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Rapid Hardening Concrete

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16. Abstract

Results of an experimental investigation on the properties of rapid hardening concrete are reported. Six potential cements that can develop 2000 lbf/in² in 3 hours and workable duration of about 20 minutes were selected based on an extensive literature search. Preliminary strength and workability tests were conducted for these six selected cements. Based on the results of the preliminary investigation, three cements were selected for further investigation. The variables evaluated were: (i) cement type, (ii) cement content, (iii) water – cement ratio, (iv) use of latex, (v) influence of retarding admixture, and (vi) ambient temperature. The response variables were: (i) strength gain with time, (ii) slump loss with time, (iii) workability under vibration, (iv) plastic and drying shrinkage, and (v) relationship between compressive strength and modulus of rupture. The following are the major findings.

- It is possible to formulate a workable concrete that can provide 2000 lbf/in² compressive strength in 3 hours.
- A modulus of rupture of 350 lbf/in² can be easily achieved at 3 hours.
- The strength gain under flexure mode is more rapid that the strength gain under compression loading.
- Retarding admixtures can be added to increase the workable duration to 25 minutes. The concrete flows well under vibration.
- The concrete retains its flowable characteristics better if the mix was kept under constant movement.
- Trial mixes should be made if the coarse aggregate is different from the 0.375 in maximum size trap rock used for the investigation.
- If the ambient temperature is between 65 and 80° F, mix proportions presented in the conclusion section will provide a workable mix for 25 minutes.
- If the ambient temperature is between 80 and 90° F, the retarder dose can be increased by 20 percent. If there is no need for extended workable time, the admixture dosage can be maintained at the same level.
- If the ambient temperature is between 50 and 65 ° F, the admixture dosage should be reduced by 50 percent.
- If the ambient temperature is less than 50° F placement is not recommended, unless heated water is used for the mix and heating blankets are used for curing for at least 3 hours. The concrete should be maintained at about 72° F for a minimum of three hours.
- Rapid Set Concrete is more susceptible to plastic shrinkage cracking as compared to ASTM Type I cement concrete. Therefore, the exposed surface should be protected with curing membrane or wet blanket to avoid any water loss. The surface protection can be applied as soon as the surface becomes hard.
- Rapid Set Concrete shrinks less and therefore cracks less under restrained conditions. It might be possible to formulate a mix that will not crack due to drying or autogenous shrinkage.

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ABSTRACT

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- Rapid Set Concrete is more susceptible to plastic shrinkage cracking as compared to ASTM Type I cement concrete. Therefore, the exposed surface should be protected with curing membrane or wet blanket to avoid any water loss. The surface protection can be applied as soon as the surface becomes hard.
- Rapid Set Concrete shrinks less and therefore cracks less under restrained conditions. It might be possible to formulate a mix that will not crack due to drying or autogenous shrinkage.

INTRODUCTION

There is a critical need for concrete that can attain reasonable compressive and flexural strengths in about 3 hours. In order to avoid interference with heavy traffic in metropolitan areas, repairs are carried out during the nighttime. Usually the lane closures occur between 9 p.m. and 5 a.m. Typical work schedule for the 8 hour window is as follows.

- Close bridge at 9 p.m.
- Mill and shot blast the bridge deck by 11 p.m.
- Place the overlay by 2 a.m.
- Open lane to traffic by 5 a.m.

This scenario provides about 3 hours for placing and finishing concrete and strength development. The research reported in this report deals with rapid set concrete mixes that can attain a reasonable strength in 3 hours. Based on the typical loads on bridge decks and previous experience, a target compressive strength of 2000 lbf/in^2 and a target modulus of rupture of 350 lbf/in^2 were chosen.

Even though a large number of accelerating admixtures are available in the market, very few, if any provides a compressive strength of 2000 lbf/in^2 in 3 hours. Therefore, special proprietary cements were chosen to achieve the objective. The results presented include extensive experimental data obtained during the current investigation and results available in the published literature[1,2].

OBJECTIVES

As mentioned in the introduction, the primary objective was to obtain a concrete mix proportion that can provide a compressive strength of 2000 lbf/in^2 and a modulus of rupture of 350 lbf/in^2 in 3 hours after placement. Additional major requirements were: (i) reasonable working time, (ii) strength gain at different temperatures, (iii) plastic and drying shrinkage cracking under restrained conditions, and (iv) heat of hydration.

RESEARCH PLAN

The research plan consisted of: (i) identifying commercially available cements, (ii) preliminary testing for strength gain and workability duration, (iii) systematic evaluation of compressive and flexural strength gain, (iv) evaluation of plastic and drying shrinkage under restraints, (v) influence of vibration and continuous mixing on workability, and (vi) castability of large slabs. This report presents the results of the first five steps.

The details of the experimental procedure, results, and discussion are presented in the following sections.

IDENTIFICATION OF SUITABLE CEMENTS

Based on the literature search, commercial contacts, and contacts with other public agencies including Virginia DOT, Port Authority of New York and New Jersey, Pen DOT, NY DOT, and New York Thruway Authority, and cement manufacturing companies, the following cements were chosen for preliminary investigation.

Cement A

Cement A, commercially known as Ultamax Cement, is a blend of Portland cement and a proprietary compound that provides a rapid set. Ultamax Company distributes this cement, some times called as sulphate cement. It is being commercially used for a number of applications, including extensive repairs in Los Angeles Airport.

Cement B

Cement B is similar to cement A, but manufactured by a different company. This cement called as CTS cement has also been used for various types of applications including pavements.

Cement C

Cement C has a silicate based additives that provide early strength gain. This cement manufactured by Five Stars had been used in Tappen Zee bridge on Interstate 287. Port Authority of New York and New Jersey has also used this cement in bridges and pavements.

For cement types A, B, and C, the major constituent is Portland cement. Therefore, the hardened concrete has mechanical properties such as modulus of elasticity similar to Portland cement concrete. Cement types A and B also provide less drying shrinkage as compared to normal Portland cement concrete[(1)].

Cement D

Cement D was magnesium phosphate cement, which is distributed as a mortar mix. This cement gains strength rapidly and has been used extensively for repairs. The major concerns are working time which can not be extended with admixtures and sensitivity to water cement ratio. Small increases in water can result in considerable reduction in strength.

The mortar mix can be extended using 0.375 in pea – gravel as a coarse aggregate.

Cements E and F

These two cements were proprietary mixes, specifically developed for rapid repair of pavements and bridge decks. Cement E is a proprietary mix, which is blend of Rapid Set Cement, sand and coarse aggregate (nominal size 0.375 in). The manufacturers recommend the amount of water to be needed.

PRELIMINARY EVALUATION

All the six cements were evaluated for strength gain with primary focus on the first four hours and workable duration. The findings were as follows:
The target slump of 4 in and a minimum workable time of 10 minutes could be achieved for the Portland based cements A, B and C. The working time could be extended using retarders.
Based on these findings, cement types A, B and C were chosen for detailed investigation.

Evaluation of Cement Types A, B, and C
Cement types A, B (Sulphate Cements) and C (Silicate Accelerator) were evaluated using a comprehensive test program to determine the influence of cement content, water cement ratio, amount of retarding admixture, and curing temperature. The response variables were compressive strength, modulus of rupture, and workability.

A total of 37 mix proportions were evaluated for strength gain. The major variables and the ranges are as follows:

- Cement content : 517 to 705 lb/yd^3
- Water-cement ratio : 0.34 to 0.52
- Retarder (citric acid) : 0.25 to 1.00 percent by weight of cement
- Admixtures : latex or high range water reducing Admixture

Concrete sand and crush rock with a maximum size of 0.375 in were used for fine and coarse aggregates respectively. The concrete was mixed using a 9 ft^3 mixer. Cylinders (4 in x 8 in) and prisms (4 x 4 x 4 in) were cast using table vibrator. The top surfaces were covered with impermeable membranes to reduce moisture loss. ASTM procedures were followed for mixing and casting.

Compressive strengths and modulus of rupture were measured at 2, 3, 4, and 24 hours, 7 and 28 days. Modulus of rupture was measured at 3 and 6 hours and at 7 days.

Workability was measured using slump test and a modified flow test. In the flow test, the mix was placed on a flat surface and vibrated to evaluate the performance under mechanical vibration. The major findings are presented in the following sections.

Strength Development

Almost all mixes developed the required 2000 lbf/in² in 3 hours.
The modulus of rupture was much higher for comparable compressive strengths of normal Portland cement concrete. For example, for the mix with a compressive strength of 3500 lbf/in² was in the range of 650 lbf/in². Tests conducted at Port Authority of New York and New Jersey confirm this trend.
Based on the results of the current investigation and limited results available in the literature, the author recommends mixes with cement contents of 611 or 658 lb/yd³. The complete mix proportions are presented in the conclusion section.

For the mixtures with cement content of 611 lb/yd³, the compressive strengths range from 2100 to 2200 lbf/in² at 3 hours for cement types A and B. Cement type C has a higher strength. The 28 day strength is about 4800 lbf/in². Modulus of rupture varies from 500 to 800 lbf/in², far exceeding the target of 350 lbf/in².

Workability

After 10 minutes, the slump is in the range of 3 to 4 in. The values reduce to 1.5 in after 15 minutes.
The mixes are thixotropic and therefore flows better under vibration. Even the mix with a slump of 1 in can be placed and compacted using a vibrator.
The mixes stay more workable under continuous mixing. Therefore it is advisable to keep the mixer running until the placement.

Influence of Temperature

The temperature influences strength gain and the workability. In order to study the influence of temperature, water baths were setup. These water baths were insulated drums filled with water maintained at various temperatures. The cylinders covered with polyethylene sheets were placed in the water baths. The results of the current investigation were combined with the results reported by Sprinkel of Virginia DOT[2].

- Variations in strength between 55 and 73°F are negligible between 2 to 4 hours.
- At 3 hours, the strength drop is about 10 percent between 55 and 73°F.
- In the temperature range of 45 and 55°F the strength decreases exponentially. At 3 hours, the strength decreases by 12 percent between 50 to 55°F and about 80 percent between 45 to 50°F.

Based on these results, it is recommended that normal placement should be done only at temperatures higher than 50°F. It is advisable to use insulation blankets below 60°F. The water temperature should be adjusted so that the concrete temperature is about 70°F.

If the repair has to be done at temperatures below 50°F, special precautions such as heated water and aggregates and heating blankets have to be used for at least 3 hours after placement. The concrete should be maintained around 70°F. The parent surface should also be heated to 70°F before placing the rapid set concrete.

Heat of Hydration and Rise in Temperature

The raise in temperature was measured in the cylinders for up to 3 hours and the raise in temperature was found to be negligible.

Plastic Shrinkage Characteristics of Rapid Set Concrete

The shrinkage characteristics of rapid set concrete during the initial and final setting period were evaluated using restrained shrinkage tests, commonly used for fiber reinforced concrete.   The results can be used to simulate the performance of slabs cast in the field during the first 24 hours and long term shrinkage induced cracking.

The test variables were cement type, and the amount of retarder. Based on the strength and workability results the cement content 611 lb/yd^3 was chosen for this study. In addition to cement types A, B, and C, ASTM Type I cement was tested as a control. The response variables were: (i) total crack area and (ii) maximum crack width measured over a square restrained concrete slab.

The test consists of drying a concrete slab which is 1.5 in thick and has a plan dimension of 3.5 x 3.5 ft. The base consists of 0.5 in thick plywood with a polyethylene sheet secured to the top surface by a spray adhesive. The polyethylene sheet provides a smooth top surface, allowing the concrete slab to shrink freely. The sides of the forms consist of two 0.75 in wooden strips. A wire mesh is placed at mid-height of the sides of the form. About 2 in of the wire mesh is exposed along the inside perimeter of the form. The secured wire mesh imbedded in the slab provided the restraint along the perimeter of the slab. When the slab shrinkage cracks develop on the surface.

In order to hasten the drying process, high velocity fans were used to blow air on the top of the slabs. The air velocity was approximately 12 mph. The slab dimensions and test procedures were based on the numerous tests conducted for fiber reinforced concrete[7,10].

Placing the slab on the vibrator vibrated the concrete. The vibration time was limited to 30 seconds. The slabs were placed on level surface and then screed once with a straight edge. High velocity fans placed near the slabs were switched on.

After 24 hours, the crack areas were obtained by measuring crack lengths and widths at a number of locations along the crack. The control slab made with ASTM Type I cement did not crack. This is consistent with results reported in the literature [7,8].

All the slabs with rapid set cements developed hairline cracks. Review of results lead to the following observations.

? Hair line cracks developed for cement types A and B. The cracks were wider for cement type C.
? The difference in behavior between cement type A and B is insignificant.
? There is a good correlation of crack area with respect to retarder dosage. Consistent increase in retarder dosage result in consistent decrease in crack area.
? The authors believe, the retarder provides a mechanism to reduce the surface tension and evaporation of water. The retarders might also reduce heat of hydration.
? Plastic shrinkage cracking is influenced by the interdependent relationship between volume change during initial setting and tensile strength development. Rapid hydration seam to change this relationship as compared to ASTM Type I cement.

Drying Shrinkage Characteristic of Rapid Set Concrete

The drying shrinkage characteristics of rapid set concrete were evaluated using ring tests, commonly used for evaluating fiber reinforced concrete. Tests were conducted for cement types A, B, and C using 611 lb/yd^3 of cement.

Ring specimens were used by a number of investigators for evaluating fiber-reinforced cement composites under restrained drying shrinkage. Essentially, a ring of concrete is cast around a stiff steel ring. As the concrete shrinks, it induces stresses on the steel ring. Since the steel ring is stiff and undergoes very little deformation, the outer concrete ring is subjected to tension. If the concrete ring is thin in relation to the internal diameter, then the stresses across the thickness can be considered uniform. The compressive stress developed at the interface between the steel ring and the concrete ring is also negligible. The researchers used various external diameters for steel rings. The thickness of the cement composite was also varied depending on the composition of the matrix. Typically, thicker sections were used with concrete containing coarse aggregates.

The concrete is sealed at the top using a sealer, allowing it to dry evenly only at the outer edge. A relatively large ratio of the width (exposed surface) to the thickness (4 or higher) can provide uniform drying across the thickness.

The concrete was cast between a steel ring and an annular outer mold. The outer mould was made of plastic. A vertical cut was made to remove the outer mold without causing disturbance to the young concrete. Care should also be taken to place the outer ring concentrically with the inner ring to avoid nonuniform thickness of the concrete ring.

The outer moulds were removed as soon as the concrete hardens. Once the outer mould was removed the specimens were subjected to the desired drying scheme.

The ring developed cracks after, 14 and 44 days for cement type B and C respectively. Specimen made with cement type A did not develop a crack for 6 months.

Cement type B developed a crack at 14 days, which was 0.0075 in wide and the crack width did not increase up to 44 days. Ring made with cement type C developed a crack at 44 days, which was 0.0057 in wide.

The shrinkage strains for concrete made with cement types A and B are much less that that of concrete made with ASTM Type I cement [(9)]. The shrinkage strains range from 277 x 10^{-6} to 390 x 10^{-6} in/in for typical compositions. The tensile strengths range from 385 to 705 lbf/in^2. Concrete with higher strengths has higher modulus of elasticity. Therefore, tensile strain at failure is about 0.0002 in/in for all strengths.

The shrinkage strain is higher than the tensile capacity and therefore cracking should be expected. If the entire shrinkage of the ring is assumed to be the crack width, the magnitude of crack width will be 0.013 in. However, the ring will sustain some strain and only part of the shrinkage will contribute to crack width. The experimental crack width of 0.004 in for cement type B confirms the low shrinkage strain of sulphate cements.

The shrinkage strain can be divided into two components consisting of: drying shrinkage and autogenous shrinkage. For the rapid set concrete studied in this investigation, the drying shrinkage can be expected to be minimal because the permeability of concrete decreases very rapidly. For concrete with latex, the permeability is further reduced. This aspect, explains lower shrinkage strain for these concrete. Typically, the shrinkage of rapid set concrete is about 30% as compared to concrete made with ASTM Type I cement. Most of the shrinkage of rapid set concrete can be assumed to be autogenous shrinkage. If this shrinkage is further reduced or if the tensile strain capacity is increased, it is possible to produce crack free concrete.

CHLORIDE PERMEABILITY

Rapid chloride permeability test (AASHTO – T 277) is being used by a number of agencies to evaluate the permeability of concrete. Low permeability is an indication of durable concrete because the ingress of chemicals from deicing salts will be low.

The tests conducted by Port Authority of New York and New Jersey using sulphate cement after 28 days of dry cure resulted in a coulomb number of 600. The control which had ASTM Type III cement had a number of 1700.

Sprinkel [(2)] reported the results for rapid set concrete with 658 lb/yd^3 of cement and latex. The test samples were cured in cylinders for 24 hours and air dried till the age at testing. The average coulomb numbers at ages of 4 weeks, 6 weeks, 5 months, and 12 months were: 1, 396 (3 samples), 639 (3 samples), 7 (5 samples), and 1 (5 samples) respectively. Each sample was the average of two specimens. The samples were taken at various locations of Rt 33 and Rte 620. Six of the ten specimens tested at 12 months-registered zero.

Based on the aforementioned results, it can be concluded that latex modified rapid set concrete provide excellent resistance for chloride ion penetration.

LARGE SLABS AND FIELD TRIAL

Three slabs that were 4, 6, and 8 in were cast for all three cements. The plan dimensions were 4 ft x 6ft. These slabs were cast to demonstrate the feasibility for making thicker slabs without excessive heat of hydration. The slabs could be cast without any problems. None of the slabs developed plastic or drying shrinkage cracks.

The slab for field trial was cast on the bridge over Interstate 287 on River Road in Piscataway, New Jersey. Prematured constituent materials were taken to the job site. The concrete was mixed and placed by the repair contractor. Surface preparation was the same as the ones used for other mixes. The mix contained 611 lb/yd^3 of cement and water-cement ratio was 0.34. Based on the observation made during the placement, the author recommends the following:

- The quality of fine aggregate should be well controlled. Particles passing through No. 200 sieve influence the workability to a large extent. Fine powder or dust presence in coarse aggregate should be avoided.
- There should be surface vibration. Vibro-screed might be a good solution.
- The finished surface should be covered with a wet blanket till the lane is opened to traffic.
- Further improvements are suggested in the recommendation section.

CONCLUSIONS

- It is possible to formulate a workable concrete that can provide 2000 lbf/in^2 compressive strength in 3 hours.
- A modulus of rupture of 350 lbf/in^2 can be easily achieved at 3 hours.
- The strength gain under flexure mode is more rapid than the strength gain under compression loading.
- Retarding admixtures can be added to increase the workable duration to 25 minutes.
- The concrete flows well under vibrations.
- The concrete retains its flowable characteristics better if the mix was kept under constant movement.
- The recommended mix proportions for sulphate cement manufactured by CTS Cement company is as follows:
  - Cement - 611 lb/yd^3
  - Fine Aggregate - 1625 lb/yd^3
  - Coarse Aggregate - 1425 lb/yd^3
  - Water - 108 lb/yd^3

- W/C - 0.34
- Latex - 194 lb/yd^3
- Retarder - 2.4 lb/yd^3
- Retarder% - 0.4%

- Retarder percent is based on cement.
- W/C: Water to Cement ratio, water in latex is included in the ratio.

* The recommended mix proportions for Ultamax Cement is as follows:
  - Cement - 611 lb/yd^3
  - Fine Aggregate - 1625 lb/yd^3
  - Coarse Aggregate - 1425 lb/yd^3
  - Water - 108 lb/yd^3
  - W/C - 0.34
  - Latex - 194 lb/yd^3
  - Retarder - 3.1 lb/yd^3
  - Retarder% - 0.5%

- Retarder percent is based on cement.
- W/C: Water to Cement ratio, water in latex is included in the ratio.

* For the cement manufactured by Five Star Products the recommended mix proportions is as follows:
  - Cement - 611 lb/yd^3
  - Fine Aggregate - 1575 lb/yd^3
  - Coarse Aggregate - 1575 lb/yd^3
  - Water - 232.2 lb/yd^3
  - W/C - 0.38
  - Retarder - 1.1 lb/yd^3
  - Retarder% - 0.18%

- Retarder percent is based on cement.
- W/C: Water to Cement ratio, water in latex is included in the ratio.

* Trail mixes are needed if the coarse aggregate is different from the 0.375 in maximum size trap rock used for the investigation.
* If the ambient temperature is between 65 and 80°F the aforementioned mix proportions will provide a workable mix for 25 minutes.
* If the ambient temperature is between 80 and 90°F, the retarder dose can be increased by 20 percent. If there is no need for extended workable time, the admixture dosage can be maintained at the same level.
* If the ambient temperature is between 50 and 65°F, the admixture dosage should be reduced by 50 percent.
* If the ambient temperature is less than 50°F placement is not recommended, unless heated water is used in the mix and heating blankets are used for curing for at least 3 hours.
* Rapid Set Concrete is more susceptible to plastic shrinkage cracking as compared to ASTM Type I cement concrete. Therefore, the exposed surface should be

protected with curing membrane or wet blanket to avoid any water loss. The surface protection can be applied as soon as the surface becomes hard.

- Rapid Set Concrete shrinks less and therefore cracks less under restrained conditions. It might be possible to formulate a mix that will not crack due to drying or autogenous shrinkage.

RECOMMENDATIONS FOR FURTHER RESEARCH TO IMPROVE FIELD APPLICATIONS

As mentioned in the conclusion section, the required strengths can be easily achieved. The primary challenges for the field applications are:

i. Placement and finishing in 25 minutes.
ii. Curing for the first 3 hours, and
iii. Reduction of shrinkage to minimize or eliminate shrinkage induced cracking.

Note that durability is adversely affected by induced cracking. Therefore, it is proposed to conduct addition in the following areas.

Task 1 – Self Compacting Concrete

The principle of self-compacting concrete has been successfully used in Europe in actual construction of bridges. The authors believe the mix proportion that provide a slump of at least 8 in can be modified with addition of high range water reducing admixture and lime powder to produce self compacting concrete.

Flow test used for normal concrete to assure self-compaction and absence of segregation will be used for the current evaluation.

Large prisms 6 X 6 X 24 in will be cast without using external vibration, except for power screed. The hardened prisms will be cut to study the aggregate and void distribution.

It is expected that at least 9 mixes will be evaluated for the three cement types. For the successful mix formulation, workability variation with time and drying shrinkage characteristics will be evaluated.

Task 2 – Curing Blanket

A number of sponges like materials that can retain large amount of water are available in the market. These blankets can hold much more water than the commercially available burlaps. It is proposed to develop blankets using this material and polyethylene sheet.

Blankets will be made using the commercially available foam sheet and polyethylene sheet. The blankets used for drying cars and industrial spills are very durable. The study will consist of the following steps:

i. Quantify the amount of water that can be retained for square foot.
ii. Evaporation loss – The wet material will be subjected to high velocity wind to quantify the water loss.
iii. Durability of blanket – The blanket will be put through wet - dry cycles to estimate the number of uses that can be obtained using a single blanket.

Task 3 – Reduction of Shrinkage

As mentioned in the conclusion section, rapid set concrete has low shrinkage. If the shrinkage can be reduced to 277 x 10^{-6} in/in, for most cases cracking due to shrinkage can be eliminated. The autogenous shrinkage can be reduced by providing internal water through the use of water saturated lightweight aggregate. The other option is to use more latex that will reduce the permeability further. Furthermore, additional latex will also increase the tensile strengths and strain.

It is proposed to test about 6 lightweight aggregate formulations (for 3 cement types) to assure strength development. The lightweight aggregate will also reduce the weight of concrete and known for their durability. These aggregates have been used with normal cements to reduce autogenous shrinkage.

In the case of latex, 10 and 20 percent will increase the dosage over the current levels. The water/cement ratio will be kept the same.

In both the cases, compressive strengths, modulus of rupture, and long term behavior under restrained conditions will be obtained.

FIELD IMPLEMENTATION

The following provides a short summary of the proposal for field implementation.

Field implementation of Rapid Hardening Concrete

Problem statement

Rapid repair of bridge decks is a common occurrence allover the country. For typical rapid repair, a durable rapid hardening concrete is needed that can generate a reasonable compressive strength and modulus of rupture in about 3 hours.

Background Information

Various forms of rapid hardening concrete are being used in the field. The mixture composition pertaining to this proposal is proportioned to obtain at least 2000 lbf/in^2 comprehensive strength at 3 hours and 350 lbf/in^2 modulus or rupture. The time period of 3 hours allows for 7 to 10 hour window for preparation, placement, curing, and opening to traffic. Typical lane closures occur between 7:00 p.m. and 5:00 a.m.
Study conducted at Rutgers University, field and research experience of DOT team at Virginia Commonwealth lead to formulations that can be used in the field. These mixtures have an initial slump of 7 to 8 in and workable up to 25 minutes.

Proposed Work

The proposed work involves field demonstration. The research team will work with a contractor who is installing the repair patches.

Task 1 – Selection of Sites

Identify at least 5 bridges where the new patching material can be used. Selection of locations will be based on exposure and geography of the state. Locations where deicing salts are used frequently are preferred.

Task 2 – Placement

The research team will assist the contractor for the successful placement. The constituent materials are readily available. The mix proportions are self-compacting. Only a vibrating screed is needed to ensure compete compaction. Field experience will be used to make minor changes in the mix composition.

Task 3 –Evaluation

The condition of the patches will be evaluated over a period of 4 years. Small site cores will be taken and tested for tensile bond strength between old and new concrete and chloride penetration. The amount of chloride ingress will be established using chemical analysis.

Deliverables

A video will be part of the final report. The final report will contain long-term performance of the repair system and a model specification that can be used by the departments of transportation.

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Table 1 A - Summary of Mix Proportions, Cement Type A

Constituent Material	Quantity,lb/yd^3														
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15
Cement	517	564	611	658	658	658	564	611	658	611	517	564	611	658	705
Fine Aggregate	1625	1650	1625	1600	1600	1600	1650	1625	1600	1625	1675	1650	1625	1600	1575
Coarse Aggregate	1525	1450	1425	1400	1400	1400	1450	1425	1400	1425	1475	1450	1425	1400	1375
Water	196.5	293	318	250	224	116	100	108	116	108	92	100	108	116	124
W/C	0.38	0.52	0.52	0.38	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Latex	-	-	-	-	-	208.00	178	194	208	194	162	178	194	208	222
Retarder	-	-	-	-	13.2	6.6	1.4	1.5	1.6	2.0	2.6	2.8	3.1	3.3	3.5
Retarder%	-	-	-	-	2.0	1.0	0.25	0.25	0.25	0.32	0.50	0.50	0.50	0.50	0.50

Note :

- Retarder percent is based on cement.
- W/C : Water to Cement ratio, water in latex is included in the ration

Table 2 A - Compressive Strength, lbf/in², Cement Type A

	Compressive Strength, lbf/in²						
	2 hrs	3 hrs	4 hrs	24 hrs	7 days	28 days	
A1	915	2600	3105	3420	5490	-	1
A2	1545	1830	2200	-	-	-	2
A3	1485	1885	1985	-	-	-	3.5
A4	1595	2030	2150	2640	-	-	3.5
A5							
A6							
A7	920	1330	1430	1910	2030	3170	5.5
A8	1765	2126	2990	3200	3500	4775	7
A9	1170	2050	2850	3150	3510	4500	7.5
A10	1750	2125	2775	3855	-	-	7.5
A11	940	1505	1655	2745	3005	3995	4.5
A12	1405	2265	2690	3695	3810	4585	6
A13	1600	2145	2750	3870	4050	4865	6.5
A14	1665	2230	2650	3885	4095	4920	8
A15	2085	2305	2755	4000	4150	5120	9

Table 1 B - Summary of Mix Proportions,
Cement Type B

Constituent Material	B1	B2	B3	B4	B5	B6	B7	B8
Cement	658	658	658	517	564	611	658	705
Fine Aggregate	1550	1600	1600	1675	1650	1625	1600	1575
Coarse Aggregate	1550	1400	1400	1475	1450	1425	1400	1375
Water	250.0	116	116	92	100	108	116	124
W/C	0.38	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Latex	-	208	208	162	178	194	208	222
Retarder	-	3.3	2.1	2.1	2.3	2.4	2.6	2.8
Retarder%	-	0.50	0.32	0.40	0.40	0.40	0.40	0.40

Note :

- Retarder percent is based on cement.
- W/C : Water to Cement ratio, water in latex is included in the ration

Table 2 B - Compressive Strength, lbf/in², Cement Type B

	Compressive Strength, lbf/in²						
	2 hrs	3 hrs	4 hrs	24 hrs	7 days	28 days	
B1	1592	-	-	-	-	-	-
B2	1500	1890	2075	-	-	-	-
B3	2025	2225	2725	3655	4575	-	7.5
B4	1115	1565	1990	2975	3240	3875	4
B5	1590	2440	2630	3745	4010	4710	5
B6	1815	2125	2645	3795	4445	4900	6.5
B7	1845	2200	2665	3605	4565	4875	7.5
B8	2125	2215	2750	3825	4700	5215	8

Table 1 C - Summary of Mix Proportions,
Cement Type C

Constituent Material	Quantity, lb/yd^3														
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**
Cement	517	564	611	658	680	705	564	611	658	705	564	611	658	705	517
Fine Aggregate	1625	1600	1575	1550	1540	1525	1600	1575	1550	1525	1600	1575	1550	1525	1650
Coarse Aggregate	1625	1600	1575	1550	1540	1525	1600	1575	1550	1525	1600	1575	1550	1525	1850
Water	196	214	232	250	258	268	214	232	250	268	214	232	250	268	196
W/C	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Retarder	-	-	-	-	-	-	1.4	1.5	1.6	1.8	1.0	1.1	1.2	1.3	-
Retarder%	-	-	-	-	-	-	0.25	0.25	0.25	0.25	0.18	0.18	0.18	0.18	-
Super Plastisizer	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10

Note :

- Retarder percent is based on cement.
- W/C : Water to Cement ratio, water in latex is included in the ration

Table 2 C - Compressive Strength, lbf/in², Cement Type C

	Compressive Strength, lbf/in²						
	2 hrs	3 hrs	4 hrs	24 hrs	7 days	28 days	
C1	1695	3960	4465	5340	5510	7015	2.00
C2	2435	3600	4000	5270	5825	7955	2.25
C3	1505	3080	3405	4375	5095	7365	2.50
C4	2045	3995	4315	5170	5530	7640	3.25
C5	3225	4295	4755	5370	5965	8335	4.00
C6	4130	5050	5410	5985	6465	8660	4.50
C7	850	1385	1990	4220	5005	6535	2.50
C8	475	1460	2220	4515	5435	6985	3.00
C9	690	1820	2720	5030	5990	7615	4.00
C10	1145	2455	3680	5235	6310	8590	5.00
C11	1005	1650	2965	5170	5685	6665	2.50
C12	505	2005	3265	4855	5850	7080	3.00
C13	955	2320	3595	5270	6245	7735	4.25
C14	1310	2755	4005	5510	6580	8545	4.75
C15	2330	3005	3545	4470	-	-	-

Table 3 A - Flexural Strength, lbf/in² - Cement Type A

	Modulus of Rupture, lbf/in²					
	4 X 4 in. prisms, center load			6 X 6 in. prisms, third point loads		
	3 hrs	6 hrs	7 days	3 hrs	6 hrs	7 days
A8	1105	1150	-	718.25	747.5	-
A9	680	765	830	442	497.25	539.5
A10	810	1110	-	526.5	721.5	-
A12	720	950	1180	468	617.5	767
A13	500	730	1095	325	474.5	711.75
A14	860	960	1275	559	624	828.75
A15	895	1005	1280	581.75	653.25	832

Table 3 B - Flexural Strength, lbf/in²- Cement Type B

	Modulus of Rupture, lbf/in²					
	4 X 4 in. prisms, center load			6 X 6 in. prisms, third point loads		
	3 hrs	6 hrs	7 days	3 hrs	6 hrs	7 days
B4	690	765	830	449	497	540
B5	725	835	915	471	543	595
B6	770	875	1035	501	569	673
B7	880	960	1115	572	624	725
B8	890	1005	1140	579	653	741