WJE

PRIMER

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Discover the destructive potential of gypsum-containing grout as well as successful approaches to remedy its damaging effects

Deleterious Expansion of Gypsum-Containing Grout

Grouts used to secure railing posts to concrete elements are expected to be volumetrically stable and durable after their installation. Far too often, the chemical composition of proprietary prebagged grout typically used for this application creates an environment ripe for volumetric expansion that occurs within the grout after installation. This expansion can cause significant damage to the grout and the surrounding concrete, resulting in falling debris hazards and/or instability of the embedded railing.

Repairs to correct existing and prevent additional damage can cost many orders of magnitude more than the original material cost of the grout. This WJE Primer is intended to educate designers, contractors, and others in the building and real estate industries about the destructive potential of this material as well as successful approaches to remedy its deleterious effects.

Embedded Railing Post Attachments

Railings used as a barrier to prevent falls from edges of structures (e.g., balconies, plazas, stadium seating areas, retaining walls) or to provide handholds at stairs must resist applied forces (i.e., people leaning against them) without overturning or rotating. These forces are often transmitted through the railing assembly and into the structure to which they are attached by embedding an extended length of the railing post within the supporting concrete structure. Construction schedules and logistics almost always preclude the railings from being cast into the structure during its placement. Rather, embedded railing posts are accommodated by forming voids during placement of the structural element or (more commonly) creating cylindrical voids in the hardened concrete structure by core drilling. After the railing assembly is positioned with its posts extending into the voids or "pockets," grout is cast into the pockets that encases and embeds the lower portion of the railing post. After hardening, these grouted pockets transmit forces applied to the railing into the concrete structure and prevent rotation of the railing assembly. Durable integrity of the grout and surrounding concrete at post pockets is critical to the railing's ability to perform its intended and code-required function.

Market Demands

This installation process requires that the railing assemblies be temporarily braced to maintain their plumbness and height until the grout hardens. As such, contractors generally prefer proprietary prebagged grouts that harden quickly (i.e., have a short "set time"). The set time of grout that uses portland, calcium sulfo-aluminate, and/or calcium aluminate cement as its primary binder can be accelerated by blending gypsum (or its various hydration forms) into the dry grout mix. The addition of gypsum also improves the flowability of the grout, facilitating placement of the grout into and completely filling the relatively small annular space

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between the post and pocket walls. The overall material cost is reduced as well, since gypsum is generally less expensive than and replaces some of the portland cement. Grouts with added gypsum have been available for decades and continue to be produced, marketed, and utilized today because demand exists.

Some commercially available grouts utilize only gypsum as a binder or overwhelmingly rely on gypsum as a binder relative to other binders.

Distress from Grout Expansion

Given adequate gypsum and portland cement content as well as exposure to moisture, internal volumetric expansion of post pocket grout can occur long after the grout's initial set. The expansion causes internal microfractures that eventually results in disintegration and loss of structural integrity of the grout. However, this distress is usually preceded by distress to the surrounding concrete.

The expansion of the grout imposes outward forces on the surrounding concrete. Given that unreinforced concrete is relatively weak in tension, the expanding grout can induce cracks in the concrete that radiate outward from the grout pocket. When located along an edge (as railings often are), this cracking often orients itself parallel to the slab, beam, or wall edge (Figure 1). With sufficient expansion and a lack of reinforcing steel near the edge, the deteriorated concrete has reduced capacity to resist rotation of the embedded railing post with an applied lateral force. Eventually, fragments of the slab edge concrete may dislodge and fall from the structure (Figure 2).

Figure 1.

Figure 2.

Volumetric expansion within the grout occurs in all directions: laterally as described above as well as vertically. Because the top of the grout pocket is typically open and unrestrained, vertical expansion within the grout can manifest as upward displacement of the grout (Figure 3) and the railing assembly. Depending on existing geometries and the amount of upward movement, the gap between the railing's bottom rail and the concrete surface may exceed the code-maximum four inches. Top- or bottom-surface spalls in the concrete (Figure 4) can also occur if a strong bond between the grout and pocket wall exists; as the grout expands upward, it drags the adjacent concrete along with it until a fragment of the concrete splits from the top or bottom surface. If the spall is deep enough, it may meaningfully reduce the post's effective embedment depth and thus the capacity to resist rotation.

Grouts with a gypsum-only (or near-only) binder are not prone to the same internal expansion; however, they are significantly more porous than portland cement-based grouts, thus are prone to absorbing and holding significantly more water. Like saturated gypsum wall board, gypsum-only grouts are prone to softening with exposure to water—even becoming viscously flowable with sufficient water. Softened or viscous gypsum grout has reduced or no meaningful capacity to resist rotation of the railing post.

Expansion-related distress typically becomes evident within a few years of installation but can be delayed if exposure to moisture is limited. Softening of gypsum-only grout material can occur even quicker with sustained exposure to liquid water. Both deterioration mechanisms are irreversible.

Figure 3.

Figure 4.

The (Very Simplified) Chemistry

A detailed review of the chemistry behind the complex reactions that result in gypsum-induced expansion of cementitious materials is beyond the scope of this primer, but a basic understanding of the process is helpful in understanding the viability of repair approaches.

Gypsum is a naturally occurring mineral composed of calcium sulfate with bonded water molecules. A carefully controlled amount of calcium sulfate is intentionally introduced into portland cement blends and is innocuously consumed during the chemical reactions that occur during setting and curing of concrete. If excess or free calcium sulfate remains in the hardened concrete or grout (as would be the case when gypsum is added to a cementitious grout mix), exposure to moisture can allow the unreacted calcium sulfate to react with aluminate compounds inherent to portland cement. The product of this reaction is the crystalline mineral ettringite that forms in pores and voids within the grout matrix. After filling available voids, the continued accumulation of ettringite crystals induces and fills microfractures. This deposition of ettringite within the grout results in irreversible volumetric expansion of the grout that is capable of imposing substantial pressures on surrounding confining materials.

Figure 5.

Sources of Water

Cementitious grouts have varying degrees of porosity and will absorb moisture. Absorbed moisture can be sufficient to initiate the expansive chemical reaction. Cracks within—and bond line separations between—the concrete and grout will permit additional water to reach the grout, resulting in an accelerated reaction and expansion. Exposure to precipitation is the most common source of moisture; however, an expansive reaction can even be triggered indoors by regular wet-cleaning of floors. On multiple projects, WJE has also documented liquid water within the full height of hollow steel and aluminum railing posts that acts as a gravity-fed reservoir (Figure 5) to feed the expansive chemical reaction.

Other Related Distress

Grouts relying on portland cement as their binder establish an alkaline environment. This alkalinity chemically passivates corrosion processes and provides natural protection around embedded steel railing posts. Grouts relying only on gypsum binders are much less alkaline, thus do not passivate corrosion of embedded steel elements. This neutral environment, in combination with gypsum's inherent porosity that creates a more damp environment, allows steel to corrode at a higher rate and more extensively (Figure 6). Corrosion of steel produces accumulation of rust scale, which also results in expansive forces within the grout pocket.

Because sulfates are water soluble, migration of sulfates from the grout-filled pockets into the surrounding concrete can occur. Multiple variables influence the amount of sulfate migration including the density and porosity of the concrete, the amount of available sulfate and water, temperature and time. In the same way that the native sulfates can react with constituents of the hardened cementitious grout, sulfates that migrate into adjacent hardened concrete can react and cause internal volumetric expansion of the concrete. However, it has been WJE's experience that significant concrete distress from grout expansion occurs first and becomes the impetus for repairs well before sulfates have an opportunity to migrate in sufficient concentrations to cause distress to—or pose a long term risk to—the integrity of the concrete.

Remedial Approaches

Where gypsum-containing grouts already exist in a building and have begun to cause distress and/or instability of the railing systems, the process should be expected to be irreversible and ever-worsening without intervention. Identifying added gypsum in hardened grouts is best achieved by determining total sulfur levels with chemical testing, supplemented with X-ray diffraction to determine calcium sulfate forms. Petrographic examination of the grout and surrounding concrete can identify the extent, degree, and nature of the distress mechanisms.

Attempts to eliminate or sufficiently reduce the amount of water that reaches gypsum-containing grouts (i.e., preventing the expansive reaction) have repeatedly proven unsuccessful. Fundamentally, there is no practical way to adequately rid the grout and surrounding concrete of moisture prior to applying waterproofing elements (e.g., joint sealants, elastomeric membranes or coatings). Application of waterproofing elements, which tend to have low vapor permeability, to damp concrete and grout traps residual moisture within the moisture-sensitive assembly. Further, waterproofing elements are often imperfect or ineffective at the time of installation and inevitably will develop breaches with exposure. Additional water introduced into and trapped within the "waterproofed" concrete and grout would accelerate the reaction and exacerbate the expansion-related distress.

Figure 6.

Removal and replacement of gypsum-containing grout has proven the most effective approach, albeit labor-intensive, to correct existing distress and mitigate continued deterioration. It is critical that all remnants of gypsum-containing grout be removed from the post pocket, including from within the bottom of hollow posts. Consideration should be given to modifying hollow posts if they are likely to collect standing water, especially if they are subject to freezing winter temperatures. WJE has coincidentally documented steel pipe posts that were split longitudinally and aluminum post walls that were deformed from the expansive force of water freezing within the post.

Preemptive Approaches

In the case of expansive grouts, an ounce of prevention is worth far more than a pound of cure. Proactively avoiding use of grouts with elevated gypsum contents on projects may feel like trivial minutia in the moment, but it can prevent property damage, occupancy disruption, repair costs, and even injury to persons. *Caveat emptor* is sage and appropriate advice to architects, engineers, contractors, and building owners and managers with regard to post pocket grouts. Be leery of:

- Grouts advertising accelerated set times. Other chemical mechanisms can accelerate set time (and aren't associated with risk of expansion), but added sulfate is common.
- Manufacturer's published limitations on exposure of their installed product to water. Although some manufacturers caution only against submersion in water, lesser exposure to moisture is often enough to trigger the expansive reaction.
- Any form of calcium sulfate listed as an ingredient on the material's Safety Data Sheet. While gypsum is $CaSO_4 \cdot 2H_2O$ or calcium sulfate dihydrate, plaster of Paris ($CaSO_4 \cdot \frac{1}{2}H_2O$ or calcium sulfate hemi-hydrate) is gypsum with fewer bonded water molecules and anhydrite ($CaSO_4$) is calcium sulfate with no bonded water molecules. While manufacturer's may list any one or more of these names, they all contain calcium sulfate and thus present the same risk for deleterious expansion.

While the above actions are reasonable first steps in evaluating the expansive potential of grouts and may be sufficient for small, low-risk projects, laboratory testing of dry samples of grout mix is the most definitive means of determining if the product contains added sulfates and has expansive potential. Initial chemical testing as part of the product submittal and approval process is prudent, even if the specifier or user has found past installations of a specific product to be successful. Construction material manufacturers are known to change product formulations periodically and without notice. For the same reason, it is prudent to perform chemical testing intermittently throughout the duration of particularly large and sensitive projects that will consume multiple pallets of grout material from multiple production batches or lots.

Other Applications

While this primer has focused on gypsum-containing grouts used to secure embedded railing systems, cementitious materials with added gypsum are marketed for other uses (e.g., repair mortars, base plate grouts, floor leveling compounds). While these materials can be durable if they are consistently kept dry, even modest periodic moisture can initiate and sustain the expansive reaction.

Summary

Gypsum-containing grouts continue to be utilized to attach embedded railing posts to concrete structures despite their destructive potential. Effort expended to avoid their use far outweighs the potential misery resulting from significant damage, disruption, repair cost, and injury.

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