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Shear Strength of Grout Type Transverse Joint

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Abstract

This is the first of two part series on experimental studies of grout type transverse joints. In this study, grout type transverse joints between precast concrete slabs are statically tested to determine the cracking loads and ultimate shear capacities of the grout type transverse joints. The tests are performed with a loading equipment designed and constructed especially in the lab to induce shear failures on the joints of the test specimens. Shape of the transverse joints, grouting materials and amount of prestress are selected as test parameters for the study. The results indicate that epoxy is an excellent grouting material which can be used in limited locations where large tensile stress is acting on the slab. Longitudinal prestressing is also an effective method to increase the shear strength of the transverse joints. A rational method to estimate the cracking and ultimate loads for the design of grout type transverse joints is proposed based on the static loading tests. Success of the tests with shear loading equipment allowed continuing the research further onto the fatigue strength of the grout type joints, which will be presented in the second part of the paper.

Keywords: grout type transverse joints, prestress and shear strength

1. Introduction

Precast concrete slabs are pre-fabricated transverse floors that are gaining a wide popularity for the construction of bridge structures. Usage of the precast slabs ensures the quality and reduces amount of shrinkage, which in turn enhances the durability of the slab.[1)] With the introduction of prestress to the precast concrete slabs, the development of cracks on the slabs due to traffic loads can also be controlled. The usage of the precast concrete slabs is an economical alternative that can reduce the cost of maintenance compared to conventional reinforced concrete slabs.[2)]

Many types of the precast concrete slabs are available. For example, full-precast concrete slabs are the factory-produced concrete slabs which cover whole depth of the bridge decks. Half-precast concrete slabs are only 7 ~ 12 cm in thickness which cover the bottom half of the bridge decks. The top half of the decks is constructed with fresh concrete after the bottom half of the precast concrete slabs are placed.

There are disadvantages in the precast concrete slab. Due to the limitation of transportation, size of the precast slabs has to be small enough to accommodate transportation.

Structurally weak transverse joints are also necessary in order to provide continuity of the precast slabs. Transverse joints can be divided into three groups depending the width of the joints. Contact type transverse joints allow each precast concrete slabs to come to a direct contact with adjacent slab. Grout type transverse joints (grouted joint) are 4~5cm in width without rebar arrangement for reinforcement. Reinforced joints are 20~30 cm in width which are reinforced with steel rebars or mechanical joints. Types of the transverse joints are shown in Fig. 1. The transverse joints must perform functions listed below;

1) joints must provide structural continuity of the precast slabs
2) joints must have enough strength to resist applied load
3) shapes of the joints have to be simple to accommodate factory production of the precast slabs, and
4) structural detail of the joints and rebar lay-out has to be simple to facilitate construction.

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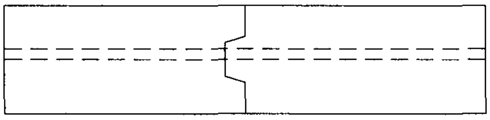
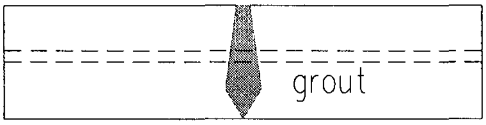
Even though research and design of the precast concrete slabs have been actively conducted,[3-5] detailed design specifications of the transverse joints have not been yet available. Usage of rebar and mechanical connection makes structural details of the precast slab very complicated and raise construction cost at the same time.[6,7] In this paper the simplest form of transverse joint, grout type, was tested using the shear test equipment that had been developed in the laboratory. The tests were conducted on the specimens with various dimensions of the joints and various amount of prestress introduced to the test specimens. Based on the test results, a rational estimation of the shear capacity for the grout type joint is also suggested.

2. Test equipment and specimens

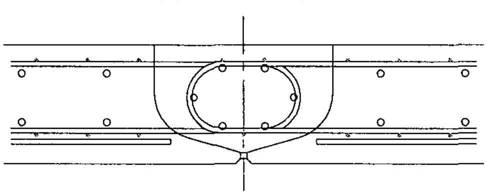
As shown in Fig. 2 and Table 1, Beam specimens are selected as simplified representations of the precast slabs with transverse joints.[8,9] Depth of the beam specimens is 250 mm, similar dimension to actual slab thickness. Three different shapes of the transverse joints constitute four models of the test specimens. The specimens with three different dimensions of the transverse joint are classified as A, B, C type specimens as shown in Fig. 2. The width of the transverse joints for the B type specimens is 75 mm, 50% wider than that of the A type specimens. The C type specimens have the same width as the A type specimens, however the height of the transverse joints is changed from 220 mm to 200 mm. Non-shrinkage mortar is used as grouting materials for the A, B, and C type specimens. The D type specimens have the same dimensions as the A type specimens. The only difference is that epoxy is used as a grout material for the D type specimens while non-shrinkage mortar is used for all other specimens. All types of specimens are tested with various amount of prestress (0 to 2.94 Mpa) introduced to the specimens in order to observe the effect of prestress. Amount of prestress is summarized in Table 1. Prestress is introduced to the specimens by the external prestressing method with two tendons on which strain gages are attached to control the tension.[10,11] As shown in Fig. 3, three-directional strain



(a) Contact type joint

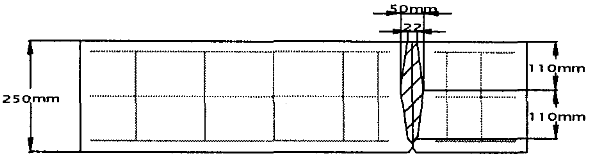


(b) Grout type joint

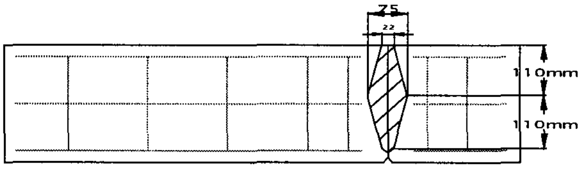


(c) Reinforced joint

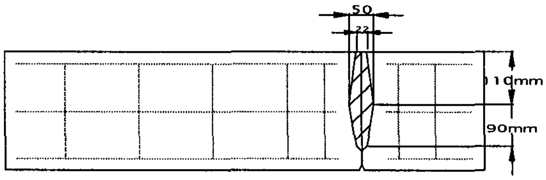
Fig. 1 Types of transverse joints



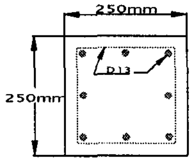
(a) A type specimen



(b) B type specimen



(c) C type specimen



(d) Cross section

Fig. 2 Test specimens

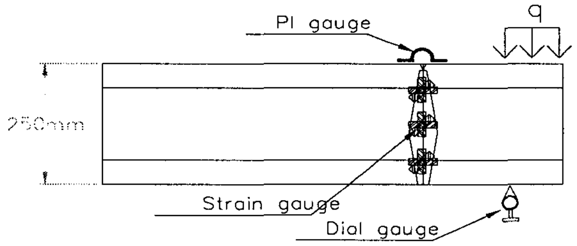


Fig. 3 Gage attachment

Table 1 Test specimens

Type of the specimens	Model name	Amount of prestress (MPa)	Number of specimens	Grout material	Material properties of grout
A type	A-0	0	2	Non-shrinkage mortar	Compressional strength : 371 kgf/cm^2 Youngs modulus : 2.12×10^5 kgf/cm^2
	A-1	0.98	2		
	A-2,	1.96	2		
	A-3	2.94	2		
B type	B-0,	0	2	Non-shrinkage mortar	Compressional strength : 378 kgf/cm^2 Youngs modulus : 2.36×10^5 kgf/cm^2
	B-1	0.98	2		
	B-2	1.96	2		
	B-3	2.94	2		
C type	C-0	0	2	Non-shrinkage mortar	Compressional strength : 385 kgf/cm^2 Youngs modulus : 2.43×10^5 kgf/cm^2
	C-1	0.98	2		
	C-2	1.96	2		
	C-3	2.94	2		
D type	D-0	0	2	Epoxy	Tensile strength : 190 kgf/cm^2 Compressional strength : 640 kgf/cm^2 Bonding strength : 134 kgf/cm^2
	D-1	0.98	2		
	D-2	1.96	2		
	D-3	2.94	2		

gages(rosette gages) are also fixed on the surfaces of the test specimens to measure the principal tensile strain and its direction[12)] during the loading. A PI gage is attached over the transverse joints to measure crack widths forming along the interface. The specimens are loaded with the shear test apparatus as shown in Fig. 4. The specimens have fixed a support at one end while rotation is constrained at the other end. As shown in Fig. 5, predominant shear force on the transverse joints is applied by placing the joint where bending moment becomes zero. Pure shear force on the transverse joints is applied because failure of the concrete slab is commonly induced by the shear force.[13)]

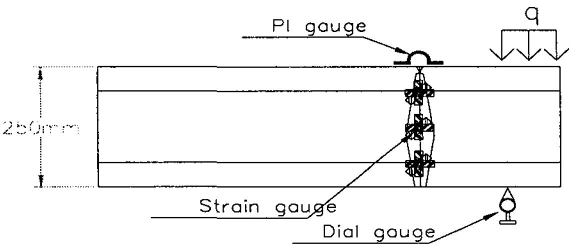


Fig. 3 Gage attachment

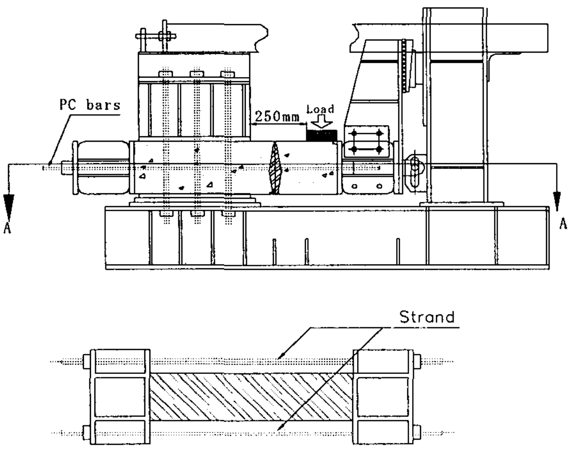
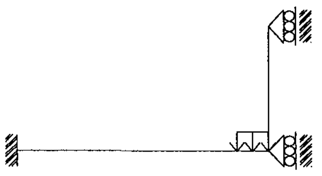
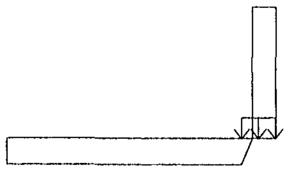


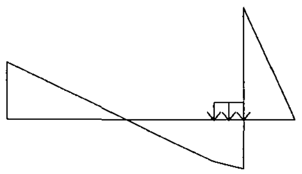
Fig. 4 Loading apparatus



(a) Loading equipment



(b) Shear diagram



(c) Moment diagram

Fig. 5 Shear and moment distribution

Table 2 Results of loading test

Model type	Model name	Prestress (MPa)	Interfacial cracking loads (KN)	Inclined shear cracking loads (KN)	Ultimate loads (KN)
A type	A-0	0	23.5	-	52.0
	A-1	0.98	63.6	141.5	186.3
	A-2	1.96	81.4	153.3	205.0
	A-3	2.94	101.0	174.2	219.7
B type	B-0	0	27.5	-	49.0
	B-1	0.98	82.4	138.6	183.9
	B-2	1.96	85.3	149.4	196.1
	B-3	2.94	97.1	185.9	245.2
C type	C-0	0	29.4	-	45.1
	C-1	0.98	59.8	147.1	196.1
	C-2	1.96	68.7	173.6	245.2
	C-3	2.94	85.3	196.2	273.8
D type	D-0	0	-	53.9	159.9
	D-1	0.98	-	55.0	166.7
	D-2	1.96	-	137.3	235.4
	D-3	2.94	-	191.2	294.2

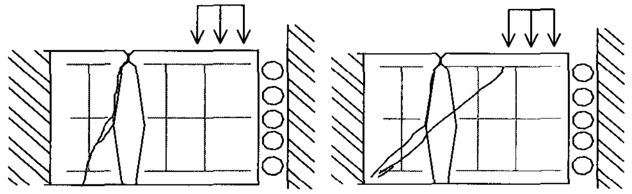
3. Test results

3.1 Cracking loads and bearing capacities of joints

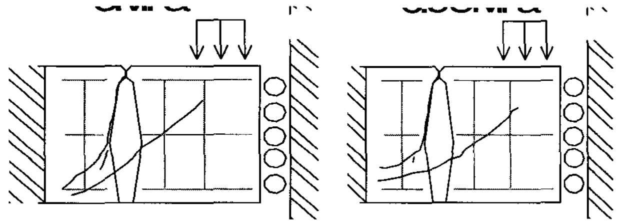
The results of the ultimate loading test are summarized in Table 2. A-0, B-0 and C-0 (specimens without prestress) have very low values of the ultimate and interfacial cracking loads. As seen in Fig. 6(a), interfacial cracks appeared at the top of the joint interfaces and continued to develop downward along the interfaces of the joints and precast specimens. Vertical interfacial cracks are results of bending moment caused by minimal, however, unavoidable amount of rotation at the supports. Propagations of the interfacial cracks are stopped at the neutral axis below which compression acts on the cross section of the specimens. Shear force is resisted by cross section of concrete in compression until a sudden failure occurred at about 52KN for A-0, B-0 and C-0 specimens.

Unlike other specimens, the interfacial cracks (tension crack) were not found for the D-0 specimen. The initial crack for D-0 specimen, formed diagonally as shown in Fig. 7(a), was found at 53.9 KN and continued to develop until the shear failure occurred at 159.9KN. Higher cracking and ultimate loads for the D-0 specimen was due to a higher strength of the epoxy material than the cement mortal used as grout for the other type specimens.

For the prestressed specimens of the A, B, and C type, formations of the vertical interfacial cracks were also found to be the initial crack pattern. However, initial cracks were formed at higher loads than the counterparts of the non-prestress specimens. This was because prestress reduced

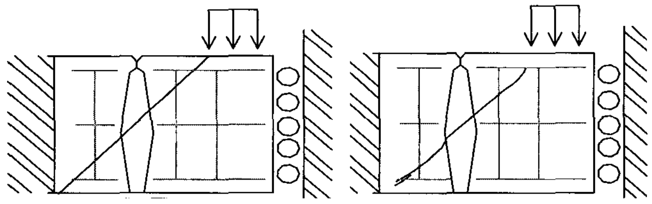


(a) A-0 specimen (b) A-1 specimen

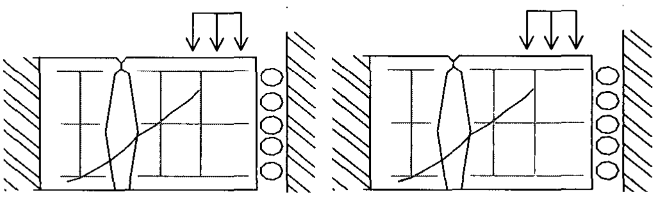


(c) A-3 specimen (d) A-4 specimen

Fig. 6 Crack patterns of A type specimens



(a) D-0 specimen (b) D-1 specimen



(c) D-2 specimen (d) D-3 specimen

Fig. 7 Crack patterns of D type specimens tensile stress developed on the joint interface, thus improving the bonding ability. Relatively high interfacial cracking loads for the B type specimens were due to the shape of the joint. Large angles of the joint layout for the B type specimens were advantageous for resisting the development of interfacial cracks because large angle of the interface reduced the tensile stress perpendicular to the joint interface. As loads were increased, diagonal shear cracks begun to form at the joints and continued to develop. Common patterns of the failure for the prestressed specimens were shear failure along the diagonal cracks. For the prestressed specimens, improvement of cracking and ultimate loads with respect to the amount of prestress could be observed from Table 2. This was because the inclination angle of the diagonal shear cracks increased as the amount of prestress became greater. In order to show the effect of prestress visually, crack patterns at the failure for the A and D type specimens are shown in Figs. 6 and 7. The inclination angle of shear cracks will be illustrated, in detail, later in the paper. It was expected that the joint dimensions and ultimate load were somehow related. The test results agree with the common expectations, producing the highest ultimate loads for the C type specimens and the lowest ones for the B type. The C and B type specimens have the most and least dimensions for the transverse joints, respectively. Failure surfaces of the A-0, B-0, and C-0 specimens (without prestress) occurred along the lines of the initial interfacial cracks. As the prestress is introduced to the specimens, failure patterns are changed to shear mode along the diagonal shear crack, with the ultimate capacity increasing with respect to the amount of prestress. All D type specimens failed in shear mode without developing vertical interfacial cracks and the ultimate loads for the D type specimens are also very high. The epoxy grouting can be considered useful for limited locations where prestressing becomes difficult or a large tensile stress is acting on a bridge deck. However, usage of epoxy is an expensive alternative to prestressing because material cost is very high. Even though it is not graphically shown in the figure, failure patterns of the B and C type specimens are very similar to those of the A type specimen.

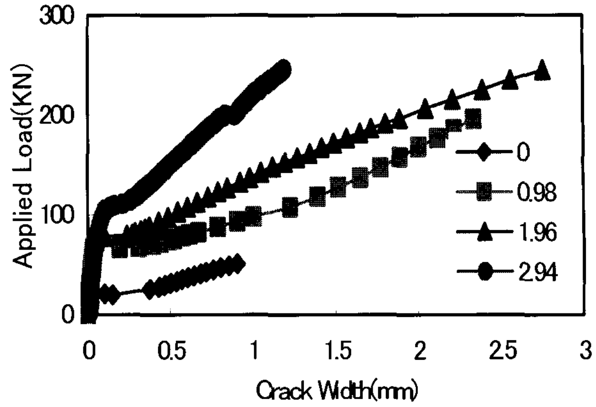


Fig. 8 Load vs. crack width for A type specimens

3.2. Crack width

Width of the vertical interfacial cracks was measured with PI gages attached to the specimen as shown in Fig. 3. The results are shown in Fig. 8. Only the measurement of the A type specimens are represented in the figure since all the tests yield identical results. The measured quantity remains to be small until the development of crack, which is indicated by the sharp decline of the slopes in the graph. As expected, bilinear characteristics are indicated for all specimens. Non-prestressed specimen (A-0) develops a crack at an early stage of loading while crack formations are delayed as the amount of prestress is increased. Especially, A-0 specimen shows only a small increase of load after en early development of crack, drawing an almost horizontal line. Reversely, large increases of bearing capacity after the crack initiation are shown for the prestressed specimens. The interfacial crack is also delayed even by the minimum amount of prestress (0.98 Mpa) introduced to the joint.

4. Estimation of shear cracking load

Shear cracking load of the transverse joint is estimated with regard to the amount of prestress. Shear cracking load is derived only based on the tensile strength of the grout

Table 3 Cracking and ultimate load (C type specimens)

Specimens	V_{exp}(KN)	V_{max}(KN)	V_{cal}(KN)	Crack angle	V_{exp} / V_{cal}	V_u(KN)	V_{max}/V_u
C-0	-	45.1	116.0	45^o	-	160.7	0.28
C-1	147.1	196.1	152.5	41.6^o	0.96	197.2	1
C-2	173.6	245.2	181.3	38.9^o	0.96	213.4	1.15
C-3	196.2	273.8	208.5	36.3^o	0.94	253.2	1.08

V_{exp} : Shear cracking load (tested), V_{cal} : Shear cracking load (calculated)
V_{max} : Ultimate load (tested), V_u : Ultimate load (calculated)
V_{cal} : Strength of stirrups (44.7kN, 2-D13)

material for the transverse joint. Using the state of stress for a concrete beam without shear reinforcement, the principal stress of the beam that is subjected to shear and prestress can be obtained by Equation (1).

$$\sigma_1 = -\left(\frac{\sigma_{pe}}{2}\right) + \sqrt{\left(\frac{\sigma_{pe}}{2}\right)^2 + \tau^2_{\max}} \qquad (1)$$

where,

σ_1 : principal stress in tension

σ_{pe} : effective prestress

$\tau_{\max}$: maximum shear stress at the neutral axis.

It is assumed that the diagonal shear crack is formed when the principal tensile stress (σ_1) reaches the tensile strength of the grout material (f_t). From Equation (1), the cracking shear stress can be determined by the equation as follows;

$$\tau_{cr} = \sqrt{f_t^2 + f_t \sigma_{pe}} \qquad (2)$$

where,

τ_{cr} : crack shear stress

f_t : tensile strength of grout material

σ_{pe} : effective prestress .

Shear force that the joint can sustain without developing the diagonal shear crack can be obtained by multiplying the shear area to Equation (2);

$$V_{cal} = 0.67\mathrm{bh}\sqrt{f_t^2 + f_t \sigma_{pe}} \qquad (3)$$

where,

V_{cal} : calculated cracking shear force (N)

b,h : dimensions of the joint section

f_t : tensile strength of grout material (N/mm^2)

σ_{pe} : effective prestress (N/mm^2).

Angle of the crack inclination, θ, also can be obtained as;

$$2\theta = \tan^{-1}\left(\frac{2\tau_{cr}}{\sigma_{pe}}\right) \qquad (4)$$

where,

θ : angle of the diagonal shear crack

f_t : tensile strength of grout material

τ_{cr} : crack shear stress

σ_{pe} : effective prestress.

In order to obtain the shear capacity with the Equation (3), strength of the beam and transverse joint have to be calculated separately. However, strength of the grout material for the joint is used for the calculation because the diagonal shear crack initiates in the transverse joint and rapidly develop through the whole depth of the beam specimen. Shear cracking loads and angle of the diagonal shear crack obtained by using above equations are presented in Table 3. Comparison is made with the C type specimens which have the highest ultimate shear capacity among all test specimens. Calculated and observed values match fairly well for the prestressed specimens which fail in shear mode. Non-prestressed specimen does not conform because C-0 specimen fail in tension along the crack developed in the interface of the joint. The maximum capacities of the specimens are also provided in Table 3. The maximum capacity(V_u) is calculated considering the yield strength of stirrups, which intersects with the diagonal shear cracks.

Principal tensile strains and directions of the diagonal shear cracks are obtained from the measurements of the 3-directional strain gages (rossette gage) attached at the neutral axis of the specimens. Direction of the shear crack that is perpendicular to the principal tensile strain is shown in Fig. 9. Shear crack is initiated when the principal strain reaches about 0.001. The angles of the shear cracks at the strain of 0.001 are observed between 35° to 45°, angles decreasing with increase of prestress. Directions of the shear crack obtained from the rosette gage reading match well with those values calculated from Equation (4). Even though estimation of the bearing capacity for the concrete members in shear force has been applicable for continuously casted members without transverse joints, this study proves that the estimation can be extended to the grout type transverse joints. In this case, prestress must be introduced to prevent interfacial tension failure. The direction of crack propagation can also be obtained, rather than assuming fixed directions of the failure surfaces.[14,15)]

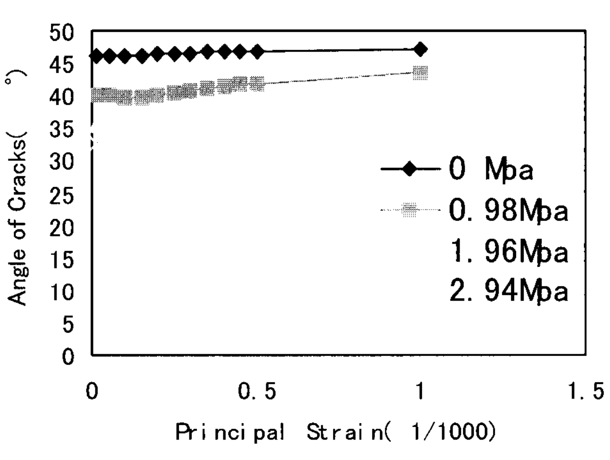


Fig. 9 Principal strain vs. crack angle

5. Conclusions

The effect of prestress on the grout type transverse joint is tested with a loading equipment designed and constructed in the lab to induce a shear failure. The followings are confirmed as results.

1) By restraining the free end of the cantilever beam from rotation, pure shear can be applied on the transverse joint of the specimens.
2) Longitudinal prestressing is an effective method to strengthen the joint against tensile failure and to increase shear strength.
3) Shear cracking load and ultimate load can be increased if epoxy is used as a grouting material.
4) Cracking and ultimate loads can be estimated if prestress is introduced to prevent tensile cracks along the joint interface.
5) Inclination of the diagonal shear crack changed from 35° to 45°, angles decreasing with increase of prestress.

The labor cost can be reduced if precast slabs are used for the construction of bridge structures. However, bearing capacity of the transverse joint must be established in order to carry out the design of the precast slabs. Estimation of shear cracking and ultimate loads for the grout type joint can be obtained with simple equations provided in this study and may accommodate the design of such joints.

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