens using a diamond blade. The material specimens were visually examined for flaws and some expression of the checking observed on the scratch coats was visible on the interior face of all specimens. Six 50 mm (6 in.) diameter specimens of scratch coat material and six 150 mm (6 in.) diameter specimens of finish coat material were also provided for testing.

The test laboratory prepared six water vapor permeability specimens, approximately 150 mm (6 in.) diameter, from each of the four materials received (Specimen 1, Specimen 2, finish coat, scratch coat) according to ASTM E96 requirements. The average specimen density was approximately 2000 kg/m^3 (125 lb/ft^3).

The test laboratory prepared sixteen water absorption coefficient specimens, 50 mm × 50 mm (2 in. × 2 in.), from each of the Specimen 1 and Specimen 2 material. Eight specimens were tested with the interior face and eight with the exterior face in contact with water. Liquid diffusivity for the materials was derived from the measured water absorption coefficient.

Material Properties. Water vapor permeability was measured according to ASTM E96 Procedure B—Water method and liquid diffusivity was measured according to draft CEN Standard 89 N 370. The results are shown in Tables 2 and 3.

Discussion. Water vapor permeability, a characteristic material property, of the three-coat material was slightly higher than that of the two-coat material (Table 2); the difference is within material and experimental tolerances. However, the water vapor permeance, a property that is thickness dependent, of both is almost the same. The difference is not significant when compared with the properties of other commonly used building materials (Table 4). The water vapor permeability of the finish coat and scratch coat was measured separately and the values were similar to those of the stucco specimens (Table 2).

Liquid diffusivity, which was determined for the stucco specimens from the interior and exterior faces (Table 3), shows that the finish coat has a slightly higher resistance to liquid diffusion than the scratch coat. The difference is not significant—it can be put into context by comparing it to liquid diffusivity of other common building materials (Table 4). With the measured liquid diffusivity, stucco will saturate within a few hours to a day if one face is in continuous contact with water.

Table 2. Water Vapor Permeability and Water Vapor Permeance as Measured by ASTM E96 Procedure B

Material	Mean water vapor permeability ng/(Pa·s·m)		Mean water vapour permeance ng/(Pa·s·m²)	No. of specimens
	Mean	St. Dev.		
Specimen 1	9.06	0.54	340	
Specimen 2	6.56	0.25	312	
Finish coat	8.42	0.62	415	
Scratch coat	7.66	0.50	388	

Table 3. Water Absorption Coefficient and Liquid Diffusivity as Measured by Draft CEN Procedure

Material	Face in contact with water	Water absorption coefficient (A) kg/(m² s^1/2)		Saturated moisture content (w_c)* kg/m³	Liquid Diffusivity (D_w) m²/s×10⁻⁸	No. of specimens
		Mean	St. Dev.			
Specimen 1	Interior	0.028	0.0029	≅152.9	3.40	8
(3-coat)	Exterior	0.026	0.0329		2.79	8
Specimen 2	Interior	0.038	0.0103	≅151.3	6.41	8
(2-coat)	Exterior	0.020	0.0022		1.77	8

* Determined from full immersion of the specimen

Table 4. Typical Water Vapor Permeability and Liquid Diffusivity of Common Building Materials

Material	Typical water vapor permeability kg/(Pa s m)	Typical liquid diffusivity* m²/s
Aerated Concrete	8.5×10^{-11} (very permeable)	10^{-7} to 10^{-9}
Mortar	2.5×10^{-11} (very permeable)	10^{-8} to 10^{-9}
Clay Brick	4.0×10^{-12} (moderately permeable)	10^{-6} to 10^{-14}
Limestone	2.5×10^{-13} (high resistance to vapour diffusion)	10^{-11}

* 10^{-7} → 25 mm thick specimen comes close to complete saturation within hours while in continuous contact with water
10^{-8} → 25 mm thick specimen comes close to complete saturation within a day while in continuous contact with water
10^{-9} → 25 mm thick specimen comes close to complete saturation within a few days while in continuous contact with water
10^{-10} → 25 mm thick specimen comes close to complete saturation within a few weeks while in continuous contact with water
10^{-11} → High resistance to liquid diffusion

Serviceability. ***Test Methods.*** The tensile strength and elastic modulus of the stucco specimens were determined through flexural tests that were conducted using a modified form of the procedures in ASTM C1185. The specimens were tested in three-point bending on a span of 250 mm (10 in.), with a 25 mm (1 in.) overhang at each support. Two digital dial gauges, symmetrically disposed near the extremities of the transverse centerline of the specimen, were used to measure vertical deflection. A cork strip was placed between the specimen and the loading platen to distribute the load uniformly. The testing laboratory elected to apply the load in increments of 9.81 N (1.0 kg mass) and the deflection was measured for each load increment.

The test results consisted of the load-central deflection curve, the tensile strength (modulus of rupture), and the elastic modulus. The tensile strength was based on the experimentally obtained cracking load; the elastic modulus was calculated using the pre-cracked portion of the load-central deflection curve.

Test Specimens. Six stucco material specimens, 150 mm × 300 mm (6 in. × 12 in.), were cut from each of the full-scale specimens using a diamond blade. The material specimens were visually examined for flaws and some expression of the checking observed on the scratch coats was visible on the interior face of all specimens.

The test laboratory cut each material specimen into two pieces, 60 mm and 80 mm wide, respectively, to produce 24 test specimens that were 300 mm (12 in.) long. The specimens were conditioned at room temperature and humidity for four days.

Material Properties. The serviceability properties measured for three-coat and two-coat stucco are presented in Table 5. For both materials, it was elected to test the 60 mm wide specimens with the lath on the compression side and the 80 mm wide specimens with the lath on the tension side. Three of the 60 mm two-coat specimens and all six of the 80 mm specimens fractured upon first load application and no results were obtained.

Table 5. Mean Values of Serviceability Properties Determined for Stucco Materials

Material	Width, mm	No. of speci-mens	Modulus of rupture, MPa		Elastic modulus, MPa		Ultimate strength, MPa	
			Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
Specimen 1	60	6	0.28	0.05	737.2	76.7	3.72	1.38
(three-coatthree-coat)	80	6	0.18	0.04	650.7	64.7	2.99	0.69
Specimen 2	60	3	0.58	0.04	2037.7	182.0	2.22	1.10
(2-coat)	80	0	---		---		---	

Discussion. It was reported that all of the specimens cracked on application of the first, second, or third load increment. However, the ultimate failure for many of the specimens typically occurred at much higher loads. Note that the uncertainty in the values is high because the weights used to measure the modulus were discretized in a coarse manner.

A majority (75%) of the two-coat test specimens fractured on application of the first load increment. The drying cracks (checking), which had been observed in the scratch coats of the specimens while they were being fabricated, are likely a contributing factor. The scratch coat of the two-coat specimen was thicker than that of the three-coat specimen and thicker cementitious layers will be more susceptible to drying cracks. In addition, it is probable that the brown coat filled some of the cracks in the scratch coat on the three-coat specimen, thus making it strong enough to endure the application of the initial load increment.

The variance of the elastic modulus and modulus of rupture values, reflecting the variability of results from nominally identical replicate specimens, is within the expected range for cementitious products. However, the number of test specimens is not sufficient to reach general conclusions about the properties of two-coat stucco.

Laboratory Conclusions

We note that the three-coat stucco prescribed in NBC and ABC is recognized by ASTM C926 and the PCA Stucco Manual, while the two-coat stucco prescribed by ABC is an extension that is beyond that recognized by industry standards.

Water Management Results. For the purposes of this study, water management properties of stucco as a material were defined by water vapor permeability and liquid diffusivity. Based on the properties measured, we would expect that two-coat stucco should have similar water management performance to three-coat stucco for the following reasons.

- The water vapor permeance is similar for both two-coat and three-coat stucco and is higher than the minimum required for sheathing paper. We conclude that both will provide equivalent performance and neither will adversely affect the water management performance of a stucco-clad wall.
- The liquid diffusivity is similar for both two-coat and three-coat stucco, and both would saturate in less than a day if the surface were in continuous contact with liquid water. Thicker stucco may take longer to saturate, but the time to saturation is such that neither can be expected to provide water management protection under all circumstances.

The expectations for water management performance assume that there are no cracks or other defects in the cladding or building envelope system. Our experience with the construction of the stucco test specimens reminds us that stucco is a cementitious material that must cure properly if drying cracks (checking) are to be avoided. As well, stucco is porous and a capillary break should be installed on the interior of stucco to prevent water that is drawn through it from being sucked through to the interior of the wall.

Drying ability is a function of climate, and the balance between wetting (by precipitation) and drying (by evaporation) is time dependent, e.g., how frequently does it rain, how dry are the periods between rainfall. In this regard, stucco can be expected to behave better in a dry, continental climate than in a damp, maritime climate. In addition, stucco has traditionally been protected from rainwater by architectural features such as roof overhangs and cornices.

The codes require that stucco be installed with flashing and caulking and ASTM C926 requires that flashing be provided at openings, etc., to minimize water entry. C926 also states that water that enters behind stucco cladding is expected to drain, but it does not provide details on how to construct a "draining" stucco cladding. It is speculated that some drainage capacity occurs as a matter of course with stucco cladding because the codes require that the lath be furred "not less than 6 mm away from the backing."

Serviceability Results. For the purposes of this study, serviceability properties were defined by modulus of rupture, elastic modulus, and ultimate strength. Based on the measured properties, we would expect that two-coat stucco cladding could have somewhat reduced serviceability performance compared to three-coat stucco cladding.

- Two-coat stucco can provide equivalent serviceability performance to three-coat stucco if the service load is below the cracking load, thus rendering inconsequential the reduction in serviceability performance of two-coat stucco. Field studies are one means of determining the service load.

- Two-coat stucco can provide equivalent serviceability performance to three-coat stucco if appropriate installation techniques are used to minimize drying cracks (checking). Otherwise, three-coat stucco may provide a margin of safety over two-coat stucco because thinner coats of stucco are inherently less prone to checking and the brown coat can provide some healing of checks in the scratch coat.
- The limited number of specimens means that it is not possible to be certain about the serviceability properties of two-coat stucco. However, even if the higher two-coat properties are confirmed, the increase in performance will not compensate for the reduction in cracking load and flexural stiffness resulting from the smaller thickness.

The expectations for serviceability performance are limited to the effects of thickness of the stucco. The serviceability performance of stucco cladding is also dependent on the building envelope system, especially the backup wall.

FIELD STUDY

The objective of the field study was to assess the effect of thickness on in-service water management and serviceability performance of stucco cladding. Our approach consisted of designing a survey instrument to conduct a directed field survey of stucco cladding, selecting 50 houses with stucco cladding of a range of climate, age, and construction, gathering information on current conditions through a visual survey with exploratory openings, and analyzing the survey information to develop an opinion on the effect of thickness on performance.

Survey Instrument

We designed a survey instrument to direct the visual survey of stucco cladding, and a computer-based template was developed to direct the surveyors in a comprehensive collection of performance information. The survey instrument collected information on the following subjects:

- Building, e.g., weather during survey, year built, type, foundation, other cladding
- Stucco cladding (three-four façades per building), e.g., size, thickness, number of coats, overhang protection, accessories, moisture content
- Stucco at penetrations through cladding:
    - windows (0-2 per cladding), e.g., condition, frame material, sill projection, accessories, flashing
    - service penetrations (0-2 per cladding), e.g., condition, type, material, accessories

The water management and serviceability performance of the stucco cladding and stucco at windows and service penetrations were rated based on the following observable conditions:

Water Management	Serviceability
Staining	Cracks
Efflorescence	Material loss
Fungi/Algae	Impact damage
Erosion	Accessories
Freeze/Thaw	Repairs
Moisture content (measured)	

The survey instrument rated each observable condition, both water management and serviceability, on a five-point scale as follows:

5. *Excellent*—functioning as intended; no deterioration observed.
4. *Good*—functioning as intended; normal deterioration observed; no maintenance anticipated within the next five years.
3. *Fair*—functioning as intended; normal deterioration and minor distress observed; maintenance will be required within the next five years to maintain functionality.
2. *Poor*—not functioning as intended; significant deterioration and distress observed; maintenance and some repair required within the next year to restore functionality.
1. *Defective*—not functioning as intended; significant deterioration and major distress observed, possible damage to support structure; may present a risk to people or materials; must be dealt with without delay.

A *good* rating would be considered a normal result. An *excellent* rating indicated unusually superior aging performance, while ratings of *fair* and *poor*, respectively, indicated that maintenance would be required within the next five years or repair within the next year to maintain functionality. A *defective* rating indicated that the cladding required attention without delay.

The water management performance of the stucco cladding on a façade was rated at the lowest rating of the observable water management conditions on the stucco cladding and stucco at windows or service penetrations. The serviceability performance was rated in the same way.

Visual Survey

We conducted a visual survey of field installations of stucco cladding to evaluate water management and serviceability performance in order to determine whether thickness and number of coats are contributing factors to distress. The buildings in the visual survey were to be selected based on the following criteria:

1. Geographic area—equal representation from different geographic areas.
2. Age of houses—15%—10 years of age or older, 60%—5 to 10 years old, with no house younger than 3 years or older than 15 years.
3. Thickness and coats—both two-coat and three-coat applications, and a range of thickness spanning from the NBC three-coat requirement (21 mm) to the proposed ABC two-coat requirement (15 mm).
4. Complexity of application—examples of stucco cladding with windows and service penetrations, changes in wall surface plane, and junctions with other cladding types.
5. Exposure—a majority oriented toward the prevailing wind-driven rain and / or with limited protection from building runoff; also, a number adjacent to human activities, e.g., pedestrian walkways.

Prior to the start of the visual survey, a trial survey was organized to evaluate the survey instrument and to set a common standard for observations. The surveyors and client representatives reviewed the stucco cladding on four houses and developed a common understanding of the types of deterioration and distress observed on stucco cladding.

A visual survey of a building involved recording the overall building details and visually reviewing the condition of the stucco cladding and the stucco at windows and service penetrations on three or four façades. We removed a 75 mm (3 in.) diameter core sample from one façade to examine the material and the underlying sheathing. We measured sheathing moisture content and stucco thickness at that location and through holes drilled in the stucco on all other façades surveyed. Moisture content was measured using a commercial wood moisture meter. The core sample and holes were located at or below shoulder height and in as unobtrusive a location as was available. The owners of a number of houses did not grant permission to remove the core or drill holes, and consequently we did not measure moisture content or stucco thickness on these buildings.

Two of the authors (Dietrich and Latimer) conducted the visual survey of the buildings. The surveyors regularly compared survey techniques during the progress of the survey to ensure consistency of performance ratings. Each façade was assessed using the survey instrument. The surveyors applied their judgement to identify performance issues that were not described in the survey instrument but that might have an impact on the project objectives.

Analysis

We surveyed 184 façades with over 400 service penetrations and windows on 47 buildings in Edmonton and Calgary, AB. Most buildings were 3 to 15 years old and about 60% of the buildings were in the 5 to 10 year old range. Three buildings outside the age range (one building 2 years old and two buildings 16 years old) were included in the survey because of the scarcity of available houses. We surveyed three or four façades on each building and consequently a range of architectural features, orientations, and moisture exposures were included in the survey.

We recorded the visual survey information using the survey instrument and documented all indications of distress related to water management and serviceability performance:

- in the field of the cladding, including control and expansion joints, and at junctions with other cladding systems;
- at junctions with windows;
- at junctions with service penetrations (e.g., electrical boxes, dryer vents).

We analyzed the visual survey information to relate the symptoms of distress to causal factors in order to assess whether the observed distress was a function of the thickness or number of coats of stucco. Note that we did not observe all possible causal factors because the visual survey, by its nature, did not investigate beneath the surface of the stucco, except at the core sample where we did not investigate beneath the sheathing.

Construction. The following specific items are noted regarding the construction of stucco cladding in Alberta.

Coats. Six of the surveyed buildings had three-coat stucco cladding and forty-one had two-coat stucco cladding. As it happened, we could not find sufficient buildings with three-coat stucco of the required age, and consequently there are insufficient three-coat stucco samples to provide a meaningful performance comparison to two-coat stucco samples.

Thickness. We measured the thickness of the stucco cladding on 137 of the 184 walls surveyed, and the measured thickness ranged from 9 mm to 23 mm. We noted the following comparisons to building code thickness requirements:

- The thickness of 30% (3 of 10) of the three-coat samples met the ABC three-coat requirement of 21 mm.
- The thickness of 13% (17 of 127) of the two-coat cladding met the ABC two-coat requirement of 19 mm.
- The thickness of 57% (78 of 137) of the samples was less than 15 mm.

Composition. We observed the following with regard to the composition of the cladding:

- A number of the 75 mm (3 inch) diameter core samples crumbled when removed, implying a deficiency in the composition of the portland cement paste.
- The majority of metal lath sampled at core locations consisted of galvanized 50 mm (2 in.) welded wire. Various gauges of wire were noted. Lath fastening nails were observed at a limited number of core holes. Spacing of the lath fasteners could not be determined with the 75 mm (3 in.) diameter core hole. We observed that the required spacing of 6 mm (1/4 in.) between the metal lath and the wall sheathing was not achieved in a number of the core samples.

- There was typically no space between the stucco cladding and the sheathing membrane, implying that effective drainage was not probable.
- All but two of the façades with the 75 mm (3 in.) diameter core had asphalt sheathing membrane, none of which were adhered to the stucco. Two had spun-bonded polyolefin sheathing membrane, one of which was adhered to the stucco.

Accessories. We observed the following with regard to the use of accessories with the cladding:

- Accessories at the boundaries of the stucco cladding, e.g., around windows and service penetrations, were rarely present.
- Typically, no accessories were used to terminate the stucco at the base of the wall, and the stucco was generally continuous with the parging over the foundation.
- Stucco corner reinforcement, in the form of expanded metal lath, was visible at locations of damaged stucco. However, in most cases it was not visible and therefore we did not confirm its presence.
- Expansion joints were rare on single-family dwellings surveyed, even on sizable two-story facades. However, multi-family dwellings typically had expansion joints at floor levels and between units.
- Caulking was normally observed around windows and service penetrations in some geographic areas and rarely observed in other areas, reflecting regional variations in standard practice.

Other. We observed the following miscellaneous issues with the stucco cladding:

- No supporting substrate was found behind the stucco on a number of façades where moisture content holes were drilled. We are uncertain as to an explanation, but it was suggested by the client that the stucco may be bridging between wall framing and a foundation that are not vertically aligned.

Water Management. The water management rating was based on five observable conditions (staining, efflorescence, fungi/algae, erosion, and freeze/thaw) and the measured moisture content. We noted the following:

- Many of the areas that had poor water management ratings were areas that were frequently wetted by sprinklers, where water could accumulate, or where water could be wicked up from the ground.
- Staining and efflorescence was typically observed at locations that were exposed to excessive wetting. Typical locations included at the bottom corners of windows or doors, adjacent to leaking roof downspouts and where roof or balcony constructions directed drained water onto the face of the stucco.

Table 6. Rating of Water Management Performance of all Walls Surveyed

Water Management Rating	3-Coat Stucco	2-Coat Stucco
Excellent	17	47
Good	4	65
Fair	2	39
Poor		6
Defective		4

- Fungi/algae were rarely observed. However, locations where it was noted consisted of shaded areas and construction details that allowed water to sit against the stucco cladding for extended periods of time. Typical locations included deck or balcony constructions that did not allow for water drainage.
- We did not observe examples of erosion.
- Freeze/thaw damage was generally observed at flashing locations, where the flashing had been improperly installed with a negative slope (back toward the building).
- The majority of surveyed walls were protected with roof overhangs. The widths of the overhangs ranged from 100 mm (4 in.) to 600 mm (24 in.). The height of the roof overhangs ranged from 3.0 m (single-story) to 6.0 m (two-story). Additional types of protection on sampled walls included cantilever construction, balconies, or decks.
- Measured sheathing moisture content was typically very low. However, sheathing moisture content was high (>15%) in 15 of 21 walls that we surveyed following recent rain or that were in close proximity to sprinklers or, in one case, a dryer vent.

We rated the water management performance of the stucco cladding on each wall as the worst of the water management observable conditions. The number of walls with each rating was as follows:

Serviceability. The serviceability rating was based on five observable conditions (cracks, material loss, impact damage, accessories, repairs).

- Cracks of various sizes were observed on all façades surveyed. Cracks were commonly observed at the corners of window and other penetrations through the stucco. The corner cracks usually were diagonal from the corner. Cracks in the field of the stucco were primarily vertical and regularly spaced. The spacing varied from wall to wall. Fine vertical cracks were observed at the base of walls and at window openings.
- Material loss was typically noted on window and door perimeters and adjacent to penetrations.
- Most cases of impact damage were observed at building corners, adjacent to traffic paths.

Table 7. Rating of Serviceability Performance of all Walls Surveyed

Serviceability Rating	3-Coat Stucco	2-Coat Stucco
Excellent		2
Good	15	96
Fair	8	56
Poor		3
Defective		4

Table 8. Rating of Overall Performance of all Walls Surveyed

Overall Rating	3-coat Stucco	2-Coat Stucco
Excellent		1
Good	15	67
Fair	8	76
Poor		9
Defective		8

- Stucco accessories were either not present or were out of view and hence it was not possible to assess by comparison whether they would have improved serviceability.
- Repairs were rarely observed. However, those that were observed were typically unsuccessful as the cause of the damage, which was usually excessive wetting, had rarely been addressed.

We rated the serviceability performance of the stucco cladding on each wall as the worst of the serviceability observable conditions. The number of walls with each rating are listed in Table 7.

Overall. We rated the overall performance of the stucco cladding on each wall as the worst of either the water management or serviceability rating; the number of walls with each rating are listed in Table 8.

CONCLUSIONS

We developed a consensus survey instrument with a five-point rating scale and used it to conduct a visual survey of the water management and serviceability performance of 184 stucco-clad walls on 47 buildings. Six of the buildings had three-coat stucco and forty-one had two-coat stucco. Because we surveyed three or four facades on each building, a range of architectural features, orientations, and moisture exposures were included in the survey.

We assessed the performance of stucco cladding specifically with regard to water management and serviceability and generally with regard to the ability of the stucco cladding to meet the intent of the building codes. We drew the following conclusions from our analysis of the survey data:

- We found no correlation between water management performance and age, orientation, thickness, or number of coats.
- We found no correlation between serviceability performance and age, orientation, thickness, or number of coats.
- A low number of the samples with measured thickness, 20 of 137 (15%), met the code thickness requirements for two-coat or three-coat stucco, and 78 of 137 (57%) were less than 15 mm thick.
- Other deficiencies observed in the survey included poor mix consistency, inadequate accessories, and lack of substrate support.
- There are not enough code-compliant three-coat samples in the survey to develop a rating for the moisture management and serviceability performance of code-compliant three-coat stucco.
- The overall performance rating is no better than fair for 57% of the two-coat stucco claddings and for 30% of the three-coat stucco claddings.

The objective of this project was to develop a professional opinion on whether 15 mm, two-coat stucco cladding would provide performance equivalent to that of code-compliant three-coat stucco cladding. Unfortunately, we did not obtain sufficient information to provide an opinion because there were insufficient three-coat samples. As well, the performance of 57% of the two-coat stucco applications that we surveyed was rated no better than fair, which is not adequate performance in our opinion. Since approximately half of the two-coat applications were at least 15 mm thick, we have reservations that 15-mm, two-coat stucco cladding will provide adequate performance.

The field investigation of stucco cladding in Alberta found that 85% of the applications were thinner than the current Building Code requirements and that 43% were thinner than the proposed 15 mm thickness. As well, the survey found that more than half of the two-coat applications surveyed would require maintenance or repair within the next five years to maintain functionality. In our opinion, these issues demonstrate a lack of quality control during application.

We recommended that a quality control program be established to address design, workmanship, and materials issues related to stucco cladding. Effective quality control requires a standard for evaluation of factors such as thickness, number of coats, materials, and workmanship and an organized program to conduct evaluations and to ensure compliance. The following ASTM standards provide a basis for evaluation of stucco cladding:

- C926, Standard specification for application of portland cement-based plaster
- C1063, Standard specification for installation of lathing and furring to receive interior and exterior Portland cement-based plaster

We also recommended that the requirements for stucco cladding in the Alberta Building Code be enhanced, and that guidance for enhanced requirements could be obtained from ASTM C926 and ASTM C1063.

POSTSCRIPT

The homebuilders' response to the project recommendations was positive and forward looking. The following summary of the homebuilders' response is excerpted from the Alberta Home Builders Association bulletin of November 2003.

> As a result of the findings in this project, AHITC started work on an action plan to improve building envelope workmanship in Alberta. The action plan involves working with builders, trades, suppliers, manufacturers, and safety code agencies to encourage action that will bring about material and workmanship improvements in the industry. The strategy is organized around education, quality control, and material improvements.
>
> In the realm of education, AHITC worked with the Alberta Wall and Ceiling Bureau to revise its stucco best practice guide and to present stucco seminars in major cities. The seminars attracted over 250 people. The main message was to ensure that plasterers and builders learn to communicate their expectations to ensure a quality stucco application. This is the first step in better quality control. AHITC is also working with the Professional Home Builders Institute of Alberta (PHBIA) to organize sessions on specifying stucco, proper application, the selection of weather barriers, and window installation.
>
> As a result of the stucco study, the City of Calgary and Alberta Municipal Affairs both produced documents that emphasized the increasing roles builders must play in ensuring the building envelope is properly constructed.
>
> Product improvement is focusing on the worst leakage area – the window/wall interface. AHITC is part of a group formed by Municipal Affairs to try to come to a consensus on a reasonable minimum window installation method for the province. The group is considering a program created by the American Architectural Manufacturers Association (AAMA) as the basis for an Alberta program. Members of AHITC will incorporate the findings of this group into the new CSA A440.4 Window Installation Standard. Discussions with window companies on window product improvement are beginning to show results.

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APPENDIX – SUMMARY OF RELEVANT STANDARDS

A*STM C926—Standard specification for application of Portland cement-based plaster*

ASTM C926 covers the requirements for the application of full thickness Portland cement-based plaster and sets forth tables for proportioning of various plaster mixes and plaster thickness. Composition and application are covered in detail. It includes three-coat plaster, 22 mm thick, installed over metal plaster base, which is the three-coat application that is set out in the NBC and ABC.

Water management is addressed in the annexes to the standard (annexes are mandatory information). It notes, as in the PCA Manual, that resistance to rain penetration is improved by densification during application, but it also states that plaster shall not be considered “waterproof.” A number of system-related water management details are prescribed including:

- the specifier is responsible for furnishing and application of flashing at openings, etc., to prevent water from getting behind plaster; and
- a drip screed or through-wall flashing shall be provided at the bottom of exterior walls “to drain away any water that may get behind the plaster.”

The appendix to the standard, which is nonmandatory information, notes that resistance to moisture movement can be improved with admixtures, but states that “use of the terms dampproofing or water proofing is misleading” and their use is discouraged.

Aspects of serviceability, specifically relief from stresses, are also addressed in the annexes. There is discussion of the provision of joints to relieve stresses, and the user is directed to ASTM C1063.

ASTM C1063 - Standard specification for installation of lathing and furring to receive interior and exterior portland cement-based plaster

ASTM C1063 covers the minimum requirements for lathing and furring for the application of portland cement-based plaster as defined in ASTM C926. The specification references fifteen ASTM Standards. Water management is specifically addressed in one reference to lapping backing so that water will flow to the exterior. Serviceability, namely, resistance to cracking, is addressed in the application of accessories including control joints.

ASTM C1185 - Standard test methods for sampling and testing non-asbestos fiber-cement flat sheet, roofing and siding shingles, and clapboards

ASTM C1185 provides standard test methods that cover sampling and testing of non-asbestos fiber-cement flat sheets, etc., that is, materials that have performance requirements closely related to stucco. The specification references six ASTM standards and three standards from other sources. Water management in materials is specifically addressed in procedures for evaluating water absorption, moisture content, and watertightness. Serviceability in materials is specifically addressed in a procedure for evaluating flexural strength.

UEAtc directives for impact testing opaque vertical building components (MOAT No 43: 1987)

This document prescribes test methods for assessing the impact resistance of vertical building components and discusses the derivation of the type of impact bodies and the impact energy. The methods can be applied to stucco cladding. Soft body tests are based on an investigation of actual shoulder impact of a moving human body, and hard body tests are based on observations of the response to hard body impacts. Vertical components are classified according to the exposure to external impacts, and impacts are classified as ‘safety impacts’ and “retention of performance impacts.” Impact energies are prescribed for soft and hard impact bodies for different exposures, and impact classifications and pass/fall criteria are defined.