BUILDING ENVELOPE TECHNOLOGY SYMPOSIUM

CEMENT PLASTER METRICS: QUANTIFYING STUCCO SHRINKAGE AND OTHER MOVEMENTS; CRACK ACCEPTABILITY CRITERIA FOR EVALUATING STUCCO

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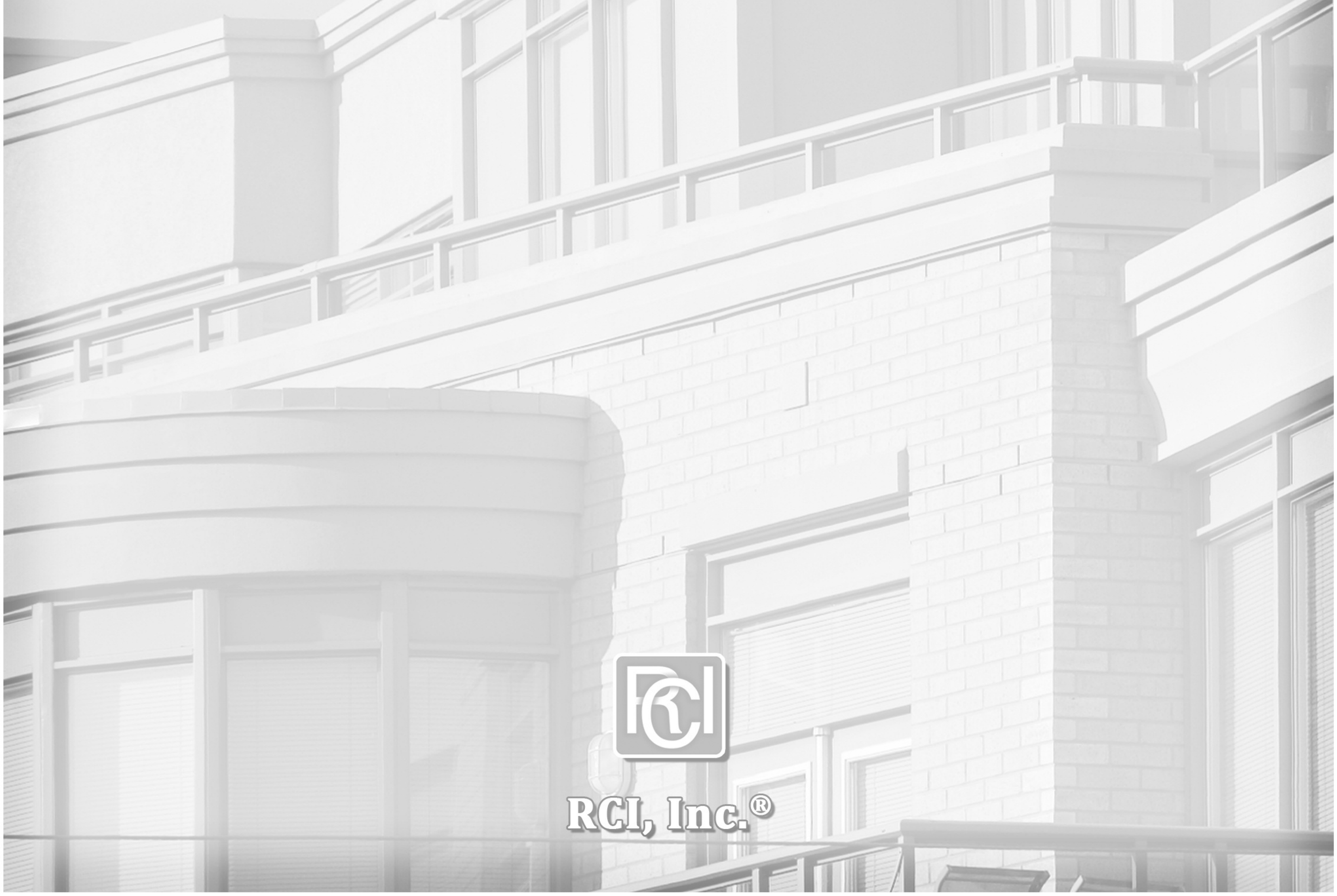

ABSTRACT

Building design and construction professionals and cement plaster product manufacturers acknowledge that Portland cement plaster (stucco) shrinks as it cures and moves with changing environmental conditions while in service, but by how much? Published information quantifying the magnitude of shrinkage and other movements is scarce but does exist for stucco installations as early as the 1940s. Detailed information from several documented stucco installations and manufactured products with published shrinkage data will be presented, compared, and discussed. Cement plaster cracking is inherently related to shrinkage and other movements. Stucco crack acceptability criteria, which vary widely, are published by a multitude of industry sources, with no objective industry consensus. Acceptability criteria from known published sources are tabulated, presented, and compared to identify common factors and anomalies. The intent is to establish objective, unbiased criteria for use by industry practitioners.

This information has been extensively researched and observed over many years. It should prove useful to interested parties in effectively understanding and accommodating cement plaster shrinkage and movement characteristics during the design and construction process and serve as a resource when evaluating cracks in stucco installations.

SPEAKER

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Jeffrey A. Bowlsby, CCS, CCCA, has over 25 years experience in architecture and construction, including new construction, renovations, and forensic investigations. He continues to research stucco performance and serves on the two principal ASTM task groups regarding cement plaster referenced in building codes: ASTM C926 and C1063. As an architect, his experience encompasses substantive commercial, residential, and institutional works with a strong emphasis on building envelope systems integration in general and cement plaster in particular.

Cement Plaster Metrics: Quantifying Stucco Shrinkage and Other Movements; Crack Acceptability Criteria for Evaluating Stucco

INTRODUCTION

It is perplexing to the architectural community that the cement plaster industry has little empirical data about certain significant performance characteristics of cement plaster, about its constituent components, and about installation techniques with which to base design decisions, performance expectations, and limitations. While cement plaster has been a primary exterior wall finish in our built environment for over a century, in many ways, it is still very much a handmade finish system. The art of cement plastering continues to require a strong emphasis on plasterers' experience, discernment, and skills. Cement plastering relies on rules of thumb and a constant reevaluation of complex variables for each set of circumstances required toward achieving the goal of a crack-free installation. For example, a wide range of dimensions and proportional guidelines are put forth by different industry sources for cement plaster control joint spacing requirements. These values (which have developed over time) are based on local installer experiences and contracting practices with regional variations. None are based on empirical material property behaviors of either cement plaster or control joint products, as determined by quantitative testing or in consideration of the variables presented by the climate or service conditions to which the cement plaster installation is subjected.

This paper is organized into two basic topics: 1) Quantifying cement plaster shrinkage, and 2) Evaluating acceptability criteria for cement plaster cracking. The relationship between shrinkage and cracking will be discussed.

The initial topic will explore and provide a basis for answering the question, "How much does stucco shrink and move?" Many in the cement plaster industry are unaware of the amount of movement that occurs due to initial cement plaster shrinkage as it cures or that it expands and contracts with temperature and other environmental factors. A basic understanding of the nature and magnitude of these movements is also unknown to those who design and install cement plaster, yet the industry acknowledges that it is a characteristic of cement plaster to shrink and to crack from these movements. Nine references, including case studies and manufacturers' product data, will be presented and discussed, documenting the movement measurements obtained from actual installations and cement plaster product manufacturers' physical properties data.

The second topic will present and discuss cement plaster crack observation, measurement, and documentation protocols. It will present 16 known and published stucco crack evaluation criteria in table form and discuss similarities and differences. Additional considerations implied but not often stated will be identified. The intent is to take a step towards a unified and comprehensive set of crack evaluation criteria for the cement plaster industry.

1. Different references often cite results in different numerical formats, so the numerical data have been converted and reported in this paper in consistent dimensional standards, stating shrinkage rates in percent; and dimensions in mils, mils per ft, and mils per 10 ft, for ease of comparison. Comparing shrinkage rates stated in percentage is intuitive. Mils are 1/1000th of an inch and are used to offer more precision than the English units of 1/32nd, 1/16th, etc., of an inch. For example, 1/8th of an in = 0.125 in = 125 mils. The 10-ft dimension is intentionally used as a datum for panel size reference, in part because lath accessories are manufactured in 10-ft lengths, and it simplifies dimensional comparisons and calculations. The objective is to achieve a firm understanding of the dynamic behaviors of cement plaster so that we can effectively engineer solutions to accommodate predictable cement plaster movement and minimize its resultant effects.

Given the many complexities and variables within the broad category of cement plaster, it is imperative to clarify the specific applicability of this paper. We will consider select characteristics of Portland cement plaster as traditionally installed in three coats: scratch, brown, and finish over a lath, water-resistive barrier, and framed support structure. This paper may not apply in whole or part to the separate but related subjects of one-coat stucco, DEFS, EIFS, noncementitious finish coats, admixtures, fiber additions, lath and fastener characteristics, continuous insulation, cement plaster direct-applied to concrete or masonry substrates, or other topics not specifically identified. The discussion regarding crack evaluations is in reference to cracks that are visible only at the finish surface. We will also not discuss crack repair methodologies except as anecdotally mentioned in *Table 3*. This paper is intended to evaluate and recognize the normal behaviors of Portland cement plaster that can be anticipated and to begin to derive rational crack control solutions that benefit cement plasters' consumers and the design and construction communities. It is not intended to be critical of any specific designer, installation, product, or manufacturer.

TOPIC 1 - QUANTIFYING CEMENT PLASTER SHRINKAGE AND MOVEMENT

How much does cement plaster shrink after it is installed? The challenge is to identify a simple, measurable dimensional rule of thumb—a stated rate or coefficient that can be used to determine a meaningful shrinkage and movement dimension. Major publications in the cement plaster industry,

6. Sampling

6.1 Take samples according to the applicable provisions of Practice C 192/C 192M from batches of hydraulic-cement mortar or concrete made in the laboratory (Note 2).

NOTE 2—When collecting samples in nonstandard conditions, such as field concrete, it is suggested that Practice C 172 be followed. Field cast specimens can show up to twice as much drying shrinkage as laboratory cast specimens from the same materials and proportions.

Figure 1 - Field sampling caveat from ASTM C157, footnote 2.

from trade associations, building codes, plaster industry manuals, and design guides were reviewed and are silent on this topic. Portland cement concrete has similarities to Portland cement plaster, but while the two are sometimes compared, concrete is not the same as cement plaster, and the comparison becomes meaningless on close examination.

The common laboratory testing method to evaluate shrinkage of cement-based materials is ASTM C157, *Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete.*[1] This standard "covers the length changes for causes other than for externally applied forces and temperature changes in hydraulic cement mortar." This intricate laboratory testing method includes samples cured in a continuous lime water-immersion curing process and is performed in a highly controlled environment. It evaluates cement mortars and cement concrete in a laboratory setting and is not specifically designed to replicate the actual performance of cement plasters installed as part of an assembly on buildings in a building construction site setting. A footnote in the test method indicates that as much as twice the amount of shrinkage may occur when using field-cast samples, which must be a necessary consideration when evaluating shrinkage information based on ASTM C157 (*Figure 1*). While useful, this test method is limited in application and is not intended to provide a complete view of the actual shrinkage of a cement plaster assembly installed on a building project site.

Research over the last several years has identified Portland cement plaster shrinkage rates in published product data from bag mix plaster basecoat producers; journal articles documenting case studies of installed cement plaster performance; and indirect information, including shrinkage rates from a recent testing program involving fiber additions to cement plaster.

Evaluated together, the data from these references suggest a narrow range of cement plaster shrinkage rates that can be useful for design and construction purposes. Shrinkage rates are indicated in three forms: Shrinkage as a percent, mils per ft, (and, for ease of comparison), mils over 10 ft of cement plaster panel length. These case study and product data references are presented in relative descending order of the shrinkage rates they document, as follows:

Reference 1:

Case study, "Crack Control in Portland Cement Plaster Panels." Bert Hall, 1947.[2]

0.120% field-measured shrinkage, 14.4 mils per lineal ft

This article describes an actual cement plaster installation at an interior suspended ceiling in the Grand Coulee Dam and its initial failures and remediation, which was also briefly referenced in Diehl.[3] The ceiling area was 52 ft long x 18 ft wide, divided by one control joint at ~26 ft. The ceiling assembly was a metal-lathed suspended support structure with three-coat cement plaster—each coat placed 24 hrs apart, damp-curing only the final coat.

Initially, the metal lath on the ceiling was installed with lath continuous through the ceiling-to-wall juncture, from the ceiling to the wall. Significant objectionable cracks developed in the cement plaster at the ceiling. It became understood that this installation created a restrained perimeter condition, i.e., restrained by the continuous lath, which accommodated no shrinkage movement within the cement plaster at the ceiling-to-wall juncture. The ceiling was later reconstructed to isolate the ceiling lath at the perimeter edges of the ceiling-to-wall juncture to allow movement capability, and the shrinkage movements were observed and documented over a one-year period. Three-quarters of an inch of shrinkage occurred over the length of this room, which was estimated to be the cumulative width of cracks that would have occurred had the perimeters not been isolated. For comparison to other data that follow, using these figures, this cement plaster shrank at the rate of 0.120%, which equals approximately 144 mils over 10 ft. The majority of shrinkage occurred within the first 90 days, but it is interesting to note that measurable shrinkage continued for over a year after installation (*Figure 2*).

Reference 2:

Spec Mix fiber base coat, product data, 2008[4]

0.119% ASTM C157 shrinkage, 14.3 mils per lineal ft

Spec Mix Fiber Base Coat is a currently available cement plaster basecoat product that includes "special admixtures to reduce shrinkage." The manufacturer's product data indicate an ASTM C157 shrinkage rate of 0.119% at 28 days. Using this figure, a

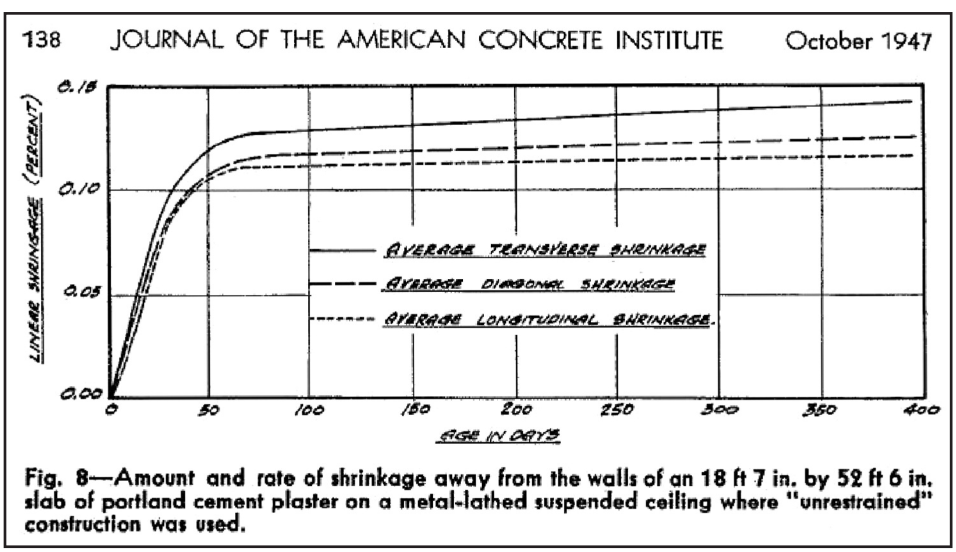


Figure 2 – Cement plaster shrinkage rate on suspended ceiling, Grand Coulee Dam, 1947.

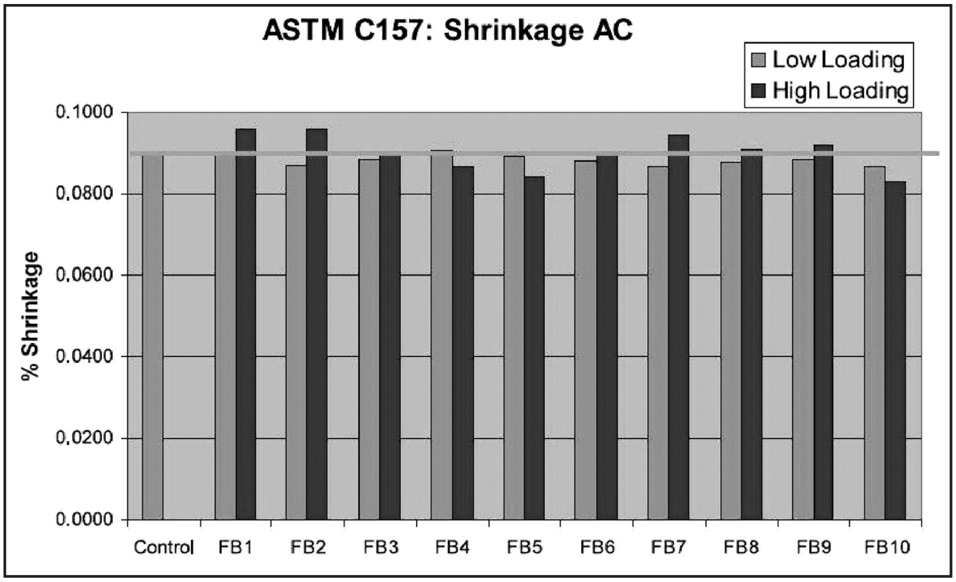


Figure 3 – Shrinkage reported in SMA fiber addition testing among 10 mixes.

10-ft dimension of Spec Mix stucco is calculated to shrink 143 mils at 28 days, subject to the caveats of ASTM C157.

Reference 3:

StoPowerwall stucco, product data, 2008[5]

>0.09% ASTM C157 shrinkage at 28 days, >10.8 mils per lineal ft

StoPowerwall Stucco is a basecoat mix by one of our industry's major manufacturers. Its published product data indicate ASTM C157 shrinkage under air-curing conditions exceeding 0.09% at 28 days. Using these figures, a 10-ft dimension of StoPowerwall Stucco will shrink in excess of 108 mils, subject to the caveats of ASTM C157.

Reference 4:

Case study, "Performance Impact of Various Fiber Additions in ASTM C926 Cement Plaster Basecoat," Stucco Manufacturers Association, June 2010[6]

0.09% ASTM C157 shrinkage of control samples, 10.8 mils per lineal ft

This recently published study documents the testing of laboratory-prepared samples of an otherwise identical cement plaster mixture with a variety of fiber additions to evaluate the effective performance characteristics of different fiber additions to Portland cement basecoats. All tested samples were compared to a control sample that had no fiber additions. Two of the tests evaluated shrinkage performance under air- and moisture-curing conditions; and perhaps surprisingly, fiber additions had only minor, if any, effect on actual shrinkage performance compared to the nonfibered control sample (*Figure 3*). Using these figures, a 10-ft dimension of this cement plaster will shrink approximately 108 mils, subject to the caveats of ASTM C157.

Reference 5:

"Controlling Shrinkage in Portland Cement Plaster," John Boland, 1985.[7]

>0.083% field-measured shrinkage, >10 mils per lineal ft

This published article documents a 45,000-sq-ft cement plaster ceiling installation in an open parking garage. The ceiling included a series of nine panels with isolated perimeter edges, which is unrestrained construction. The largest panels were 75 ft x 90 ft, further divided by control joints into 15-ft by 15-ft square areas. The ceiling assembly included 1.5-in channel at 4 ft on center, supported by 3/16-in hangers 3 ft apart. Cross furring was a ¾-in channel at 12 ft [*sic*] on center. The lath was 3.4 lb/sy diamond mesh tied to cross furring and solid zinc casing beads, and control joints were installed. Channels and metal lath were not continuous between adjacent panels, which terminated in casing beads. Panels were isolated from perimeter walls with casing beads spaced .25 in from walls. The assembly is three-coat Portland cement plaster with a finish coat of white cement, silica sand, and hydrated lime.

There were no cracks reported anywhere, with shrinkage gaps observed at ceiling perimeters. Ceiling areas reportedly shrank towards the center from the perimeter. The author of the study felt that sand gradation, the cement-to-sand ratio, and floating brown, damp curing were important. The article recommends control joints at 10 ft on center, not the 15 ft on center that they used. This article documents the

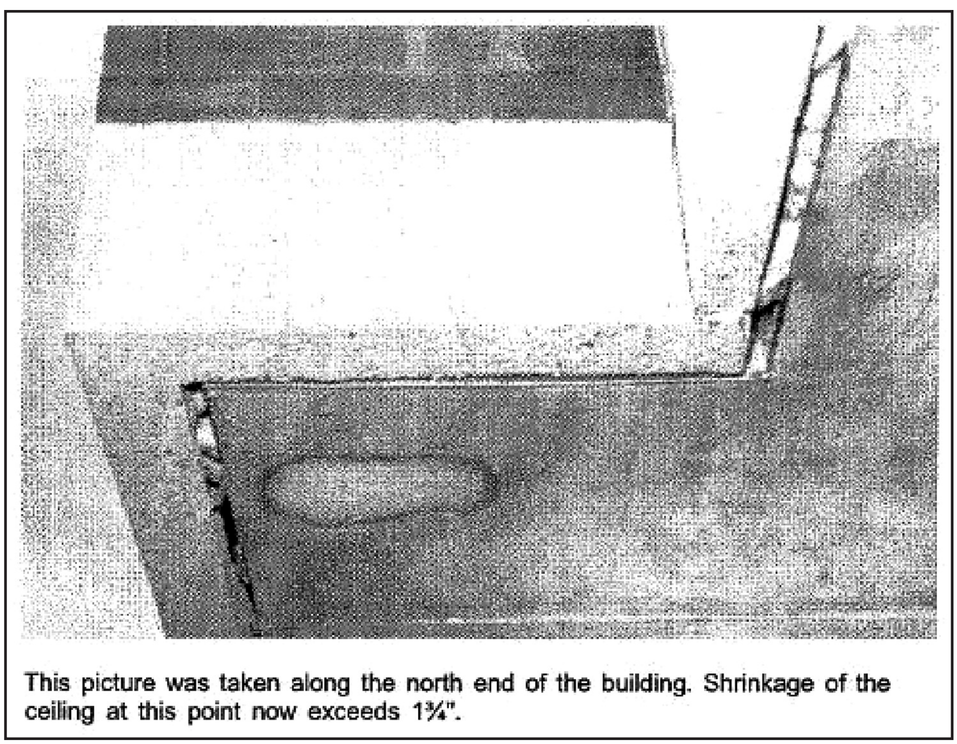


Photo 1 – Perimeter shrinkage at large suspended ceiling (Boland).

importance of a cement plaster membrane on lath that is free to move independently of its supports. To accommodate shrinkage movement, the lath was wire-tied to horizontal channels, causing slippage (*Photo 1*).

Reference 6:

Surewall FRP Sanded, one-coat stucco bag mix product data, 2004.[8]

0.07% shrinkage at 28 days, 8.4 mils per lineal ft

Surewall FRP Sanded is described in company literature as "highly crack-resistant." It is a stucco product developed for one-coat stucco assemblies. Using the published shrinkage data, a 10-ft dimension of Surewall FRP Sanded will shrink approximately 84 mils. While the testing protocol is not stated, we assume that ASTM C157 was used to determine the shrinkage rate of this product, so actual shrinkage characteristics of this product installed in the field may be subject to the caveats of ASTM C157.

Reference 7:

Builders' *Guide to Stucco Lath and Plaster*, Max Schwartz, 2007.[9]

~0.0525% shrinkage, ~6.3 mils per lineal ft

This recently published book states on page 32, "Cement plaster, like concrete and all other cement-based materials, will shrink slightly when it dries. In typical concrete, this change amounts to about 63 mils over 10 ft. The same condition exists when we are talking about Portland cement plaster."

The shrinkage rate indicated in this reference is the smallest identified for cement plaster. It is based on a reference to Portland cement concrete, which is then suggested to be the same as that of Portland cement plaster, without any supporting evidence for why cement plaster and concrete are similar in this regard. The author and publisher of this book refer to virtually the same text from a Portland Cement Association publication. Portland cement, sand, and water are used in both concrete and cement plaster. Cement plaster differs from concrete in more respects than it is similar—aggregates and gradation, water-to-cement ratios, additives, substrates, installation orientation (horizontal vs. vertical), lath type and fastening, finishing and curing, layering vs. single-pour homogenous, etc.—that it is not reasonable to compare or equate the two materials. They have different constituents, different variables, and different performance characteristics. This reference is included here only to illustrate that concrete behavioral and performance characteristics regarding shrinkage are not reasonably comparable to cement plaster.

Reference 8:

Cement plaster expansion and contraction from cyclical temperature changes

Cement plaster is also subject to thermal expansion and contraction resulting from changes in ambient service temperatures. The changes in service temperatures are dependent on the geographical location of the plaster installation, on the building itself (is the stucco in a sunny or shady location?) and seasonal temperature variations of the local climate.

Portland cement plaster is Portland cement mortar: Portland cement, sand, and water. The National Research Council of Canada, Institute for Research in Construction (NRCC-IRC), in *Canadian Building Digest CBD-30*,[10] originally published in 1962 and located on NRCC-IRC's Web site since 2003, includes a table with the approximate expansion and contraction rates for Portland cement mortar (*Figure 4*).

Using the NRCC thermal expansion rates of 0.04 to 0.06%, a 10-ft dimension of cement plaster will expand approximately 48 to 72 mils over a 100°F temperature change.

The *Keene Technical Manual*, Penn Metal Products, from about 1983,[11] indicates the thermal coefficient of expansion for exterior plaster as $5.9x10^{\wedge-6}$ in per in per degree Fahrenheit, from 32°F to 212°F. This coefficient corroborates the NRCC dimensional values when calculated.

John Bucholz, PE, cites the thermal expansion/contraction coefficient of cement plaster as $6.5x10^{\wedge-6}$ in per in per degree Fahrenheit.[12] Using this thermal expansion rate, a 10-ft dimension of cement plaster will expand approximately 78 mils over a 100°F temperature change.

Another source, *Masterwall Technical Bulletin MW# 148-010104*, dated 2004,[13] indicates the thermal expansion coefficient for exterior plaster as $7.0x10^{\wedge-6}$ in per in per degree Fahrenheit. Using this thermal expansion rate, a 10-ft dimension of cement plaster will expand approximately 84 mils over a 100°F temperature change.

These values require consideration when calculating overall shrinkage and movement, in that they approach one half the amount for the initial shrinkage. Note that this movement occurs only in fully cured cement plaster, as ambient temperatures change. Fully cured cement plaster at 70°F would further shrink by half this thermal movement value when ambient temperatures reached 20°F and expand by half this value at 120°F, which is possible in some geographic locations.

Reference 9:

Cement plaster expansion and contraction from wetting and drying cycles (precipitation)

Installed cement plaster is subject to rain, wind, and snow, as well as building maintenance activities (power washing). As a cementitious material, it is capable of reabsorbing and releasing some amount of water or rehydration on a cyclical basis.

Using the NRCC10 wetting expansion rates of 0.005% to 0.03% (*Figure 4*), a 10-ft dimension of cement plaster, when rewetted, will expand approximately 6 to 36 mils. Rewetting movement is always initially expansive, resulting from water absorption and then contractive back to a stable condition as things dry out. Complete resaturation is not likely, and the rate of expansion due to wetting is of relatively minor concern.

Table I Thermal and Moisture Expansions of Various Materials

	Thermal expansion per cent length change for 100F deg	Expansion on wetting per cent length change	Modulus elasticity $x10^{-6}$
Limestones	0.01 to 0.05	0.002 to 0.01	3 to 10.4
Clay and shale bricks	0.02 to 0.05	0.002 to 0.01*	1.4 to 5
Concrete	0.05 to 0.08	0.01 to 0.2**	2.5
Steel	0.067		30
Portland cement mortar	0.04 to 0.06	0.005 to 0.03	3.5
Lime mortar	0.04 to 0.05	0.001 to 0.02	0.5

Figure 4 – NRCC thermal and moisture expansion rates.

SUMMARY OF CEMENT PLASTER SHRINKAGE AND MOVEMENTS

To summarize, there are many variables that affect the initial shrinkage and dimensional movement rates of Portland cement plaster; accordingly, a single value cannot sufficiently predict all conditions. Laboratory testing is an indication of shrinkage trends, and documented field installations validate the trends observed in lab testing.

Note that the shrinkage and movement values indicated above are actual dimensional measurements from actual installations and laboratory testing. Frequently, for design and construction purposes, there has been no documented consideration given for construction tolerances, unusual building substrate conditions, weather anomalies, and many other unanticipated but real-world factors that may be important in mitigating cement plaster shrinkage. Conservative design and construction practices make accommodation for unusual conditions by providing performance safety factors. Performance safety factors should be considered by designers and builders when using cement plaster.

The shrinkage and movement rates presented above are summarized in *Table 1*, which should then be further tempered in terms of the caveats of ASTM C157, movements related to in-service ambient temperature and moisture conditions, and considerations for reasonable performance safety factors.

Considered collectively, these data suggest a basic range of shrinkage and expansion movement for design and installation purposes of cement plaster systems. The largest magnitude of cement plaster movement is initial shrinkage during curing, which occurs immediately after installation until the cement plaster becomes relatively stable after approximately three months or 90 days. Thermal movements occur with ambient temperature cycles and can be either expansive or contractive. For the initial shrinkage and thermal contraction movement ranges suggested below, the amount of thermal movement estimated is 50% of the total movement over a 100°F temperature range, because a cement plaster installation will not experience a 100°F rise or drop in temperature after installation.

Without provisions for performance safety factors, the total initial shrinkage and thermal contraction movements = 100% initial shrinkage + 50% thermal movement.

COMPARISON OF CEMENT PLASTER SHRINKAGE AND MOVEMENTS

Reference	Initial shrink %	Mils per ft	Mils per 10 ft
1. Bert Hall	0.120	14.4	144
2. Spec Mix	0.119	14.3	143
3. Powerwall	>0.090	>10.8	>108
4. Stucco Mfrs. Assn.	0.090	10.8	108
5. Boland	>0.083	>10.0	>100
6. Surewall	0.070	8.4	84
Reference	**Thermal mvmt. %**	**Mils per ft**	**Mils per 10 ft**
8. Masterwall	0.070	8.4	84
8. Bucholz	~0.07	7.8	78
8. Keene	0.049	5.9	59
8. NRCC	0.04 to 0.06	48 to 72	48 to 72
Reference	**Moisture expan. %**	**Mils per ft**	**Mils per 10 ft**
10. NRCC	0.005 to 0.02	.6 to 3.6	6 to 36

Table 1

The lowest is Surewall at 0.07% + NRCC at 0.02% = 0.09%
The highest is Bert Hall at 0.12% + Masterwall at 0.042% = 0.164%

Therefore, a preliminary anticipated total range of initial shrinkage and thermal contractive movements for cement plaster would be in the range of 0.09% to 0.164%, which dimensionally is 108 to 197 mils over 10 ft.

Performance safety factors are an accepted best design practice, but the cement plaster industry has published no safety factor guidelines for designers to consider for accommodating cement plaster movements. Indeed, there may be a range of reasonable safety factors dependent on variables with cement plaster mix design, substrate conditions, lath or lath-fastening characteristics, control joint performance characteristics—the list of variables is long. The performance safety factor determined may reflect the importance of a crack-free cement plaster installation to the particular building.

For design purposes, including a hypothetical 20% performance safety factor in addition to the above, the total range of initial shrinkage and thermal contractive movements for cement plaster may be in the range of 0.108% to 0.197%, which dimensionally equals approximately 130 to 237 mils over 10 ft.

Control joints for cement plaster were first developed by Raymond C. Clark in 1962 to control "the subsequent cracking and faulting of the [cement plaster] due to the stresses and strains of expansion and contraction caused by initial drying, by subsequent variations in temperature and humidity of the surrounding atmosphere, and also by structural movement and settling of the building."[14] Those are high expectations, and the unfortunate reality is that control joints even today have not been proven to solve all cement plaster cracking conditions.

Other recent relevant research by Bowlsby[15] documents the actual movement performance ranges of select, commonly available, and installed cement plaster control joint products with ¾-in grounds. Other products and other ground dimensions not tested are assumed to perform differently because of the potential for different characteristics and geometry and resultant resistance to movement. The testing evaluated the performance characteristics of the No. 15 and XJ-15 profiles of galvanized steel, zinc alloy, and vinyl control joint products in several installation configurations. The results identified the most beneficial installation configuration (control joint product fastening and lath parameters) for maximizing control joint movement capability, with a consideration for controlling edge curling of the cement plaster. The best performing control joint installation configuration requires discontinuous lath at the control joint, where the lath edges are fastened to supports, and the control joint product is wire-tied to the lath edges over the lath.

The maximum control joint movement

RESULTING CEMENT PLASTER CONTROL JOINT XJ15 PERFORMANCE	
¾-in ground XJ-15 control joint product	**Maximum installed control joint movement capacity**
Galvanized steel – expanded flanges	40 mils
Zinc alloy – expanded flanges	80 mils
Zinc alloy – perforated sheet flanges	130 mils
PVC – perforated sheet flanges	450 mils

Table 2

dimension of the assembly was determined to be the width dimension at the physical disengagement of the control joint product from the edge of the cement plaster base coat. The No. 15 control joint profile creates a gap between the joint product and the edge of cement plaster as shrinkage occurs, which can allow water intrusion behind the cement plaster. For this reason, it is not recommended by some waterproofing consultants, even though it provides the most movement capacity. The control joint testing primarily documented the actual installed maximum movement capacity of the XJ-15 control joint assemblies at the point of failure, without safety factors, in the most beneficial installation configuration, as indicated in *Table 2*.[15]

Today, the disparity is obvious between the anticipated cement plaster shrinkage and thermal movements and the movement capacity of control joint products currently available, when installed following current industry standard spacing. A ¾-in ground, galvanized XJ-15 control joint that moves 40 mils maximum cannot accommodate the initial shrinkage and thermal movements required by a 10-ft-long panel of cement plaster that shrinks from between 100 - 230 mils. The disparity increases when control joint spacing becomes 12 or 18 ft and more, as recommended by some control joint installation standards. Control joints are not typically installed in the configuration for maximum movement potential that testing has documented. Control joint products, as they are produced, designed, and installed into buildings today, are not able to fully mitigate cement plaster shrinkage or other movements.

Control joint performance is not the only consideration in accommodating cement plaster shrinkage and movement. Lath fasteners and lath type both restrict cement plaster movement, substrate movements can cause cracks, and there are other factors that contribute to cracking. Using current cement plaster products and technology, the standards for determining the location and spacing of control joints on a building appear problematic and should be reduced. This is supported by evidence that installations with smaller panel areas are known to have fewer cracks.

Our industry should revisit these conditions and derive new solutions if we are to mitigate cement plaster cracking. There may be promise in other plastering methods, materials, and products yet untried. Using shrinkage-compensating cement; developing an yet-to-be produced miracle admixture or control joint product; and, of course, the wide range of finish coat solutions that cover cracks when they do occur could be windfall solutions. But until we can resolve these issues, stucco will continue to crack.

CONCLUSIONS – CEMENT PLASTER SHRINKAGE AND MOVEMENTS

To more effectively accommodate cement plaster shrinkage and thermal movements and to minimize cracking, the following solutions are proposed:

1. Cement plaster systems should be designed and constructed to accommodate from 100 to 200 mils of cement plaster shrinkage movement or more for every 10-ft increment of cement plaster panel length.
2. Smaller cement plaster panel sizes (defined by control joints and perimeters) than current standards allow should be used to minimize cracking.
3. Specify and install zinc-alloy or nonmetallic control joint products to maximize control joint product movement performance.
4. Design and install the control joint installation configuration for maximum movement performance. Require discontinuous lath at the control joint, fasten the lath edges to supports, and wire-tie the control joint product to the lath edges.

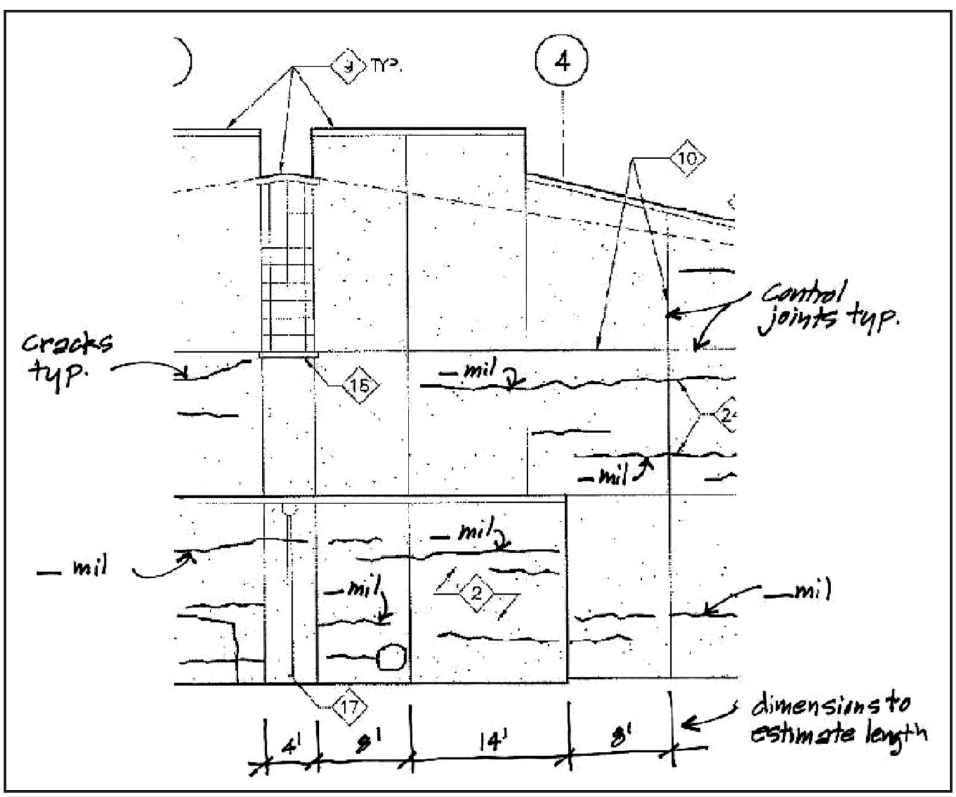


Figure 5 – Partial wall elevation, mapping the stucco cracks as related to adjacent building components.

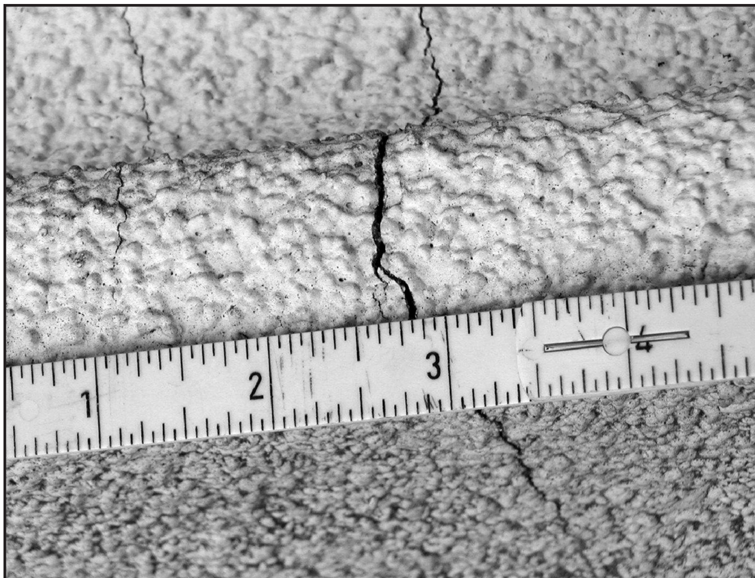
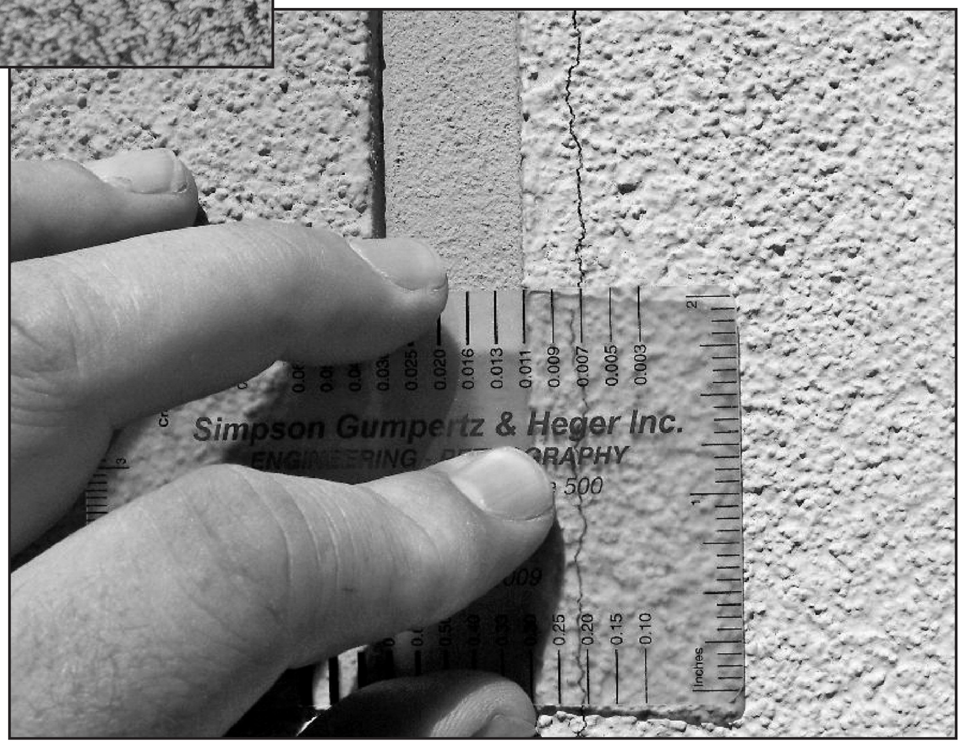


Photo 2 – A tape measure is an ineffective tool to measure crack widths.

Photo 3 – A crack comparator tool accurately measures crack widths.



TOPIC 2 – CEMENT PLASTER CRACK EVALUATION CRITERIA

The preponderance of various cement plaster "crack policies" and published crack acceptance criteria show that consensus may never be reached without a coordinated effort, collaboration, and compromise among competing interests. Evaluating cement plaster is subjective and is rooted in the individual values and persuasions of the evaluator. The range of crack widths on stucco buildings varies due to some of the factors outlined in Topic 1. The width, number, and location of cracks need to be evaluated to determine the extent and nature of any potential problem.

Start with Documentation

Architects know that sketching what one sees is a great aid in understanding something one is not initially familiar with. As one observes and draws what he or she sees, questions arise, causing the viewer to look more intently at intricacies and relationships. The first step in evaluating cement plaster cracks is to document what is observable and record all pertinent data. Draw a map of the cracks in relationship to other adjacent conditions, as in *Figure 5*.

Document the observation date, air temperature, ambient humidity, wall location, relationships to other wall elements, and patterns as accurately as possible. These conditions may need to be revisited at some later date or under other conditions in order to observe any changes that may occur over time.

Measure the crack width. The use of meaningful dimensional units and terminology is significant. The term hairline is imprecise—how wide is a hairline crack? There is no standard width of human hair, which has been measured from between 0.7 to 7 mils thick.[16] Black hair is thicker than red hair, baby hair is finer than adult hair. The use of fractional inches using English units – 1/32, 1/16 of an inch, etc., is too imprecise, and using a tape measure, calipers, or architect/engineer scale is ineffective (*Photo 2*). Using common objects such as coins, credit cards, and business cards is also ineffective, because they cannot be inserted into a crack to determine its width.

It is recommended to measure the width of cement plaster cracks in mils—thousandths of an inch—to the closest 10-mil increment; or metric equivalents, by using a crack comparator tool (*Photo 3*). Document the widths and lengths of cracks, document the locations, and look for repetitive patterns.

Once the data on cracks are collected, the evaluation process can begin.

Objective Criteria, Functional – Keeping Bulk Water Out

An important objective criteria is whether or not a cement plaster crack will allow water intrusion into the wall assembly that could cause damage. Cracks on walls and surfaces exposed to the weather can be a concern if the crack penetrates the full depth of the cement plaster thickness to the water-resistive barrier. How wide must a crack be to allow water penetration? According to Simpson, Gumpertz & Heger's staff chemist, Paul C. Scheiner, PhD, "a mil or so wide [.001 inches] is enough to allow water intrusion."

Another resource for objective crack width criteria is ACI 224-R1, *Control of*

Photo 4 – Corroded metal lath.

Figure 6 – Crack width acceptability from ACI 224-R1 is based on ambient exposures.

Table 4.1—Guide to reasonable* crack widths, reinforced concrete under service loads

Exposure condition	Crack width, in.	Crack width, mm
Dry air or protective membrane	0.016	0.41
Humidity, moist air, soil	0.012	0.30
Deicing chemicals	0.007	0.18
Seawater and seawater spray, wetting and drying	0.006	0.15
Water-retaining structures†	0.004	0.10

* It should be expected that a portion of the cracks in the structure will exceed these values. With time, a significant portion can exceed these values. These are general guidelines for design to be used in conjunction with sound engineering judgement.
† Exclusing nonpressure pipes.

Cracking in Concrete Structures.[17] According to ACI 224-R1, cracks in structural concrete can allow moisture into the concrete that can corrode reinforcement, not unlike cracks in cement plaster. When concealed metal lath corrodes, it expands and can cause staining of the cement plaster finish (*Photo 4*).

Crack width criteria may be of equal or greater importance to cement plaster when considering water intrusion compared to structural concrete, in that concrete typically has thicker concrete coverage over reinforcement than cement plaster, and metal lath for cement plaster is much smaller in cross section than concrete reinforcement. ACI 224-R1 evaluates crack width acceptability in terms of the service environment—be it dry air, moist air, or saltwater exposure (*Figure 6*).

Any visible cracks or gaps are potential bulkwater entry pathways into the cement plaster assembly. Therefore, any visible crack can cause damage if the crack cannot keep water out. Consider also that even nonweather-exposed locations have the potential to allow bulk water intrusion at cracks from temporary water sources such as building maintenance hose-downs, power-washing, and misaligned landscaping irrigation sprinkler heads.

Cement plaster cracks can also be two-way gateways into and out of the wall. If bulkwater can enter into the cement plaster through cracks, it can also emanate from cracks, bringing efflorescence and staining to an otherwise attractive and serviceable cement plaster finish, which may affect the esthetic and functional performance of the wall (*Photo 5*).

Photo 5 – Efflorescence and corrosion staining emanating from stucco cracks.

Subjective Criteria, Aesthetic – Visual Impacts and General Considerations

Cracks that allow no water penetration and cause no resultant damage are generally reduced to just an aesthetic issue. A cement plaster crack is not a defect in and of itself; to crack is a characteristic of the material, and the good news is that cracks can be repaired. The specific characteristics of a particular crack and its location will determine the most effective repair methodology or if it requires repair at all.

Finish stucco textures, whether smooth or rough, can affect the visual perception of a crack. Smooth textures make cracks more visible, and the plastering industry recommends medium-to-heavy finish textures to

Photo 6 – Does this condition require further investigation?

anticipate this possibility.

Cement plaster cracks can be indicative of evidence of undesirable concealed conditions. Efflorescence or biological growth may be indicators of hidden conditions that require further investigation (*Photo 6*).

Viewing Distance

A commonly suggested viewing distance for evaluating cracks is 10 ft minimum, but this is not reasonable for all conditions. The viewing distance should be determined by where a normal viewer would experience the location. At a building entrance, for example, the viewer's distance will be less than 10 ft and may, in fact, be only a few inches (*Photo 7*). A wall location on an upper level may be 20, 30, or more ft away when viewed from the ground.

Lighting Conditions

Directly sunlit, light-colored surfaces may mask cracks. The viewer can also be hampered by glare and fatigue from looking at details. Cracks on these same surfaces, when viewed in shadow, may become readily apparent. Determine the critical lighting condition or angled sunlight specific to a crack's location.

Crack Pattern

Are cracks repetitive or random? Vertical or horizontal cracks at regular intervals can mirror underlying conditions that warrant further, often intrusive, investigation (*Photo 8*).

Crack Location

Linear gaps parallel to cement plaster trim suggest installation errors (*Photo 9*). Cracks in visually sensitive locations such as building entrances can be problematic, whereas the same cracks on upper floors or at visually inaccessible locations may be otherwise acceptable.

Crack Width and the Related Visual Density (Spacing or Patterns)

This is perhaps the most widely debated criterion, but it is not the only consideration, and unfortunately, it takes the focus of attention away from other equally impor-

Photo 7 – Crack at entry door.

Photo 8 – Repetitive cracking patterns may conceal conditions requiring further investigation.

Photo 9 – Crack parallel to aluminum reveal trim.

tant criteria previously mentioned. A survey of industry crack width criteria may be found on *Table 3*, which includes the criteria addressing crack width from known published sources. These crack width criteria generally fall into three-dimensional ranges, suggesting parameters of acceptability without repairs and other conditions when cracks require repairs. Note that these sources include the crack acceptability policies of cement plaster product manufacturers, plastering trade organizations, and consultants but no building owner or end-user representatives. Building owners and cement plaster consumers rely on the integrity of the cement plaster industry to provide a product of the highest reasonable quality within its technological limits.

Some of the referenced crack width criteria use undefined terms, such as “hairline,” “minor,” etc. A useful crack policy will indicate specific crack widths in measurable units.

CONCLUSIONS – CEMENT PLASTER CRACK ACCEPTABILITY CRITERIA

1. Cement plaster crack evaluation requires careful collection and documentation of all pertinent data about the cracks – date, time and temperature, locations, patterns, widths and lengths, weather exposure, or critical lighting.
2. Use a crack comparator tool to accurately measure crack widths to the nearest 10-mil or metric-equivalent increments. Avoid subjective crack width description terms such as “hairline” or “minor.”
3. Any visible cement plaster crack has the potential to allow bulkwater intrusion and result in concealed damage.
4. Crack width criteria are the primary focus of most published “crack policies.” Subjective crack criteria generally concern esthetics, including crack viewing distance, critical lighting, patterns, and locations, but may be just as important as crack width.
5. Considered collectively, the trend in crack width acceptability from the surveyed sources suggests that cracks 30 mils and less in width are generally considered aesthetically acceptable without repairs but this is so only when other criteria such as crack location, critical lighting, and water intrusion performance are deemed less significant or noncritical. When cracks wider than 30 mils are discussed, it is usually in the context of recommended repair approaches.

RECOMMENDATIONS - CEMENT PLASTER SHRINKAGE AND CRACKING

Given the significant ramifications of cement plaster cracking (real or perceived) to the success of any building project, we recommend the following:

1. The cement plaster industry would benefit by developing a reliable field test to evaluate the actual shrinkage of individual batches of cement plaster as they are installed.
2. Cement plaster product manufacturers are encouraged to evaluate their products in field-installed conditions and to publish the detailed mix design and installation requirements to achieve reliable shrinkage performance of their products.
3. Cement plaster control joint product manufacturers are encouraged to field test their control joint and other movement joint products in installed conditions to determine performance and to publish detailed installation requirements and movement performance characteristics for their products.
4. Architects and others who determine the location of control joints need a more complete and reliable methodology than currently exists to locate control joints based on the anticipated material performance characteristics of products and in-service conditions.
5. Using currently available cement plaster installation techniques and control joint materials, control joints should be located closer together than current industry standards recommend.
6. Several control joint product manufacturers recommend zinc alloy or nonmetallic control joints for exterior locations due to concerns for corrosion. Manufacturers should also recommend zinc alloy or nonmetallic control joints for maximum cement plaster shrinkage and movement performance and to minimize cement plaster cracking.
7. Reasonable performance safety factors related to shrinkage control provisions, control joint product, and cement plaster mix design should be considered by designers and builders.
8. The cement plaster industry would benefit from a single, unified cement plaster crack acceptability policy that is comprehensive and gives rational evaluation criteria. It should consider and address all objective and subjective criteria (not

just crack width) and include participation from cement plaster end-users and consumers, as well as cement plaster industry representatives.

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STUCCO CRACK WIDTH EVALUATION - SURVEY OF INDUSTRY RESOURCES

STATE LAWS

California Senate Bill 800[18]
Undefined Crack Widths:
- "Stucco, exterior siding, and other exterior wall finishes and fixtures, including, but not limited to, pot shelves, horizontal surfaces, columns, and plant-ons, shall not contain significant cracks or separations."

California Contractors License Board[19]
Crack Widths >30-125 mils:
- As published in Workmanship Guidelines, "Deficiency: Cracks in Stucco. Acceptable Tolerance: Hairline cracks, if not excessively numerous, are acceptable. If cracks exceed 94 mils, it is unacceptable and should be repaired."

TRADE ASSOCIATIONS

ACI - American Concrete Institute, 224R-01[17]
Crack Widths ≤30 mils:
- Reasonable crack widths for reinforced concrete under service loads, in dry air, or with protected membrane = 16 mils.

ACI - American Concrete Institute, 524R-93[20]
Undefined Crack Widths:
- "Minor fracturing is expected as normal." Repair "static hairline" [width undefined] cracks with acrylic/latex paints or coatings. Repair "dynamic hairline" [width undefined] cracks by filling/bridging with acrylic/latex paints or coating systems.
- "Larger cracks [width undefined] may be filled with elastomeric sealants, refer to sealant manufacturers."

PCA - Portland Cement Association[21]
Crack Widths ≤30 mils:
- 10-15 mils, acceptable.
- 8 mils, structural concrete - weather exposed.
- 4 mils, structural concrete - watertightness required.
- <15 mils, may be tolerable.

PCA - Portland Cement Association[22]
Undefined Crack Widths:
- "Minor cracking at corners of windows and doors and other stress points is not unreasonable and should be anticipated."

Crack Widths >30-125 mils:
- 60 mils and less when occurring in the first 30 days, can be repaired with finish coat material. Repair cracks only if visible from more than 10 feet away, or if they are leak sources.

SMA - Stucco Manufacturers Association, through April 2008[23]
Undefined Crack Widths:
- "Minor cracking at corners of doors and windows is reasonable and should be expected."

Crack Widths >30-125 mils:
- Hairline crack = 60 mils or less width - Repair not recommended. If hairline cracks must be repaired, then fog coat.
- 60 mils and less when occurring in the first 30 days can be repaired with finish coat material. Repair cracks only if visible from more than 10 feet away, or if they are leak sources.

Plaster Council, beginning May 2008[24]
Undefined Crack Widths:
- "Building owners should expect hairline and diagonal cracks emanating from window and door corners."
- "Cracks should be repaired if wide enough to permit water entry thru exterior cladding system."

Crack Widths >30-125 mils:
- "Generally, repair cracks 60 mils and wider."

NAHB - National Association of Homebuilders[25]
Crack Widths >125-500 mils:
- 125 mils and larger require repair.

Table 3

STUCCO CRACK WIDTH EVALUATION - SURVEY OF INDUSTRY RESOURCES

Minnesota Lath and Plaster Bureau[26]

Crack Widths ≤30 mils:

- Visual tests have shown that cracks less than 2 mils wide in relatively smooth, flat surfaces are rarely noticed. The viewing distance, nature of the surface and prestige of the structure affect objections. At a distance of three feet, a crack as wide as 13 mils is not readily noticed if the surface has a moderate texture.' Repair with brush-grade filler and new finish coat over entire area.

Crack Widths >30-125 mils:

- Larger cracks = 125 mils or less.
- Repair with brush grade filler, then new reinforced EIFS finish coat over entire wall area.

Crack Widths >125-500 mils:

- Very large cracks = 125-250 mils.
- Repair with brush grade filler, strip fabric reinforcement in flexible EIFS base coat, then new reinforced EIFS finish coat over entire wall area.

INDUSTRY CONSULTANTS – JOURNALS / BOOKS

MacLellan[27]

Crack Widths >30-125 mils:

- Exterior stucco-covered walls, soffits, and/or garden walls should not have any cracks exceeding 125 mils in width or 125 mils in adjacent surface displacement. Cracks less than 125 mils [width] covering more than 33% of a 1-ft-sq area of a dry surface wall (similar to a spider web pattern) are unacceptable. Wet walls show a disproportionate number of surface irregularities and cracks. This guideline applies to walls measured when dry.

Crack Widths >125-500 mils:

- >125 mils width or 125 mils adjacent surface displacement is not acceptable, requires repair.

Pruter[28]

Crack Widths ≤30 mils:

- "Hairline" = <0.5 mil, no repair.
- "Hairline" = 0.5-10 mils, repair with elastomeric coating.
- "Objectionable" = 15-30 mils, no repair described.

Crack Widths >30-125 mils:

- [No descriptor term] = 30-125 mils, repair with elastomeric sealant band.

Crack Widths >125-500 mils:

- "Structural" = 125-250 mils, repair with elastomeric sealant band.
- "Serious movement" = 250-500 mils, repair with sealant fill.

Bucholz[12]

Crack Widths ≤30 mils, Acceptable Quantity of Cracking:

- 4 LF of 15 mils per 100 sq ft.

Crack Widths >30-125 mils, Acceptable Quantity of Cracking:

- 2 LF of 30 mils per 100 sq ft
- 1 LF of 60 mils per 100 sq ft

Repairs:

- Hairline up to 60 mils wide - patch with finish coat overlay. 60-125 mils wide - patch with fiberglass fabric, then finish coat. Over patches, add 20 mil DFT elastomeric coating.

Bucholz[29]

Crack Widths >30-125 mils:

- "Hairline" = cracks that won't accept the edge of a dime [50 mils] and if rare, do not require repair."
- "Hairline cracking in stucco thinner than the edge of a dime [50 mils] and 25 to 30 ft in total length in a 100 sq ft panel, can be considered 'normal.'"
- "Cracks greater than 50 mils are better hidden. Thinner cracks are acceptable as long as there aren't too many of them. If there are far too many, a new skim coat of finish is in order. "

Continued on next page

Table 3 continued

STUCCO CRACK WIDTH EVALUATION - SURVEY OF INDUSTRY RESOURCES

- “Normal” = Cracks up to 60 mils wide.
- “Excessive cracking = cracks more than 60 mils wide, and there are many of them. “
- “Cracks that exceed 90 mils must be repaired.”
- “Large cracks” = 125 mils wide.

Nordmeyer[30]
Crack Widths ≤30 mils:
- “Hairline cracks” = 30 mils and less.

Crack Widths >30-125 mils:
- Cracks up to 90 mils = Use elastomeric coating to repair, prefill cracks wider than 90 mils.

Goldberg[31]
Crack Widths >30-125 mils:
- <125 mils no structural repair required, but isolate adhered finishes spanning the crack.

Crack Widths >125-500 mils:
- Regarding concrete structural members, 125 mils and > occurring throughout the section is a “structural crack” and requires repair with epoxy/methacrylate injection.

Schwartz[9]
Crack Widths ≤30 mils:
- Hairline= “Very fine cracks in either random or essentially straight line patterns that are just visible to the naked eye.”

MANUFACTURERS / INSTALLERS

El Rey[32]
Undefined Crack Widths:
- Hairline’ [width not defined], no repair required.
- Small to medium [width not defined] and not growing, repair by patching.

Crack Widths >125-500 mils:
- “Large” and growing = 125 mils and wider, patch, fabric mesh, refinish.

Parex[33]
Undefined Crack Widths:
- “Minor cracking at the corners of doors, windows, and other high stress point areas is common and may be expected.”

Parex[34]
Crack Widths >30-125 mils:
- Cracks wider than 100 mils need to be patched.

Phoenix Plastering[35]
Crack Widths ≤30 mils:
- 7-30 mils, “cover with normal coating procedures”

Crack Widths >30-125 mils:
- 30-125 mils, cover with elastomeric brush-on sealant.

Crack Widths >125-500 mils:
- 125-500 mils, repairable if static. Repair with combination of sealant, stucco patch, mesh, elastomeric coating.

Thermocromex[36]
Crack Widths ≤30 mils:
- <16 mils = “microcracking”

Crack Widths >30-125 mils:
- 16-63 mils = “macrocracking”; >63 mils = “fissures”

Masterwall Technical Bulletin[37]
Crack Widths >30-125 mils:
- Structural cracks are usually 62 mils or larger. Some type of structural condition usually causes these cracks. Consult a professional for recommended repairs.

Note: Dimensions originally shown in English units have been converted/rounded to mils for uniformity.

Table 3 continued