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This paper contains a summary of research performed in the area of reproducing and determining the cause of soft grout, which has been found in several bridges around the United States. In these bridges, the grout was found to be soft (unhydrated) and contain high levels of moisture and potentially damaging chemicals several years after construction was complete. A modified version of the Euronorm inclined tube test (called the modified inclined tube test [MITT]) was developed to conduct the majority of the testing. Other common grout fresh property tests, including flow cone, wet density, unit weight, dynamic shear rheometer, and pressure bleed were conducted parallel to MITT. The research focused on low-reactivity fillers' effect on the formation of soft grout in plain grout formulations of portland cement, ground calcium carbonate, and high-range water-reducing admixture. Mixtures with 45% and 35% additional filler material consistently generated more soft grout than mixtures with 0% additional filler for any given water-solids ratio (w/s).

KEYWORDS

cement filler; high-range water reducer; particle size; post-tensioning.

RESEARCH SIGNIFICANCE

The research focused on the effect of low-reactivity fillers on the formation of soft grout in plain grout formulations of portland cement, ground calcium carbonate, and high-range water-reducing admixture. The modified inclined tube test can be used to test prepackaged or custom-formulated grout mixtures for bleed and soft or other irregular grout formation. Inert filler material increased the tendency to produce soft grout in plain grout formulations that included high-range water reducers (HRWRs). These filler effects should be carefully considered to ensure a PT grout which is robust and performs well.

INTRODUCTION

In post-tensioned (PT) concrete, high-strength steel tendons are installed in ducts and tensioned against anchors that are cast into the concrete with the ducts. A prepackaged portland cement grout mixture, which provides corrosion protection and structurally bonds the tendon to the surrounding concrete, is then injected into the duct. This system has proven to be an efficient and long-lasting design choice in PT tendons. Problems have been discovered with grout in several bridges in the United States. In these bridges, the grout was found to be soft (unhydrated) and contain high levels of moisture and potentially damaging chemicals several years after construction was complete. The unhydrated grout material that accumulated under the cap on PT anchors had a texture similar to wet clay. Soft grout samples can be collected by gently scraping the material, and moisture contents are typically 50 to 80%.

In some cases, tendons encased by this deficient grout exhibited severe corrosion. Although there have been no catastrophic structural failures related to grout in the United States, expensive repairs must be made to prevent such failures in the future. This paper covers experimental work on plain grout mixtures with varying percentages of inert filler material and HRWRs aimed at discovering the cause of soft grout. The majority of the testing was done using a modified inclined tube test alongside common fresh grout property tests which collected data on viscosity, unit weight, moisture content, grout bleed, and soft grout formation.

BACKGROUND

Grout bleed occurs when excess water rises to the top of the grout as cement particles settle to the bottom

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(Schokker et al. 1999). If bleeding occurs in sufficient volume, then structural bond is lost and prestressing steel may be exposed and at risk of corrosion. Excessive bleeding can also lead to segregation of solids, which may result in the formation of soft grout. While bleed water can be reabsorbed by the grout during hydration, soft grout has a lower pH, retains moisture, and can be extremely corrosive to the tendon. Soft grout has been found near corroded tendons and tube sections in both the United States and abroad and has been attributed to grout segregation (Bertolini and Carsana 2011).

Identifying problems with grout bleed and segregation in high-performance PT grout has customarily been accomplished using the pressure bleed test (ASTM C1741 2012) and the wick-induced bleed test, which is a modified version of ASTM C940 (2010). In the late 1990s (Fuzier 2001; Chaussin and Chabert 2001), a method for determining bleed resistance was developed in Europe. The inclined tube test has been used for several years in Europe to test grout mixture designs to determine the potential for bleed under simulated field conditions, and was introduced as a mandotory test in PTI 2012. The standard for the inclined tube test is given in Euronorm EN445 (2007). The test consists of an inclined tube containing twelve 0.6 in. (15 mm) diameter unstressed PT strands and placed at a 30-degree incline from horizontal. PT grout is injected into the low point of the inclined tube and discharged at the top of the incline. The exit valve is then shut off and the grout pressure is then maintained at the value and for the duration specified in the method statement. In the 24 hours following grout injection, visual observations are made of the tube to determine if bleed water has collected at the top of the tube or if overall volume has changed. The tube used for the inclined tube is transparent, which allows for visual identification of bleed and segregation. Grout segregation is identified by a change in color along the length of the tube.

Mineral additives such as fly ash, slag, and other supplemental cementitious materials are permitted as ingredients of Class D grouts, but are prohibited in all other grout classes (PTI 2013). Fine aggregates or fillers had been commonly used in prepackaged PT grouts. Filler material acts as a cost-effective way to minimize the quantity of portland cement used per bag. Furthermore, inert fillers such as calcium carbonate used in portland cement paste will decrease the temperature sensitivity of the cement paste (Jue 2012). This could make filler material a desirable component in PT grouts for hot-weather injection. A common misconception about calcium carbonate is that it is completely inert. It has been shown that the calcium carbonate, when used as filler up to 5%, does react to some degree with the tricalcium aluminate that occurs when portland cement and water react to form monocarboaluminate (Hawkins et al. 2003). The calcium carbonate filler material has been shown to decrease the initial and final set time when substituted into portland cement mixtures (El-Didamony et al. 1994).

GROUT MATERIALS

Type I/II portland cement is a hydraulic cement that reacts with water and results in a hardened material that is impervious to water. There are many variations of portland cement that range from Type I to Type V, with additional types that include air-entraining agents, for example. Portland cement undergoes a hydration process where the chemical compound tricalcium aluminate (C_3A) undergoes a rapid initial hydration. The hydration process can continue for an extended period of time after the initial cement hydration. This hydration process can sometimes last for years (Corven and Moreton 2004). ASTM C150/C150M (2012) specifies that portland cement can be composed of up to 5% limestone filler material, and that certain physical properties must be verified to be qualified under ASTM C150/C150M. These physical requirements are: setting time, soundness, fineness, consistency, compressive strength, heat of hydration, loss of ignition, and specific gravity.

Fly ash is a by-product of the production of coal through a combustion process and reduces bleed and permeability of the grout. Fly ash also reduces the amount of HRWR needed to achieve desirable rheological properties in grout (Schokker et al. 1999). Studies have shown that not only does the fly ash strongly improve the workability of the blended portland cement pastes but it also is capable of exerting a substantial influence on the strength and durability characteristics of the hardened composite at the advanced stage of hydration (Helmuth 1987).

Silica fume is an extremely fine material that is the by-product of silicon manufacturing. It can be produced in three forms: slurry, undensified, and densified. Densified silica fume is produced by tumbling undensified silica fume in a silo, which statically charges the particles, causing them to clump together and increase the bulk density in the remaining material, which makes for easier transportation methods. Silica fume, due to its ultrafine particles, leads to an acceleration of portland cement hydration reactions and to a lowering of calcium hydroxide content. Therefore, blended portland cement pastes with silica fume are highly resistant to sulfate solutions. As in the case of fly ash or slag replacements, silica fume also changes the pore size distribution of portland cement pastes from larger to finer pores (Mehta 1989).

Undensified silica fume is used almost exclusively in PT grout. Densified silica fume is not permitted per the PTI grouting specification (PTI Committe M-55 2012). Silica fume can reduce bleed and permeability while increasing the strength of the grout. The demand for dosage of HRWR is increased when using silica fume, and it increases the thixotropic nature of the grout (Schokker et al. 1999). Blast-furnace slag that is Type 120 is used in prepackaged PT grouts. The grades of blast-furnace slag are categorized based on their activity index, which gives the mixture designer an idea of how the compressive strength of the material will be affected by the use of ground-granulated blast-furnace slag. The durability of the resulting cement is improved because there is an increased production of calcium silicate hydrate during the pozzolanic reaction between the blast furnace slag and water and cement (Cervantes and Roesler 2007).

Clean potable water is used when mixing prepackaged PT grouts. The temperature of the water may sometimes need to be adjusted prior to mixing to better suit the ambient conditions present at the construction site. Water can be present in various places along the pathway of the grout, such as the grout hoses, inside the tubes, and inside the grout pump that is used to place the fluid grout. Excess water can mix with the grout that is being injected, which is why it is recommended by the FHWA Grouting Manual to discharge at least 2 gal. (7.56 L) of consistent grout through the exit valves before grouting can be terminated (Corven and Moreton 2004). Excess mix water is one way moisture content levels are increased in the tubes, which may result in corrosion of the steel tendons.

Provisions and procedures by the LCP-STRA directive for ensuring the durability of PT tendons and the French approach to testing the performance of cement grouts were incorporated in the research (Lecinq 2004). It has been observed that the type of bleed test currently specified in most national codes fails to identify potentially unstable grouts; a test using a small glass or plastic cylinder inadequately represents the true conditions inside ducts. Inspected tendons have been grouted with a grout mixture using superplasticizers. After opening a few ducts, large voids were observed, partially filled with a humid, inconsistent, whitish paste. Under certain circumstances, the use of some superplasticizer admixtures prompts the migration of mineral species forming during grout setting. Then, density can segregate lighter elements, such as ettringite and portlandite from the hardening grout suspension (Lecinq 2004).

Chemical admixtures can serve multiple roles in PT grouts. They can help with pumpability by reducing the viscosity of the grout, while also helping with controlling the time it takes for the grout to set. Reduction in water is another advantage to using chemical admixtures, while corrosion control, volume control, and air entrainment are also benefits to using chemical admixtures in PT grouts. HRWR admixtures are used to achieve low water-solids ratios (*w/s*) in prepackaged grouts. They can be either polycarboxylate-, melamine sulfonate-, or naphthalene sulfano-based. Polycarboxylate-based HRWR are used in post-tensioning applications. Experimental data has shown that the yield stress and plastic viscosity for a cement paste with a polycarboxylate-based HRWR decreases as the HRWR dosage is increased up to the saturation dosage. High temperatures can have an interesting effect on cement pastes with polycarboxylate-based HRWR. An increase in temperature will amplify the thixotropic nature of a cement paste that has polycarboxylate-based HRWR (Martini and Nehdi 2009). HRWRs do have their drawbacks. Bleed has been shown to increase when HRWRs are used in PT grouts. Additionally, HRWRs have been shown to increase the time in which it takes for the grout to set, which can lead to additional bleeding.

TESTED MATERIALS

Testing was conducted on plain grouts containing portland cement, pulverized limestone, HRWR, and water; the materials used in testing are described as follows.

Plain grout formulation

Plain grout was formulated and tested with portland cement and ground limestone to determine the effect that inert filler had on the development of soft grout. The plain grout mixtures were formulated from water, portland cement, ground limestone, and HRWR.

Filler was tested at 0, 35, and 45% by weight of total solids. The mixtures are identified with the label Cxx-yy, where xx is the ratio of water to total solids (portland cement and ground limestone), and yy is the percentage of filler by weight of solids. For example, C55-45 indicates a *w/s* of 0.55 and 45% filler.

Portland cement

ASTM C150 Type I/II portland cement was used to produce the plain grout mixtures for testing. The portland cement was obtained from Florida Rock in Gainesville, FL. Three total particle size analyses were conducted on the Type I/II portland cement used in these experiments, with the following mean and standard deviation values: [0.620, 0.561, 0.634, 0.675, 0.584, 0.417 mil] [15.74 (μm), 14.26 (μm)], [16.1 (μm), 17.14 (μm)], [14.83 (μm), 10.59 (μm)].

Filler material

Pulverized limestone (calcium carbonate) was obtained at a local farm supply store for use as filler in the plain grout formulations. Three total particle size analyses were conducted on the material used, with the following mean and standard deviation values: [1.182, 1.574, 0.264, 1.346, 1.177, 1.543 mil] [30.03 (μm), 39.99 (μm)], [6.70 (μm), 34.19 (μm)], [29.89 (μm), 39.19 (μm)].

High-range water-reducing admixtures

Adva-cast 600, which is a Type F polycarboxylate-based HRWR, was used to control the viscosity of the grout. The dosage of HRWR was adjusted with each mixture to maintain a maximum dynamic viscosity of 250 mPa·s (250 cP) when measured using the nominal shear rate (NSR) viscosity test. Information on this test procedure can be found in Hamilton and Piper (2014). Specific HRWR dosages are discussed further in the results section.

RESEARCH APPROACH

To study the effects of low-reactivity fillers on the performance of PT grout, a modified version of the inclined tube test specified in Euronorm standards (EN445 2007) was used (Hamilton et al. 2014). The MITT uses a 15 ft (4.6 m) long tube with twelve 14 ft (4.3 m) long prestressing strands; this leaves a short length of tube at the top of the inclined that is not occupied by strands, which allows more convenient sampling. The tube is injected with grout and then monitored over the following 24 hours for the formation of bleed water and air at the top of the inclined tube. The specimen is then dissected 24 hours after injection to determine if soft grout is present at the top of the inclined tube. In addition, grout samples are taken at the bottom, top, and mid-length of the tube and tested for moisture content using ASTM C566 (1997).

The ideal benchmark to determine the relative quality of hardened grout samples is unit weight. Relative unit weight would show whether or not the grout is homogenous throughout the tube. A sample containing voids or excessive water would have a lower unit weight than one that did not. Determining the unit weight of a small, irregular shaped sample is impractical and probably unnecessary. Instead of unit weight, the moisture content of grout samples collected along the length of the tube was measured. If the grout segregated along the length of the inclined column, then it is expected that the moisture content of the grout at the top of the column would be higher than that at the bottom of the column.

Ultimately, moisture content provides a quantitative comparison between grout samples collected from the inclined tubes. The change in elevation between the top and bottom of the inclined test tube causes bleed water to rise (Fig. 1). The rising bleed water carries less-dense particles in suspension upward until contact is made with the strand bundle or tube. At this point, the particles are carried to the top of the incline, resulting in the formation of unreacted material near the free surface of the grout at the exit of the inclined tube. This soft grout is thought to be the result of segregation of particles within the suspension based on their density. Hardened grout, though, is typically still present along the remainder of the length of the tube.

TEST PROCEDURES

Grout mixtures were prepared in a production size high-shear colloidal mixer large enough to mix volumes of 8 to 13 ft^3 (0.23 to 0.37 m^3) with the capacity of conveying the fluid grout at a constant pressure and flow rate as typically seen in full-scale operations. After mixing, the grout was transferred to the agitator to await injection into the

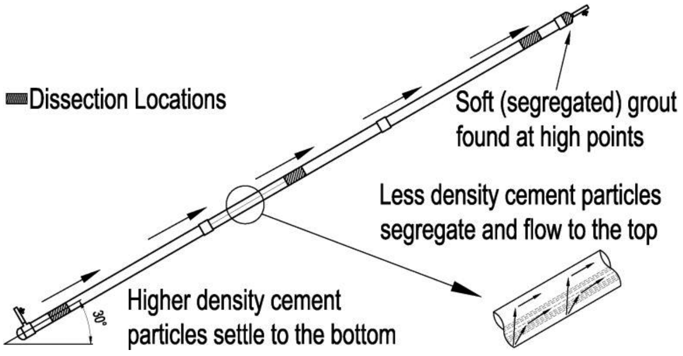


Fig. 1—Schematic of MITT sample location and segregation mechanism.

inclined tube. Initially, approximately 2 gal. (7.6 L) were used to collect samples for conducting flow cone, mud balance, unit weight, and pressure bleed tests. Next, the grout was injected into the tubes on the inclined stand. Approximately 2 gal. (7.6 L) of grout was collected from the discharge point; flow cone, mud balance, and unit weight tests were conducted on this material.

Observations through the tube were taken 0, 0.5, 1, 3, and 24 hours after injection. As expected, bleed water typically accumulated when testing plain grouts. For these tests, tubes were removed from the inclined stand and the top exit valve was removed. The tube was then carefully tilted so that bleed water was decanted into a large graduated cylinder for measurement of the volume.

After the grout had been allowed to set for at least 24 hours, grout samples were collected along the length of the tube. Early in the testing program, each tube was generally sampled in four to five locations along its length. As inclined testing progressed, results indicated that the sampling procedure could be simplified to avoid having to cut the strands and to sample in fewer locations without weakening the overall results of the test. Three locations were found to be sufficient to characterize the moisture content of the grout and to recover soft grout that might be present. Figure 1 shows the dissection locations. The base and midheight of the inclined tube were sampled by cutting and removing the PVC tube over a length of approximately 6 in. (180 mm). Grout samples were then taken from around the strand bundle without the need to cut the strand. At the top of the incline, grout was more easily sampled due to lack of strand near the top. Samples were taken in two locations: one under the end cap and over a 6 in. (180 mm) length near the end of the strand bundle. Because the primary focus of the inclined testing was on measurement of soft grout and moisture content, opaque tubes were used to reduce testing costs. Bleed-water volume was measured directly rather than visually through the transparent tube.

The moisture content of grout samples was determined using ASTM C566 (1997). Moisture content was sampled at the various locations to determine the variation with specimen length to be evaluated.

The following procedures were used to determine moisture content in a sample of grout:

1. Moisture content samples of approximately 0.88 oz (25 g) were taken from the top and bottom of the cross section at locations shown in Fig. 1 for a total sample size at each location of approximately 1.76 oz (50 g).
2. Measure initial mass of the grout sample.
3. Dry sample in oven at 230°F (110°C). Sample is dry when two consecutive 24-hour mass readings exhibit less than 0.5% difference.
4. Moisture content is defined as the difference between initial weight and dry weight divided by initial weight.

RESULTS AND DISCUSSION

The objective of the testing was to determine the effect of filler material (calcium carbonate) on the formation of soft grout at varying water-cement ratios (*w*/*c*) and percentages of filler additions.

Viscosity control

Plain grout mixtures were formulated so that the initial viscosity was at or below 250 mPa·s (250 cP) for all of the plain grout tests, which gave flow cone values of approximately 3 to 10 seconds. This was accomplished by adjusting the HRWR dosage using the flow cone values and visual observation of the material in the mixing tank during mixing. Measurements of viscosity made after mixing were recorded. Results show the HRWR quantity used for each mixture decreased for all cases in which the percentage of filler material increased versus the w/*c*.

Figure 2 shows the resulting viscosity levels and flow cone results for the plain grout tests and demonstrates that the apparent viscosities were all maintained near 250 mPa·s (250 cP). The vertical axis limits for Fig. 2 were selected based on the results of C55-45. This test required a pumping pressure of over 90 psi (0.6 MPa) to inject the grout into the inclined tube, while all other tests were easily controllable with 40 psi (0.3 MPa) of pumping pressure. This is because only 3.4 oz (100 mL) of HRWR was used, resulting in a dynamic viscosity of 1038 mPa·s (250 cP).

The resulting initial flow cone efflux times increased for all cases as the *w*/*c* decreased; increasing the percentage of filler caused a slight increase in the flow cone time. This was expected because for any given *w*/*c*, the same amount of water was used to mix the grout, so increasing the percentage of filler adds solids to the mixture, which would increase the grout viscosity.

Soft grout

Figure 3 illustrates low-reactivity fillers' effect on *w*/*c*, *w*/*s*, and the mass of soft grout produced with MITT. Generally, the quantity of soft grout increased as *w*/*s* increased, indicating that, no matter the formulation, additional water will encourage the formation of more soft grout. Furthermore, higher percentages of filler increased the propensity to form soft grout, even at lower *w/s* values. Yet, a sufficiently low *w/s* achieved zero soft grout for all mixtures, even those containing large proportions of filler material.

Moisture content

Figure 4 shows moisture content variation along the length of the tube for varying proportions of filler material. Several trends are noteworthy. First, moisture content below the discharge generally ranged from a low of 15% to a high of 30%. As would be expected, the increase in moisture content followed the increase in *w/c*. Also, moisture content increased gradually along the length of the

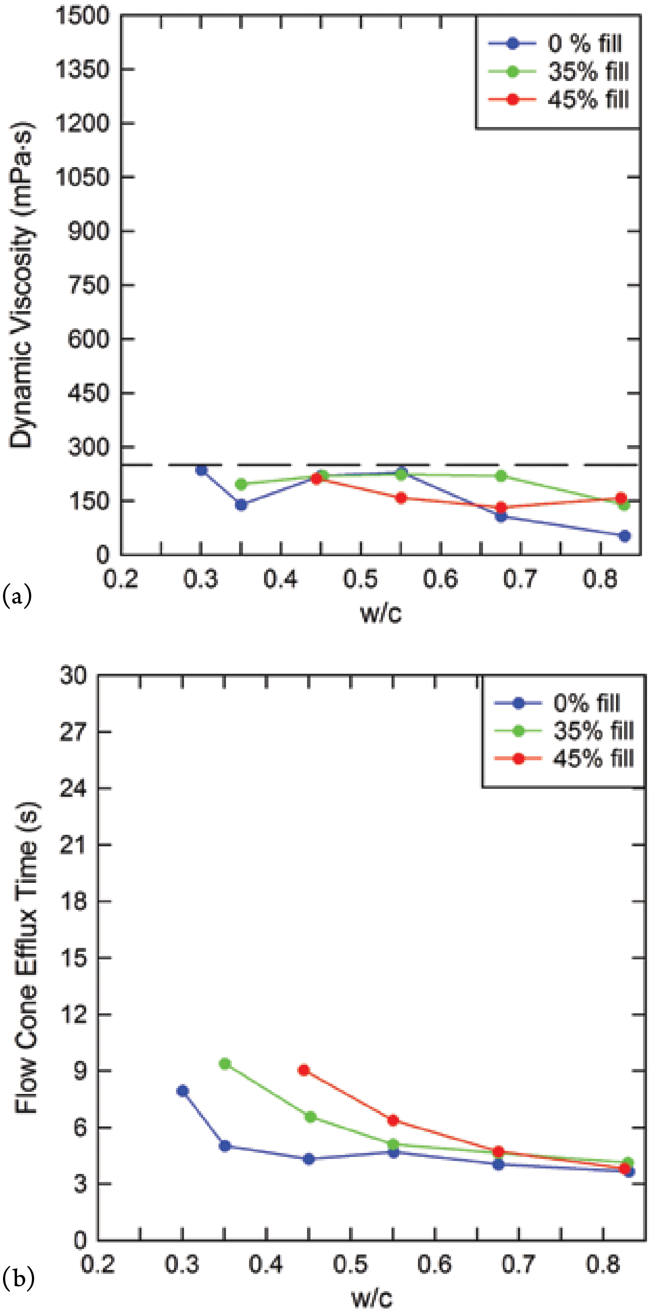


Fig. 2—Results of viscosity testing on grout: (a) dynamic viscosity; and (b) modified flow cone.

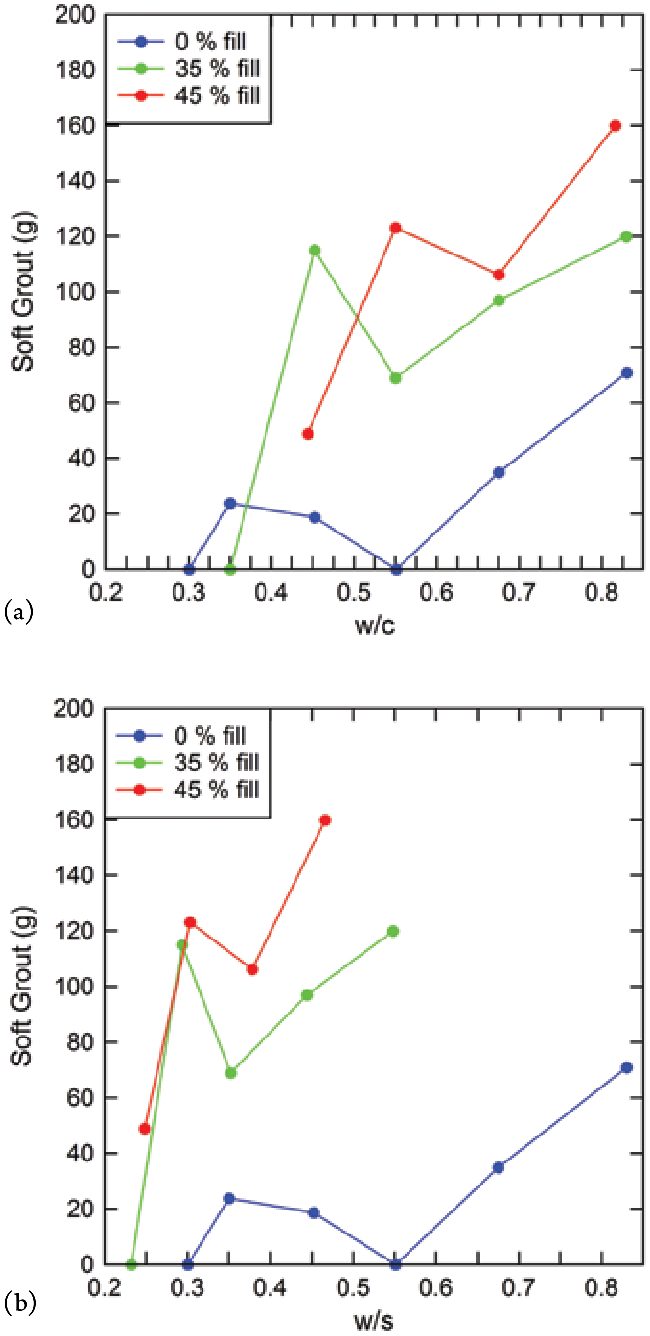
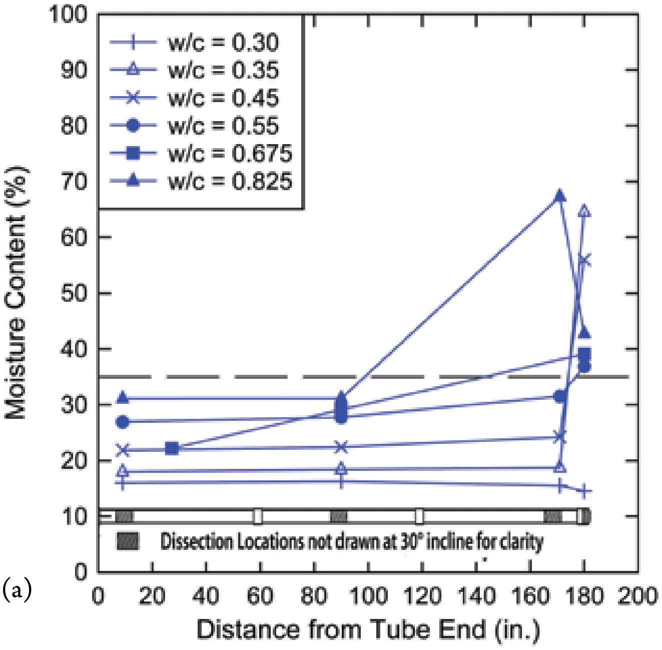


Fig. 3—Variation of soft grout with: (a) w/c*; and (b)* w/s.

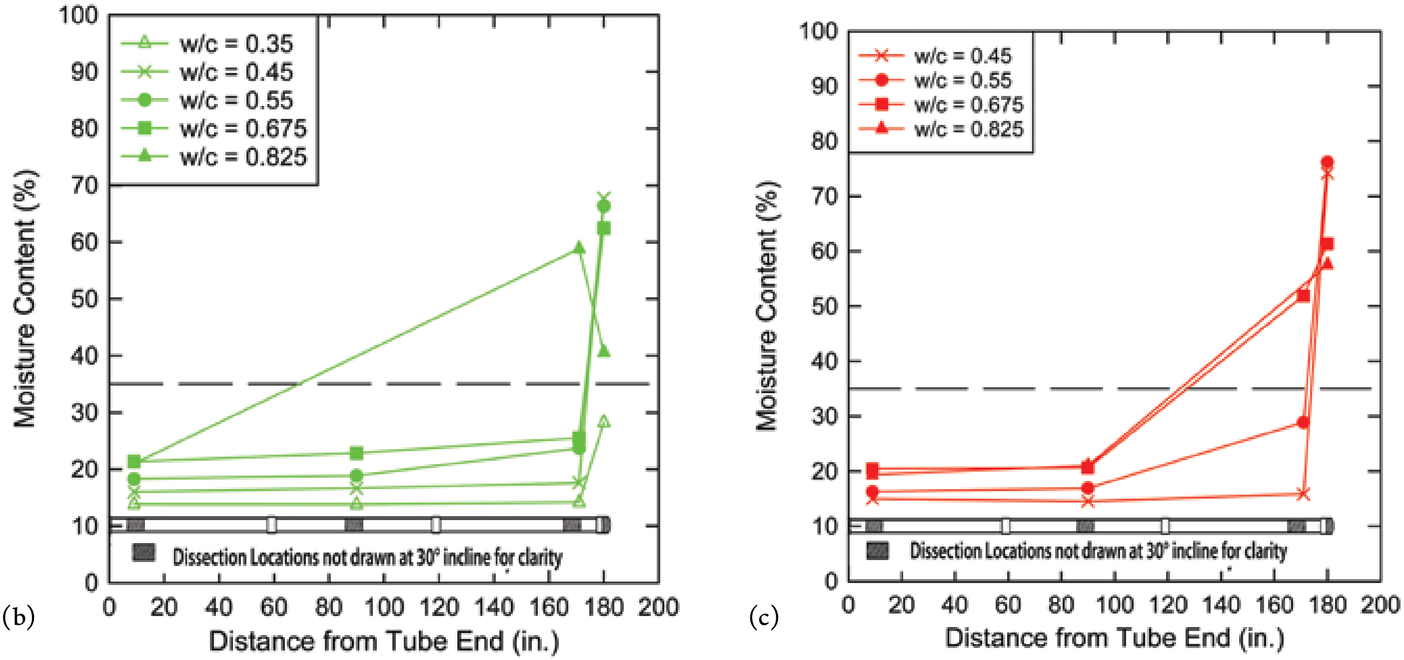
tube up to the discharge point, where large increases and variations in moisture content were measured. Because the HRWR was used in conjunction with water to limit the initial viscosity for most of the tests, all but three of the tests resulted in soft grout near the exit region. The relatively high moisture contents near the exit region are a clear indication of this.

Figure 4 has moisture contents that are consistently below 20% and resulted in zero measurable soft grout. This test also required the highest dose of HRWR to limit the initial viscosity. This is a clear indication that with a low enough *w/c*, large amounts of HRWR can be used to achieve desirable fluidity characteristics without resulting in segregation of the portland cement and filler material. What other harmful effects this high dosage might cause, however, are unclear.

Figure 5 shows the entire set of moisture content values divided into tests that produced no soft grout and soft grout. Both Fig. 5(a) and 5(b) show the constant and relatively low moisture content along the length of the tube up to the exit region at the top of the tube that is almost exclusively observed for inclined tests resulting in soft grout. Only at the top of the specimen does the moisture content increase abruptly in the specimens that showed soft grout. In general, when the moisture content was above the range of 35 to 50%, then that test was likely to have produced soft grout. As would be expected, when the moisture content increases, a direct relation to the increased *w/c* and *w/s* follows. As was illustrated in Fig. 4, all moisture content below 20%, which included the use HRWR and inert fillers, produced no soft grout. These results indicate that a low *w/c* can minimize segregation of portland cement and filler materials.



(a)



(b) (c)

Fig. 4—Moisture content along inclined tube for: (a) 0% filler; (b) 35% filler; and (c) 45% filler. (Note: 1 in. = 25.4 mm.)

Bleed

The results of the pressure bleed test and the volume of bleed water decanted from the tubes after testing are shown in Fig. 6. According to Fig. 6(a), increasing the percentage of filler decreases the amount of bleed water at higher *w/c*. However, at a lower *w/c* such as 0.45, there is no bleed water present for any of the percentages of filler, including plain cement. PT grouts are typically mixed at *w/c* less than 0.45, so the use of filler material for reducing bleed is not justifiable based on these findings.

Figure 6(b) shows that increasing the percentage of filler at any *w/c* will decrease bleed. PT grout bleed is typically addressed using small-scale laboratory tests such as the pressure bleed test. Based on the results from Fig. 6,

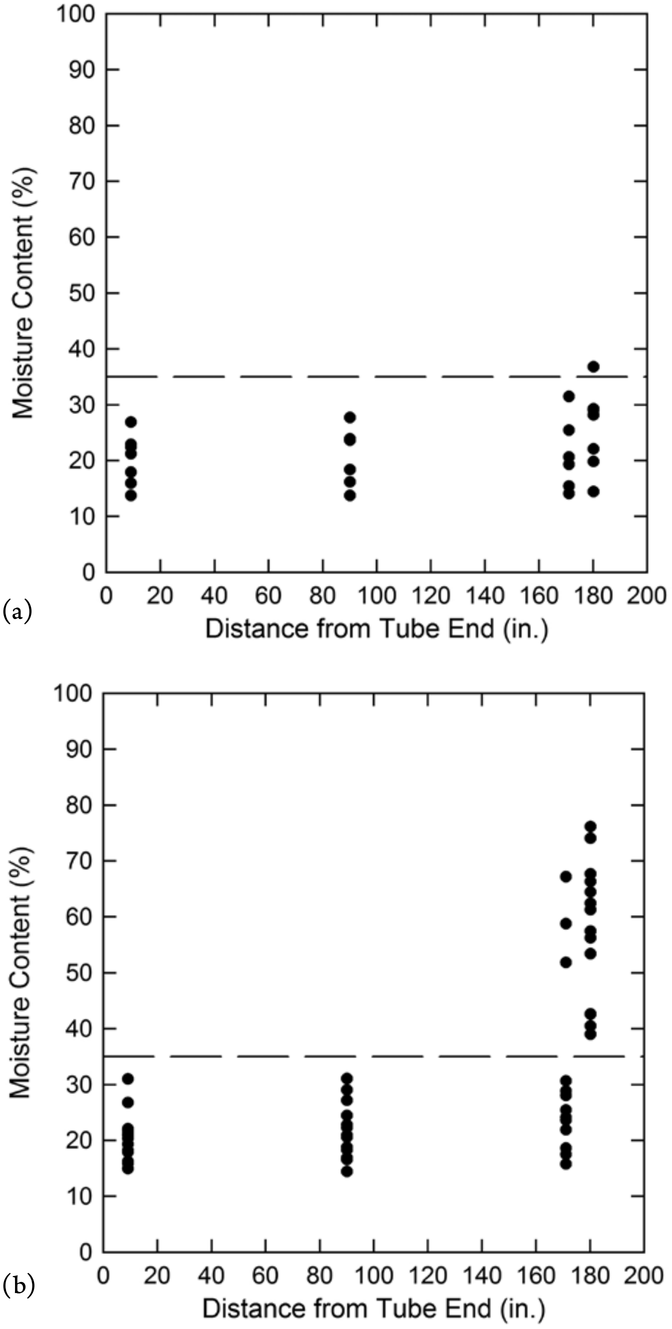


Fig. 5—MITT moisture content for tests with: (a) no soft grout; and (b) soft grout detected. (Note: 1 in. = 25.4 mm.)

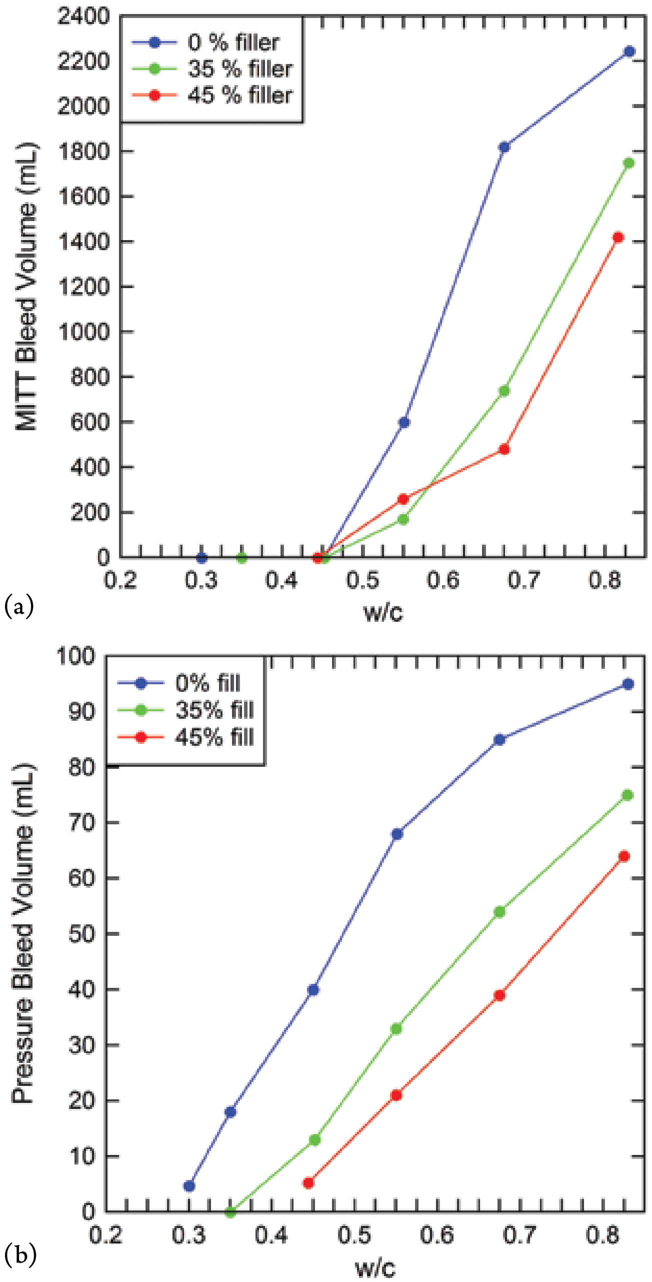


Fig. 6—Effect of w/c on bleed volume from: (a) MITT; and (b) pressure bleed test.

the pressure bleed test detects bleed susceptibility over all ranges of filler content and *w/c*. Inclined bleed, however, is not detected at lower *w/c*, which are also the levels at which the PT grouts are mixed.

The effectiveness of the test methods can also be compared herein. As the water content is decreased, MITT results in several tests in which no bleed was measured. There was only one pressure bleed test, however, in which no bleed was detected, indicating that the pressure bleed test is a better indicator of bleed than MITT.

HRWR and segregation

Figure 7 shows that increased HRWR dosage resulted in increased segregation as measured by moisture content. The moisture content is relatively consistent with the exception of the top of the incline, where the mixture with no fillers containing HRWR has nearly twice the moisture content as that of the mixture without HRWR. It is possible that the small percentage of the inert filler material that is present in the portland cement was segregated because of the use of the HRWR.

Based on Fig. 7, the moisture contents along the length of the tube are consistently higher when no HRWR is used, except at the exit of the inclined tube, where they are consistently lower. One explanation for this behavior is that HRWR caused filler material segregation from the cementitious material due to excessive bleeding, which resulted in normal hardened grout along the length of the tube up to the exit.

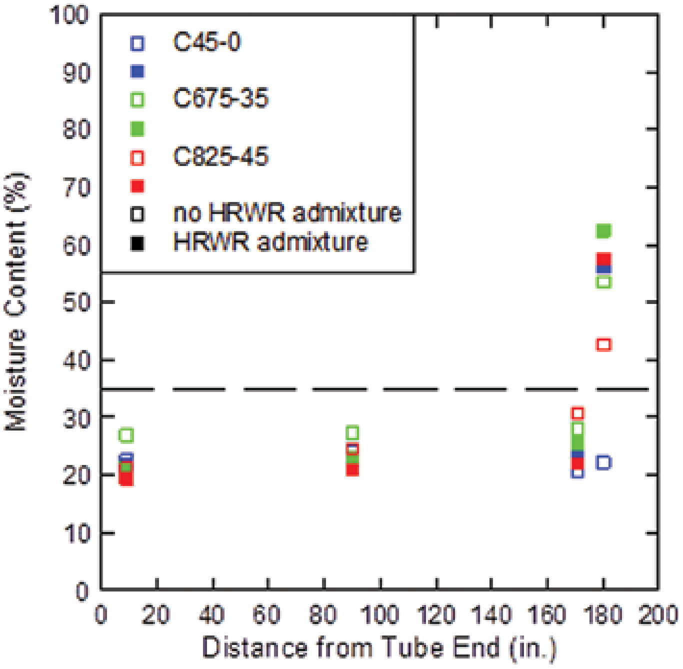


Fig. 7—Moisture content for C45-0, C675-35, and C825-45. (Note: 1 in. = 25.4 mm.)

Figures 8 through 10 show the bleed, soft grout, and viscosity readings from multiple experiments, respectively. Based on the comparison between multiple tests conducted at the same *w/c* and percentages of filler material, the use of HRWR increased the grout bleed and soft grout quantities observed in the inclined tube. HRWR also decreased the viscosity of the grout in fluid form substantially.

SUMMARY AND CONCLUSIONS

This paper describes research focused on determining causes of soft grout, which have been found in PT tendons in several bridges across the United States. Testing focused on the effect of low-reactivity fillers on the production of soft grout in plain grout formulations. A plain grout formulation consisting of ASTM C150 Type I/II portland cement, varying percentages of ground calcium carbonate, varying levels of HRWR to achieve a dynamic viscosity below 250 mPa·s (250 cP), and *w/c* was tested to determine how the formation of soft grout and bleed was affected by each constituent.

A modified version of the Euronorm inclined tube test, the MITT, was developed and used to conduct the majority of the testing. The inclined test tube offered a configuration that could be used in a laboratory setting to simulate grout bleed and segregation during full-scale mixing and injection. The change in elevation between the top and the bottom of the test tube causes the concentration of bleed to occur at the top of the tube due to the pressure head. This bleed then filters or washes out the less-dense particles present in suspension, resulting in an unreacted putty grout near the free surface of the grout at the top of the test tube, and normal hardened grout along the length of the tube. The MITT included sampling and inspection of soft grout at top, bottom, and midheight of the specimen and measuring moisture content in sampled grout.

Other common grout fresh property tests including flow cone, wet density, unit weight, and pressure bleed were routinely conducted in parallel with the MITT. Apparent viscosity testing was conducted using a dynamic shear rheometer in parallel with the MITT to determine if a correlation could be established between the rheology of the grout and its affinity for producing soft grout. The following conclusions are offered:

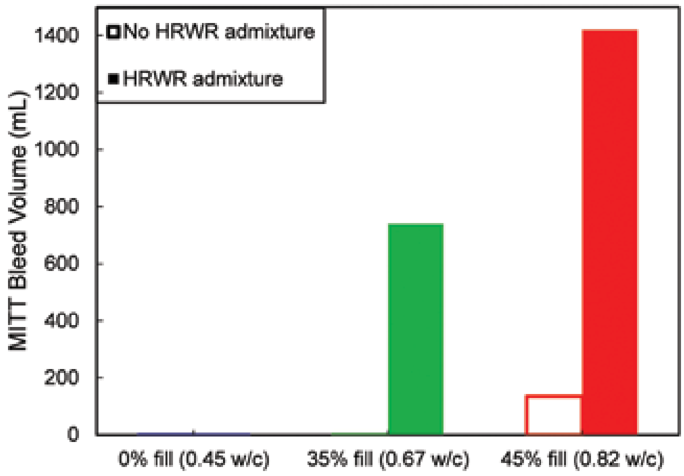


Fig. 8—Bleed volume for mixtures with and without HRWR (neither mixture with w/c = 0.45 produced soft grout).

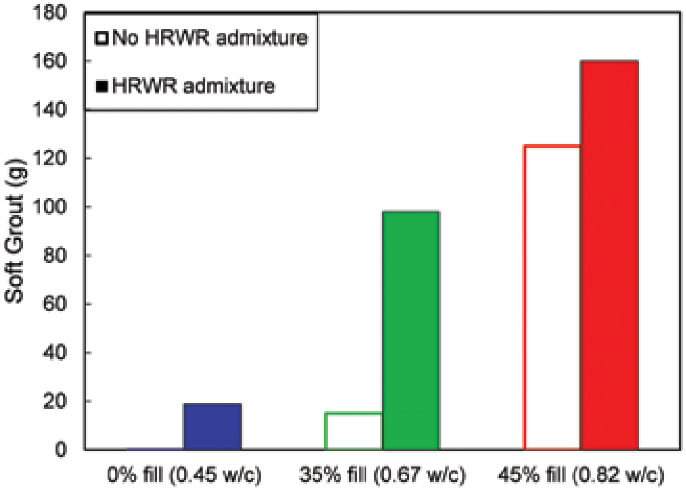


Fig. 9—Soft grout for mixtures with and without HRWR.

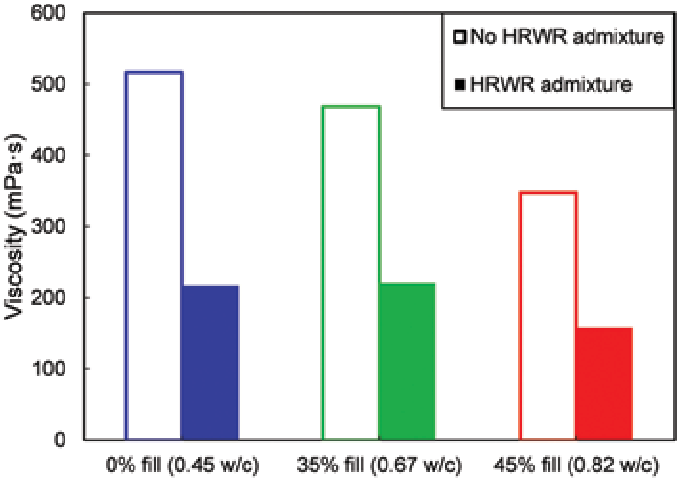


Fig. 10—Viscosity for mixtures with and without HRWR.

- Mixtures with 45 and 35% additional filler material consistently generated twice the amount of soft grout than mixtures with 0% additional filler for any given *w/s*.
- Mixtures with low *w/c*, large HRWR dosage, and 35 or 45% filler material achieved desirable fluidity characteristics without resulting in segregation of the portland cement and filler material. Increases in water dosage, however, resulted in the formation of soft grout.
- Moisture content along the length of the tube for tests conducted on plain grouts resulting in soft grout consistently had an excessively high moisture content level near the exit region, which ranged from 35% to over 50%.
- All tests conducted with the MITT at 0, 35, and 45% additional filler material exhibited no bleed when the *w/c* was reduced below 0.45. Pressure bleed test, however, detected bleed tendency in plain grouts at a lower *w/c* than the MITT.
- For a given *w/s* above 0.3, increasing the percentage of filler material increased the amount of bleed water in the inclined tube by at least three times the amount of bleed due to 0% fillers.
- In plain grout tests, HRWR decreased the viscosity of the mixture, increased the moisture content near the exit region of the inclined tube, and increased the volume of bleed and segregation.

RECOMMENDATIONS

The following observations based on the research reported herein may be useful for improving the performance of PT grouts.

- The modified inclined tube test can be used to test prepackaged or custom-formulated grout mixtures for bleed and soft or other irregular grout formation. Testing should include bleed, volume, and hardened grout moisture content.
- To encourage a robust formulation, PT grouts should be tested using more mix water than the maximum recommended by the manufacturer. Measures should be taken to ensure that the manufacturers do not artificially decrease their MWD.
- Inert filler material increased the tendency to produce soft grout in plain grout formulations that included high-range water reducers. Their use should be carefully considered in PT grout.

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