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Evaluating Applicability of ASTM C 928 Approach in Assessing Adequacy of Patch Repair of Bridge Piers

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P A P E R I N F O

A B S T R A C T

Severe environmental conditions in many parts of Iran could adversely affect infrastructures, especially bridge piers. This research evaluates the efficiency of fiber-reinforced polymer-modified self-compacting concrete in patch repair of bridge piers. The efficiency of this material for repair has been verified using ASTM C 928 and a novel testing method (patch test) that uses a cylindrical compression test simulating indirect force transfer from old (existing) concrete to new (patch repaired) concrete. To investigate the efficiency of self-compacting concrete in patch repair and derive the correlation between bond strength and patch strength, two sets of specimens have been included in the experimental program. These include 24 and 27 specimens which are prepared for patch and slant shear tests, respectively. Test results show significant improvement in strength due to use of polymer modified and fiber reinforced self-compacting concrete in slant shear tests, where strength enhancement as much as 50% (compared to undamaged specimens) was observed. Meanwhile, in the patch tests, repaired specimens are only able to barely exceed the original strength of undamaged specimens. In the slant shear tests, the use of polymer is very effective in increasing bond strength and using fibers reduces observed variation in the strength of repaired specimens. Considering force path in the patch repair and regardless of materials used for repair, the results show that judging the efficiency of the repair method based on the slant shear test, as proposed by ASTM C 928, in the case of patch repaired elements could be misleading.

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1. INTRODUCTION

Due to increasing infrastructure life in recent years, repair and reconstruction of the existing structures have become a major part of construction activities. Some estimates indicate that in 2010 repair and maintenance costs accounted for about 85% of total construction costs in the world [1]. Hence, it is important to select simple, applicable, efficient, and low-cost methods for repairing damaged structures.

Bridge piers are subjected to severe environmental conditions, and commonly are in need of localized patch repairs. There are different options for these repair attempts, including [2]

- steel jacket
- FRP jacket
- concrete jacketing using normal strength concrete
- self-compacting concrete jacket.

Steel jackets are relatively easy to install, and have less thickness in comparison with the RC jackets [3-5], where cement or epoxy mortar are used to fill the gaps between the jacket and column. However, in contrast to concrete jackets, steel jackets are difficult to apply especially in the case of round bridge piers. Steel jackets provide a useful solution for element-wise repair/retrofit as opposed to patch repair and are not suitable for aggressive environments.

FRP jackets provide a corrosion resistant, lightweight and durable solution for repair of damaged reinforced concrete elements [6-8]. This method is also used extensively in retrofitting historic buildings [9-10] and different structural elements [11]. But on the other hand, it is expensive and weak when exposed to fire and ultraviolet radiation.

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Normal strength concrete (NSC) jackets, due to the need for compaction, are difficult to apply in small thickness [12-13]. In contrast, self-compacting concrete (SCC) jackets are easy to apply in narrow thicknesses with no need for compaction. These have led to a wide range of SCC applications for improving and repairing concrete bridges and tunnels [14-15] and they are applicable at thicknesses less than 50 mm even with reinforcement layers. This allows the possibility of repairing structures with slight changes in their rigidity and dynamic properties, which are very important in controlling structural performance.

Different researchers have investigated improvement in bond strength between old and new concrete making use of polymer-modified cement mortar. In polymer modified concrete, part of the resistance is due to the hydration in the cement matrix and the other part is due to the formation of a polymer film around the aggregates. This leads to improved adhesion and bonding between the cement matrix and the concrete grains. Compared to NSC, the compressive strength of polymer-modified concrete increases at a higher rate, even after 28 days. Park et al., [16] with the aim of investigating the flexural behavior of beams repaired with cementitious mortar, tested 8 beams repaired in the tension region with ordinary Portland and polymer-modified cement mortar. They concluded that polymer-modified mortar, due to its high adhesion to base concrete, performs better in repairing beam tensile zones than ordinary Portland cement mortar. To investigate the effect of polymer used on the adhesion of base and repair concrete, Pellegrino et al. [17] experimentally investigated the enhancement in the strength of samples with polymer-modified mortar. The results indicated that deep repair including longitudinal reinforcement will behave well but the surface repair did not perform well due to early separation of repaired concrete from the old one.

Addition of fiber improves different durability characteristics of reinforced concrete element including fire endurance, freezing and thawing resistance, weathering, scaling and corrosion resistance [18-19]. At the same time, application of steel fibers in repair concrete leads to increased ductility and energy absorption of the concrete samples [20]. Polymer and fibers, both improve the durability of the structure against aggressive environmental factors and reduce the likelihood of damage to the structure.

Repair measures could be classified as local (patch) versus element-wise. Different tests have been devised and widely used for measuring the efficiency of the repair. These include, but is not limited to the following tests

- Slant shear test
- Indirect tensile test that is also called splitting tensile test
- Pull-off test
- Compression test
- Flexural test

Table 1 presents a description of different versions of these tests reported or used by different researchers or standards.

As can be seen in Table 1, ASTM C928 [22] that covers rapid repair of concrete pavements and structures using cementitious mortar or concrete materials, makes use of slant shear test of ASTM C882 to measure bond strength between repair material and old concrete. It should be noted that ASTM C928 is also considered as the standard covering requirements for patch repairs. Slant shear test was originally used in ASTM C882 on cylindrical samples to evaluate epoxy bond strength. The test uses a cylindrical mold, where repair material is poured on dummy section with slant interface that is skewed 30° from the cylinder axis. Different researchers used different variants of this test to evaluate bond strength between old and new concrete, making use of cylindrical and rectangular prism samples with different slant angles ranging from 30 to 70°. An important observation made in this test was that its strength strongly depends on the surface preparation of the interface. Austin et al. [25] using Mohr-Coulomb failure envelope concluded that the critical slant angle (associated with minimum compressive strength) for different types of surface preparation varies between 19~27°.

Dave [32] concluded that slant shear test has a large deviation, requiring careful sample preparation. They do not include slant shear test in the set of their recommended tests required for checking adequacy of repair material for partial depth repair attempts as an alternative for ASTM C928. They also found that considering the stress field in concrete slabs for partial depth repairs, there is no correlation between bond strength (evaluated adopting ASTM C900 anchor pullout test) and flexural strength of the partial depth repairs. It should be noted that stress fields for patch repair of bridge piers is similar to that of partial depth repairs in the bridge deck.

In Table 1, there are also other types of bond strength evaluation tests including indirect tensile and pull-off tests. Indirect tensile test also known as splitting tensile test similarly is used to measure bond strength between old and new concrete. Again, cylindrical and rectangular prism samples are used as an alternative. Contrary to those seen in the slant shear test, observations show less dependence of this test to surface preparation. Pull-off test is also proposed by some researchers to evaluate bond strength. In fact, the appropriateness of different tests for given conditions of the bonding interface depends on the stress state at the interface.

All of the above-mentioned tests assume a continuous path of load in old to new concrete accompanied mainly by some form of shear transfer in between. This is not the case for localized repair attempts, where there is indirect force transfer from old concrete to the repair concrete. This is accompanied by some form of stress concentration in the repair location in the old concrete. In the patch repair, the main contribution of the repair

TABLE 1. Testing methods employed by different researchers for evaluating repair efficiency

Test	Researcher	Used for evaluating	Variants
Slant shear test	ASTM C882 [21]	Epoxy bond strength	Cylindrical, Angle 30°
	ASTM C928 [22]	Repaired concrete	Uses ASTM C882 to measure bond strength
	BS EN 12615 [23]		Rectangular prism, Angle 30°
	Knab and Spring [24]		Cylindrical, Angle 30°
	Austin et al. [25]		Cylindrical sample Different preparation of interface
	Ehsani et al. [26]		Rectangular prism, Angle 30°
	Momayez et al. [27]		Different preparation of interface
	Muñoz [28]		Rectangular prism, Angle 20, 30, 35° Different preparation of interface
	Pan [29]		Rectangular prism, Angle 70° Different preparation of interface
	Nayak et al. [30]	Evaluating bond strength	Cylindrical, Angle 30°
Indirect tensile test	Ehsani et al. Momayez et al.		Prism
	Nayak et al.		Cylindrical sample
	Pan		
Pull-off test	Ehsani et al. Momayez et al.		Cylindrical sample
	Pan		
	Cleland and Long [31]		
Modified pull-out test	Dave [32]		Uses ASTM C900 developed for anchor pull-out test
Compression test	Pan		Rectangular prism
	Dave	Repaired concrete	Cylindrical sample
Flexural test	Dave		Rectangular prism / three points flexural test

concrete is to provide a protective shield and some degree of confinement. This discontinuous stress field could not be simulated by the above-mentioned tests and consequently the results could not be trusted as the actual behavior of the repaired section/element.

This study investigates application of SCC with polymer and fiber in patch repair of bridge piers. Two testing methods are used in this study, including slant shear test as required by ASTM C928 and a novel compression test accounting for indirect load transfer from old to new concrete (hereafter called patch test). The latter is developed in this study to simulate stress fields in the elements with patch repair. In the following, first materials used in the study are introduced and then the testing methods are described in detail. Finally results of tests are reviewed and the correlation between the two testing methods considered in this study is assessed.

2. MATERIALS

The materials used in this study include:

- Cement: the used cement is type 2 cement of Urmia cement plant.
- Water: The used water is drinking water with a pH between 5 and 8.5
- Aggregates: River aggregates are obtained from Ghar e Ghom mine in Khoy with a maximum grain size of 6.35 mm.
- Micro-silica: Micro-silica used in self-compacting concrete is manufactured by Lorestan Ferro-silica plant.
- Limestone powder: Limestone powder is obtained from Azarshahr Lime Plant.
- Polymer: The polymer used was Latex Styrene-Butadiene Rubber (SBR) latex for modifying self-compacting concrete, it was a milky white liquid polymer with a pH of about 8.
- Steel fibers: Steel fibers used are per ASTM 510M standard with a tensile strength of 1500 MPa, and a hook at its ends for better development in concrete. The fiber length is 30 mm, its diameter is 0.6 mm and its apparent ratio is 50.

- Superplasticizer: The used superplasticizer is polycarboxylate ether (PCE) type in accordance with ASTM C 1017.

Table 2 shows the mixing proportion for normal strength concrete (NSC), self-compacting concrete (SCC), polymer modified SCC (PM-SCC), and fiber reinforced PM-SCC (FR-PM-SCC). Strength of the hardened concrete samples are given in Tables 3 and 4.

3. TESTING METHODS AND SPECIMENS

The experimental program includes two sets of specimens, including:

- New test, called patch test that is designed to

simulate indirect force transfer from old concrete to repaired one and discussed in section 3.1.

- Slant shear test in conformance with ASTM C 928, which is mainly designed to verify adequacy of bond strength between the two concretes. The specimens used in this test are introduced in section 3.2.

3. 1. Patch Test   The test called patch test is designed to simulate indirect force transfer from old to new concrete. While in bond strength evaluation tests such as slant shear test, old and new (repair) concrete experience the same stress field, in the patch test, load is mainly introduced through old concrete. This is the loading situation that patched piers experience during their life time.

TABLE 2. Mixing proportion for different types of concrete used in this study.

Concrete	Cement content (kg)	Water (kg)	w/c	Plasticizer (kg)	Micro-silica (kg)	Limestone Powder (kg)	Sand (kg)	Aggregate (kg)	Polymer (kg)	Steel fiber (kg)
NSC	300	201	0.67	-	-	-	1150	800	-	-
SCC	420	152	0.36	17	80	175	1500	-	-	-
PM-SCC	420	153	0.36	26	80	175	1500	-	32	-
FR-PM-SCC	445	147	0.33	28	85	185	1403	-	33	60

TABLE 3. Specimen description in the patch tests.

Designation	Damage/Repair	No. of specimens	Old concrete type/ Strength (MPa)	Repair concrete type/ Strength (MPa)	Interface
PD	**Damaged Specimen**: Damage induced/No repair	6	NSC/24	-	-
PC	**Control Specimen**: No damage/No repair	6	NSC/24	-	No interface
PR1	**Repaired Specimen**: Damage induced/Repaired	6	NSC/24	PM-SCC/50	Roughened with long. grooves
PR2	**Repaired Specimen**: Damage induced/Repaired	6	NSC/24	FR-PM-SCC/60	Roughened with long. grooves

TABLE 4. Specimens description in the slant shear tests

Designation	No. of specimens	Old concrete type/ Strength (MPa)	New concrete type/ Strength (MPa)	Interface
S1A	3			Smooth interface
S1B	3		NSC/20	Brushed interface
S1C	3			Crossover grooved interface
S2A	3			Smooth interface
S2B	3	NSC/20	PM-SCC/50	Brushed interface
S2C	3			Crossover grooved interface
S3A	3			Smooth interface
S3B	3		FR-PM-SCC/44	Brushed interface
S3C	3			Crossover grooved interface

The patch test specimens consist of a core cylinder of height and diameter of 310 and 120 mm from old concrete, and a surrounding cylinder from repair concrete of 300 mm in height with interior and exterior diameter of 120 and 150 mm (Figure 1a). Compression load is applied through old concrete, and there is no direction load application on the top and bottom surfaces of repair concrete .

Table 3 gives a description of the specimens considered in the tests simulating patch repair. These include six control samples (undamaged specimens PC) and eighteen cylindrical samples with induced damage. After opening the mold for a period of up to 28 days, the samples were cured in water of 20°C. In samples simulating damage a circumferential layer of 15 mm thickness is removed (specimens PD, PR1 and PR2), reducing the diameter of the damaged sample to 120 mm.

Specimens PR1 and PR2 are repaired using different methods as described in Table 3.

The lateral surface of damaged samples (interface) is roughened by longitudinal grooves of width and depth of 4 mm and with spacing of 20 mm (Figure 1b). A specimen ready for test is shown in Figure 1c. Table 3 also gives strength of different concretes (old and repair concrete) used in the tests. The repaired samples were cured by 1 day dry, 3 days water curing, and then 24 days with nylon coating in the laboratory condition (20 ± 2°C). The repaired samples were loaded under compressive axial load 28 days after repair and their load-bearing capacity and axial deformations were read .

The loading rate of the samples in the axial loading test was set at 1 MPa / sec. The load-displacement values were read up to load reduction of about 70% of the failure load.
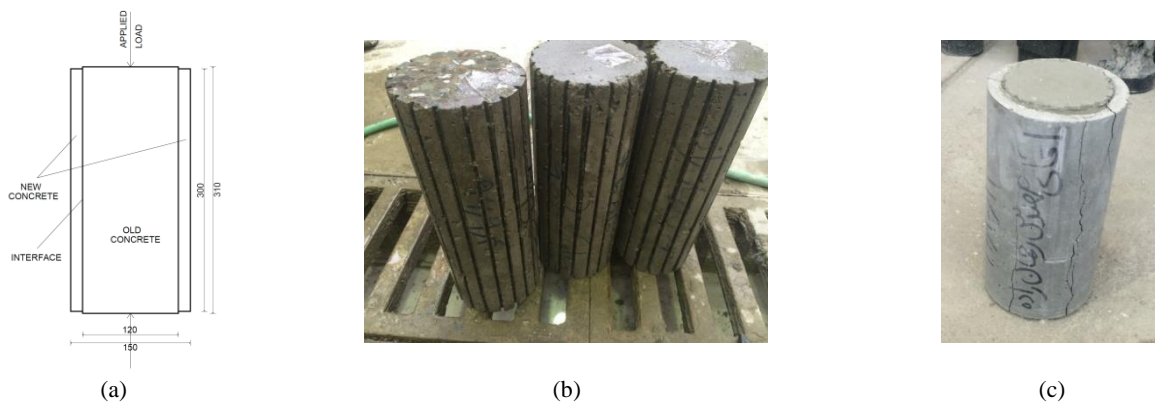

Figure 1. Patch test specimen, a) dimensions, b) damaged concrete (old concrete) of diameter 120 mm, c) tested specimen

3. 2. Slant Shear Test

To evaluate bond strength between old and repaired concrete interface, 27 samples of cylindrical slant tests are molded as depicted in Figure 2. The skewed interface has a slope of 45°. Table 4 gives a description of specimens tested in the slant shear tests. As described in Table 4, three types of surface are considered in the slant shear tests, which include: a) smooth surface, b) brushed surface, c) surface with crossover grooves of width and depth of 4
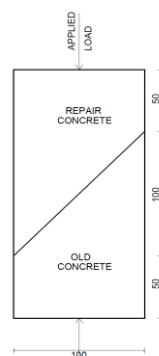

Figure 2. Dimensions of slant shear test

Figure 3. Surface preparations in slant shear tests, a) smooth surface, b) brushed surface, c) grooved surface

mm at intervals of about 20 mm (Figure 3). After 28 days, the second part the specimen is constructed and after curing they are subjected to compressive axial loading.

4. TEST RESULTS

4. 1. Patch Tests   Figure 4 depicts cracking pattern of two specimens in the patch test. The first crack in the repaired samples are longitudinal cracks in the surface of repair concrete. Due to the application of the load on the core concrete, the formation of longitudinal cracks in repair concrete have been due to different modulus of elasticity and consequently different transverse deformation of the core and repair concrete. In the repaired specimens, four longitudinal cracks occur at approximately equal radial angles.

The load-displacement curve for different specimens is shown in Figure 5. The maximum load carrying capacity of repaired specimens (PR1 and PR2) barely exceed that of control specimen (PC). Figure 6 gives minimum, maximum and mean of different specimens evaluated using the patch test. The results of the compression test on the patch specimens could be summarized as follows:

- The mean load carrying capacity of the control and damaged samples (PC versus PD) are 389 and 226 kN respectively. This shows a reduction of about 42% for damaged samples. It should be noted that the cross-sectional area of core concrete in damaged samples is reduced by 36% compared to the control samples.
- Introduction of damage resulted in about 60% reduction in axial stiffness. Repair attempts introduces no improvement in increasing stiffness of the repaired samples.

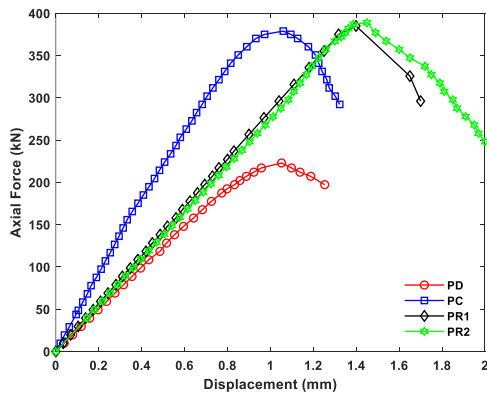**Figure 4.** Cracking pattern of repaired specimens in patch tests

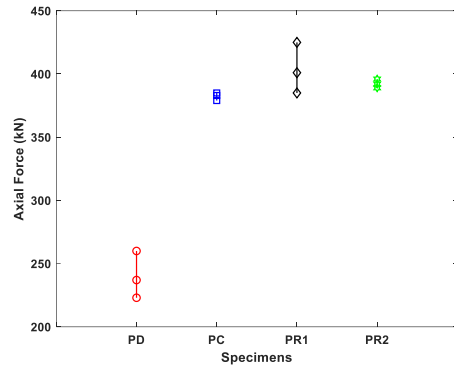**Figure 5.** Typical load-displacement of specimens in patch test

Figure 6. Results of patch tests including minimum, mean and maximum axial strengths

- Samples repaired by PM-SCC has a mean load carrying capacity of 387 kN, which shows an increase of about 71% compared to the damaged samples and slightly lower than the control specimen.
- Samples repaired using FR-PM-SCC has a mean load carrying capacity of 392 kN, an increase of about 73% compared to the damaged samples and slightly larger than the control specimen.
- Introduction of damage increases anticipated variation in the specimen's strength. On the other hand, the use of fiber reinforced repair concrete significantly reduces the variation in the strength.
- Referring to Table 3, although strength of old concrete is about 24 MPa and repair materials have much higher strength between 50~60 MPa, there is only slight increase in the strength of the repaired specimens compared to the old concrete. This shows that due to existing load path in the repaired specimens, even with high quality repair materials, strength of old concrete limits the efficiency of the repair method.

Compared to the control samples, it can be seen that by repairing the damaged samples, the load carrying capacity of the control samples could be recovered.

4. 2. Slant Shear Tests   Figure 7 depicts failure pattern of two specimens tested using the slant shear test method. Interface between the two concretes is also visible in one of the figures. Figure 8 depicts results of the tests. By reviewing results for different specimens, the following conclusions could be drawn:

- In specimens repaired by PM-SCC or FR-PM-SCC, there is about 50% increase in strength compared to the specimens repaired by NSC. It can be inferred that the use of SBR latex polymer has significant effect on the adhesion between old and repair concrete.
- Different surface treatment methods have substantial impact on the strength of the repaired specimen. Increased effort in preparing interface from smooth to brushed and grooved surfaces, increases the strength of the specimens. No interface failure is observed for specimens with minimal surface

Figure 7. Failure pattern of typical specimens in slant shear tests

Figure 9. Evaluating correlation between slant shear and patch tests
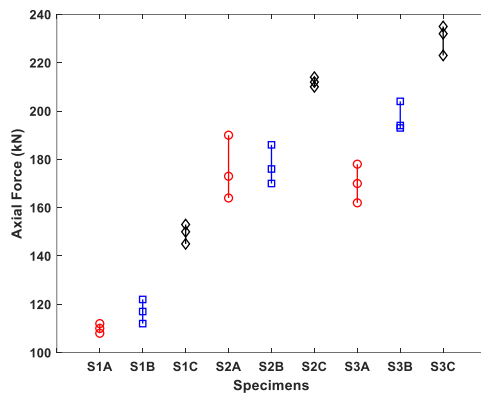

Figure 8. Results of slant shear tests including minimum, mean and maximum strengths

preparation attempt, i.e. specimens with brushed or grooved interface.

- There is reduced sensitivity to the interface preparation method in the specimens repaired by PM-SCC or FR-PM-SCC concrete. This is another indication of superior performance of latex in improving bond strength between old and repair concrete.
- Making use of fiber reduces anticipated variation in the results of slant shear strength. The same pattern is also observed in patch tests.
- Referring to Tables 3 and 4, strength of repair martials is smaller than those used in the patch test, however the results of the slant shear test shows more efficient repair.

4. 3. Correlation between Patch and Slant Shear Tests

ASTM C 928 uses slant shear test to evaluate the adequacy of concrete repair. The main question is that by using the results of slant shear test, is it possible to evaluate the adequacy and efficiency of repair in increasing load carrying capacity of the repaired element. To answer this question, in the present study, the correlation between the results of the patch tests
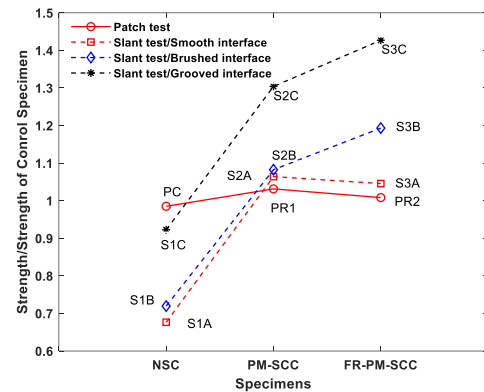
(section 4.1) and slant shear tests (section 4.2) is evaluated. Figure 9 shows the efficiency of different repair methods compared with the compressive strength of the old concrete as assessed using two different testing methods. It is anticipated that as the patch test accounts for indirect load transfer to the repaired concrete, it provides a better estimate of the repaired element. As could be seen, while use of latex significantly improves strength evaluated by the slant shear test results, there is only a slight increase in the strength as assessed by the patch test.

In patch repair, due to the short length of the repair, the repaired concrete could not be considered fully effective. Indirect load transfer from old concrete to repair concrete in patch repair could not be simulated by the slant shear test. Accounting for load path in patch repair, strength of the old concrete introduces a limit on the maximum efficiency of the repair material and method. The slant shear test is more appropriate for testing continuous shear transfer in elementwise repairs rather than local patch repairs.

5. CONCLUSION

This study was conducted to investigate the efficiency of using polymer modified self-compacting concrete with or without steel fiber for patch repair of damaged laboratory samples. Two testing methods are considered in the study for evaluating the effectiveness of the repair procedure, including ASTM C 928 proposed slant shear test and a novel testing method devised to simulate indirect force transfer path in patch repairs. The following results were obtained.

- Results of slant shear tests show the effectiveness of latex polymer in enhancing bond strength between old and repair concrete.
- Results of the patch tests and slant shear tests, both show that use of fibers reduces variation in the strength of the specimens, and results in more predictable repair material.

- Observed variation in the strength of the specimens tested by the patch test and slant shear test is approximately on the same order.

- Strength of old concrete as a weak link in the load path should impose an upper limit on the strength of the repaired specimens. This is not the case for the slant shear test and using repair materials of higher strength leads to higher strength for the repaired specimens in the slant shear test. Although slant shear test shows about an 50% increase in strength compared to undamaged specimens, new proposed test methods evaluating patch repair effectiveness show little if any increase in the strength of the repaired specimens compared to the undamaged specimens.

- Considering force path in the patch repair and regardless of the materials used for repair, the efficiency and adequacy of patch repair could not be evaluated using slant shear test as suggested by ASTM C 928 and the use of this test in evaluating adequacy of patch repair could be misleading.

6. REFERENCES

1. Mourad, S.M., Shannag, M.J., Repair and strengthening of reinforced concrete square samples using ferro-cement jackets, *Cement and Concrete Composites*, Vol. 34, No. 2, (2012), 288–294, https://doi.org/10.1016/j.cemconcomp.2011.09.010.

2. Delatte, N., Failure, Distress and Repair of Concrete Structures, Elsevier, (2009).

3. Giménez, E., Adam, J. M., Ivorra, S., Moragues, J. J., & Calderón, P. A. (2009). Full-Scale Testing of Axially Loaded RC Columns Strengthened by Steel Angles and Strips. *Advances in Structural Engineering*, Vol. 12, No. 2, (2009), 169–181. https://doi.org/10.1260/136943309788251704.

4. Choi, E., Chung, Y-S., Park, J., Cho, B-S., Behavior of Reinforced Concrete Samples Confined by New Steel-Jacketing Method, **ACI Structural Journal**, Vol. 107, No. 6, (2010), 654-662.

5. Islam, N., Hoque, M., Strengthening of reinforced concrete columns by steel jacketing: a state of review, *Asian Transaction on Engineering*, Vol. 5, No. 3, (2015), 6-14.

6. He, R., Grelle, S., Sneed, L.H., Belarbi, A., Rapid repair of a severely damaged RC column having fractured bars using externally bonded CFRP, *Composite Structures*, Vol. 101, (2013), 225-242, https://doi.org/10.1016/j.compstruct.2013.02.012.

7. Chellapandian, M., Prakash, S.S., Sharma, A., Axial compression–bending interaction behavior of severely damaged RC columns rapid repaired and strengthened using hybrid FRP composites. *Construction and Building Materials*, Vol. 195, (2019), 390-404, https://doi.org/10.1016/j.conbuildmat.2018.11.090

8. Mohammed, A.A., Manalo, A.C., Ferdous, W., Zhuge, Y., Vijay, P.V., Alkinani, A.Q., Fam, A., State-of-the-art of prefabricated FRP composite jackets for structural repair, Engineering *Science and Technology*, (2020), https://doi.org/10.1016/j.jestch.2020.02.006.

9. Ozturk, B., Senturk, T., Yilmaz, C., Analytical investigation of effect of retrofit application using CFRP on seismic behavior of a monumental building at historical Cappadocia region of Turkey, 9th U.S. National and 10th Canadian Conference on Earthquake Engineering, Toronto, Canada (2010).

10. Ozturk, B., Yilmaz, C., Senturk, T., Effect of FRP retrofitting application on seismic behavior of a historical building at Nigde, Turkey, 14th European Conference on Earthquake Engineering, Ohrid (2010).

11. Dehghani, H., Fadaee, M.J., Reliabilty-based torsional design of reinforced concrete beams strengthened with CFRP laminate, *International Journal of Engineering, Transactions A: Basics*, Vol. 26, No. 10, (2013), 1103-1110.

12. Júlio E.N.B.S., Branco F.A., Reinforced concrete jacketing-interface influence on cyclic loading response, **ACI Structural Journal**, V. 105, No. 4, (2008), 471-477.

13. Rodrigues, H., Pradhan, P.M., Furtado, A.F., Rocha, P., Vila-Pouca, N., Structural repair and strengthening of RC elements with concrete jacketing, *Strengthening and Retrofitting of Existing Structures, Springer*, Vol. 9, (2018), 181–198.

14. Omar, M.Y.M., Gomes, R.B., Reis, A.P.A., Experimental analysis of reinforced concrete samples strengthened with self-compacting concrete, *Revista IBRACON de Estruturas e Materiais*, Vol. 3, No. 3, (2010), 271–283.

15. Dubey, R., Kumar, P., Experimental study of the effectiveness of repairing RC cylindrical samples using self-compacting concrete jackets, *Construction and Building Materials*, Vol. 124, (2016), 104–117.

16. Park S.K., Yang D.S., Flexural behavior of reinforced concrete beams with cementitious repair materials, *Materials and Structures*, Vol. 38, (2005), 329–341.

17. Pellegrino, C., Porto, F., Modena, C., Rehabilitation of reinforced concrete axially loaded elements with polymer-modified cementicious mortar, *Construction and Building Materials*, Vol. 23, (2009), 3129–3137.

18. Lampropoulos, A.P., Paschalis, S.A., Tsioulou, O.T., Dritsos, S.E., Strengthening of reinforced concrete beams using ultra high performance fibre reinforced concrete (UHPFRC), *Engineering Structures*, Volume 106, (2016), 370-384, https://doi.org/10.1016/j.engstruct.2015.10.042

19. Meda, A., Mostosi, S., Rinaldi, Z., Corroded RC columns repair and strengthening with high performance fiber reinforced concrete jacket. *Materials and Structures*. Vol. 49, (2016), 1967–1978, https://doi.org/10.1617/s11527-015-0627-1.

20. Beddar, M., Ayadat, T., Belgara, L., Optimizing of steel fiber reinforced concrete mix design *International Journal of Engineering, Transactions B: Applications*, Vol. 17(1), (2004) 41-50.

21. ASTM C 882, Test method for bond strength of epoxy-resin systems used with concrete by slant shear, American Society for Testing and Materials, (2005).

22. ASTM C 928, Standard specification for packaged, dry, rapid-hardening cementitious materials for concrete repairs, American Society for Testing and Materials, (2008).

23. BS EN 12615, Products and systems for the protection and repair of concrete structures: Test methods- Determination of slant shear strength, (1999).

24. Knab, L.I., Spring, C.B., Evaluation of test methods for measuring the bond strength of Portland cement-based repair materials to concrete, National Bureau of Standards, (1988).

25. Austin, S., Robins, P., Pan, Y., Shear bond testing of concrete repairs, *Cement and Concrete Research* Vol. 29, (1999), 1067–1076.

26. Ehsani, M.R., Rajaie, H., Raezanianpour, A., Momayez, A., Experimental investigation of the methods of evaluating the bond strength between concrete substrate and repair materials, *International Journal of Engineering, Transactions A: Basics*, Vol. 15, No. 4, (2002), 319-332.

27. Momayez, A., Ehsani, M.R., Ramezanianpour, A.A., Rajaie, H., Comparison of methods for evaluating bond strength between concrete substrate and repair materials, *Cement and Concrete Research*, Vol. 35, (2005), 748–757.

28. Muñoz, M.A.C., 2012, Compatibility of ultra high-performance concrete as repair material: Bond characterization with concrete under different loading scenarios, M.S. Thesis, Michigan Technology University.

29. Pan, Y., Bond Strength of Concrete Patch Repairs: An Evaluation of Test Methods and the influence of workmanship and environment, PhD Thesis, Loughborough University of Technology, (1995).

30. Nayak, D., Pattnaik, R.R., Bhoi, K.C., Panda, B., (2019). Investigation into material strength and direction of applied forces

to assess bonding behavior of micro-concrete. *Journal of The Institution of Engineers (India): Series A*, 100, 75–82 (2019). https://doi.org/10.1007/s40030-018-0338-z.

31. Cleland, D.J., Long, A.E., The pull-off test for concrete patch repairs, Proceeding of Institute for Civil Engineering Structures and Buildings, Vol. 122, (1997), 451-460.

32. Dave, E.V., Evaluation of concrete and mortars for partial depth repairs, Research Report 2014-41, University of Minnesota Duluth, (2014).

Persian Abstract

چکیده

شرایط محیطی شدید در بسیاری از مناطق ایران می‌تواند منجر به آسیب به زیرساخت‌ها به خصوص پایه پل‌ها شود. این تحقیق به بررسی کارایی بتن خودتراکم اصلاح شده با پلیمر و فیبر به عنوان یک ماده ترمیم و کاربرد آنها در تعمیر لکه‌گیری پایه پل می‌پردازد. راندمان این مواد برای تعمیر لکه‌گیری با استفاده از روند ارائه شده در ASTM C 928 و یک آزمایش جدید (آزمایش لکه‌گیری) کنترل می‌شود. آزمایش لکه‌گیری برای ارزیابی مقاومت المان لکه‌گیری شده با در نظر گرفتن انتقال نیروی غیرمستقیم از بتن قدیمی (موجود) به بتن جدید (بتن لکه‌گیری) تدوین شده است. به منظور بررسی کارآیی بتن خودتراکم در ترمیم لکه‌گیری دو مجموعه از آزمایشات مرکب از آزمایشات لکه‌گیری و برش اریب انجام شدند. نتایج آزمایشات برش اریب بهبود قابل توجهی در استحکام به دلیل استفاده از خودتراکم اصلاح شده با و تقویت شده با الیاف حتی تا میزان ۵۰٪ افزایش مقاومت در مقایسه با نمونه های بدون آسیب نشان دادند. در حالی که در آزمایشات لکه‌گیری روی نمونه‌های آسیب‌دیده، نمونه‌های تعمیر شده به سختی قادر به تامین مقاومت نمونه‌های آسیب‌ندیده بودند. در آزمایشات برش اریب استفاده از پلیمر در افزایش استحکام پیوستگی بتن جدید و قدیم بسیار مؤثر ارزیابی شد و در عین حال استفاده از الیاف منجر به کاهش در پراکندگی مقاومت مصالح شد. بدون توجه به مصالح مورد استفاده برای تعمیر، نتایج این مطالعه نشان می‌دهد که قضاوت در مورد کارآیی روش ترمیم بر اساس آزمایش برش اریب آن چنان که در ASTM C 928 پیشنهاد شده است در مورد مقاومت المان‌های تعمیرشده با لکه‌گیری می‌تواند گمراه‌کننده باشد.