Performance of Transverse Joint Grout Materials in Full-Depth Precast Concrete Bridge Deck Systems

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Over the past three decades, bridge deck construction using precast concrete components has become the system of choice for contractors and transportation officials. This preference for precast concrete systems is due to the rapid erection of its relatively lightweight components, reduction in overall mobilization and equipment costs, and structural durability. While precast concrete panels perform well under large and highly repetitive loadings, the grouted joints between concrete panels can become problematic. This paper evaluates the performance of four different grout materials in precast concrete deck systems; these are Set Grout, Set 45 for normal temperatures, Set 45 for hot weather, and polymer concrete. A total of 36 full-scale specimens were fabricated and tested for vertical shear, direct tension, and flexural capacity. Polymer concrete was found to be the best material for transverse joints in terms of strength, bond, and mode of failure. However, the use of Set Grout is recommended in transverse deck joints due to its ease of use and satisfactory performance. In special cases where the joint is subjected to excessive stresses or quick resumption of traffic is critical, the proper application of the more expensive polymer concrete is recommended.

Precast concrete deck systems have been increasingly used for bridge construction for three decades. To provide load transfer between adjacent precast slabs, the transverse joint can be grouted using a variety of materials. Joints between precast elements may be filled with grout, epoxy mortar, or polymer concrete to bond the two slabs, thus making the joint itself a structural element in the bridge. As such, transverse joints must resist vertical shear when wheel loads cross the transverse joint and bending induced by moving vehicular loads. Drying shrinkage of the grouting material and transverse shortening of the precast concrete slabs further subject the joint to direct tension.

Testing of individual transverse joint materials under vertical shear, tensile, and flexural loading is essential to establish grout quality and serviceability. If the grouting material is not strong enough to resist in-service stresses, cracking will result. Leaking joints allow penetration of foreign materials, gradually weakening the joint. Investigations of bridge joints over the years have revealed that many transverse joints exhibit leakage and vertical faults, requiring extensive maintenance and costly repairs.

While new construction materials were rapidly being developed and marketed, many of these materials were not adequately evaluated under situations encountered in actual structures. Set 45, Set 45 hot weather (HW), Set Grout, and polymer concrete are the most commonly used joint materials in civil infrastructure.

The purpose of this research is to investigate the behavior of transverse joints grouted with these grout materials in precast concrete segments under in-service conditions of vertical shear, tension, and bending, thus providing engineers with realistic guidelines for determining the best grout material for use under various conditions.*

LITERATURE REVIEW

In 1995, Gulyas et al.[1] reported an evaluation of precast panel keyways. The experiments consisted of vertical shear, direct tension, and direct longitudinal shear tests of joints filled with non-shrink and Set 45 grout materials. Composite assemblies prepared with Set 45 exhibited better behavior than non-shrink grout in each mode of testing. The drying shrinkage of Set 45 mortar was found to be significantly lower than concrete with a 0.32 water-cementitious material ratio (*w/cm*). The effect of carbonation at the inter-

* All grouting materials used in this study are products of Master Builders.

Fig. 1. Typical female-to-female joint between precast slabs on a construction site.

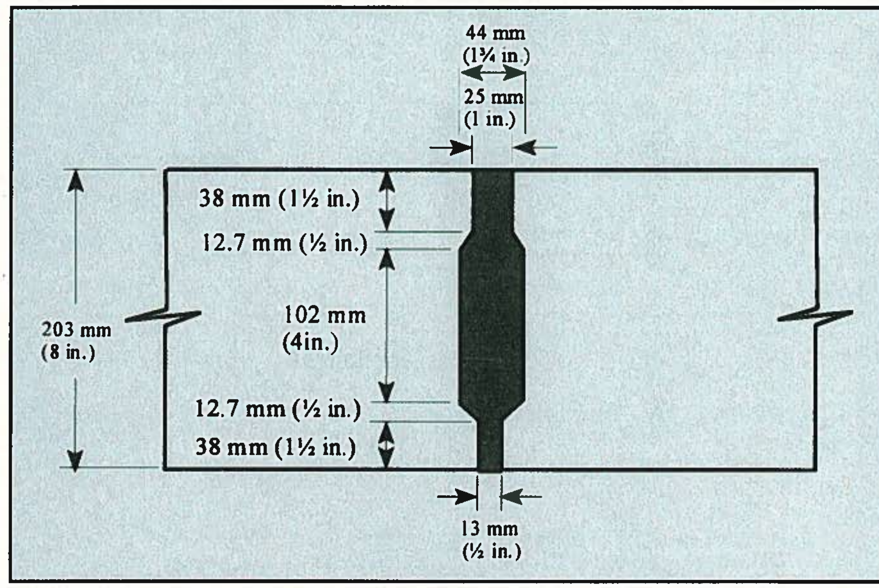

Fig. 2. Configuration of female-to-female joint.

Table 1. Transverse joint specimen data.

Type of test	Type of material	Specimen dimensions (in.) width x length x height
Vertical shear	Set 45 Set 45 HW (hot weather) Set Grout Polymer concrete	5 x 17 x 26
Tensile	Set 45 Set 45 HW Set Grout Polymer concrete	5 x 21 x 8
Flexural	Set 45 Set 45 HW Set Grout Polymer concrete	6 x 21 x 6

Note: 1 in. = 25.4 mm.

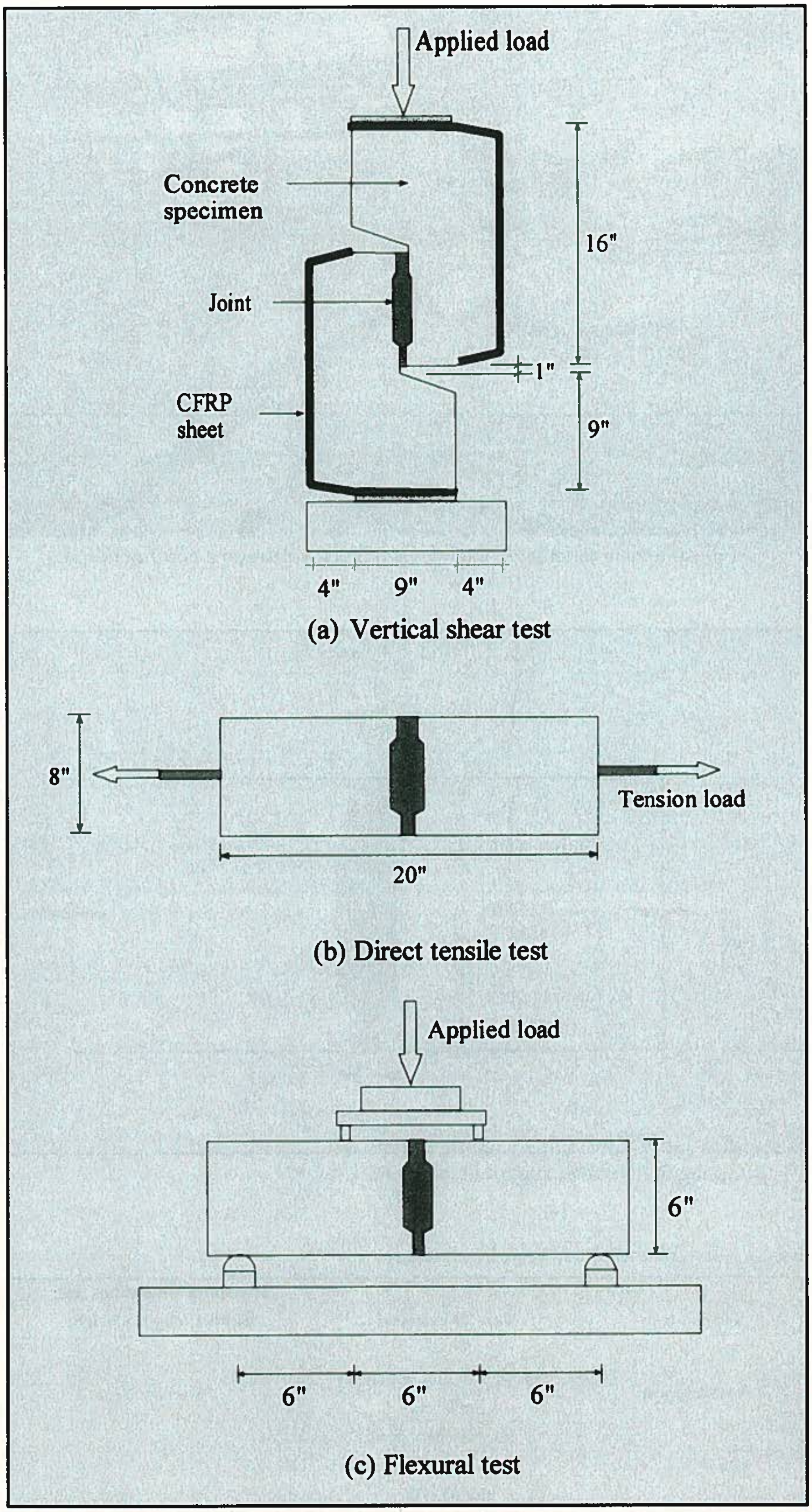

Fig. 3. Configuration and test setups for transverse joints.

face of the concrete produced lower bond strength with the Set 45 composite system. It was concluded that composite testing of the grouted assemblies, rather than component materials testing, is a more accurate way to evaluate the performance of the grouting materials.

In 1975, Kropp et al.[2] investigated three different shapes of joints. A common form (match-cast) was used to ensure a good male-to-female fitting. It was concluded that the flat shape joint was superior to the others.

In 1995, Issa et al.[3,4,5] carried out visual inspections on existing joint systems in bridges throughout the nation. The tongue-and-groove joint was found impractical due to difficulties encountered with the grouting process. The butt joint was found ineffective because it caused leakage through the joint as a result of the deck being in tension. The female-to-female joint with a closed section at the bottom created some problems in matching the adjacent slab and, as a result, the slabs were damaged under repeated wheel loads. Cracking, spalling, and leakage at the precast slab joint were observed. Bridge decks with female-to-female joints and openings at the top and bottom experienced virtually no problem.

The conclusion of that investigation was that the transverse joints between the precast slabs should be female-to-female (shear key) and have a minimum nominal width of $1^1/_4$ in. (32 mm) at the top and $^1/_2$ in. (13 mm) at the bottom. Longitudinal post-tensioning was also recommended to secure tightness of the joints.

EXPERIMENTAL PROGRAM

In this program, full-scale specimens were prepared using a female-to-female joint (see Fig. 1). Configuration of the specimens tested is shown in Fig. 2. Specimen dimensions are provided in Table 1. The specimens were tested for vertical shear, direct tensile strength and flexural behavior (see Fig. 3).

The first vertical shear test was initiated by testing the configuration shown in Fig. 4. The specimens were designed to transfer the load to the joint so that the joint experienced only shear forces. However, the area provided in the upper stub caused the concrete to fail prematurely at that juncture. Consequently, a design was implemented by increasing the area of this stub. In addition, specimens were wrapped with carbon fiber reinforced polymer (CFRP) sheets, as shown in Fig. 3a.

The vertical shear test consisted of two panels connected via grouting materials, and the load was transmitted to the joint, inducing shear forces. A No. 5 (16M) steel reinforcing bar was cast inside the concrete specimen, providing sufficient area to anchor the load. Initially, a 4 in. (100 mm) long steel bar was welded near the end of the steel bar to form a cross shape. A second specimen was fabricated using No. 4 (13M) steel rebar without the cross shape. A straight No. 4 rebar with an anchor length of 8 in. (200 mm) into the concrete specimen was found to be satisfactory.

As a result, all specimens were prepared with one embedded bar of 8 in. (200 mm) length at the opposite side of the joint surface as shown in Fig. 5. The grouted specimen was subjected to tensile loading by gripping the ends of the rebars with the cross head of the testing machine. The flexural specimen consisted of two precast panels connected with grouting materials and subject to third-point loading.

Fig. 4. First direct shear test model.

Fig. 5. Specimens for direct tension test.

Materials and Mixing Procedure

Precast concrete specimens were prepared using two concrete mixtures (see Table 2). Type I portland cement was used as the binding material. A maximum coarse aggregate size of $^3/_4$ in. (19 mm) and a fine aggregate size of $^3/_{16}$ in. (5 mm) were used. The *w/cm* ratios of 0.54 and 0.45 were used for Mix 1 and Mix 2, respectively. Superplasticizer in the amount of 8 fl oz per 100 lbs of cement (5.2 mL/kg) was added to Mix 2 to achieve the required workability. Control cylinders were prepared to determine the compressive strength of the concrete. The mix proportions, slump, and 28-day compressive strengths of both mixes were recorded (see Table 2).

The joints were cast with Set 45, Set 45 HW, Set Grout, and polymer concrete. The mix proportions for the grouting materials are given in Table 3. Control cubes were prepared during casting of the joints. In addition, cubes and briquettes were made from Set 45, Set grout, and polymer concrete to monitor the compressive and tensile strength development of the grouting materials (see Table 4).

The Set 45 and Set 45 HW grout material have a prescribed proportion of water ranging between 1.6 and 2.0 quarts per 50 lbs of material (66 and 84 mL/kg). In this study, 2 quarts per 50 lbs of cement (84 mL/kg) was initially used. However, since Set 45 is very sensitive to the amount of water present, better results were obtained once the joint surface was dry and the water was reduced to 1.9 quarts per 50 lbs of cement (80 mL/kg).

The Set 45 grout is a heterogeneous material composed of various elements with different properties. Hence, the mixes were produced in 50 lb (22.7 kg) concrete batches, since the Set 45 bags weigh 50 lbs each.

In casting the joint, a duration of 10 minutes was found to be the optimal recommended time not to be exceeded. In the case of Set 45 HW, the casting duration was extended to 35 minutes. To mix the Set 45 grouting material, at first the water was added to the mixer, and then Set 45 was added and mixed for 12 minutes. The Set Grout was prepared with a water proportion of 3.4 quarts per 50 lbs of cement (141 mL/kg). The optimal mixing time for achieving the best consistency of Set Grout with water was found to be 3 minutes with the casting duration lasting as long as 1 to 2 hours.

The polymer concrete (Emaco 2020 Regular) is composed of three parts, denominated A, B, and C, for binder, aggregate, and initiator, respectively. The mix proportions were 1.0:10.9:0.1. The mix was very flowable for ease in pouring. First, a primer (Emaco 2041) was applied to the precast surface of the joint 3 hours prior to grout mixing.

Table 2. Mix proportions and compressive strength of concrete.

Ingredients	Mix #1	Mix #2
Cement, lb/yd^3	597	621
Coarse aggregate, lb/yd^3	1668	1958
Fine aggregate, lb/yd^3	1460	1138
Total water content, lb/yd^3	322	279
w/cm	0.54	0.45
Superplasticizer, RB-1000, fl oz per 100 lb cement	0	8
Slump, in.	3.5	4.5
Compressive strength @ 28 days, psi	6250	6500

Note: 1 lb/yd^3 = 0.593 kg/m^3; 1 lb = 0.454 kg; 1 psi = 0.0069 MPa; 1 fl.oz = 29.574 mL.

Table 3. Mix proportions and compressive strength of grouting material.

Mix design and properties	Grouting material			
	Set 45	Set 45 HW	Set Grout	Polymer (Emaco 2020)
Grouting material, lb	50	50	50	Part A : B : C = 1.0 : 10.9 : 0.1
Mix water, lb	3.97	3.97	7.05	
Compressive strength at the age of testing of specimens, psi	5820	5658	7700	10,810

Note: 1 lb = 0.454 kg; 1 psi = 0.0069 MPa.

Table 4. Strength development of grouting material.

Age at testing	Type of test	Strength of grouting material, psi		
		Set 45	Set Grout	Polymer concrete
3 hours	Compressive	—	—	9752
6 hours	Compressive	3718	—	10169
1 day	Compressive	3775	2841	10357
3 days	Compressive	4294	5109	10460
	Tensile	574	548	988
7 days	Compressive	5516	6312	10550
	Tensile	587	598	1130
28 days	Compressive	6122	10031	10756
	Tensile	605	703	1153

Note: 1 psi = 0.0069 MPa.

Fig. 6. Typical test specimens with sandblasted surface.

Next, the liquid component (A) and the aggregate component (B) were mixed for 1 minute. Last, the activator (C) was added and mixed for 30 seconds. The mixed material was carefully checked for lumps.

Surface Preparation, Curing, and Test Procedure

The joint surfaces of all precast slab segments were prepared by sandblasting to achieve optimum bonding of the grout. The sandblasting was performed until the coarse aggregate was slightly exposed (see Fig. 6). Dust was removed from the concrete surface using air pressure followed by high-pressure washing. For the surfaces where Set 45 and Set 45 HW grout were used, and after sandblasting the surfaces were dried for at least 4 hours before application of the mortar.

If the specimens were exposed to laboratory air for several days after sandblasting, the joint surfaces experienced carbonation. Since Set 45 and Set 45 HW are susceptible to carbonation, the surface was tested using 10 percent HCL solution to identify signs of carbonation. If any carbonation existed, the surface was properly cleaned with an additional 10 percent HCL solution and washed with water. The joint surfaces for Set Grout and polymer concrete, however, did not require treatment for carbonation.

The concrete surface was dried for at least 4 hours before casting of Set 45 and Set 45 HW in the joints. The curing procedure involved placing plastic sheets over the joints for 24 hours. In the case of Set Grout, the concrete surface was moist cured for 24 hours prior to casting of joints, and casting took place before the surface dried. Humidity on the surface improves the bond and prevents any exchange of water between the surface and cement paste.

After grouting, the Set Grout composite specimens were cured for 6 hours using wet burlap, and after set time a curing compound was applied. The concrete joint surfaces for the polymer concrete joints were dried and a primer was placed on the precast surfaces 3 hours before mixing. No curing was required for the specimens grouted with polymer concrete. Tests were performed on three specimens for each type of joint material. Composite specimens were tested for direct shear, tension, and flexure.

Direct Shear Test

The final specimen configuration and vertical shear test setup is shown on Fig. 3a. A lead plate was placed on the top and bottom of the specimen to secure a uniform load distribution. A servo-hydraulic Instron machine with a capacity of 50 kips (222 kN) was used for testing the specimens (see Fig. 7). The load rate used was 0.01 in./min (0.25 mm/min). The load was applied to the specimen in such a way that the resultant of the load acted exactly at the center of the joint. As a result, the load transferred into the joint, forcing the joint to fail in shear. The ultimate load and mode of failure were recorded.

Fig. 7. Direct shear test setup.

Fig. 8. Direct tension test setup.

Direct Tension Test

A Universal digitally controlled testing machine with a variable cross head speed was used for testing the specimens in direct tension (see Fig. 8). The steel reinforcing bars at the end of the specimen were gripped by the upper and lower cross head of the testing machine. The test was carried out in a load control mode. The transverse cross-sectional area of the tensile specimen was 40 sq in. (25800 mm^2). The ultimate load and mode of failure of each type of specimen were recorded.

Flexural Testing

The flexure test was conducted with a three-point loading fixture used in ordinary flexure tests of concrete beams. A Universal digitally-controlled testing machine with a variable cross head speed was used for testing the specimens (see Fig. 9). The test was carried out in a load-control mode according to ASTM C 78. The ultimate load and mode of failure were recorded.

RESULTS AND DISCUSSION

A total of 36 specimens were tested for vertical shear, direct tension, and flexure with three specimens fabricated for each type of test. The joints were cast using the four different materials. All observed strengths and modes of failure were compared.

At the inception of testing, the joint surfaces were not sandblasted, commonly resulting in bond failure. As a result, all the specimens were sandblasted, a procedure that produced satisfactory results. Initially, a significant number of specimens using Set 45 were rejected due to bond failure at the joint interface; this was attributed to the moisture at the joint surface and the composition of the Set 45 mix. Furthermore, after sandblasting and exposing the joint surface to air for a longer period of time, bond strength was significantly decreased due to carbonation.

The load carried by the specimens with dry joint surfaces was nearly twice that of specimens with moist surfaces. For Set Grout, the joint surface should be saturated at the time of

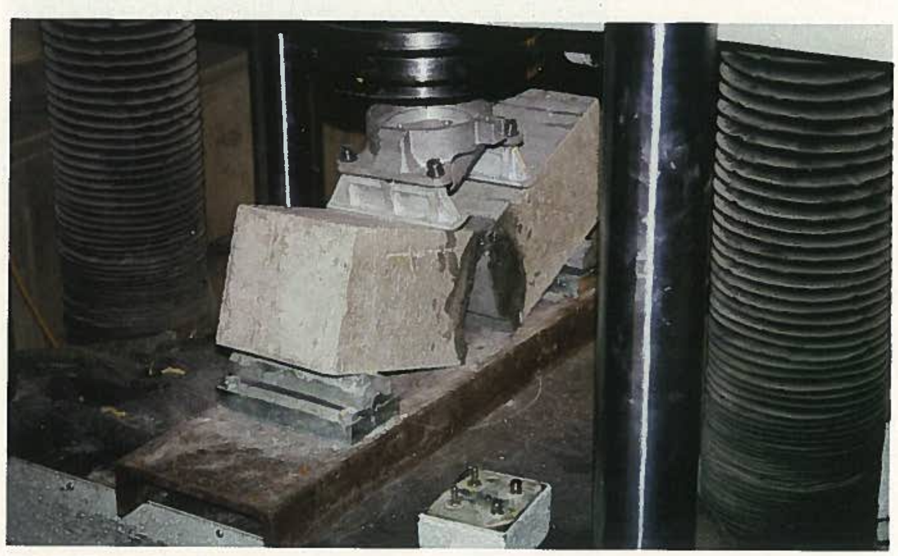

Fig. 9. Flexural testing setup.

Table 5. Direct shear test results.

Material type	Specimen number	Shear stress (psi)	Average shear stress (psi)	Concrete f'_c (psi)	Grouting material f'_c (psi)	Mode of failure
Set 45	S1	301.1	325.2	6500	5820	Fracture through joint
	S2	320.4				
	S3	354.1				
Set 45 HW	S1	285.3	298.7	6250	5658	Fracture through joint
	S2	305.9				Fracture through joint
	S3	305.0				Fracture through joint and concrete
Set Grout	S1	401.5	358.3	6500	7700	Fracture through joint and concrete
	S2	343.3				
	S3	330.1				
Polymer concrete	S1	748.4	704.3	6500	10810	Fracture of concrete away from joint
	S2	667.1				
	S3	697.4				

Note: 1 psi = 0.0069 MPa.

Fig. 10. Typical failure mode of vertical shear specimen cast with polymer concrete.

casting since preliminary tests indicated this procedure improves bond. In case of polymer concrete, specific procedures for casting must be carefully followed, necessitating the use of experienced testing personnel. To monitor the strength development of the grouting materials, cubes and briquettes were prepared from Set 45, Set Grout, and polymer concrete and tested at different ages. Compressive and tensile strengths of the grouting materials tested were recorded at different ages (see Table 4).

Direct Shear Test Results

Shear stresses for the specimens made with various grouting materials are reported in Table 5. The average shear stress in Set 45 specimens was a little higher than those of Set 45 HW specimens. This was due to the lower compressive strength of Set 45 HW

Table 6. Direct tensile test results.

Material type	Specimen number	Tensile stress (psi)	Average tensile stress (psi)	Concrete f'_c (psi)	Grouting material f'_c (psi)	Mode of failure
Set 45	T1	207.8	200.9	6250	5820	Fracture through joint
	T2	175.9				
	T3	219.0				
Set 45 HW	T1	198.4	205.6	6250	5658	Bond (interface)
	T2	214.6				Fracture through joint
	T3	203.8				Fracture through joint
Set Grout	T1	197.0	223.7	6250	7700	Fracture through joint and concrete
	T2	246.3				
	T3	227.9				
Polymer concrete	T1	330.1	291.6	6250	10810	Fracture of concrete away from joint
	T2	288.8				
	T3	256.0				

Note: 1 psi = 0.0069 MPa.

grouting material. Failure was initiated by fracture through the joint. The average shear stress of Set Grout specimens was higher than that of Set 45 and Set 45 HW grout specimens. Failure occurred through both the joint material and the surrounding concrete.

Joints cast with polymer concrete proved to be the best in terms of shear strength, fracture, and bond behavior (Table 5). The shear strength of polymer concrete joint was twice the shear strength of the joints cast with Set 45, Set 45 HW, and Set Grout. Bond was excellent and no apparent cracks were observed at the joint interfaces. Fracture was always induced away from the joint in the concrete (see Fig. 10).

Direct Tension Test Results

The observed tensile stress values for the specimens made with various grouting materials are listed in Table 6. It can be seen that the tensile stresses of specimens with Set 45 and Set 45 HW are almost the same. In all specimens cast with Set 45 and Set 45 HW grout material, failure was through the joint, with the exception of one Set 45 HW specimen which failed at the bond interface. The average tensile stress for the Set Grout specimens was higher than that of Set 45 and Set 45 HW specimens. Failure in the Set Grout specimens always occurred in both the joint and the surrounding concrete. Hence, better bond was attributed to this type of material.

The polymer concrete once again proved to be superior to the other materials (Table 6). The tensile strengths were higher than those for Set 45, Set 45 HW, and Set Grout materials. Failure occurred in the concrete away from the joint. The modes of failure for Set 45, Set Grout, and polymer concrete specimens are shown in Figs. 11, 12, and 13, respectively.

Fig. 11. Typical failure mode of direct tension specimen cast with Set 45.

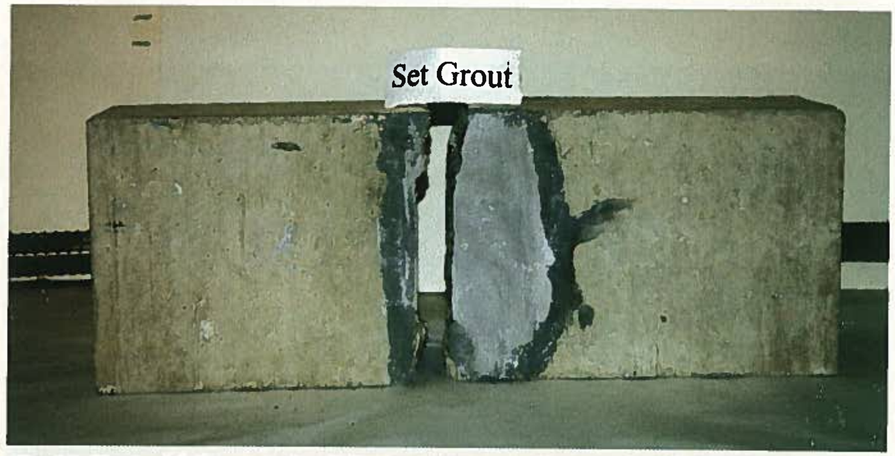

Fig. 12. Typical failure mode of direct tension specimen cast with Set Grout.

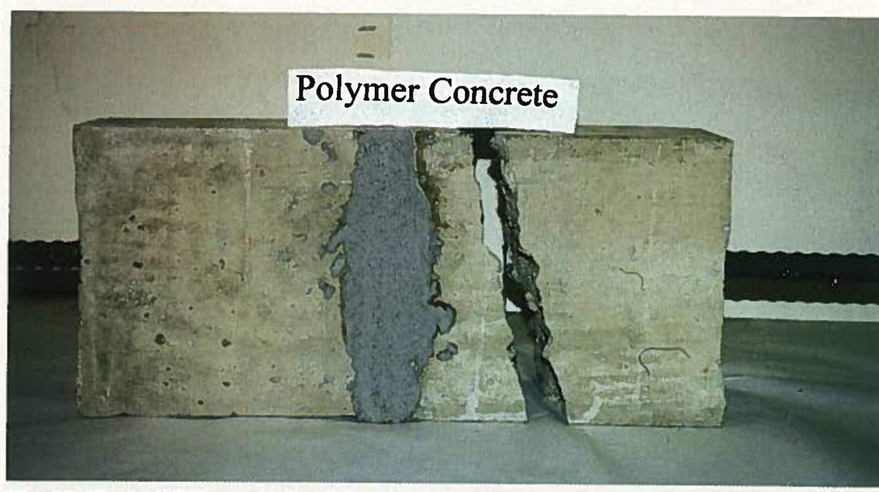

Fig. 13. Typical failure mode of direct tension specimen cast with polymer concrete.

Flexural Test Results

The observed flexural strength results for all four types of materials are reported in Table 7. The flexural strength of polymer concrete joints was 2.8, 1.5, and 1.2 times the flexural strength of the joints with Set 45, Set 45 HW, and Set Grout, respectively. Bond was superior in the polymer concrete specimens, followed by the Set Grout specimens, and finally the Set 45 specimens.

The modes of failure for the three materials followed the same trend as previously encountered in the direct shear and direct tension tests. Failure occurred at the joint juncture with some apparent loss of concrete for the Set 45 specimens. Failure occurred in both concrete and joint for the Set Grout specimens. Once again, failure for the polymer concrete specimens was away from the joint, in the concrete material. Figs. 14, 15, and 16 show typical failure modes for the Set

Table 7. Flexural test results.

Material type	Specimen number	Flexural stress (psi)	Average flexural stress (psi)	Concrete f'_c (psi)	Grouting material f'_c (psi)	Mode of failure
Set 45	F1	266.6	272.7	6250	5820	Fracture through joint
	F2	284.3				
	F3	267.6				
Set 45 HW	F1	516.5	498.1	6500	5658	Bond (interface)
	F2	531.4				
	F3	446.5				
Set Grout	F1	633.9	620.3	6250	7700	Fracture through joint and concrete
	F2	601.4				
	F3	625.6				
Polymer concrete	F1	783.9	773.1	6250	10810	Fracture of concrete away from joint
	F2	685.6				
	F3	849.7				

Note: 1 psi = 0.0069 MPa.

Fig. 14. Failure mode in Set 45 flexural specimen.

Fig. 15. Failure mode in Set Grout flexural specimen.

45, Set Grout, and polymer concrete specimens, respectively.

Chloride Permeability Tests

A permeability investigation was carried out in accordance with ASTM C 1202-97, which entails the determination of the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions. Slices from 4 x 8 in. (100 x 200 mm) cylinders were made to obtain disks 4 in. (100 mm) in diameter and 2 in. (50 mm) thick. In this test, electrical current passes through a concrete sample during a six-hour exposure period, and the result is expressed in terms of Coulombs. The average results from three samples for each type of material are shown in Table 8.

The polymer concrete was the least permeable among all the grouting materials evaluated. A considerably higher Coulomb value was observed for the Set Grout specimens, which may be attributed to more water used in the Set Grout mixes.

Shrinkage Measurement

Material shrinkage was determined according to ASTM C 157. Three prism specimens of size 1 x 1 x $11^1/_4$ in. (25 x 25 x 285 mm) were cast from each joint material. Six hours after casting, specimens were demolded and immersed in lime-saturated water for 15 minutes. After taking comparator readings, all the prisms were kept under laboratory temperature and humidity conditions. Comparator readings for each specimen were taken every day for 7 days and once weekly thereafter.

The observed shrinkage values are plotted in Fig. 17. It was observed that polymer concrete had the best shrinkage performance among all joint materials. The very high value of shrinkage for the Set Grout specimens was due to the high water content used to make the mix flowable.

Finite Element Analysis

Finite element analysis methodology (FEM) was performed for the direct shear test specimen using the computer program ANSYS. The objectives were to determine stress distributions and modes of failure for the joint using each of the four types of grouting material. The exact geometric configuration of the specimen was meshed using SOLID65 elements (solid elements capable of depicting the nonlinear behavior of concrete and its failure in cracking or crushing).

A maximum element size of 1 in. (25 mm) was adopted for the discretization of the model, and a full Newton-Raphson algorithm was employed to trace the solution path. The bottom flange of the specimen was restrained against translational motion, and load was applied on the top flange of the specimen as shown in Fig. 18. Lateral movement of the two slabs was also restrained to prevent bending.

Analysis Results

Analysis showed that failure was mainly due to crushing and cracking of the grouting material along the joint. Polymer concrete experienced the least amount of cracking and crushing, and the specimen failed at an applied load of 25.15 kips (112 kN). Minor cracks were noted in the lower neck of the joint but occurred mostly in the concrete slab along the joint line (see Fig. 19). Shear stress for this specimen ranged between 477 and 757 psi (3.3 and 5.2 MPa) across the face of the joint, with values on the order of 898 psi (6.2 MPa) recorded at the upper and lower edges of the joint (see Fig. 20). The average shear stress from experimental results was 704 psi (4.9 MPa).

Set Grout failed at a load of 17.1 kips (76 kN) with a more pronounced crushing pattern at the upper and lower necks of the joint (see Fig. 21). Shear stresses ranged between 288 and 458 psi (2.0 and 3.2 MPa) across the joint (see Fig. 22). Set Grout exhibited shear stresses of 800 psi (5.5 MPa) at the upper and lower necks of the joint. The average shear stress obtained experimentally was 358 psi (2.5 MPa).

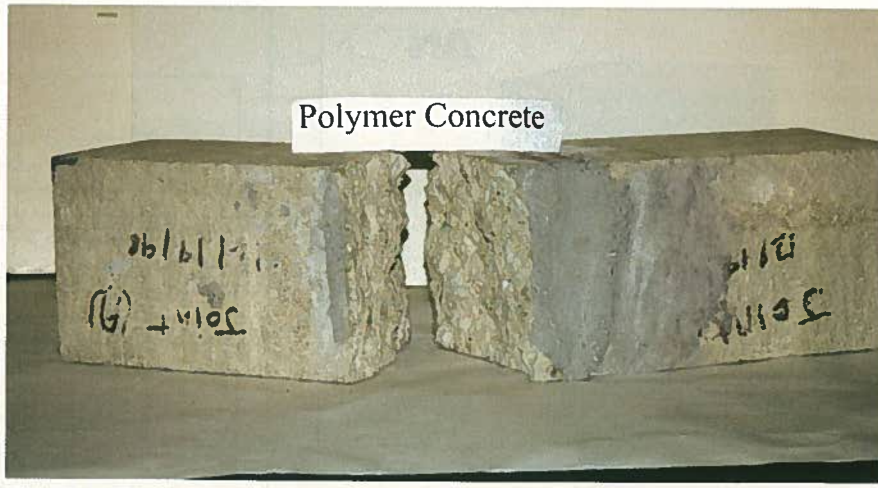

Fig. 16. Failure mode in polymer concrete flexural specimen.

Table 8. Coulomb permeability test results.

Material type	Average Coulomb value	Chloride ion permeability
Set 45	606	Very low
Set Grout	2544	Moderate
Polymer concrete	22	Negligible

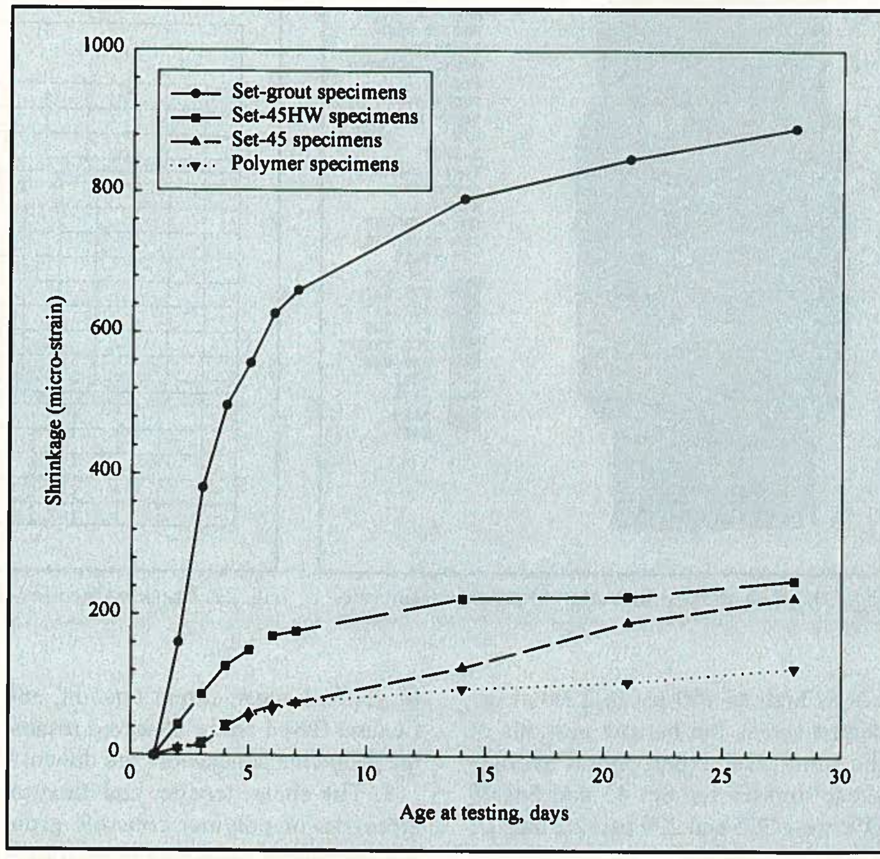

Fig. 17. Shrinkage test results of joint materials.

Set 45 and Set 45 HW had comparable compressive strengths, and hence developed similar crushing patterns within the joint material at failure loads of 16.5 and 15.5 kips (73.4 and 69 kN), respectively. Shear stress distribution for the Set 45 model is shown in Fig. 23. The strength distribution values ranged between 277 and 441 psi (1.9 and 3.0 MPa), while val-

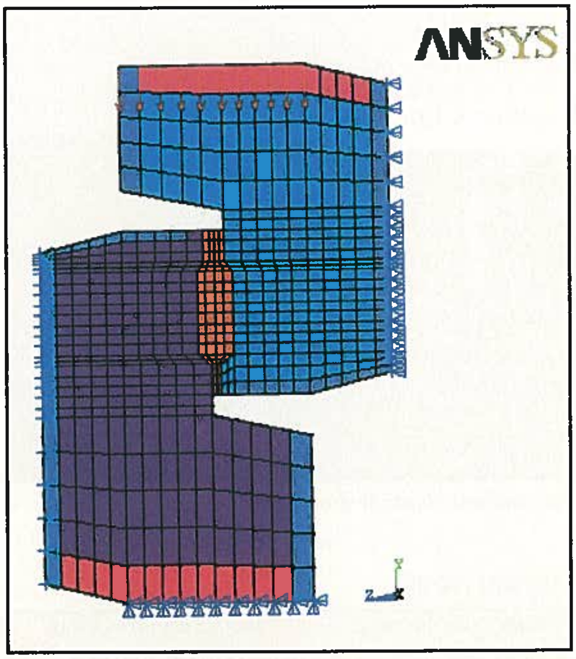

Fig. 18. Finite element mesh and boundary conditions.

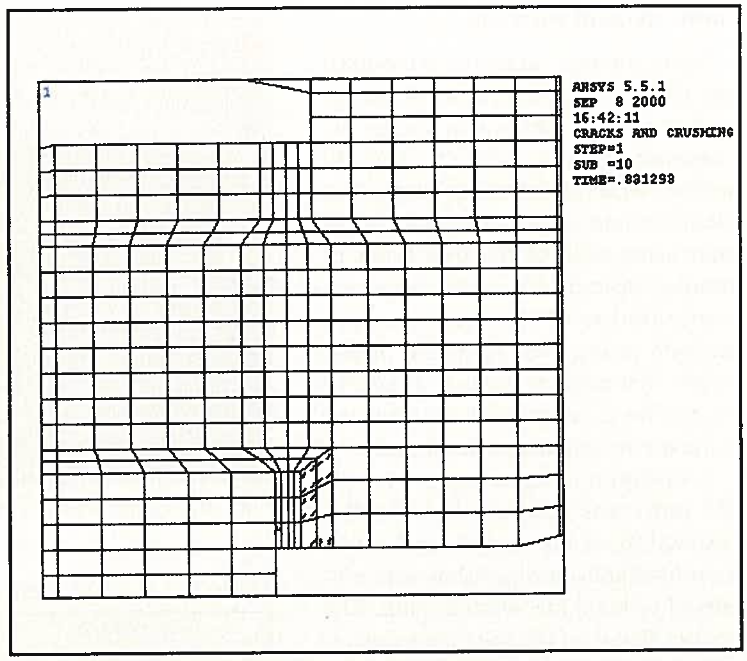

Fig. 19. Crack pattern in polymer concrete model.

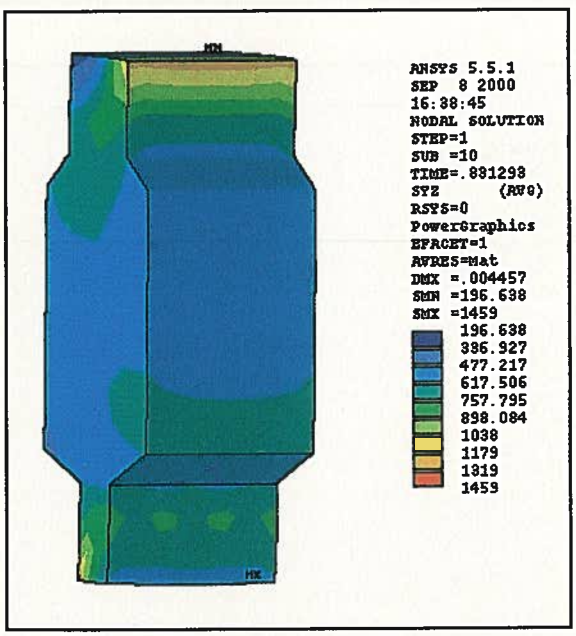

Fig. 20. Shear stress distribution in polymer concrete.

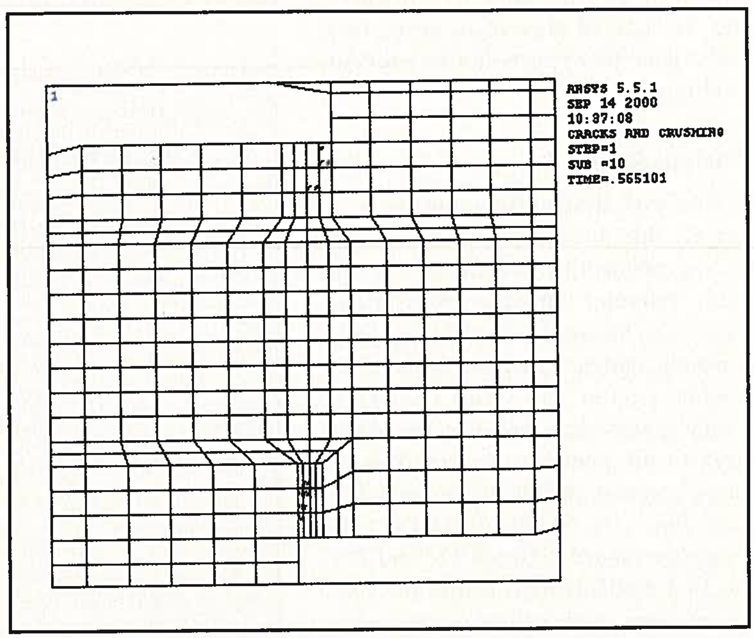

Fig. 21. Crack pattern in Set Grout model.

ues as high as 750 psi (5.2 MPa) occurred across the narrow portions of the joint. The experimental average shear stresses for Set 45 and Set 45 HW were 325 and 299 psi (2.2 and 2.1 MPa), respectively.

SUMMARY AND CONCLUSIONS

A significant number of specimens were tested to evaluate the performance of grouting materials subjected to vertical shear, direct tension, and flexure. Based on the observed results, the following conclusions are drawn:

1. The shear, tensile, and flexural strengths of polymer concrete grout are the highest among all types for the materials studied.

2. Moisture and carbonation at the joint surface adversely affect the bond and strength of Set 45 grouting material. Set 45 sets very fast, and may have an adverse effect on construction scheduling.

3. Shear, tensile, and flexural strengths of Set Grout are higher than those of Set 45. Furthermore, the Set Grout is easy to apply and performs satisfactorily in terms of bond behavior.

4. Polymer concrete acquires its required strength in a very short time [4500 psi (31 MPa) in one hour]. A rapid set is critical when interruptions to bridge traffic must be minimized or where there are contractual penalties for delays.

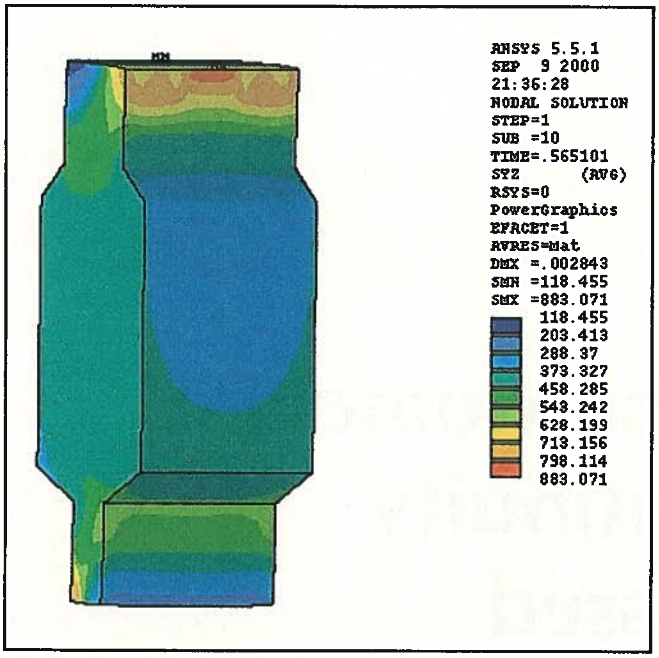

Fig. 22. Shear stress distribution in Set Grout.

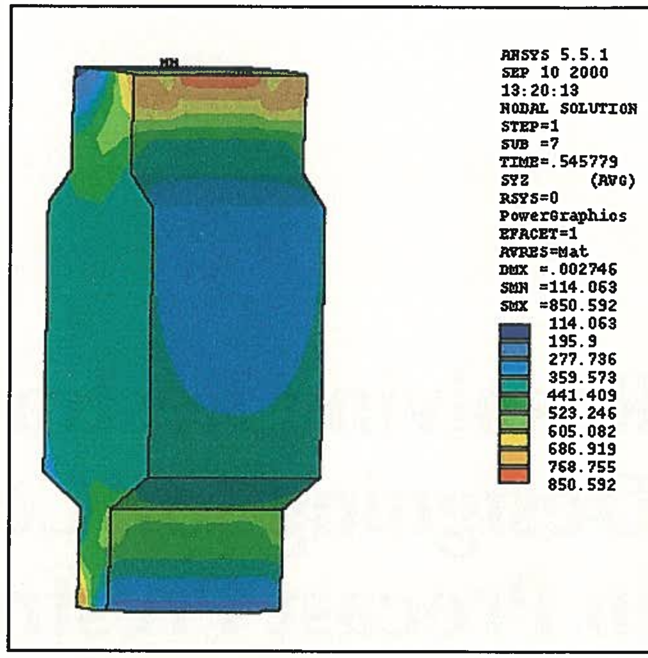

Fig. 23. Shear stress distribution in Set 45.

5. Polymer concrete is the least permeable among all the materials studied, while set grout has a considerably higher Coulomb value.

6. Polymer concrete performs best among all joint materials in terms of shrinkage. The very high shrinkage value for Set Grout is due to its high water content.

7. FEM results indicated that polymer concrete experiences the least amount of cracking and crushing, with specimen failure occurring at an applied load of 25.15 kips (112 kN) in this study. Set Grout failed at a load of 17.1 kips (76 kN) with a more pronounced crushing pattern at the upper and lower necks of the joint. Set 45 and Set 45 HW exhibited similar crushing patterns within the joint material failure at loads of 16.5 and 15.5 kips (73.4 and 69.0 kN), respectively.

RECOMMENDATIONS

Based on the laboratory experimental results of transverse joints, FEM, field performance of full-depth precast concrete bridge systems in 15 states, and full-scale testing of full-depth precast, prestressed concrete slabs installed on steel stringers, the following recommendations are offered:

1. The transverse joint between precast panels should be of female-to-female type and have a nominal width of $1^1/_4$ in. (32 mm) at the top and $^1/_2$ in. (13 mm) at the bottom. The width of the joint can be adjusted in the field by $\pm^1/_4$ in. (±6 mm) to account for casting tolerances. Other minor concrete dimensional growth can be compensated for in the closure pours at the ends of the span.

2. For rapid replacement of bridge decks, polymer grout or grout materials of equivalent performance are recommended in the transverse joint to allow for post-tensioning of the precast units approximately one hour later. Alternatively, Set Grout can be used within the transverse joints if the post-tensioning is not required immediately after casting.

3. It is recommended that polymer grout be used in critically stressed joint locations and Set Grout for the rest of the joints, as polymer concrete is very expensive and requires careful application, including thorough surface preparation and adequate mixing.

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