Evaluation of Keyway Grout Test Methods for Precast Concrete Bridges*

by Robert J. Gulyas, Gregory J. Wirthlin and Jeffrey T. Champa

Comments by Dennis Nottingham and Authors

DENNIS NOTTINGHAM†

The authors have taken a subject previously lacking in technical information and provided solid background research for improving the performance of keyway grouts and joint details. Joint grout and joint details do not usually receive the required attention and are now showing poor performance in many cases. The development of ways to test grout, specifically for keyways, and the development of an effective grout, as detailed by the authors, is greatly appreciated.

Peratrovich, Nottingham & Drage, Inc. (PN&D) first began grouted precast concrete panel bridge and dock design in 1980 with two significant projects: the Kuparuk River Bridge on the North Slope of Alaska [2300 ton (2086 t) design live load] and the Klawock logging dock in southeast Alaska [80 ton (72 t) axle design live load].

Both structures have adequately handled the large and often highly repetitious loadings, but not without some grouted joint maintenance. Joint grout problems have been traced to three key problems: (1) weak grout; (2) poor joint details; and (3) inconsistent grouting procedures. Following these initial designs, attention was given to greater detail in the design of joints, shear keys, joint forming, grout materials and grouting procedures.

As time progressed and poor grout performance began to become apparent, various grouts were examined for constructability and performance. Subsequent designs now feature detailed grouting procedures and strict specifications for grout materials. The path to consistent design performance has been based on input from many people, including contractors, suppliers and PN&D engineers.

Many large existing structures and structures under construction use grouted precast concrete deck panels, as evidenced by the recently completed 1450 ft (442 m) Ketchikan Tourship Dock (see Fig. A). Precast, prestressed concrete deck panels composite with steel box girders allowed this project to be designed and built in only 8 months. Prestressing was also applied to supporting steel pipe pile rock anchors grouted into bedrock as a means of resisting severe ship and seismic forces.

Fig. A. Typical precast, prestressed concrete grouted dock deck, Ketchikan, Alaska.

Joint details are as important to construction as they are to the required design performance. Often overlooked, precast concrete element tolerance can lead to improper joint fit and incomplete grouting. Fig. B shows some of the problems exhibited by joint details. As can be seen in the illustrations, joints are never full strength and can be

* PCI JOURNAL, V. 40, No. 1, January-February 1995, pp. 44-57.

† President, Peratrovich, Nottingham & Drage, Inc., Anchorage, Alaska.

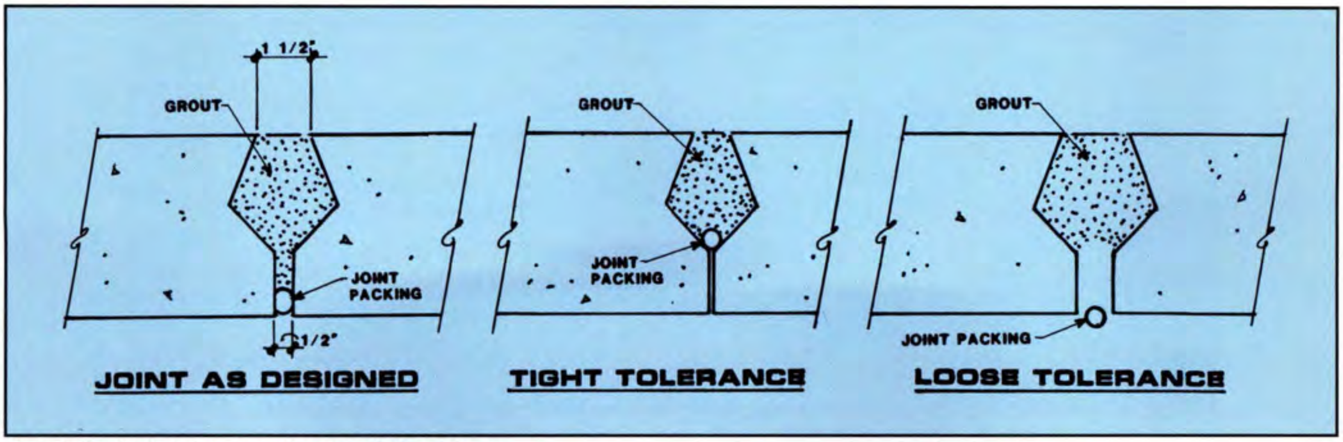

Fig. B. Typical examples of grouted shear keys.

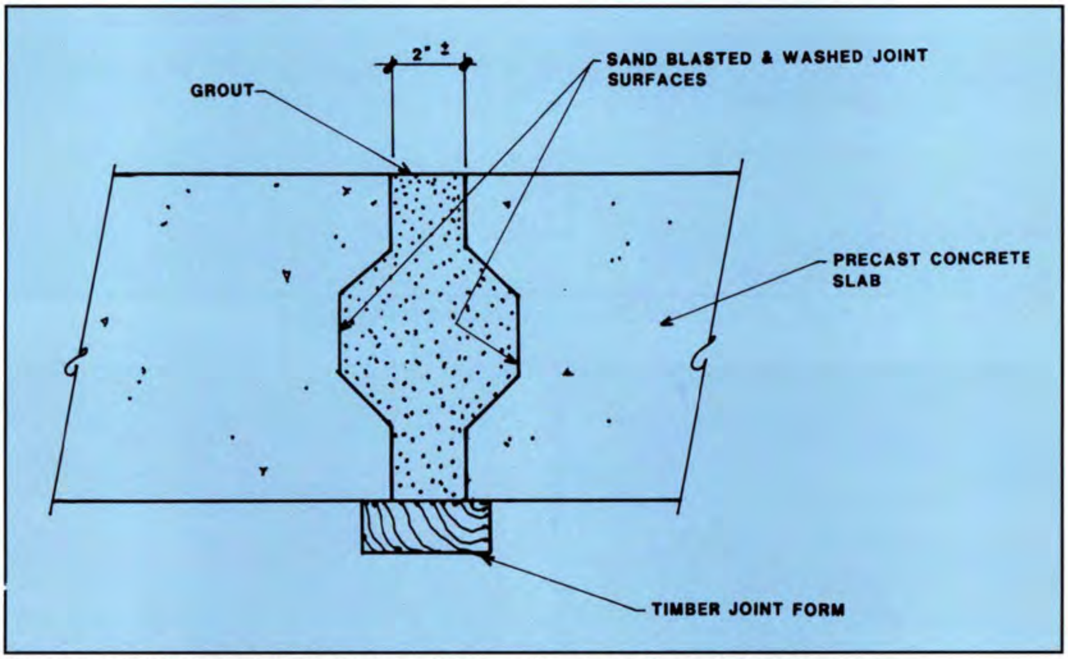

Fig. C. Typical Peratrovich, Nottingham & Drage, Inc. grouted panel shear key.

much weaker than envisioned by the designer.

Fig. C shows a typical formed grout joint and the type of forming now used exclusively. These joints are now sufficiently large to handle panel tolerance and ensure maximum construction speed with full grout-to-panel contact.

Fig. D shows typical forming, grout paths, and pockets over steel girders. This configuration ensures easy and controlled grouting and complete filling of all voids.

PN&D realized that the short time it takes to adequately form joints is often not much longer than it takes to install poorly fitting foam packing rods. However, the results of each method cannot be compared for adequacy. Foam packing rods should never be used in structural grouted joints.

Often, precast slab joints are formed using steel forms and the resulting joint surfaces are smooth, glassy and can become carbonated. These surfaces must be sandblasted and pressure washed just prior to grouting. The bond capacity of grout to precast concrete surfaces will be greatly diminished if this procedure is not strictly followed.

Grouting is a subtle operation and, like most concrete operations, can be nothing short of controlled chaos. It is imperative that grout channel design not contribute to the problem. Many approaches to grout channel design have been tried with various degrees of success.

PN&D has found that large joints and flow channels with frequent access points from the top work the best. Grout placed in well located paths flows easily from access point to access point and full grouting capacity is ensured. Workers can visually check quality after only a short training period.

Grout specified in early Alaskan designs was often not carefully planned and was left to the construction contractor to formulate. A sample specification might read as follows:

> "When the plans provide for keyways between adjacent concrete members to be filled with grout, the grout shall consist by volume of one part portland cement, three parts clean concrete sand, and minimum water necessary for placement. The grout shall be thoroughly mixed, before placement, until a uniform consistency is obtained."

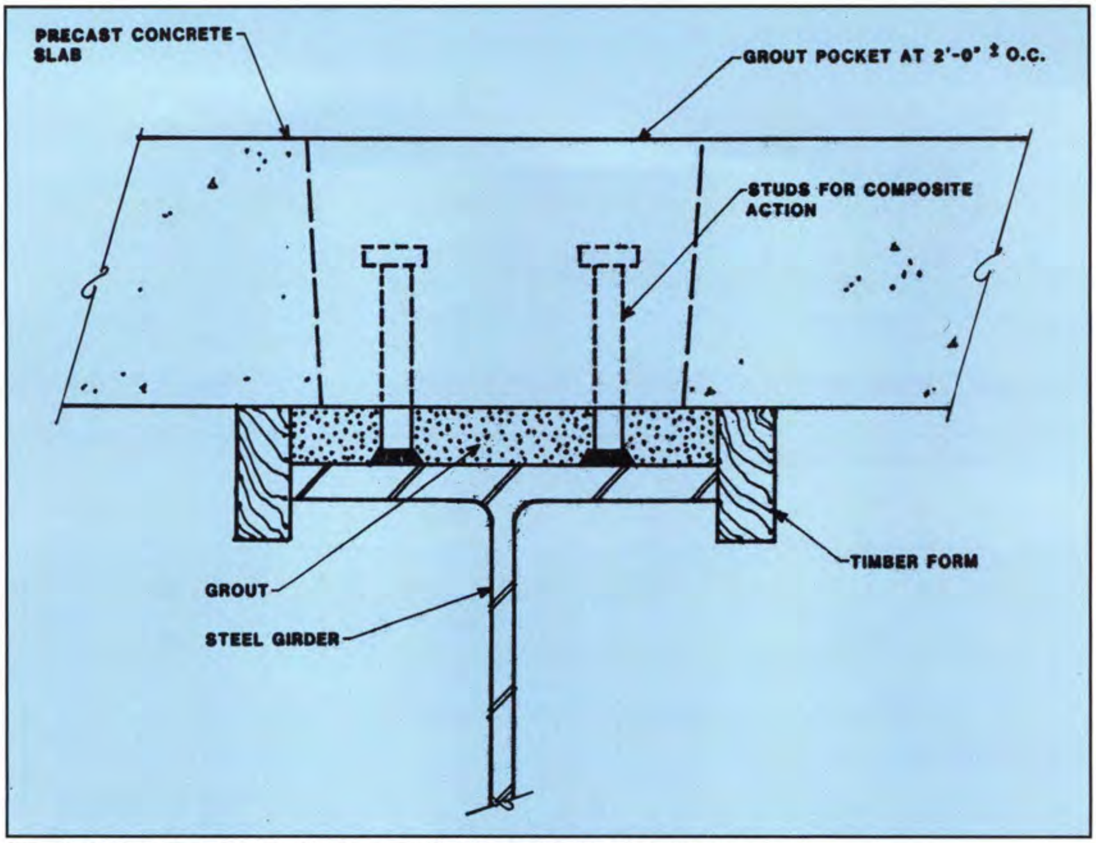

Fig. D. Typical Peratrovich, Nottingham & Drage, Inc. grouted girder haunch.

Fig. E. Portland cement based grout joint.

Fig. F. Set 45 extended magnesium ammonium phosphate grout joint.

Sometimes, expanding admixtures were specified, often with some question as to exact amount.

Following grout deterioration on some early projects, investigation showed that the construction contractor designs and quality control were so variable that grout quality and consistency could not be relied on. Serious over-application of expanding agents resulted in high air content and very weak grouts in some cases, while excess water produced high shrinkage and weak grout in others.

The very nature of portland cement grouts virtually assures some shrinkage cracks in grout joints regardless of quality control (see Fig. E). PN&D has tried high quality portland cement concrete as joint grout with better success but shrinkage cracks, although subdued, were still common.

It became apparent that a high quality, low shrinkage, impermeable, high bond, high early strength grout with user friendly characteristics and low temperature curing ability was needed. If a prepackaged grout mix were available to construction workers to which exact prescribed amounts of water could be added, high quality joints would be more consistently obtained.

To date, the material most closely meeting these requirements has been prepackaged magnesium ammonium phosphate based grout, often extended with pea gravel. The best results have been realized when the grout supplier provides on-the-job training for workers and monitors startup. Also, very strict and specific construction procedures must be specified.

Fig. F shows the results of properly applying such a grout, sold commercially as Set 45. Note that both pockets and joints show complete bond after 2 years in this heavily used arctic bridge.

AUTHORS' CLOSURE by ROBERT J. GULYAS,* GREGORY J. WIRTHLIN,† and JEFFREY T. CHAMPA‡

The authors would like to thank Mr. Nottingham for his comments regarding the testing methods used for selecting keyway grouts. We find it very refreshing that his firsthand field experiences reinforce some of the laboratory testing evaluation of different families of keyway grouts.

The authors agree that the best methods of evaluation and product applications can be rendered ineffective when sound constructability concepts are not used in producing a functional grouted keyway. The concept of proper joint design to increase bond contact surfaces is indeed a very worthwhile approach, as is shown in Mr. Nottingham's Figs. C and D.

There are two additional items the authors would like to illustrate that are implied in Mr. Nottingham's discussion. The first item relates to the importance of the comparative drying shrinkage behavior of the keyway grout as it relates to the shear and tensile capacities of the keyway composites. The second consideration deals with the exposure conditions experienced with some of these types of grouts in harsh environments.

1. To lend some confirmation to the comparative shrinkage of non-shrink grout vs. magnesium ammonium phosphate ($MgNH_4PO_4$) keyway grouting performance, some additional work was performed in the laboratory. The testing followed the same procedures previously reported. The precast concrete sections used the same DOT mix design and were allowed 7 days of moist curing followed by 28 days of air drying to simulate a precast concrete member whose initial shrinkage has occurred in the yard or at site storage.

Rather than test the grouted keyway composite at 7 days, as was done in the previous study, a drying period of 42 days at 90°F (32°C) was provided for the non-shrink grout following the 7-day moist cure period. The $MgNH_4PO_4$ grouted keyways were given a 49-day air dry period at the same 90°F (32°C) storage temperature.

ASTM C 109 compressive strength 2 in. (50.8 mm) cube specimens and 1 x 1 x 10 in. (25.4 x 25.4 x 254 mm) ASTM

* Manager Sales/Marketing — Technical Support, Master Builders Technologies, Cleveland, Ohio.

† Sales Engineer, Master Builders Technologies, Cleveland, Ohio.

‡ Senior Product Developer, Master Builders Technologies, Cleveland, Ohio.

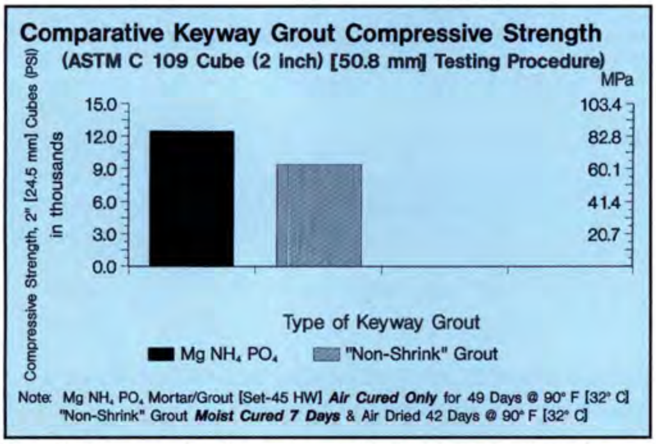

Fig. G. Comparative keyway grout compressive strength [ASTM C 109 cube 2 in. (50.8 mm) testing procedure].

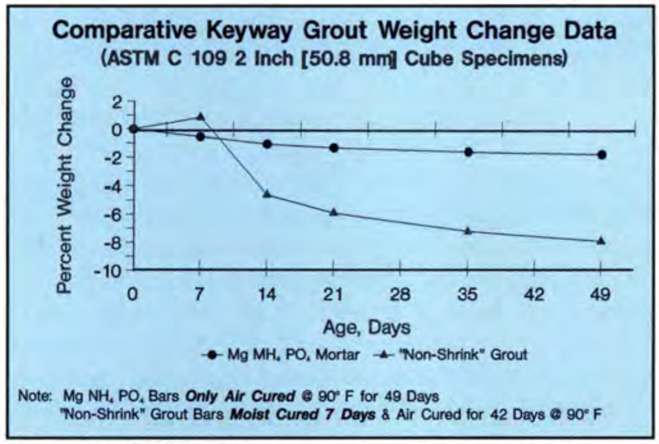

Fig. H. Comparative keyway grout weight change data [ASTM C 109 2 in. (50.8 mm) cube specimens].

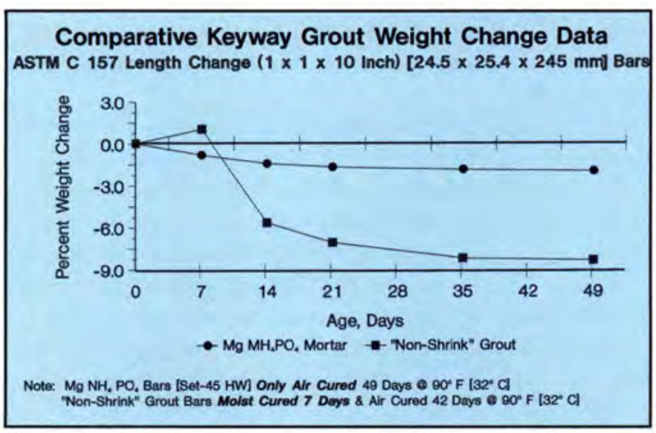

Fig. I. Comparative keyway grout weight change data [ASTM C 157 length change 1 x 1 x 10 in. (24.5 x 24.5 x 254 mm) bars].

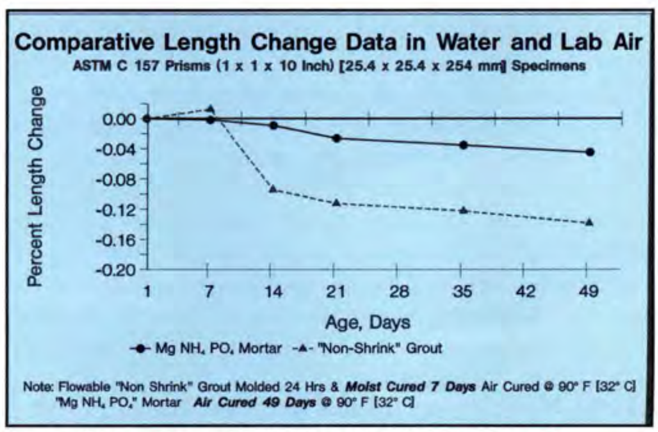

Fig. J. Comparative length change data in water and laboratory air [ASTM C 157 prisms 1 x 1 x 10 in. (25.4 x 25.4 x 254 mm) specimens].

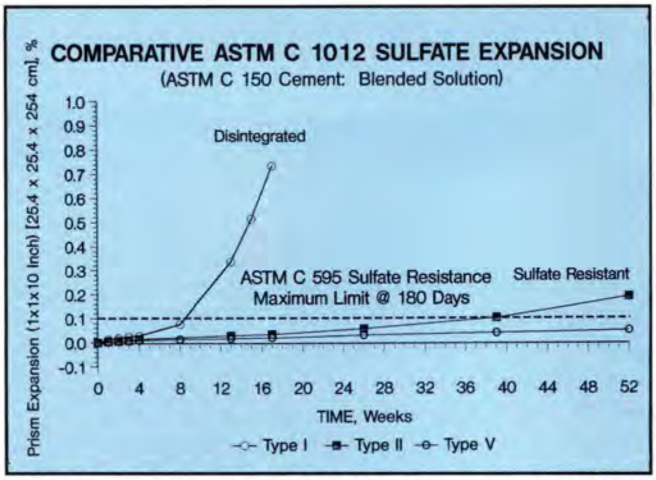

Fig. K. Comparative ASTM C 1012 sulfate expansion (ASTM C 150 cement: blended solution).

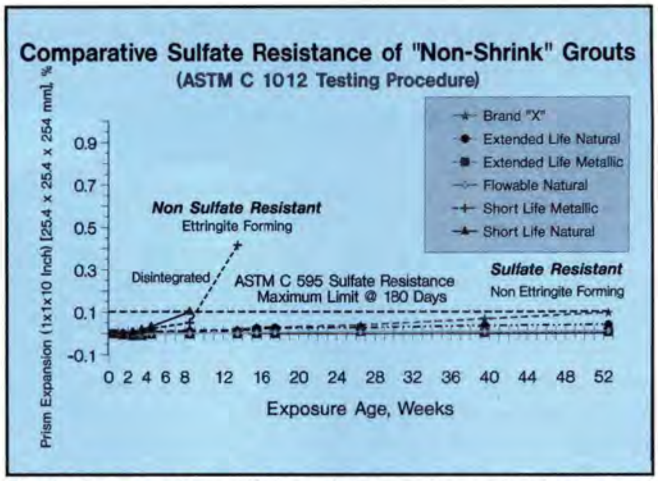

Fig. L. Comparative sulfate resistance of non-shrink grouts (ASTM C 1012 testing procedure).

C 157 length change specimens were made from both materials used to grout the keyways in the initial study. Both types of keyway assemblies were sandblasted and flushed with water prior to grouting — similar to Mr. Nottingham's recommended procedure. These specimens were tracked for weight loss and, in the case of the ASTM C 157 prisms, length change. The comparative differences are shown in Figs. G through J.

Fig. G shows the component comparative compressive strength of the two different grouts at 49 days — the age of testing of the composite specimens. Both of the materials exceeded the 6000 psi (41 MPa) strength recommendation.

The comparative weight change of the 2 in. (50.8 mm) cube specimens are reported in Fig. H. Swelling of the non-shrink grout is indicated by the positive weight change during immersion in water. This swelling provides the positive height change for these grouts for compliance to the ASTM C 1107 Table 1 requirements when tested according to ASTM C 1090. After the initial moist cure period, there was a subsequent weight loss during exposure of these specimens to the 90°F (32°C) air dry exposure period. The $MgNH_4PO_4$ specimens only showed weight loss; at 49 days, these specimens displayed a four- to five-fold lower weight loss than the non-shrink grout specimens.

A similar type of comparative weight change behavior was observed in the length change prism specimens, although the volume-to-surface area ratios of the cubes vs. the prisms were different. This length change behavior is depicted in Fig. I. The cubes had a volume-to-surface area ratio of 1:0.33 (8/24) while the prisms had a volume-to-surface area ratio of 1:0.22 (10/44).

Like the cube specimens, these similar comparative differences were also observed in the ASTM C 157 length change prism results. The $MgNH_4PO_4$ specimens were always more dimensionally stable than the non-shrink grout specimens when exposed to air drying environments, as shown in Fig. J.

These elevated temperatures and lower humidity levels would likely be encountered by any keyway grouting material. Perhaps this comparative performance is what accounts for the differences noted in Mr. Nottingham's Figs. E and F

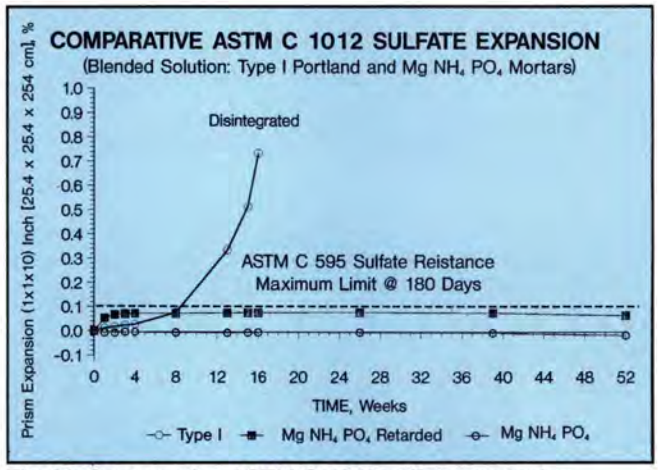

Fig. M. Comparative ASTM C 1012 sulfate expansion (blended solution: Type I portland and $MgNH_4PO_4$ mortars).

showing grouted installations that have experienced seasonal changes as well as drying shrinkage.

For reference purposes, two 8 in. (203 mm) composite grouted keyway specimens of each type of keyway grouting material evaluated were tested in direct tension similar to the previously reported test program. This time, the specimens were allowed to undergo significant drying at elevated temperatures similar to that which is experienced in the field. Table A indicates the comparative difference in performance.

Both keyway grouting materials showed lower tensile strengths than initially reported. There was a large reduction in the composite direct tensile strength of the non-shrink grouted specimens with failures once again occurring at the bond line. Only a slight difference in composite tensile strength occurred with the $MgNH_4PO_4$ grouted specimens. Failure occurred in the precast concrete substrate. This may also explain the differences between Mr. Nottingham's Figs. E and F. Perhaps the large reduction in direct tension strength of the non-shrink grout composite is related to its comparatively large weight loss and shortening due to the drying shrinkage of that type of material.

2. The basis of attaining the positive height change per

Table A. Comparative composite test results: non-shrink grout vs. $MgNH_4PO_4$ mortar.

Type of test	Failure load, in lbs (kN), before and after air dry period		
	Non-shrink grout	Set 45 hot weather	Percent increase vs. Non-shrink grout
8 in. (20.3 cm) keyway Initial direct tension	1940* (8.6)	5730† (25.5)	295
8 in. (20.3 cm) keyway Dried direct tension	1245* (5.5)	5390† (24.0)	433
Percent reduction	35.8	5.9	

Note: * Indicates bond line failure.
† Indicates base concrete through grout failure.

ASTM C 1090 for some grouts that are required to comply with ASTM C 1107 Table 1 requirements should be investigated — especially if the grout is being considered for keyway grouting. Mr. Nottingham's keyway grout experiences occur in severe environments where the grouts are subject to freezing and thawing, salt exposure, and sulfate attack from sea water and brackish water that contain both chlorides and magnesium sulfates. Note that the ASTM C 1107 Table 1 requirements do not require any non-shrink grout to possess freeze-thaw or salt scale resistance, or even sulfate resistance properties.

More importantly, some of these non-shrink grouts rely on their positive vertical height change characteristics from development of ettringite, which occurs in all portland cements. In some expansive type materials, this additional ettringite formation is responsible for the positive controlled expansion necessary to attain compliance to the required ASTM C 1107 specification. Additional sulfates supplied to these types of grouts can cause continued expansion that may deteriorate any grout exposed to marine splashes or coastal fogs.

ASTM C 1012 is a test method used to determine the sulfate resistance of ASTM C 150 portland cement and ASTM C 595 blended cement mortar bars by immersion in a sulfate solution and tracking the length change of the specimens. Materials that are not sulfate resistant will ultimately show an increasingly greater length change compared to sulfate resisting materials, which show only a very slow and nearly constant rate of length change. Typical ASTM C 150 Type I, Type II and Type V portland cement mortar comparative performance is shown in Fig. K; the minor length change results of Type V cement indicate its excellent sulfate resistance.

Comparative length change performance is noted for six different non-shrink grouts — all complying with ASTM C 1107 requirements. Some of these grouts are extended working time grouts and some are metallic aggregate grouts. The ettringite forming grouts disintegrated with a few months exposure in this test solution, as shown in Fig. L. These types of grouts should never be used in sea water environments.

The same ASTM C 1012 test procedure was used to evaluate performance of the $MgNH_4PO_4$ materials used for keyway grouting. Compared to the ASTM C 150 Type I portland cement mortar, the $MgNH_4PO_4$ materials all displayed excellent sulfate resistance with either regular or retarded setting formulations, as indicated in Fig. M.

These materials should be used in environments exposed to sea water and coastal fog environments. They contain no reactive aluminate compounds to propagate the formation of ettringite, as do some non-shrink grouts. Perhaps this is the reason for Mr. Nottingham's observed good performance in docks in coastal areas with magnesium ammonium phosphate keyway grouts — which, incidentally, were used in untopped precast, prestressed concrete docks and decks.