Structural grouting of load-bearing precast concrete elements: Issues and solutions

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The purpose of this white paper is to continue to raise construction industry awareness regarding structural grouting of precast concrete projects in the United States. Incidents related to structural grouting have occurred with both precast concrete systems and other building systems (namely steel), and designers, architects, owners, insurance carriers, and the construction industry in general are becoming increasingly aware of deficient grouting installation methods and verification procedures.

Specific issues of concern include the following:

- the timeliness of grout installation during the erection process
- the lack of grout on some components of finished projects
- the poor quality of installed grout

These concerns pertain to horizontal connection joints of critical load-bearing elements between foundations and precast concrete columns and walls, stacked precast concrete columns, and stacked precast concrete walls. Current building codes and standards provide no requirements and limited guidance for the installation or special inspection of these critical horizontal joints. In an effort to address this gap in building codes and standards, as it specifically relates to precast concrete structural products, some precast concrete producers and erectors are implementing several strategies and new procedures, as noted and further developed in this white paper. Several industry experts are assisting in this endeavor on local, national committee, and task force levels. These experts are evaluating current and potential future risks via field structural grout installation procedure/inspection checklists. Moreover, *Structure* magazine published an article by Mullens and Parker[1] in September 2019 identifying the seriousness of this issue.

Certain precast concrete producers and erectors are beginning to refine their quality assurance/quality control (QA/QC) programs to ensure that grouting is commensurate with their erection stability plan requirements and the project design loads. For example, some producers and erectors have noted that installing grout by dry-packing methods in horizontal column-to-column and column-to-foundation joints may be a potentially deficient technique for critically loaded conditions. In some cases, installers are developing and implementing procedures for installing grout with a flowable or fluid (pumpable) consistency for specific load-critical connections. For guidance, please refer to specific grout manufacturers' definitions of plastic, dry-pack, flowable or fluid consistency and associated placement methods.

Further, forensic engineering firms are developing and preparing to release formal technical test data regarding capacities of these horizontal joints when composed of less than fully grouted conditions and/or combinations of original and supplemental shim stack additions in retrofitted applications. The test data indicate inconsistencies in current building code analysis methods of load-resistance determination.

Nationally, the PCI Field Safety Task Group has developed recommendations that all PCI-certified erectors include documentation in their daily field reports that identifies each grouted joint and grout sleeve, the date grouting was completed, and the corresponding locations on the building. Furthermore, additional recommended documentation and verification steps are being developed by some precasters and as a requirement of some insurance carriers. This white paper will describe these recommended grouting practices in greater detail.

PCI recommends that contract document specifications for structural precast concrete projects include, as a minimum, the following items:

- Request submittal of a formal grouting QA/QC program that includes the temperature of substrates at the time of placement and during the curing process as required by the grout manufacturer, as well as grout material technical data sheets, placement procedures, placement verification procedures, and structural stability requirements.
- Require precast concrete installation by a PCI-certified erector.
- Submit the precaster's and/or erector's quality monitoring reports to the general contractor/construction manager, recognizing that many local testing laboratories generally do not have the capacity for this special testing or ongoing documentation.

In light of several recent grouting-related incidents on structural precast concrete panel projects, it is critical that the industry recognize this current problem and elevated risk, share knowledge of recent analyses and responsive procedures being developed, and enact change to ensure that this highly popular and successful method of prefabricated concrete construction continues for decades to come.

Grout types

ASTM C1107 defines various grouts in the following ways.

Plastic grout

A grout consistency having a flow of 100 to 125 by the flow test in accordance with the applicable provisions of test method ASTM C1437; the flow after 5 drops of the flow table in 3s.

Flowable grout

A grout consistency having a flow of 125 to 145 by the flow test in accordance with the applicable provisions of test method ASTM C1437; the flow after 5 drops of the flow table in 3s.

Fluid grout

A grout consistency having a time of efflux of 10 to 30s when tested by the flow cone procedure of ASTM test method C939.

Defining the problem and associated risk

Type of construction

The precast concrete structure connection details discussed in this white paper are horizontal joints of load-bearing elements between foundations and precast concrete column bases, foundation to walls, stacked precast concrete columns, and stacked precast concrete wall sections. **Figures 1** through **4** illustrate these details in generic form.

How did we get here?

Precast concrete solutions are gaining in popularity because they provide schedule and cost-saving benefits compared with other building methods. These types of structures are becoming taller and concrete panel sizes are growing, which increases the loads at the lower levels and adds reliance on grouted connections as the permanent load-transfer method. There is corroborated industry concurrence that engineers,

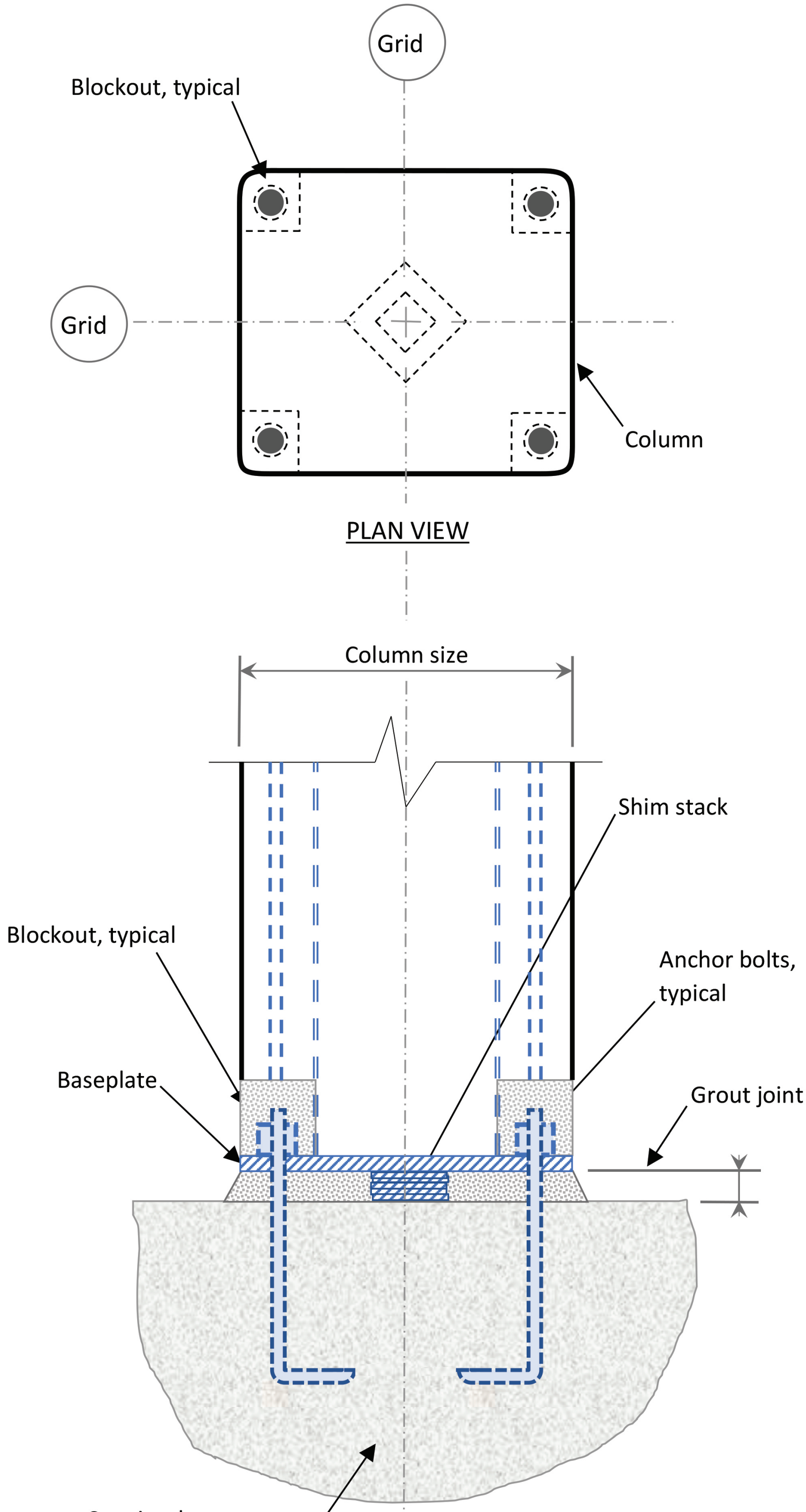

Figure 1. Column-to-foundation grouted joint. Courtesy of Zurich Risk Engineering.

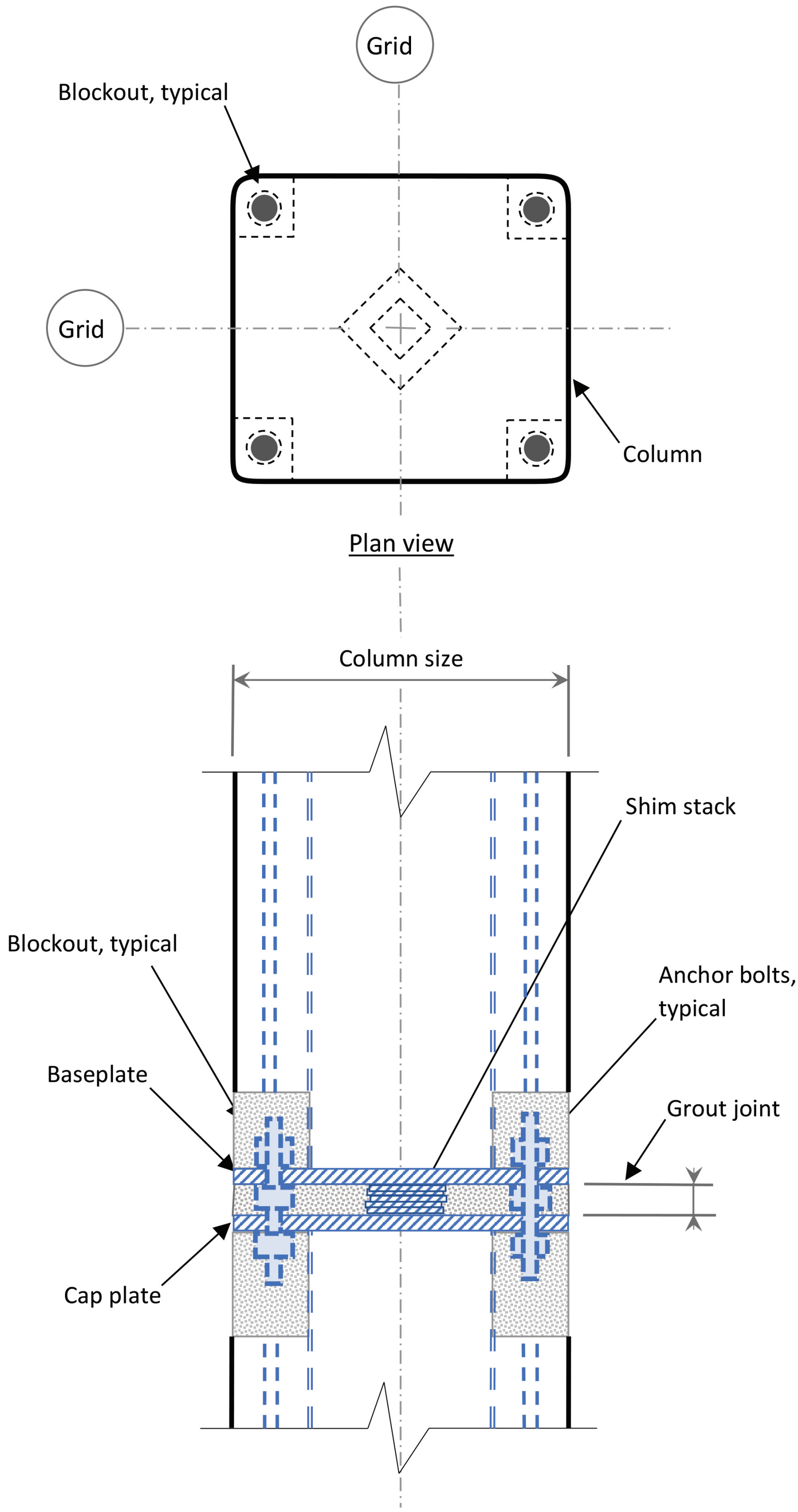

Figure 2. Column-to-column grouted joint. Courtesy of Zurich Risk Engineering.

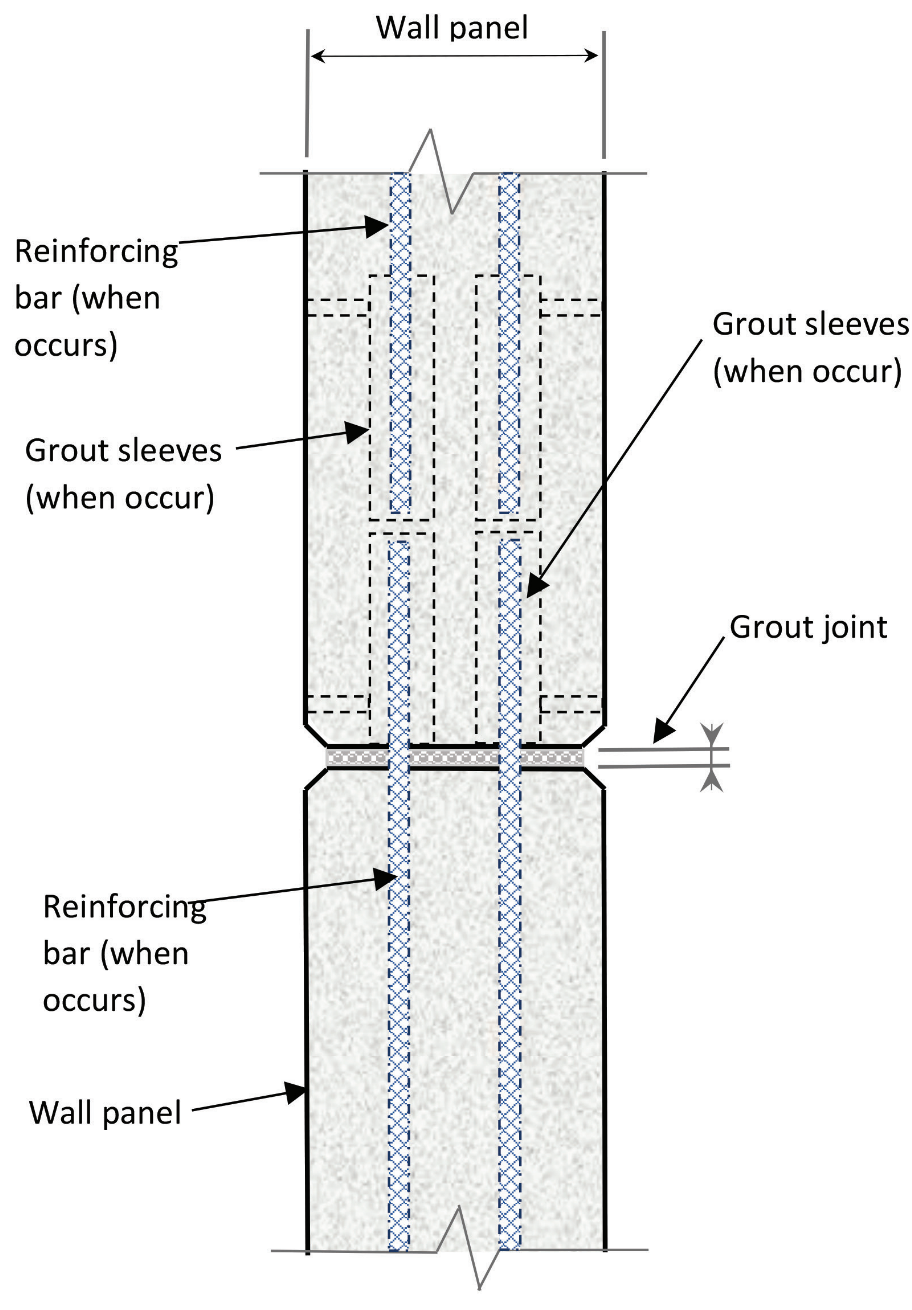

Figure 3. Wall-to-wall grouted joint. Courtesy of Zurich Risk Engineering.

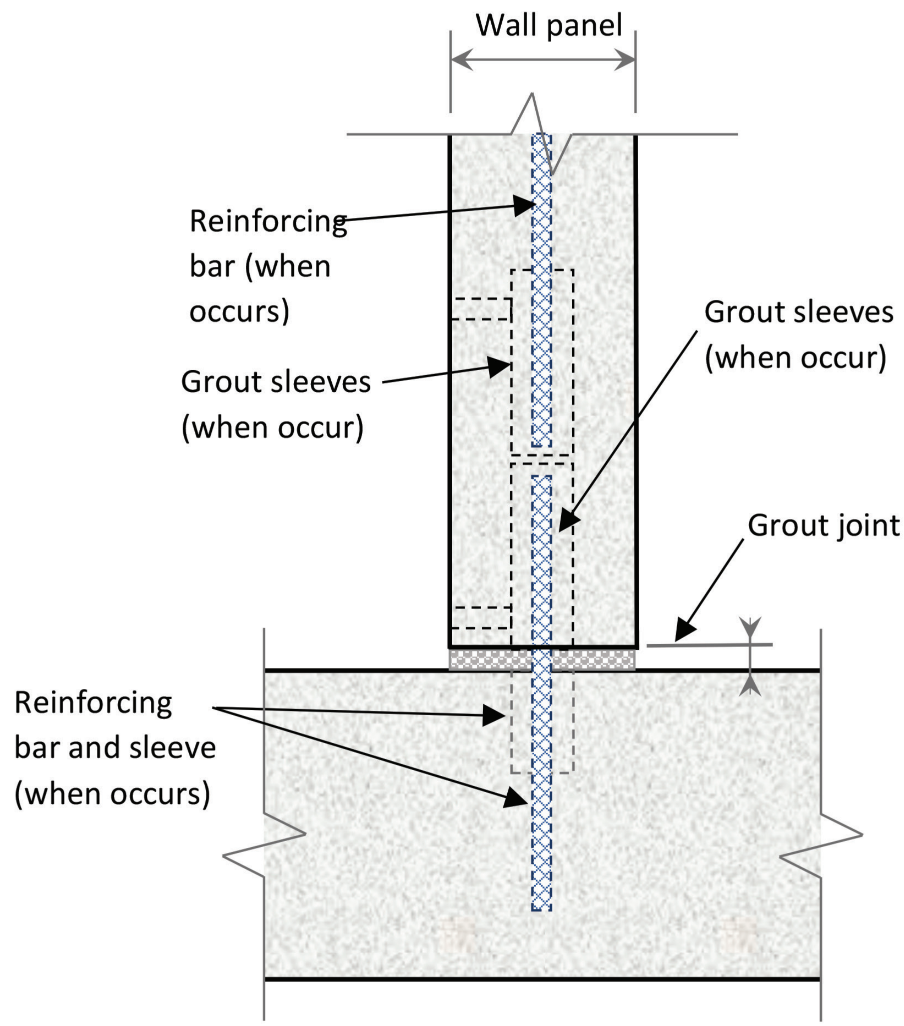

Figure 4. Wall-to-foundation grouted joint. Courtesy of Zurich Risk Engineering.

precasters, erectors, and general contractors on some projects have not paid sufficient attention to the proper installation of these critical grouted connections or grouted joints.

Past and recent project discoveries have included the following:

- There has been a lack of timeliness of structural grouting during the precast concrete element installation process to achieve structural stability.
- There has been a complete lack of grouting under some critical load-bearing elements of completed structures resulting in reliance of shim material for vertical loading.
- There has been poor quality of installed grout (that is, a risk of soft grout or no grout near the center area of joints at panel thickness due to potential hydration issues). For example, when older precast concrete structures were dismantled, perimeter halos of grout and limited grout near the center of the joint were observed.

Outdated grouting methods: The mindset must change

Based on recent proprietary forensic analysis and load testing undertaken in response to some of these incidents, investigators have concluded that partially grouted or poorly grouted connection details and joints have significantly less capacity than fully grouted and properly shimmed joint conditions would in theory have; however, it is important to note that a detail callout note of "fully grouted" is not structurally required in many scenarios. For example, a shimmed-only condition may provide more than enough permanent joint-bearing capacity to resist the required service loads. In this case, a shimmed-only condition along with a perimeter installation of dry-packed or plastic placed grout for corrosion protection, aesthetics, and the like, may be sufficient. Proper attention by engineers of record (EORs) and precast concrete engineers regarding the load analysis and design capacity of individual connections is critical to determine grouting requirements. These issues are discussed in greater detail in a subsequent section on engineering analysis and considerations.

Lack of a standard for investigating completeness on-site

As noted by Mullens and Parker[1] and stated again in this white paper, there are no requirements in building codes or standards for the installation or inspection of grouted connections or grouted joints. Furthermore, and as also noted in this white paper, typical third-party grout collection methods and testing of material samples can be inaccurate and may fail to identify problems of incomplete installations. It is imperative to recognize that local testing laboratories frequently lack the equipment and trained personnel to create proper grout test cubes. This lack of requirements or standards, coupled with common deficiencies in third-party collection methods, exacerbates the current inability of project teams to verify grouted joints or connections on-site.

Examples of connection failures and near misses

Horizontal wall-to-wall joint sudden closure—no grout

Figure 5 shows an example of a horizontal wall-to-wall joint closure. Precast concrete wall panels are traditionally supported by steel or plastic shims along with welded or other connections. The joints between these panels are traditionally filled with a nonshrink grout suitable to withstand the compressive force; however, when the grout bed is missing or insufficient, the joint becomes strained and can exceed the capacity of the shims or the concrete itself and lead to a sudden failure. Improperly grouted horizontal joints can also cause overloading of the welded connections, exceeding their capacity and resulting in the reduction of the original joint. It is not uncommon to see the steel shims punch vertically into the wall panel above or below and disappear into the concrete panel. In cases where plastic shims are used, improper grouting can overload the plastic shims, causing them to compress from their original height.

Figure 5. Horizontal wall-to-wall joint sudden closure—no grout.

Stacked precast concrete column-to-column joint closed—no grout

Figure 6 shows an example of precast concrete column failure. Like wall panels, precast concrete columns rest temporarily on steel shims that create the vertical height for the grout joint. Most columns will have a base plate for attachment to the foundation or another precast concrete element through anchor bolts, splice sleeves, or both. This base plate is normally constructed of ¾ in. thick (19 mm thick) steel and covers the entire surface; however, some columns may only use this plate at the corners for anchor bolts. In this case, the steel shim will be set and bear only on concrete. Because columns are usually primary load-bearing elements, the forces transmitted can be extreme. When the grout is missing or insufficient, the shim stack and anchor bolts become compressed and can fail or overload the footer or column concrete, causing the joint to suddenly close, leading to potentially catastrophic failure.

Figure 6. Failure of precast concrete column—no grout.

Precast concrete column-to-foundation joint closed—no grout and evidence of partially grouted conditions

In 2012, a six-story precast concrete parking structure in Miami, Fla., was under construction when a portion of the structure collapsed (**Fig. 7**), killing four people and injuring three others. The Occupational Safety and Health Administration's Construction Incidents Investigation Engineering Report[2] concluded that the collapse occurred,

> *because grout was not placed, as required, at the base of an interior column to adequately transfer the column load to the footing. As loads on the column gradually increased on the day of the incident, the bearing of the column over the shim plates exceeded its capacity, resulting in failure. This triggered a cascade of collapse of columns, inverted tee beams, and double tees on all five floors weighing approximately 3300 tons over an area of approximately 16,000 square feet.*

In this instance, the grouting and inspecting was not part of the erector or precast concrete producer's contract. The contractor responsible for the erection stability plan and the critical grouting activity was disconnected from the producer and/or erector.

Estimating- and planning-stage considerations

Applying lessons learned from the previously described failures and near misses, the precast concrete producer should perform a review of the project-specific precast concrete connection details on the bid drawings and specifications as follows.

- Based on the expected loads on the structural members, roughly size these members and plan initially which grout installation method (plastic, flowable, or fluid grout installation) is most appropriate for the installation and loading conditions. Perform an initial engineering comparison of shims needed to hold the required loading and grout strengths against the strengths indicated by the grout manufacturer for each consistency type, taking into account connection access, any geometry challenges, and other project-specific constructibility issues.

- If the project specifications provide insufficient detail in defining the project requirements as related to structural component sizes, grout location, grout procedures, and the like, inform the EOR of the differences before project bidding. Such communication can include more fully developed specification language. A sample structural grouting specification is available for download from the Structural Engineers Association of Colorado website.[3]

- Carefully consider weather conditions for planned grouting, and include relevant hot- and cold-weather-related requirements in the project analysis. Extremely hot or cold weather can have a significant impact on quality, schedule, and cost.

- Discuss with project stakeholders the expected grouting conditions and verify that the installation sequence and erection stability plan clearly denotes when grout is needed and how much cure time is required before building construction continues to progress. Up-front education of all critical stakeholders is fundamental to the successful installation of these critical precast concrete building elements and establishing the project schedule.

Engineering analysis and considerations

As previously presented, whether through curing (hydration) issues, weather conditions, poor workmanship, or other issues, soft grout and/or missing grout near the centers of grouted joints (resulting in a perimeter halo condition of good grout) can occur. Even perimeter-visible grout has been found to be deficient in some cases. It is critical that the following preparatory steps and engineering analysis considerations be conducted to ensure proper grouting and panel installation.

First, to understand the magnitude of construction and final service loads on every column and wall stack, it is imperative that load-transfer paths be calculated. This step is necessary to ensure that the grout requirements and installation methods best suited for each condition for every joint can be determined. To avoid confusion, the precast concrete engineer should consider standardizing the grout installation method for like conditions. For example, a general rule might be "all column-to-foundation horizontal joints shall be flowable grout." It is recommended that the precast concrete engineer clearly establish the performance criteria of the grout, thus helping to differentiate between plastic, flowable, and fluid installations, as water content determines grout strength.

Some of the previously mentioned incidents have triggered extensive and advanced forensic engineering analyses, resulting in more-refined bearing capacity equations, designs, and

Figure 7. View of the Miami, Fla., parking structure collapse. Courtesy of Occupational Safety and Health Administration.

testing of the capacities of several of these types of grouted joints (fully grouted, partially grouted, and correspondingly retrofitted grouted and/or added-shim conditions). These analyses are not yet available to the general public, but some of the general findings are noted in the following paragraphs.

The 1968 Hawkins equation[4] to estimate the bearing strength of concrete loaded concentrically through rigid plates (shims) and the bearing equation (derived from the 1968 Hawkins equation) in the American Concrete Institute's *Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary (ACI 318R-19)*[5] both contain limitations in developing an accurate bearing capacity of a partially grouted condition with shim and added grout and/or additional shim(s) in a retrofitted condition. There is currently limited published research on the analysis of these conditions; however, testing has indicated that the ACI 318 bearing equation does a reasonably good job at estimating the bearing capacity of the connection in a fully grouted condition.

As further indicated by this testing and as also noted by Mullens and Parker,[1] most grouted joints have a meaningfully different aspect ratio and confinement than the 2 in. (50.8 mm) grout cube tests (typically used in the industry) would derive for grout strength verification. Therefore, designers and engineers need to consider related adjustments for this variance while also being mindful of further modifications for grout mixing, water content, and strength variations. This aspect ratio issue is a factor in fully grouted conditions, but it is an even more important concern in partially grouted conditions.

In addition, whether the grouted connection is ultimately retrofitted from a partially grouted condition or fully grouted in an initial design state, it is strongly suggested that the connection designer evaluate the shim failure mechanism and cured grout contribution to the overall performance of the connection (such as splitting failure of concrete abutting members compared with a noncatastrophic closing of joint and crushing of shims/grout). Recent forensic engineering studies have concluded that varying shim sizes, placement locations, and joint sizes together play a significant role in the performance of these grouted connections. (These forensic studies are currently confidential and will be shared by PCI when they become available.) In all grouted condition cases, however, the mechanics of joint behavior and failure mechanisms, according to this recent testing, are not intuitive and should be evaluated by a structural engineer.

Moreover, this additional testing indicated that supplemental shims (in a retrofitted condition) do not always provide additional bearing resistance equivalent to that of shims installed during the original erection, loading, and grouting sequence. Although supplemental shims can strengthen joints in a retrofit scenario, the corresponding loss of grout showed that grout and supplemental shim materials do not work together at full strengths. With that in mind, the researchers deemed that estimating joint strengths (assuming equivalent original and retrofit shim contributions in conjunction with resistance from grout) significantly overestimated the actual strengths. These tests further indicated that an appropriate estimate of retrofitted joint strength with supplemental shims can be obtained by considering only the area of all steel-bearing elements (that is, with no grout contribution), or solely the elements of the original construction (that is, with no supplemental shim contribution), whichever combination provides the larger resistance. Once again, although such advanced analysis methods and findings resulting from research and testing are not yet available to the general public, the understanding is that certain entities will be able to report these findings in both *PCI Journal* and *ACI Structural Journal* to increase knowledge in this area.

In light of the previously mentioned retrofitted condition and acknowledging that neither the use of the Hawkins 1968 bearing-strength equation nor the derived general ACI 318 equation for bearing capacity is completely accurate in a partially grouted scenario, an experienced structural engineer should be consulted for guidance if this situation occurs. To avoid this challenging situation, best practice is to enact a "do it right the first time" program approach by ensuring that consistent quality grout is installed throughout the joint such that the ACI bearing equation can be used with reasonable accuracy.

Finally, not only is it critical to develop and maintain a robust grouting installation procedure, it may also be prudent to establish a verification protocol of grout extents at the site. An on-site verification procedure is discussed further in a subsequent section.

Grout preinstallation recommendations

Necessity for an erection stability plan

As the previously noted case study of the Miami parking structure collapse illustrates, developing and executing a comprehensive erection stability plan is critical. This planning should occur during the preconstruction phase of a project to ensure that timely grouting operations are well understood and ultimately executed in accordance with the project drawings and specifications. The stability plan must provide detailed directives for grouting, including cured grout hold and completion points that clearly identify safe minimum grouting area requirements and critical connections that need cured grout to be completed before erection continues. It is important that welded or other connection requirements directly related to stability be established, understood, and explicitly adhered to before erection continues.

The ideal scenario is that the erector controls and performs the grouting operations. If the erector provides only precast concrete erection services with no grouting operations, it is necessary to ensure that the precast concrete supplier, grout subcontractor, general contractor, or any other entity that is installing or testing the grout has a clear understanding of grouting issues addressed in this white paper as well as the project stability plan. This entity must also be able to meet the requirements for the PCI field quality audit report (FQAR) sections 2.4.2.4

and 2.4.2.5, given in PCI's *Erector's Manual* (MNL 127),[6] as well as any other grout-related activities listed on the FQAR. Failing to ensure that these items are met can create unsafe and potentially catastrophic conditions in the field.

Each project's erection sequence is unique and requires a detailed stability analysis and plan (with explicit instructions) developed by a professional engineer. Erected piece counts per day will always be a significant benchmark in the industry, but following through on corresponding grouting operations and strict adherence to a detailed stability plan should take precedence over meeting such benchmarks. The erector should avoid traditional rule-of-thumb protocols of grout installation timeliness because they can be too generic and will not encompass critical or unusual conditions on the structure.

Stability plan requirements will be unique to each specific project and should contain the components given in the following section.

Stability plan components

Per section 2.1.2 of PCI MNL 127,[6] considerations for structural stability must be evaluated before precast concrete erection begins. The plan should include a "stop work directive" process and procedures. The following items shall be addressed in the project-specific stability plan, in addition to ensuring conformance to PCI MNL 127:

- Shoring and bracing
  - locations for critical shoring
  - calculations to determine the required shoring system and bracing element sizes and the required connections to meet load requirements (inclusive of appropriate safety factors)
  - inclusion of shores or braces that need to be attached before unhooking the precast concrete component from the crane
  - criteria that must be met before the removal of shores and bracing

- Welding requirements
  - amount of weld required before unhooking the precast concrete component from the crane
  - identification of both permanent structural connections and temporary erection connections
  - recognition of the many variables (sequence changes, erection speed, etc.) that could cause critically loaded connections to require final welding much faster than would be indicated by a fixed time requirement (such as "connection must be welded 'X' hours after panel is erected"); as noted previously, the stability plan should clearly delineate what must be welded before erection can continue (note: if welds are not specifically called out as "for erection only," "erection connection," or something similar, the controlling entity, EOR, and weld inspector will assume that all connections are structural connections)

- Grouting
  - the minimum design strength required for the grout being installed
  - the number of levels of precast concrete that can be stacked on shims only
  - the expected grout cure time before additional loading is allowed; times should be specified for different situations and at ambient temperatures
  - the grout placement requirements: plastic, flowable, or fluid
  - the QA/QC requirements for both the company performing the grouting operations and the jobsite

It is recommended that any company performing grouting operations should have a formal training program. Proper grouting procedures and training should be taken very seriously; as previously stated, grout is a structural component of the building that requires proper and timely placement to avoid catastrophic failure.

Grouting procedures and training program

It is recommended that each company create its own grouting procedures manual along with a training and testing process to ensure that all grout installation teams are skilled in the use of the material and understand how to safely and properly perform installation tasks. The following items are suggested components of a robust grouting procedures manual and training program.

Procedures manual A company's grouting procedures manual should include the following:

- manufacturer's recommendations for the products used (grout manufacturer tech sheet)

- explanation of how the procedures manual ties into the company's overall quality management program

- details specific to regional demands and project needs

Training program A grouter training program should be conducted for all new employees. In addition, retraining should be executed on a yearly basis to update employees on any changes within the program and new materials being used and to reaffirm best practices. The training and retraining should accomplish the following objectives:

- cover the basics of grout mixing and installation

- reinforce the importance of proper and timely grouting

- cover the company's grouting procedures manual

Testing Training should conclude with a written test and a practical test. The written test provides formal documentation of the training and the named individuals involved. The written test should be basic and cover critical items that the test taker will need to know to convey pertinent information if questioned by field supervisors or contractors. Some suggested test questions are as follows:

- How much water should be added for the grout(s) used (at what fluid level)?
- What is the proper mixing procedure for the grout(s) used?
- What is the proper mixing time for the grout(s) used?
- What is the working time for the grout(s) used (based on ambient temperature)?
- What is the curing time for the grout(s) used (partial or full cure; 3 days or 28 days)?
- Where can employees find grouting requirements for a project?
- What are proper placement techniques for the grout(s) used?
- What is the proper procedure for pumping splice sleeves, and what grout should be used in these applications?
- What are your firm's hot-weather grouting procedures?
- What are your firm's cold-weather grouting procedures?

Practical testing should assess the hands-on aspects of the training: employees should demonstrate that they understand how to properly mix and place grout and that they can define what grout "looks like," "feels like," and "acts like" for each of the company's placement methods. Practical testing should include the following:

- mixing the grout to proper consistency and for proper mixing time
- forming a joint
- placing the grout
- proper cleaning and maintenance of equipment
- maintaining a point of contact with the precast concrete engineer should grouting issues arise

Practical testing can be conducted off-site using precast concrete plant or manufacturing facilities or on-site with a mentor to ensure proper placement of structural grout. The practical test should be documented in the form of a reviewer check sheet and performance evaluation.

Grout installation recommendations

As noted, grout is a critical structural component of all precast concrete buildings. Therefore, it is imperative to ensure that all grout is installed in the proper locations as required per approved precast concrete erection drawings and to verify that the grout is of the required design strength and quality. It is strongly recommended that each company develop a formal QA/QC program for all grouting operations. This program complements preinstallation training and testing and serves as a verification that workers actually learned and are maintaining successful practices. When developing a specific grouting QA/QC program, consult PCI MNL 127[6] in addition to the recommendations of this white paper.

Refer to appendixes A, B, and C for a comprehensive inventory of QA/QC checklist items, a sample one-page field checklist, and as-built documentation recommendations for grouted connections to ensure that an overall robust field structural grouting QA/QC program is in place or can be developed.

On-site testing of grouted joints

As briefly discussed by Mullens and Parker[1] and as noted in this white paper, grout cube testing does not necessarily provide a good representation of the strength of grouted joints at the site. Although such testing indicates the performance of the grout material relative to the manufacturer's stated test data and properties, precasters should consider conducting destructive on-site testing to verify that completed grout joints have minimal voids and do not include soft pockets through the full depth or width of the joint.

If any version of a poorly grouted joint is discovered during on-site testing, the grout plan should include a response protocol to determine the rough percentage of substandard grout. On-site testing should also include some data-driven determination of the connection's capacity compared with the design requirements. The precast concrete engineer, EOR, and installer should determine any potential remediation that might be necessary to resolve any grout concerns and modifications to the ongoing grouting process. Recently, the use of resistance drilling has been adopted by some precasters to check for poor or incomplete placement at cured grouted joints. This informal procedure uses a $^{5}/_{16}$ in. (8 mm) hammer drill bit, drilled into the grout joint at predetermined intervals for wall joints and in a hashtag pattern (#) for columns. If the grout is solid and difficult to drill, the grout is deemed to be acceptable. If the grout seems soft or the drill lurches forward due to pockets of poor consolidation, the precast concrete engineer may deem the grout unacceptable and require replacement using proper procedures. The development of specific procedures will depend on the amount of grout to be replaced. The drill holes should ultimately be filled with grout so as to not create voids in the joint assembly that would reduce the load-carrying capacity.

Recognizing that currently there is no ASTM standard for this type of testing, such a procedure should not be formally included in any contracts, specifications, or any other contract documents, nor shall it be used to supersede findings from approved ACI tests with an ASTM number. If or when an

ASTM standard for this type of destructive testing is written and adopted, PCI will release more information at that time.

As a final comment, it is noted that some erectors previously have used special cameras during grouting as another way to check installation extents. Although this method does not verify the final strength of grout, it can help confirm whether voids exist in critical sections of grouted joints during grout placement and initial curing.

Conclusion

As demonstrated throughout this white paper, engineers, construction managers, precast concrete erectors, and grout installers all require critical education and training on structural grouting between load-bearing elements. This training and education must encompass preliminary project planning and design stages through preinstallation, erection stability planning, product installation, as-built modifications, quality assurance, and final verification. Near misses, localized failures, and catastrophic collapse of elements of precast concrete structures have taught the industry painful lessons. As Mullins and Parker have also discussed,[1] steel column base grouted connections to foundation elements have experienced similar misfortune.

The industry must consistently produce and adhere to project-specific erection stability plans that incorporate allowable building progress with welded and grouted completion points and issue stop work directives, without exception, if not achieved.

Furthermore, companies must ensure that their workers are well trained on proper grout mixing and placing restraints and the associated challenges and retaught whenever significant time passes between projects. Training must also be conducted whenever new members join field crews.

Moreover, each project must have a dependable methodology and procedure to ensure that all grouting required by the precast concrete engineer is properly installed. This procedure must include mechanisms to mark completion for all inspector/reviewer entities to visibly see (such as buried columns or grouted couplers). The procedure must also require certain individuals (such as the precast concrete erection supervisor, main grouter, or field engineer or manager) to be accountable for following the erection stability plan and its corresponding grouting and welding requirements.

Last, although current building codes and standards provide *no* specific requirements and *limited* guidance for installation or special inspection of these grouted joints, steps must be taken by responsible entities to begin to develop and formalize procedures to ascertain the quality and extents of installed grout, especially in nonvisible places. Plans must be in place to assess and address conditions of effectively partially grouted joints, and these plans must have a technical basis to determine whether any potential remediation might be necessary. Grout cube testing should be considered a component of an overall verification procedure of installed grout strength, but it is important to be mindful of the connection joint aspect ratio and confinement considerations previously noted.

It is imperative that lessons learned from the historical lack of consistent attention to this highly critical building connective element be shared so that the industry can move forward from these past issues while maintaining a permanent mindset of the risk to life safety if grout is not given the utmost attention.

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Appendix A: Grout quality assurance/quality control checklist items

This appendix provides a comprehensive inventory of grout quality assurance/quality control checklist items.

i. Grout type and storage

1. Confirm that the grout type(s) to be used on-site (for example, nonshrink, nonmetallic, correct manufacturer) are per drawings and specifications.

2. For all products being used in your operation, ensure that crews understand the technical data and manufacturers' recommendations for mixing.

3. Make grout product technical data sheets available to the crews for reference and review.

4. Record grout bag lot numbers. Develop a placement tracking procedure in case a lot number is recalled.

5. Track and verify grout expiration dates. (Typical shelf life is one year.)

6. Ensure that grout is stored in a cool, clean, dry place. (Ideal storage temperature is 70°F [21.1°C]; avoid storage below 40°F [4.4°C] or above 95°F [35°C].)

ii. Grouting supplies

1. Make sure that the necessary items (for example, proper mixer for material type, wheelbarrow, shovel, water, measuring devices and/or containers, buckets, and grout) are within easy reach of the working area.

2. Ensure the employees are trained in the use, cleanup, and maintenance of all grouting equipment.

3. Confirm that the equipment is generally clean and working properly.

iii. Substrate preparation

1. Verify that joint surfaces are clean and free of debris.

2. Verify that freestanding water is removed from joint surfaces.

3. If required by the grout manufacturer, ensure that the joint substrates will be prepped to a premoistened or saturated surface dry condition.

4. Confirm that the steel or plastic bearing shims are the correct size and grade material for wall and/or column joints.

iv. Joint forming (plastic, dry-pack, flowable, and fluid grout applications)

1. Check whether the joint height exceeds the grout manufacturer's recommendations or design allowances. If it does, take steps to add pea gravel to the grout mixture per the manufacturer's recommendations. Note that if gravel is added, test cylinders are required; test cubes are not acceptable.

2. Confirm that the joint height is not less than the grout manufacturer's or precaster's installation manual recommendations.

3. Make sure formwork parts are oiled to avoid grout damage at removal.

4. For a plastic or dry-pack grout application, pack the grout against a well-braced backboard.

5. For a flowable or fluid grout application, ensure that forms are watertight or sealed with material such as tape, caulking, or foam, with required air-weep ports to ensure void filling.

v. Substrate and ambient temperature

1. Check ambient temperatures of the grout and substrate(s) before grouting. Grout-manufacturer-specified temperature ranges are generally 40°F to 95°F (4.4°C to 35°C). If temperatures are outside of this range, follow cold-weather or hot-weather grouting procedures. See items xi and xii.

2. Determine whether any monitoring devices will be cast into the grout mixture to track temperature during curing. If not, take other means to track, measure, and control grout temperature during curing.

vi. Grout mixing

1. Ensure that the mixing water is clean and potable.

2. Confirm that the water temperature is suitable to maintain a general grout temperature range between 40°F and 95°F (4.4°C and 35°C).

3. Make sure the correct water-to-grout ratio has been used for the fluid state per the manufacturer's requirements.

4. Formally record the amount of water added to the grout on a mandated checklist or inspection form.

5. During mixing, make sure surface water has sufficiently dissipated, yielding a uniform consistency.

6. If additional water must be added, make sure that the maximum water requirements have not been exceeded.

7. Follow the manufacturer's mixing-time instructions to ensure dry admixture dispersion.

8. Measure the grout temperature upon conclusion of mixing. Verify that the temperature has not exceeded the manufacturer's recommendations.

vii. For plastic and dry-pack grout placement

1. Recheck the backboard form for stability.

2. Double-check that the proper amount of water has been added to the grout mixture. (An additional visual check can consist of squeezing a handful of grout into a tightly packed ball and confirming that the ball does not crumble.)

3. Ensure that placement starts immediately after mixing. The installer should not allow grout to set up before placement. Some amount of agitating is acceptable; retempering a mixture by adding water to grout after stiffening is not acceptable.

4. Ideally, pack the joint with grout in a horizontal fashion and in relatively small sections, with adequate force to compact the grout.

5. Follow the manufacturer's specified placement times.

viii. For flowable grout placement (commonly referred to as flow-fill or pourable grout, where grout can be poured from a bucket, for example, in smaller or localized applications)

1. Ensure that placement starts immediately after mixing. The installer should not allow grout to set up before placement. Remixing is acceptable; retempering a mixture by adding water to grout after stiffening is not acceptable.

2. Double-check the proper installation of the formwork.

3. Ideally, place grout in a continuous process until the joint is completely full, thus burping air out and eliminating voids.

4. Take steps to avoid entrapment of air. Ideally, begin grouting at the initial application position and direct the flow away

from that position, pushing air ahead of the grouting operation.

5. Confirm that an air vent gap has been placed and maintained on the opposite side of the joint or component being grouted.

6. As needed, use items such as metal straps and bands for tamping to help distribute grout through the joint and discharge trapped air.

7. Follow the manufacturer's specified placement times.

ix. For fluid grout placement (for reinforcing bar splice sleeves, hollow-core keyways or applications where pumping is required and grout is provided by a ready-mixed company)

1. Ensure that placement starts immediately after mixing. The installer should not allow grout to set up before placement. Remixing is acceptable; retempering the mixture by adding water to the grout after stiffening is not acceptable. When placing ready-mixed grout, ensure placement is complete 90 minutes after batching.

2. Double-check the proper installation of the formwork.

3. Ideally, place grout in a continuous process until the joint is completely full.

4. Start placement at the *far* end of the joint being grouted so that during pumping, the nozzle can be slowly backed out (while staying submerged) to prevent air entrapment.

5. Maintain continuous pressure on the pump.

6. Follow the manufacturer's specified placement times.

x. Grout curing

1. Leave forms in place until grout is self-supporting.

2. Confirm that the grout and surrounding concrete maintain a temperature within the manufacturer's specified range (generally between 40°F and 95°F [4.4°C and 35°C] and for a period of 24 hours). See items xi and xii for additional specific hot- and cold-weather grouting requirements and techniques.

3. Check the joint for surface voids, cracks, and similar issues when forms are removed.

4. If forms or overpoured areas must be removed before the final cure of the grout, apply wet rags or a curing compound to prevent moisture loss.

xi. Hot-weather grouting (ambient temperature generally above about 95°F [35°C])

1. Condition materials during mixing to maintain a temperature below 95°F (for example, chilled water can be used for mixing grout).

2. To control substrate temperatures, enact surface-cooling measures (for example, presoak concrete surfaces or shade them from direct sunlight).

3. After grout placement, take precautions to maintain grout and surrounding concrete temperatures within the manufacturer's specified range (for example, cover exposed surfaces, add curing compounds, protect forms).

xii. Cold-weather grouting (ambient temperature generally below about 40°F [4.4°C])

1. Condition materials during mixing to maintain a temperature above 40°F (for example, use hot water, portable space heaters, and/or combustion heaters).

2. To control substrate temperatures, use portable space heaters, combustion heaters, or other heating mechanisms for surface-warming measures.

3. After grout placement, take precautions to maintain grout and surrounding concrete temperatures within the manufacturer's specified range (for example, cover exposed surfaces and maintain heating measures).

xiii. Grout test cubes (see ASTM C109,[1] ASTM C109 modified per ASTM C1107[2] for flow, and ASTM C1611[3])

1. Confirm whether a third-party testing agency will take grout cube samples to verify strengths.

2. If no third-party testing agency will be taking samples, it is strongly recommended that the erector, grouter, or contractor do so. Cubes should be taken at a frequency of one set per lot of grout used on the project. This assumes good documentation of mixing and batching for each installation day.

3. Ensure that samples are placed in brass molds, properly collected, to produce 2 in. (50.8 mm) cube specimens.

4. Confirm that cubes are removed from molds after approximately 16 hours of curing. To ensure cubes are not mishandled, ensure that the entire loaded cube mold is delivered to the laboratory that will conduct testing.

5. Ensure that the cube specimens are labeled with job identifier, date, time that the sample was taken, and location on the building.

xiv. Grout connection completion assurance

1. Ensure that the grout crew or erector uses a set of project drawings to formally track and record connection completion.

2. Verify that 100% of the grouted connections are formally checked and recorded as completed.

3. To ensure structural stability, confirm that concrete panel erection sequence hold points are clearly identified, indicating critical grouting and connections (such as column-to-column or wall-to-wall joints) that must be grouted before precast concrete panel installation can continue.

4. Enact formal procedures (such as emails and executed forms and/or checklists) to ensure that the erector and grouter communicate to verify that critical grouting has been completed, thus allowing erection to continue or cease.

5. Verify that final grout strengths are confirmed (test strength at 7-day and 28-day cures and compare findings with required design strength). Ensure that aspect ratio and confinement issue considerations are taken into account during the confirmation process.

xv. On-site testing of joints

1. Consider on-site testing procedures, such as resistance drilling, to verify that completed grout joints have minimal voids, and do not include soft pockets through the full depth of the joint. Refer to the section on on-site testing of grouted joints in the main part of this white paper for discussion of this item.

xvi. Grout installation training and grouter qualifications

1. Ensure that individuals performing grouting have received formal competency training, including a written test and hands-on training.

References

1. ASTM Subcommittee C01.27. 2020. *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50 mm] Cube Specimens)*. ASTM C109/C109M. West Conshohocken, PA: ASTM International.

2. ASTM Subcommittee C09.43. 2020. *Standard Specification for Packaged Dry, Hydraulic-Cement Grout (Nonshrink)*. ASTM C1107/C1107M. West Conshohocken, PA: ASTM International.

3. ASTM Subcommittee C09.47. 2018. *Standard Test Method for Slump Flow of Self-Consolidating Concrete*. ASTM C1611/C1611M. West Conshohocken, PA: ASTM International.

Appendix B: Sample one-page field grout checklist

Sample grout quality assurance/quality control checklist			
Project name			
Date			
Weather			
Supervisor name			
Signature			
Yes	No	n/a	Has erection stability been reviewed by all erection and grout crews?
Yes	No	n/a	Are splice sleeves being grouted per manufacturer's recommendations?
Yes	No	n/a	Is grout being stored in a cool, dry environment?
Yes	No	n/a	Is the required equipment on-site, operating appropriately, and used as specified?
Yes	No	n/a	Is the surface free from all debris and contaminants that may act as a bond breaker?
Yes	No	n/a	Is the area to be grouted free from standing water?
Yes	No	n/a	Is concrete in saturated surface dry condition, as required by the manufacturer's recommendations?
Yes	No	n/a	Is the temperature of the grouted area between 40°F and 95°F (4.4°C and 35°C)?
Yes	No	n/a	For temperatures below 40°F, are cold-weather grouting procedures being implemented?
Yes	No	n/a	For temperatures above 95°F, are hot-weather grouting procedures being implemented?
Yes	No	n/a	Is potable water being used for mixing the grout?
Yes	No	n/a	Is the grout being mixed according to the manufacturer's specifications?
Yes	No	n/a	Is the grout being allowed to cure for 24 hours without disturbance?
Yes	No	n/a	Are minimum grouting requirements being met before erection proceeds?
Yes	No	n/a	Is grout placement being documented in accordance with the company's quality assurance program?
Yes	No	n/a	Were grout test cubes taken?
Yes	No	n/a	Are separate drawings being retained for grout placement location recording? If not, what elevations or product control numbers were grouted today? ______ ______
______			Lot number(s) for the grout
______			Method of placement (dry-pack, plastic, flowable, or fluid)
______			How much water is being added to achieve the desired consistency?
Comments:			

Note: n/a = not applicable.

Appendix C: As-built documentation recommendations for grouted connections

It is recommended that each project keep a set of as-built drawings for documentation of the grouting operations. With recent advancements in project management software, it may be advantageous to use one of those platforms to create as-built drawings with linked documents or photos for each grout placement location. The following are recommendations for items to be included in as-built documentation:

- date, location, and lot number for each grout placement
- photos of grout placed at each location
- grout cube test results
- backup documentation for any other means of testing or placement monitoring

Abstract

Structural grouting between load-bearing elements is a critical component of precast concrete erection stability planning. Engineers, construction managers, precast concrete erectors, and grout installers require critical education and training to avoid localized structural failures and, in extreme cases, catastrophic collapses of total structures. Although current building codes and standards provide no specific requirements and limited guidance for installation or special inspection of these grouted joints, steps must be taken by responsible entities to begin to develop and formalize procedures to ascertain the quality and extent of installed grout, especially in nonvisible places. Each project must have a dependable methodology and procedure to ensure that all grouting required by the precast concrete engineer is properly installed, and this procedure must include mechanisms to mark completion for all inspector/reviewer entities to visibly see (such as buried columns or grouted couplers). The procedure must also require certain individuals (such as the precast concrete erection supervisor, main grouter, or field engineer or manager) to be accountable for following the erection stability plan and its corresponding grouting and welding requirements. Companies responsible for installing structural grout must ensure that their workers are well trained on proper grout mixing, placing restraints, and associated challenges and are retaught whenever significant time passes between projects. Training must also be conducted whenever new members join field crews. As demonstrated throughout this white paper, the industry must consistently produce and adhere to project-specific erection stability plans that incorporate allowable building progress with welded and grouted completion points and issue stop work directives, without exception, if not achieved. Moreover, each project must have a dependable methodology and procedure to ensure that all grouting required by the precast concrete engineer is properly installed. It is imperative that lessons learned from the historical lack of consistent attention to this highly critical building connective element be shared so that the industry can move forward from these past issues while maintaining a permanent mindset of the risk to life safety if grout is not given the utmost attention.

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Erection, field safety, insurance, horizontal joints, structural grouting.

Reader comments

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