ISSUE NO. 13

INSIGHT™

A technical newsletter by Raths, Raths & Johnson, Inc. for the construction industry.

"Insight: to see into and understand; an item of knowledge gained by this power."

In this issue of *RRJ Insight* we discuss the effects of using the wrong grout in exterior applications such as railing pockets or stone cladding kerfs. The *Project Profile* article talks about an investigation RRJ performed in order to determine the cause of stone spalling in an exterior facade. The *Tech Tip* article discusses how to avoid grout-related failures, including connection failures, by following a few simple rules. And finally, the *Lab News* article shows the expansive results of combining gypsum and portland cement-based grout materials.

INSIDE

Stone structures can develop connection problems if expansive grout is used in the kerfs.

Project Profile

Grouted Stone Facade Kerf Failures

RRJ was recently called upon to determine the cause of extensive stone kerf (slot in stone to accommodate anchor) failures on a new building in Washington, D.C. The exterior facade consisted of large granite panels up to 6 inches thick attached to the concrete building frame with stainless steel anchors inserted into grouted plunge-cut kerfs in the edges of the stones (Figure 1). Semicircular spalls had separated from the stone panels at failed locations. **The failures appeared to be clustered in limited areas, with new spalls reported by the building manager regularly.**

From a distance the outward appearance of the failed kerfs mimicked the conditions typically produced by excessive anchor loads. Calculations evaluating anchor loads and accompanying stone stresses from dead loads, wind loads, and thermal expansion and contraction failed to explain the locations and continuing appearance of the semicircular stone fractures. What then was causing the problem?

Close examination of some of the failed stones revealed expansive patterns within the kerf grout (Figure 5). **Laboratory petrography analysis of the grout identified clusters of ettringite within a matrix of portland cement, gypsum, and silica sand.** Ettringite is formed by an expansive chemical reaction between portland cement and gypsum under moist conditions (refer to this month's Tech Tip article). The expansive conversion of portland cement and gypsum had forced the failed kerfs apart, much like air inflating a tire, eventually causing the stone to fracture. Mystery solved! **Grout expansion from weather-related wet/dry cycling of the stone (and the grout within the kerfs) had caused the kerf failures.**

Review of the stone installer's project records revealed a new mystery; no purchases or deliveries of either portland cement or gypsum were indicated. Instead, in compliance with the Project Specifications, the installer had purchased only pre-packaged grout materials from a major manufacturer. Early and late shipments were all of a cement-based product. Partly through the project, however, a shipment of a gypsum-based grout was received in lieu of the usual portland cement-based material. Review of the project sequencing and completion records revealed the affected areas corresponded with the work performed while the two materials were concurrently on site. **Laboratory testing by RRJ (refer to this month's *Lab News* article) confirmed the destructive potential of mixing the two products.**

- Kurt R. Hoigard, P.E

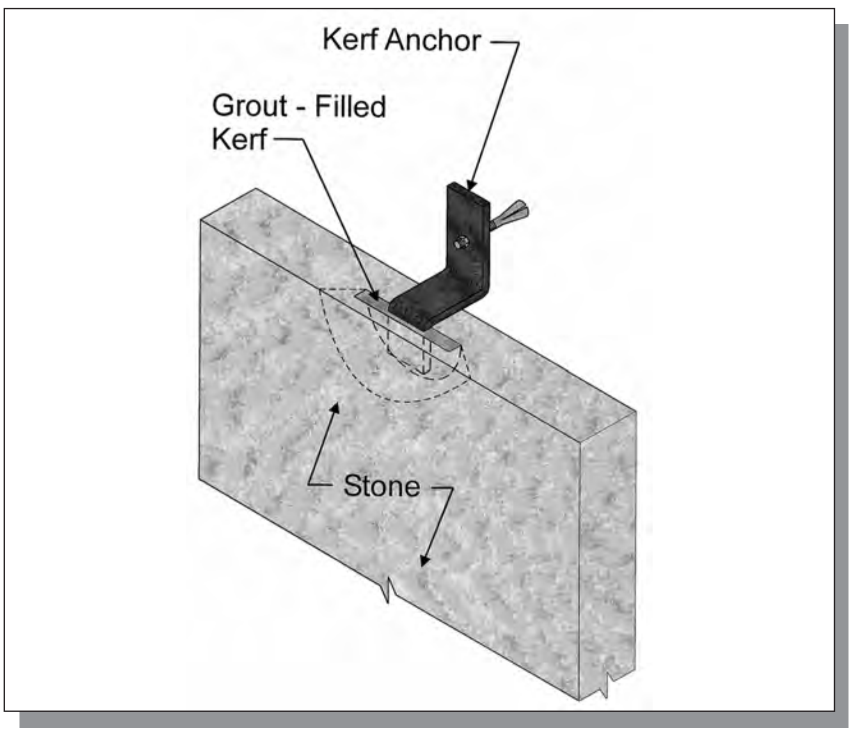

Figure 1 - Plunge cut kerf anchor.

Lab News

Portland Cement and Gypsum — An Expansive Combination

The granite kerf failures discussed in this month's Project Profile prompted RRJ to initiate a laboratory testing program to assess the destructive potential of mixing portland cement and gypsum-based grout products available from a major manufacturer. **This work was undertaken to confirm RRJ's suspicion that mixing of the two products had caused the observed granite kerf failures via the formation of ettringite** (an expansive by-product of a chemical reaction between portland cement and gypsum).

RRJ's test program included the preparation of 2 inch grout test cubes (figure 4) and grout-filled kerfs (figure 6) in two types of granite and two types of limestone. Six test grouts were prepared with the ratios of the portland cement and gypsum-based products shown in Table 1. Grout A was the gypsum-based product and Grout B was the portland cement-based product. Laboratory analyses of Grouts A and B provided information on the base constituents for each used in determining the reported portland/gypsum/sand/other ratios as percents by weight.

After curing according to the manufacturer's recommendations the test specimens were subjected to repeated cycles of wetting and drying. Each wet/dry cycle included 24 hours of water submersion followed by 24 hours in an oven at 125 degrees F. The cube specimens were checked for unrestrained

Table 1 - Test Grout Contents

Mix Number	Grout A (lbs.) Gypsum	Grout B (lbs.) Portland	Portland/Gypsum/Sand/Other (percents)
1	0	5	44.1 / 0.0 / 55.2 / 0.7
2	1	4	35.7 / 13.6 / 50.2 / 0.5
3	2	3	27.3 / 27.2 / 45.1 / 0.4
4	3	2	18.8 / 40.8 / 40.1 / 0.3
5	4	1	10.4 / 54.4 / 35 / 0.2
6	5	0	2.0 / 68.0 / 30.0 / 0.0

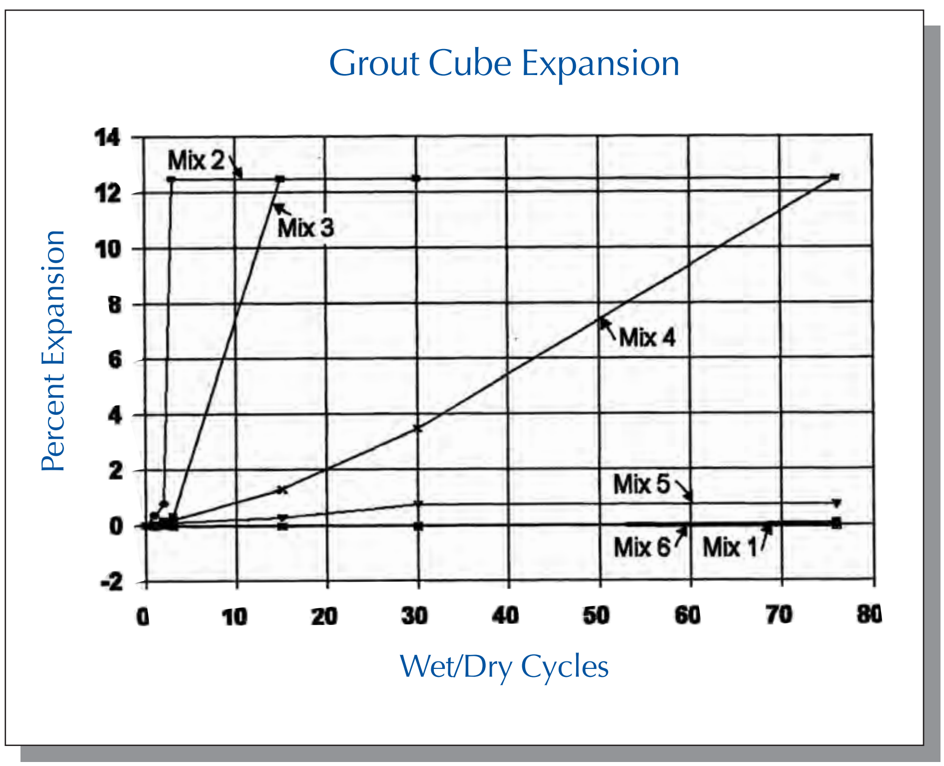

Figure 3 - Grout cube test plot of percent expansion versus wet/dry cycles.

Tech Tip

Specifying Exterior Grout

Over the past 15 years many articles have been written discussing the negative aspects of using gypsum-based grout products in moisture prone applications such as railing pockets or stone cladding kerfs. Gypsum grouts are made of gypsum (more commonly known as plaster of Paris) and silica sand, with trace amounts of other proprietary substances to reduce curing shrinkage. Advantages include rapid initial set times (change from liquid to solid), high strength, and low cost. **Known problems with gypsum grouts exposed to moisture include softening, wash-out, corrosion of embedded aluminum and steel components, and sulfate attack of surrounding concrete.**

Grout manufacturers have developed new materials for exterior use in response to the growing concerns surrounding gypsum grouts. These new products typically incorporate portland cement, silica sand, and small amounts of admixtures designed to accelerate initial set and reduce shrinkage. Advantages include good moisture resistance, passive protection of embedded steel components, and no sulfate attack of surrounding concrete. Disadvantages include slower initial set and higher cost.

The concurrent availability of portland cement and gypsum-based grouts (with some manufacturers offering both), combined with the slower set and higher cost associated with the portland cement-based products, has led to the two product types being either inadvertently or purposely mixed together at the job site (adding gypsum to portland cement-based grouts speeds initial set and reduces cost). Subsequent moisture exposure of the resulting hybrid typically causes destructive expansion from a chemical reaction resulting in the formation of ettringite (a by-product whose volume is greater than the original gypsum and portland cement). **Wetting and drying cycles driven by exterior exposure compound the situation by forming more ettringite with each cycle, resulting in large volumetric expansions of the original grout placement that can split concrete and fail stone cladding kerf connections** (refer to Figures 2, 3 and 5 of this issue for more information).

In order to avoid grout-related failures, including the connection failures that befell the granite facade discussed in this month's *Project Profile* article, **RRJ recommends adhering to the following simple rules when specifying grout for exterior applications:**

- Never use gypsum-based grouts in exterior applications or interior applications subject to wetting, because softening, wash-out, metal corrosion, and concrete attack may occur.
- Avoid preparing your own "custom" grout. Instead, stick with a proven commercially available product.
- If you must prepare your own grout, never add gypsum to a portland cement base. Ettringite expansion can fracture concrete, granite, and other building stones.
- When using commercially available grout products avoid mixing different products, even from the same manufacturer. The hybrid formed may have poorer performance than either of the parent materials and could result in expansive cracking from the formation of ettringite.

- Kurt R. Hoigard, P.E.

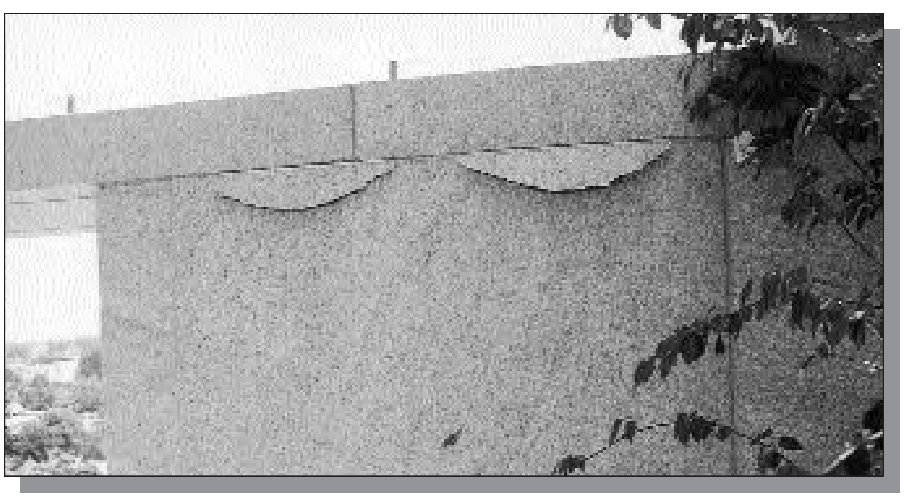

Figure 2 - Expansive grout causes surrounding stone to crack thereby weakening the connection resulting in an unsafe condition.

expansion by visual examination for cracking and periodic measurement of the cube specimen dimensions. The kerf specimens were periodically examined for cracking of the stone. The results were astounding. As shown in Figure 3, Mix 1 (no gypsum) experienced no expansion or cracking. Mixes 2, 3, and 4 all rapidly disintegrated due to expansive fracture. Mix 5 initially cracked and expanded, but then stabilized. Mix 6 experienced minor initial cracking, and then shrank in size as surface material dissolved during repeated wetting. Of the stone kerf specimens, stone fracture was observed on all Mix 2 samples, regardless of stone type, after only 15 wet/dry cycles (Figure 6). After 80 cycles no other kerf failures were observed.

The results of these tests confirmed RRJ's suspicion that mixing of the two products could result in expansive fracture of the grout and failure of grout-filled stone kerfs, and formed the basis for the recommendations provided in this month's Tech Tip article.

- Kurt R. Hoigard, P.E.

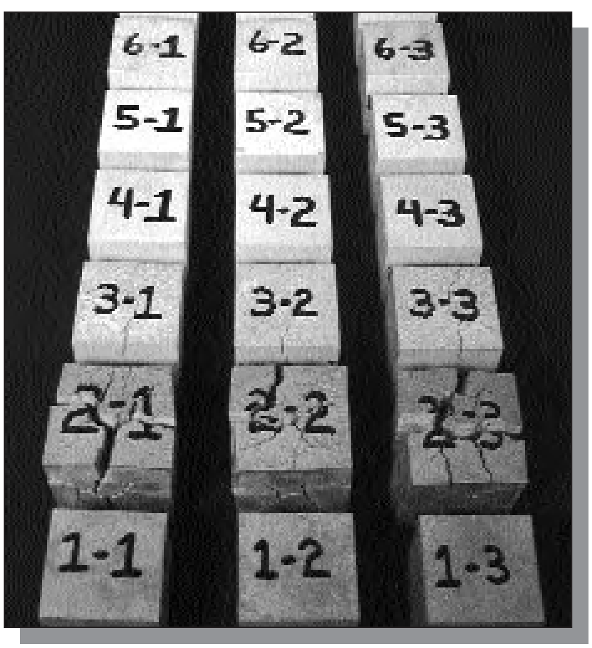

Figure 4 - Test grout cube samples after 80 wet/dry cycles.

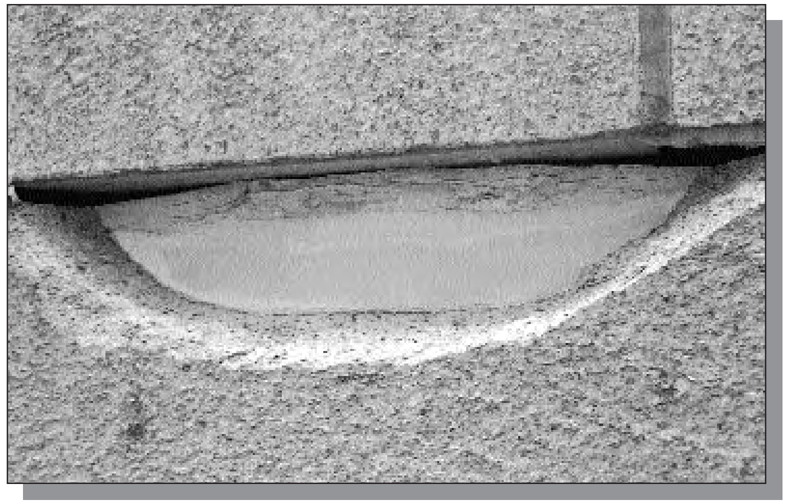

Figure 5 - Close up of kerf grout pocket. Expansion of grout into joint and outward caused stone to fail.

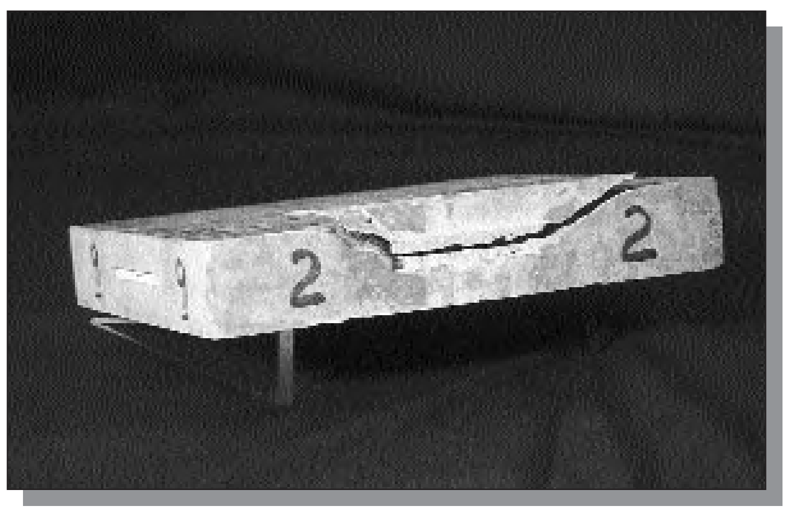

Figure 6 - Stone specimen with expansive grout in the kerf simulates field performance in the laboratory.

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