Influence of Construction Joints in Wet-Mix Shotcrete Panels

by Jean-Francois Trottier, Dean Forgeron, and Michael Mahoney
Department of Civil Engineering—Dalhousie University—Halifax, Nova Scotia, Canada

Where a section of shotcrete is left incomplete at the end of a shooting shift, some provision must be made to ensure that the joint will not develop a plane of weakness at this point. According to the American Concrete Institute's "Guide to Shotcrete"[1] and the "Unified Facilities Guide Specifications,"[2] construction joints should be tapered to a shallow edge form, about 25 mm thick. (1 in.) Therefore, in North America, contract specifications will typically require that shotcrete construction joints be tapered to a 45-degree edge and be thoroughly cleaned and wetted prior to the application of additional shotcrete. When welded wire mesh reinforcement is used, some contractors will also overlap two layers of mesh at the expected location of construction joints in the anticipation that the shotcrete at the joint may be weaker than the unjointed portions of the shotcrete.

Globally, the use of steel and structural synthetic fiber reinforcement instead of welded wire mesh is rapidly growing in a variety of shotcrete applications. Recent wet-mix shotcrete test programs involving the use of the South African Water Bed[3] and Round Determinate Panel[4] test methods have demonstrated that both high-performance steel and structural synthetic fibers offered superior cracking resistance when compared with conventional welded wire mesh.[5] Concerns have been raised, however, by a number of contractors and engineers about the effectiveness of fiber reinforcement in offering a level of continuity comparable to that of welded wire mesh at the location of construction joints. When fiber-reinforced shotcrete is used, some designers have even recommended that strips of mesh be installed at the construction joint locations to provide sufficient continuity across the joints.

In an effort to evaluate the effectiveness of fibers and mesh in transferring stresses across construction joints, the flexural performance of large shotcrete panels (fiber and welded wire-mesh-reinforced panels with and without construction joints) was evaluated using the South African Water Bed test method. The objective of this investigation was to determine if special precautions should be taken at the construction joint locations when using fiber reinforcement. This paper also discusses the relative performance (flexural toughness, cracking pattern) of the various reinforcement alternatives investigated.

Test Program

To make comparisons between the different reinforcing alternatives as realistic as possible, the same shotcrete mixture design was used for all

Table 1: Wet-mix shotcrete proportions

Material	Notes	Quantity kg/m³ (lb/yd³)
Cement	CSA Type 10	400 (675)
Silica fume	—	30 (51)
Fly ash	Class F	45 (76)
Water	Moisture corrected	180 (300)
Coarse aggregate	10 mm max. size	450 (758)
Fine aggregate	Concrete sand	1210 (2040)
Air entrainment*	Darex II	for 7 to 10%
Water-reducing admixture	WRDA	1200 ml (0.32 gal.)
Superplasticizer†	ADVA	2000 ml (0.52 gal.)

**Air entrainment specified to 7 to 10% initial content with final as shot content measured to 2 to 3%.*
†Superplasticizer added only to fiber-reinforced mixtures to achieve desired final slump of 60 to 80 mm (2.4 to 3.2 in.).

shotcrete evaluated. This mixture is similar to that used for permanent shotcrete linings in tunnels and mines, slope stabilization, and infrastructure rehabilitation projects in North America. Details of the mixture proportions are presented in Table 1.

The concrete mixture was delivered by ready-mix trucks to the shooting site where the properties of slump, air content, and temperature were verified before and after fiber addition. Fibers were added to the ready-mix truck and mixed for 5 min at full mixing speed to ensure proper fiber distribution. Four compressive strength cylinders (100 x 200 mm [4 x 8 in.]) and four flexural beam specimens (100 x 100 x 350 mm [4 x 4 x 14 in.]) for toughness evaluation, as per ASTM C 1018, were prepared for each option evaluated using the concrete directly from the ready-mix truck.

The equipment used for the projection consisted of a MAYCO piston ball concrete pump and a 185 CFM air compressor. At the pump, the line had a 100 mm (4 in.) inside diameter and was reduced by a metal reducer to 50 mm (2 in.) all the way to the nozzle, with no reduction at the nozzle.

Two large 1600 x 1600 x 75 mm (63 x 63 x 3 in.) thick South African panels were shot for each of the following reinforcing options evaluated (note: all jointed panels were shot in 2 consecutive days with an approximate 150 mm [6 in.] wide chamber at the center). The mesh was placed at the middepth of the panels:

- Plain shotcrete panels—with (P1) and without (P) construction joint;
- Welded wire mesh (102 x 102 x 4.1 mm/4.1 mm gage [4x4-W2.1xW2.1]) reinforced panels—with (A1) and without (A) construction joint. Note that the mesh had a 200 mm (8 in.) overlap at the joint location for the jointed panels (as recommended in practice). The unjointed panels had no mesh overlap;
- Hooked-end steel fiber-reinforced panels (40 kg/m^3 [67 lb/yd^3])—with (H1) and without (H) construction joint;
- Monofilament fibrillating synthetic fiber-reinforced panels (6.9 kg/m^3 [11.6 lb/yd^3])—with (C1) and without (C) construction joint; and
- Monofilament fibrillating synthetic fiber-reinforced panels (6.9 kg/m^3 [11.6 lb/yd^3]) with 300 mm (12 in.) wide strip of 102 x 102 x 4.1 mm/4.1 mm (4x4-W2.1xW2.1) gage welded wire mesh at the joint location—with (C1M) a construction joint.

A total of 18 South African Water Bed panels were required for this program. A schematic of the fibers and mesh evaluated in this investigation is presented in Table 2.

Figure 1 shows a view of the different shooting stations under preparation. Figure 2 and 3 show a

Figure 1: South African panel shooting stations.

Table 2: Fibers and mesh investigated

ID	Reinforced dimensions (mm)	Material
A	102; 102; (4 in. x 4 in. 8/8); 4.1	steel
C before mixing	50; 0.37; 1.1	monofilament fibrillating polymer blend
C after mixing	50; Various 0.05 - 1.0	
H	4; 30; 4; 2; 0.55	steel

[1 mm = 0.4 in.]

Figure 2: Mesh reinforced South African panel (jointed) before shooting.

Figure 3: Mesh reinforced South African panel (jointed) after shooting.

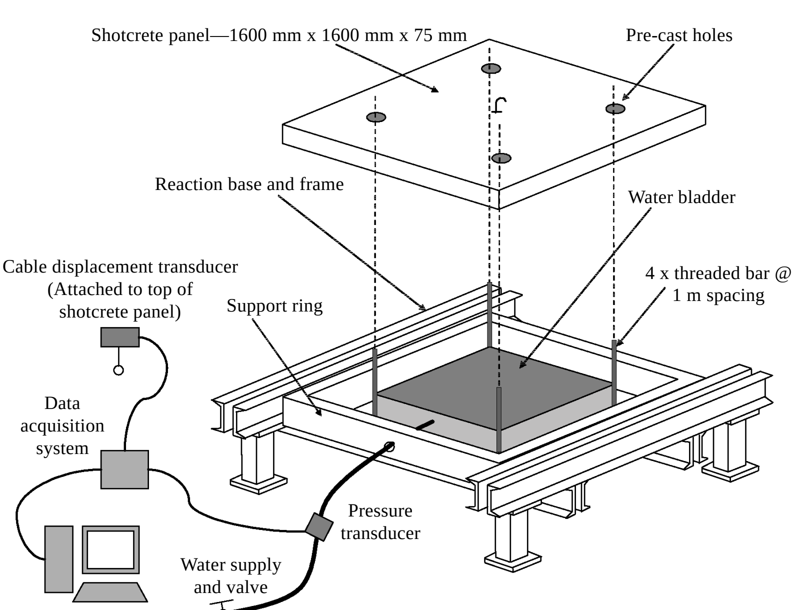


Figure 4: Schematic of South African Water Bed Test.

view of the jointed panels reinforced with the welded wire mesh before and after shooting. Notice in Fig. 2 that the mesh overlapped a 200 mm (8 in.) width right at the center of the panel. All joints were centered in the panels and tapered creating a chamber of approximately 150 mm (6 in.) width. Immediately after shooting, all panels were finished using a smooth steel trowel to obtain a uniform thickness of 75 mm (3 in.). The panels were covered with a wet burlap and wrapped in a plastic sheet to prevent evaporation. The shooting of all panels with a construction joint was completed 24 h following the initial shotcrete application. All panels were left onsite for 72 h and then transported to the laboratory for 7-day testing.

Test Results and Discussion

Figure 4 shows a schematic of the South African Water Bed test apparatus used in this investigation.

Table 3 presents the average results obtained for all different reinforcing options evaluated. The results include the panel cracking load and peak load in kN, and the cumulative energy in J, measured at 25, 50, 75, 100, and 150 mm (1, 2, 3, 4, and 6 in.) center point deflections. Figure 5 shows the averaged load-deflection curves of all options evaluated. Although only two large panels were tested for each reinforcing option investigated, the variation between similar panels was extremely low when compared to trends usually observed on small beam specimens. The authors are, therefore, very confident that a larger number of samples were not required to produce statistically valid data.

A close look at the results obtained on the plain shotcrete panels (P and P1) seems to indicate that the presence of the construction joint did not have a negative effect on the flexural behavior of the panels. The cracking pattern of Panels P1 showed that the jointed panels did not crack along the location of the construction joint and these panels displayed a similar crack pattern to the unjointed Panels P. As expected, due to the absence of reinforcement in Panels P and P1, the number of cracks was very low at the 150 mm (6 in.) deflection limit and the crack widths of the few cracks present were very large. As shown in Table 3, the cumulative energy of the jointed plain shotcrete panels (P1) was slightly higher, at all deflections, compared with that of the companion plain unjointed shotcrete panels (P).

The cracking pattern of the unjointed mesh reinforced panels (A) was very simple with only four major cracks of significant width. As mentioned previously, the mesh jointed panels (A1) had a 200 mm (8 in.) mesh overlap at the joint location to increase the amount of steel at the joint location in anticipation that the joint area may be weaker

Table 3: Summary of South African Water Best Test Results

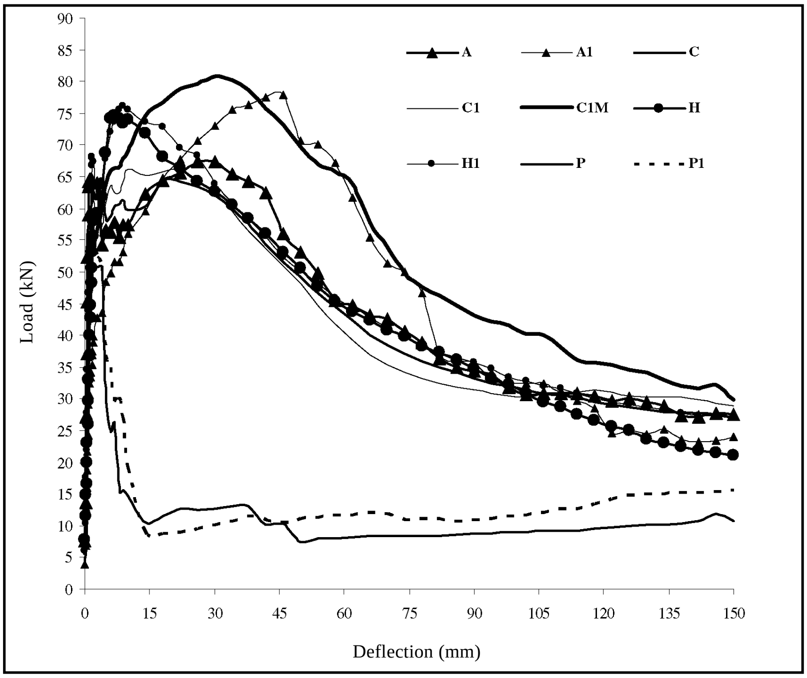
Panel ID	Crack load (kN [kips])	Peak load (kN [kips])	SAWB Energy (J) to given deflection (mm)				
			25 mm (1 in.)	50 mm (2 in.)	75 mm (3 in.)	100 mm (4 in.)	150 mm (6 in.)
A	64 (14.4)	71 (16.0)	1501	3073	4199	5065	6545
A1	42 (9.4)	78 (17.5)	1387	3266	4776	5700	7030
C	65 (14.6)	70 (15.7)	1506	2935	3993	4840	6294
C1	62 (13.9)	68 (15.3)	1565	2984	3974	4769	6289
C1M	55 (12.4)	81 (18.2)	1724	3657	5175	6289	8045
H	60 (13.5)	77 (17.3)	1654	3110	4210	5097	6362
H1	69 (15.5)	78 (17.5)	1728	3192	4301	5203	6678
P	51 (11.5)	51 (11.5)	453	739	944	1159	1654
P1	56 (12.6)	56 (12.6)	517	785	1074	1350	1839

than the rest of the panel. The cracking pattern of the jointed mesh reinforced panels (A1) was more complex with a greater number of smaller width cracks.

As shown in Table 3, the mesh reinforced jointed panel (A1) cracking load was 34% lower than that of its unjointed counterpart. The negative impact from the construction joint on the mesh reinforced panels was observed for deflections up to approximately 20 mm (0.8 in.). It is possible that the decreased performance at initial cracking and small deflections was caused by voiding behind the double layer of mesh at the joint location. A visual observation of the panels after demolding revealed that both jointed panels had developed cracks (bottom face of the panel) along the length of the construction joint possibly attributed to voiding.

Given that the data generated on the plain shotcrete panels (P and P1) indicated that the construction joint did not affect the flexural performance of the panels, this could indicate that the overlap of the mesh itself was responsible for the lower performance of the mesh jointed panels (A1). The performance of the jointed panels (A1) was significantly superior, from 20 mm (0.8 in.) to 75 mm (3 in.), when compared with the unjointed mesh reinforced panels (A). This improvement is attributed to the increased amount of steel in Panels A1.

The panels reinforced with the coarse monofilament synthetic fibrillating fiber at 6.9 kg/m^3 (11.6 lb/yd^3) (C and C1) behaved almost identically, which would indicate that the presence of the construction joint did not have a negative impact on the flexural behavior of the panels. The cracking pattern of Panels C and C1 was fairly complex and resembled that of Panels A1 that had a double layer of mesh at the joint location. As mentioned previously, Panels C1M, which



[1 mm = 0.4 in., 1 kN = 225 lbf]

Figure 5: South African Water Bed Test load-deflection curves.

incorporated the same fiber type and dosage, had a 300 mm (12 in.) wide strip of 102 x 102 x 4.1 mm/4.1 mm (4x4-W2.1xW2.1) gage welded wire mesh at the joint location. The performance and cracking pattern of Panels C and C1 have demonstrated that this mesh strip is not required to warrant proper continuity at the location of construction joints with this type of fiber reinforcement. The interest has now moved to the observation of any added benefits that this mesh strip could offer to the fiber-reinforced panels. Interestingly, as can be seen in Table 3, there is a possible indication from the cracking load of Panels C1M, when compared with that of Panels C and C1, that the presence of the mesh was again responsible for the lower breaking loads, as seen with Panels A1. Apart from the slight reduction in the cracking load, the total cumulative energy at the 150 mm (6 in.) deflection limit of panels C1M was 28% greater than that of the companion Panels C1. The excellent performance of Panels C1M generated very complex cracking patterns (large numbers of cracks of very fine dimensions).

The cracking pattern of Panels H and H1 was similar and resembled that of Panels A1 (double layer of mesh at the joint location) and the synthetic fiber-reinforced Panels C and C1. As shown in Table 3, the panels with the construction joint displayed higher overall performance than their unjointed counterparts.

On the relative performance of the various reinforcing alternatives evaluated, the following observations can be made. As expected, the plain unreinforced shotcrete panels displayed the lowest flexural cracking resistance of all panels evaluated.

The performances of the unjointed mesh reinforced panels (A) and the coarse monofilament synthetic fiber-reinforced panels (C) are almost identical at all deflections with the only difference being that the fiber-reinforced panels displayed a larger number of small width cracks compared to a few significantly larger cracks for the mesh reinforced panels. The unjointed steel fiber-reinforced panels (H) outperformed both mesh (A) and synthetic fiber (C) reinforced panels up to a deflection of approximately 25 mm (1 in.) and provided similar load-carrying capacity between 25 and 100 mm (1 and 4 in.) center point deflection, followed by a lower performance beyond 100 mm (4 in.).

Conclusions

Based on the results generated by this testing program on large jointed and unjointed South African Water Bed panels, the following conclusions can be made:

- The presence of construction joints did not have a detrimental effect on the cracking behavior of plain, monofilament fibrillating synthetic and hooked-end steel fiber-reinforced shotcrete panels. It is anticipated that similar trends will be observed in the field. It is, therefore, concluded that when steel or synthetic fibers are used in the field, no particular precaution, other than the proper fabrication and preparation of the joint itself, is required at the construction joint locations;
- The presence of a construction joint on a mesh reinforced shotcrete panel in which the mesh has been overlapped at the joint location appears to have a detrimental impact on the initial cracking load and behavior at small deflections of the panels. It is possible that the mesh may cause voiding during the shooting process and create a weakness at the construction joint location. Based on the results obtained with the plain jointed shotcrete panels, the authors conclude that the overlapping of the mesh at the construction joint is not required. The reduced amount of mesh at the joint location should also reduce the potential of voiding behind the mesh; and
- The performance of both fiber types investigated in this program offered similar or superior performance, as measured with the South African Water Bed Test method, to the performance of the 102 x 102 x 4.1 mm/4.1 mm (4x4-W2.1xW2.1) gage welded wire mesh.

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References

1. ACI 506.R-90 (Reapproved 1995), 1995, "Guide to Shotcrete ," American Concrete Institute, Farmington Hills, MI, 1995, 41 pp.

2. "United Facilities Guide Specifications, Division 03—Concrete," Section 03371, *Shotcrete*, September 2001.

3. Kirsten, H. A. D., *Report on System Ductility of Long Fiber Reinforced Shotcrete*, Report No. 208905/1, Steffen, Robertson and Kirsten, Consulting Engineers and Scientists, June 1997.

4. Bernard, E. S., *The Behavior of Round Steel Fiber Reinforced Concrete Panels Under Point Loads*, Engineering Report No. CE8, School of Civil Engineering and Environment, UWS Nepean, Kingswood, NSW, Australia, 1998.

5. Morgan, D. R.; Heere, R.; McAskill, N.; and Chan, C., *System Ductility of Mesh and Fiber Reinforced Shotcretes*, AGRA Earth and Environmental, Burnaby, BC, 1999.

Note

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