

Temporary Precast Panels and Self-Consolidating Concrete for Accelerated Slab Replacement

Jamshid Armaghani¹, Kamal Tawfiq², Steven Squillacote³ and Michael Bergin⁴

Abstract

An innovative method was developed to accelerate replacement of segments of slabs in concrete pavement rehabilitation projects with the goal of increasing production and reducing construction time. The two-component method involved the use temporary and reusable precast panels and self-consolidating concrete (SCC). Laboratory tests were performed to develop the proper SCC mix and precast panel design. Field demonstration was conducted in a dedicated test track to validate the method. The SCC mix incorporated 1" (25 mm) maximum size coarse aggregate, low w/c and as a combination of admixtures to increase and maintain workability, and accelerate early strength development. Two precast panels were prepared to be installed in slab replacement pits. A pavement test track was used to demonstrate validity of the method. Inside the track a slab-replacement test-pit was prepared and used to evaluate the installation and removal of the panels, as well as the casting of the replacement slab using the SCC mix. The precast panels and replacement slab were tested under multiple cycles of heavy trucks without experiencing panel failure or cracking. The method was validated for speed of panel installation, as well as rapid SCC mix discharge, workability retention and high early strength.

Introduction

Slab replacement is the main activity in most concrete pavement rehabilitation projects. Cracked segments of or full slabs are replace with new concrete as part of pavement rehabilitation projects to extend service life of the pavement (ACPA 1997). Due to the short construction window, high early strength is specified for concrete used to cast the replacement slabs. In urban streets, highly congested roads and highways, the lane closure time for slab replacement may range from eight to ten hours, and mostly, during nighttime. During the lane closure period, the contractor starts by setting up traffic barriers, then proceeds with saw-cutting the perimeter of the deteriorated slab segment and removing it; retrofitting new dowel bars and placing a dowel basket for intermediate joints; repairing disturbed base, casting, consolidating, finishing and curing the replacement slab; and finally removing the traffic barriers to re-open the lane to traffic (ACPA 1995). The concrete strength has to reach a minimum 2,200 psi (15 MPa) to allow lane opening to traffic according to FDOT specification 353 (FDOT 2013).

¹ Jamshid Armaghani, Ph.D., P.E., Member ISCP, Global Sustainable Solutions, 5408 NW 67th street, Gainesville, FL, Jamshid@bellsouth.net

² Kamal Tawfiq, Ph.D., P.E., tawfiq@eng.fsu.edu

³ Steven Squillacote, scs08d@my.fsu.edu, FAMU-FSU Civil & Environmental Eng. Dept., Tallahassee, FL.

⁴ Michael Bergin, P.E., Michael.Bergin@dot.state.fl.us, Florida DOT, State Materials Office, Gainesville, Florida.

The short construction window, time consuming construction activities, as well as the FDOT strength requirement for lane opening, severely limit the contractor's production rate with respect to the number of segments or full slabs to be replaced. According to a survey of Florida DOT and contractors conducted by the authors (Tawfiq 2014), the quantity of replacement concrete cast during a lane closure period of 8-10 hours may only reach 50 yd³ (42 m³) and can even be as low as 25 yd³ (21 m³). This low concrete volume adds significant cost to concrete production during nighttime, and is reflected in high project bid prices. The low rate of slab replacement also prolongs project completion time and increases the cost for the required maintenance of traffic.

In an effort to modestly increase productivity, some contractors saw the deteriorated slab segments and retain them in place under traffic until the next lane closure to then remove and replace them. Others shorten the time between casting the last slab and lane opening time to place more replacement slabs. However this drastic step to shorten the concrete curing and strength development time to meet the lane opening strength, requires the use of high amounts of cement and accelerating admixture and lower w/c in the mix. Such mixes produce high heat, low workability which may cause honeycombing and segregation in concrete, and the high thermal stresses may result in premature cracking of the replacement slabs. These step may slightly increase production, however, they also carry significant risk to the structural integrity and long term performance of the replacement slabs.

Self-consolidating concrete (SCC) mixes have primarily been used in cast-in-place and precast structural members with highly congested reinforcement. SCC mixes are highly workable and consolidate without the need for internal vibration (Yang 2004). Conventional SCC mixes are usually designed using small size aggregate, such as grade 89 (9.5 to 1.18 mm) or smaller, and incorporate high dosages of admixtures to achieve a very high workability and retain it for an extended period of time. During this period the concrete can flow swiftly through the narrow spaces between the reinforcing bars without segregation and consolidate without internal vibration. The SCC mixes have a normal setting time and develop strength gradually. In fact, there might be a delay in the setting time due to the high dosage rates of high range water reducing admixtures, retarders and viscosity modifiers.

There have not been SCC applications in highway pavements. However, research had been conducted in Iowa to study the feasibility and application of SCC for slip-form paving (Wang et al. 2005 and 2011). In the feasibility phase, the researchers developed an SCC mix that would be adapted to slip-form paving. The mix possessed higher workability while maintaining good shape stability of the extruded concrete.

A Florida DOT sponsored a research conducted by Florida Agricultural and mechanical University-Florida State University (FAMU-FSU) to develop an innovative method to accelerate slab replacement concrete pavement rehabilitation projects, involving the use of temporary and reusable precast panels and SCC mix.

Objective

The main objective of the research project was to develop a method using temporary reusable precast panels and SCC mix to accelerate the construction of replacement slabs in concrete rehabilitation projects.

To meet the research objective required accomplishment of the following tasks:

1. Develop a SCC mix in the laboratory with the required high workability and early strength that meets the Florida DOT 2,200 psi (15 MPa) specified for lane opening.
2. Design and construct precast panels for multiple temporary installations.
3. Demonstrate panel handling and installation in the replacement slab pits.
4. Produce and sustain a highly workable SCC mix in field casting of replacement slabs.
5. Test the precast panels and the SCC replacement slab under repeated truck loading.
6. Determine execution time of various construction steps.

Research Significance

The research products will accelerate the construction process of replacement slabs, increase contractor's productivity, and shorten the maintenance of traffic and overall construction time. Other potential benefits from the research include mitigation of premature cracking, and cost savings to the highway agency and contractors.

SCC Mix for Replacement Slabs

The first step was to develop an SCC mix with high workability to allow for rapid discharge and slab casting, and would develop a high early strength of 2,200 psi (15 MPa) required by the Florida DOT for lane opening. Several trial mixes were prepared and tested for workability and strength to arrive at the final SCC mix design (Armaghani et al. 2015). The workability of each mix was tested, immediately after adding and thoroughly mixing the accelerator, using the slump flow and T-20 test method according to ASTM C1611/C1611M-14. The final SCC mix design was developed and refined after adjusting the original admixture quantities in the successive trial mixes. The final SCC mix design is shown in Table 1.

Workability Retention

The SCC mix was evaluated for retention of high workability by performing the slump flow and T-20 tests. The purpose of the evaluation was to determine the ability of the mix to maintain high slump flow for rapid discharge of concrete from a truck mixer and shorten placement of the slabs. This evaluation was necessary before preparing a large quantity of SCC mix at a concrete plant, then transporting it to the test track and casting the concrete in the prepared slab replacement pit.

When the truck mixer arrives to the jobsite, the accelerator is added followed by additional mixing prior to casting the first replacement slabs. The truck carries at least 8 cu. yds. (6 m³) quantity of the mix sufficient for casting one large replacement slab or several small segments of slabs. This may involve intermittent idle periods when the truck is traveling between two consecutive slab replacement pits. During the travel time the drum is maintained in an agitation mode.

To simulate the impact of truck idle time on the SCC workability after addition of the accelerator, the slump flow of the mix was evaluated for a period of 60 minutes. This was done to determine the ability of the SCC mix to retain high workability during the waiting period between successive concrete discharges. Laboratory tests were performed on two batches, B1 and B2, using the same SCC mix design in Table 1. The evaluation involved performing the slump flow and T-20 tests at different time intervals over a test period.

Table 1. SCC final mix design (Armaghani et al. 2015)

Ingredients	Mix lb/yd.³ (kg/m³)	Description
Cement	830 (492)	Type I/II cement used – AASHTO M85
Coarse Aggregate	1625 (964)	Limestone grade size 57
Fine Aggregate	1224 (726)	Silica sand
Mix Water	280 (166)	Mix water adjusted to aggregate moisture and water content in the accelerator admixture
W/C	0.34	
Admixtures	fl Oz/yd.³ (mL/m³)	
Workability Retainer	42 (1,242)	ASTM C 494/C 494M, Type S, specific performance admixture
HRWR - Polycarboxylate	50 (1,479)	ASTM C 494, Type A, water-reducing, and Type F, high-range water-reducing admixture
Accelerator	473 (13,987)	ASTM C 494 Type C, accelerating, and Type E, water-reducing and accelerating, and admixture.
Water Reducer & Retarder	42 (1,242)	ASTM C 494/C 494M, Type A, water-reducing, Type B, retarding, and Type D, water-reducing and retarding admixture

Results of the slump flow and T-20 tests for B1 and B2 are shown in Table 2. The slump flow was consistently retained above 20 inches, and the T-20 was about 4 seconds for the duration of the test. The test results demonstrated the ability of the SCC mix to retain its workability for at least 60 minutes after the addition of the accelerator provided the mixer was kept in an uninterrupted agitation. Also slightly higher agitation speed of the mixing drum was determined to be necessary to maintain high mix workability and prevent setting of the concrete.

Two possible explanations are offered for the ability of the SCC mix to retain high workability after addition of the accelerator. First, the continuous agitation of the mix allowed the workability retainer, the high-range water reducer, and the set retarder admixtures to reach their maximum effectiveness. Second, the continuous agitation may have prevented early negative impact of the accelerator on the SCC mix workability and setting time. This was further demonstrated by the stable temperature of the agitated concrete inside the mixer. However, after completing the slump flow test, it was noticed that stationary concrete test sample immediately started to lose its workability and underwent rapid setting. This was another indication that the accelerator had a swift impact on the workability when the SCC mix became stationary.

Table 2. Slump Flow and T-20 Test results

Time Min	B1		B2	
	Slump Flow in (mm)	T-20 (sec)	Slump Flow in (mm)	T-20 (sec)
0 *	20 (480)	9	22 (550)	1
10	28 (710)	2	-----	----
15	-----	----	24 (600)	2
20	29 (737)	2	-----	----
25	-----	----	27 (675)	3
30	28 (700)	2	-----	----
35	-----	----	29 (725)	3
40	26 (648)	3	-----	----
50	22 (546)	4	-----	----
60	15 (380)	> 10	29 (725)	3

** This test was performed after 6 minutes from adding accelerator and remixing*

Also, during the slump flow tests, the SCC mix seemed to maintain good cohesion with no noticeable segregation as evident from Figure 1. The absence of any visible segregation was the result of using a proper dosage of the workability retaining admixture (Armaghani et. Al 2015). This finding was even more interesting when considering the fact that grade 57 (25 to 4.75 mm) aggregate was used in the mix. This size of aggregate is considered by industry to be the upper limit of any coarse aggregate size allowed in SCC mixes.

**Figure 1. Slump flow test**

Pavement Test Track

Field validation of the temporary precast panels and SCC mix for slab replacement was performed at a pavement test track south of Jacksonville, Florida. The oval shaped test track is a 400 ft. (122 m) long and 14 ft. (4.27 m) wide asphalt pavement, as shown in Figure 2. It was designed to evaluate pavement products and new technologies. Traffic loads are simulated using a loaded truck traveling at 10 mph and applying repeated loads on test sections as it travels around the track.



Figure 2. Pavement Test track

Preparation of Replacement Slab Test Pit

A 24' x 14' (7.32 m x 4.27 m) section of the test track pavement was removed to construct a model test pit of a replacement slab surrounded by concrete pavement as shown in Figure 3. After removing the asphalt and base layers, forms were installed to cast concrete around the test pit. The test pit dimensions were 12.25' x 12.25' x 9" (3.73 m x 3.73 m x 0.225 m), and was designed to accommodate two 6' x 12' x 8" (1.83 m x 3.65 m x 0.20 m) precast panels. The selection of the dimensions for the slab replacement pit was made based on the largest standard size specified for replacement slabs in this method. Other standard pit sizes that are specified in the proposed method, include 6' x 12', 8' x 12', and 10' x 12' (1.83 m x 3.65 m, 2.44 m x 3.65 m, and 3.05 m x 3.65 m). For larger pit sizes, the Florida DOT requires full slab replacement (FDOT 2010). According to the proposed pit sizes, the contractor needs to prepare only two precast panel sizes with 6' x 12' and 4' x 12' (1.83 m x 3.65 m, and 1.33 m x 3.65 m) dimensions, as one or two of these panels can fit every pit size specified in this method.

A 4,000 psi (28 MPa) concrete mix was prepared in a commercial batch plant and cast around the test pit to model an existing concrete pavement around a removed distressed area (replacement slab pit) of a pavement. The Concrete was then covered with a plastic sheet for proper curing.

The difference of 1 in (25 mm) between the depth of the pit and the thickness of the panels was intended to simulate such possible mismatch in project sites. To overcome

the mismatch in dimensions, a 1 in (25 mm) layer of fine recycled concrete aggregate, which was available at the site, was placed and compacted in the pit as a leveling (bedding) course to establish the required 8" (0.2 m) pit depth (Figure 3). In addition to its availability and low cost, the fine recycled concrete aggregate can achieve high stiffness upon compaction and would be compatible with the concrete mix for the new slab. Other leveling material options would include builder's sand and geosynthetic mats.

The dimensions of the test pit allowed the installation of two standard 6'x 12'x 8" panels positioned with the 12' sides in the transverse direction. Once installed, there would be three joints in the pit. Two of the joints would be between the panels and the surrounding concrete, and the third joint would be between the two panels.



Figure 3. Test pit with fine recycled concrete aggregate leveling course

This placement pattern was selected to test the structural stability of two panels installed side by side under true loading conditions. Also, the use of two precast panels side by side in the pit may be considered less stable placement set up compared to a single panel installation.

No dowel bar holes were drilled into of the adjacent concrete. The high cost of drilling and the difficulty in finding a contractor for such a small job were the reasons for skipping this required step. It should be emphasized that this step is part of the precast/SCC system being proposed. This activity would normally involve drilling holes at the sawed face of the adjacent concrete for the retrofit dowels prior to installing the precast panels. Upon removal of the temporary precast panels and prior to casting the SCC mix for the new replacement slab, the holes would be cleaned from dust and debris, filled with epoxy, and then the new dowel bars would be inserted.

Design and Construction of Temporary Precast Panels

Two precast panels were used in the evaluations. The panel dimensions were 6'x 12'x 8" (1.83 m x 3.65 m x 0.20 m). Each panel had two reinforcing mats. In the first panel size #4 (# 13 or 12.7 mm) rebars were used for reinforcement, and in the second panel, #5 (# 16 or 15.9 mm) bars were used. Using two bar sizes was intended to test the structural integrity of the panels in order to optimize the final reinforcement design requirements and panel weights. The reinforcing bars were spaced at 12" (300 mm) on centers in both directions. Also, four lift anchors were positioned in each panel and fastened to the reinforcement.

The planar dimensions of the two panels were approximately 3" (75 mm) shorter than the pit dimensions, which created a 1.5" (37 mm) gap between each panels and the surrounding concrete. The perimeter of each panel was grooved and fitted with 1.5" (37 mm) backer rod foam to fill the gap between the adjoining sides of the panels as well as the gap with surrounding concrete, as shown in Figure 5. The backer rod was intended to facilitate the panel installation in and removal from the test pit.

The panels were designed to be robust to withstand multiple field applications. To ensure their stability inside the pit, four 8" x 0.75 " (200 mm x 20 mm) recessed strips were fabricated along the bottom surface of each panel as shown in Figure 5. This pattern of ridges and valleys was intended to maximize friction and interlock between the panels and the base of the pit, since they would not be anchored or doweled to the surrounding pavement. Maximizing friction would minimize shifting of the panels under the action of traffic.

The panels were cast using 4,000 psi concrete supplied by a commercial concrete plant (Figure 4). After casting, the forms were covered with plastic sheets for proper curing until reaching the required concrete strength.

Installation of Precast Panels

Using steel chains, the panels were rigged to the bucket of an excavator and lifted from their form. Perfectly shaped ridges and valleys had formed at the bottom surface of the panels as shown in Figure 4.

A 1.5" (37 mm) diameter backer rod was glued to the grooved perimeter of each panel. The backer rod foam was preferred over stiffer rubber gaskets because of its significantly lower cost, common use in pavements, and its high malleability to be squeezed between the panels and at joints with the surrounding concrete. Also, the foam has the ability to absorb minor impact of the panel against the surrounding concrete.

To facilitate installation in and removal from the slab replacement pit, the backer rod was lubricated with a biodegradable lubricant. An excavator was used to lift the panels and install them in the replacement pit, as shown in Figure 5. The choice of using the excavator was due to its availability on site. However, at jobsites, the contractor may use this or a more efficient and steady lifting system such as a backhoe tractor with a steel I-beam attachment, or a forklift with an extended lift boom.

Prior to installation, the panels were subjected to multiple lifting and maneuvering cycles. These repeated motions and swings were intended to test the robustness of the anchors, the handling method, and the structural adequacy of the two reinforcing designs of the panels. No cracks or damages were observed in either panel as result of repeated lifting and maneuvering of the panels.

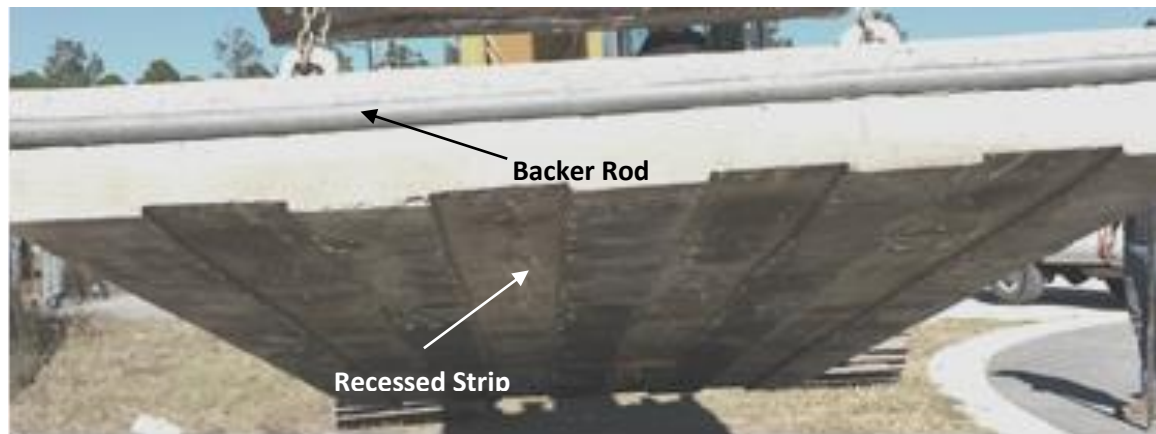


Figure 4. Features of the precast panel



Figure 5. Rigged precast panel for installation in slab replacement pit

After some adjustments, the two panels were lowered into the test pit. The 3" (75 mm) gap between the panels and the surrounding concrete as well as the lubricated backer rod provided the flexibility to make minor adjustments in positioning the panels to achieve a good fit inside the pit. Minor faulting of about 1/4" (6 mm) was noticed at the joints between panels and the surrounding pavement. This faulting would be considered acceptable by the fact that the precast panels would be temporary place holders in the slab replacement pits. The installation period of the panel(s) would normally be less than one week prior to casting the permanent replacement slab.

The process of lowering the two panels took about 20 minutes to complete. However, at project sites, with the proper equipment, tools, and experience, the process of installing the panels in replacement slab pits would probably take less than 10 minutes. It should be noted that proper leveling of the base surface underneath the precast panels is important to establish a fairly uniform contact area and to prevent any "rocking" action of the panels. A simple leveling tool would be recommended to ensure uniformly leveled pit.

Instrumentation and Test Loading of Precast Panels With the two precast panels installed in the test pit, eight LVDTs were placed at key points on the surfaces of the panels. The

LVDTs were intended to measure vertical movements of the panel under truck wheel loads, as well as any horizontal shifting during abrupt breaking of the loading truck on the panels.

A 60,000 lb. concrete pump truck was used to load the precast panels. The wheel configuration included a single and a double tandem axles as shown in Figure 6. The truck traveled at a slow speed of 5 to 10 mph on the precast panels. The movements of the panels were monitored visually and were also measured by the LVDTs and recorded.

The truck made 50 passes on the panels. During the initial passes, minor seating (faulting) of the panels was noticed. However, upon subsequent passes, no additional faulting was detected.

The truck made additional passes with abrupt breaking on the panel. This maneuver was intended to check if any horizontal panel shifting would occur in the panels as the truck suddenly stopped. No noticeable movement was detected in the panels. This stability could be attributed to the strong friction and interlock between the recessed strips at the bottom of the panels and the leveling course.



Figure 6. Load testing of precast panels

Also, this test showed that there was no difference in structural adequacy or toughness between the panel with # 4 (#13) reinforcing bars compared to the panel with # 5 (#16) bars.

After completing the load testing, the precast panels were left in place for a period of four weeks prior to their removal. A day prior to casting the replacement slab, the two panels were removed using the same excavator as in the original installation. The removal of both panels took less than 10 minutes.

Casting of Replacement Slab in Test Pit

The research team partnered with a concrete producer in Jacksonville, Florida to prepare a 4.5 cu. yd. (3.5 m³) SCC mix. Prior to preparing the large mix, properties of the SCC mix were verified in six trial batches using the producer's material and equipment. Tests were performed on SCC samples including, slump flow for workability and workability retention, and compressive strength at early hours after batching.

Upon verification of its workability and early strength properties, the 4.5 cu. yd. (3.5 m³) SCC mix was batched at the plant inside a truck mixer at an ambient temperature of 78° F (26 °C). After mixing, the slump flow was measured at 25 in (635 mm) and T-20 at 4 sec. It took about 45 minutes to transport the SCC mix to the test track. At the test track, a second slump flow was performed and measured 19 in (475 mm). This was a reduction of about 6 in from the slump measurement at the batch plant. The accelerator was then added to the mixer, followed by 5 minutes of remixing. A third slump flow test was performed and resulted in 21 in (535 mm) spread in 5 seconds. Immediately following this slump flow test, the truck proceeded to discharge the SCC mix to fill the 12' x 12' x 8" (1.83 m x 3.65 m x 0.20 m) replacement slab pit, as shown in Figure 7. The mix was cohesive as it moved rapidly down the mixer chute. No segregation was noticed during discharge. Once poured, the mix moved inside the pit swiftly and uniformly in all directions. It took less than 3 minutes to fill the entire 12' x 12' x 8" (3.73 m x 3.73 m x 0.20 m) pit. Compared to conventional high early strength mix, the SCC mix showed superior performance. It had a much faster discharge rate and shorter placement time without any segregation. Once it settled in the pit, the mix started to set quickly and its temperature started to elevate rapidly.

It was not possible to achieve a smooth surface finish because of lack of proper finishing tools and professional finishers at the site as the mix started to set rapidly. However, at jobsites, with the availability of skilled labor and proper finishing equipment such as rolling or vibratory screeds, the slab would be cast and finished in less than 10 minutes. This rate will contribute to a much higher productivity compared to conventional high early strength concrete mixes.

It is important to note that once the accelerator is added, the mixer has to continue uninterrupted in agitation mode and at a slightly higher revolution speed than conventional agitation, until completely discharging its full load of SCC mix. If the mixer is allowed to slow down or stop even for a brief period, the concrete will most likely set inside the mixer. This will require elaborate and possibly expensive process to dislodge the set or hardened concrete from inside the mixer drum.

Proper timing of the accelerator addition and of managing the withheld mix water in the SCC mix are very important in achieving the full benefits of the SCC mix in slab replacements. Based on the authors' experience, it is recommended to reduce the amount of the accelerator when the ambient temperature exceeds 85° F (29 °C). This may not be an issue during nighttime paving, but could impact mix performance during daytime in warm weather. The high ambient temperature at the site will accelerate cement hydration, which in turn will significantly raise the concrete temperature. This situation can be managed by withholding a certain quantity of the accelerator from the mix.

At the test track, six 6" (150 mm) cylinder specimens were prepared to be tested at 4 and 6 hours. Also, the slab was covered with a plastic sheet to maximize curing, achieve uniform temperature across the slab surface, and achieve early strength. The temperature of the concrete was monitored regularly using an infrared laser thermometer. The maximum measured surface temperature reached about 135° F (57 °C).



Figure 7. Casting SCC mix in replacement slab pit at test track

The concrete cylinders were transported to the producer's plant for testing. However, due to limited access to the laboratory after normal working hours, it was only possible to test three cylinders at 4 hours. The remaining three specimens were transported to FAMU-FSU labs, and were tested later. The average 4-hour compressive strength was 1,400 psi (10 MPa).

Truck Loading of Replacement Slab

Six hours after casting, the replacement slab was repeatedly loaded with a 25,000 lb. The truck, shown in Figure 8, had single front and double rear axles. The truck represents a typical heavy construction or utility truck in an urban streets or road. The truck made 100 passes on the slab. Between the passes the slab was wetted and checked for crack. No cracks were detected. The 100 passes were completed in about one hour. A final close examination of the slab did not reveal any damage or cracking in the slab.



Figure 8. Load testing of the replacement slab using a 25,000 lb truck

Following the truck loading. Nine cores were obtained from the slab at the corners, edges and center locations. The cores were carefully examined to check if any segregation had taken place during casting of the slab. No segregation was detected. The samples were later tested at 28 days. The average strength of concrete at 28 days was 10,140 psi (70 MPa).

Conclusions

The objective of this research was to develop a method to accelerate construction of replacement slabs in concrete pavement rehabilitation projects. The process has the potential to increase contractor productivity, as well as reduce maintenance of traffic, construction time and overall project cost.

Specific conclusions can be drawn from this work:

1. Due to their robust design, the temporary precast panels were highly durable during handling and installation, and were very stable under load in the slab replacement pit.
2. The SCC mix with Type I/II cement, 57 grade (25-4.75 mm) aggregate, silica sand, low w/c as well as a combination of HRWR, workability retainer and accelerator met the high workability requirements for rapid discharge and shorter casting time, and exceeded the 2,200 psi (15 MPa) strength required by the Florida DOT for lane opening.
3. The SCC mix retained a high slump flow for almost 60 minutes without significant loss of workability. This makes it very adaptable to batch plant mixing, truck mixer transport and accelerated slab casting without segregation.
4. The SCC mix design was highly effective for casting slab replacements without the need for internal vibration. This would potentially save time and manpower.
5. Strength of the SCC mix at six hours greatly exceeded the required Florida DOT strength requirement for lane opening.
6. The time required for precast installation in the slab replacement pit and its removal was reasonably short. This process could be further enhanced by experienced contractors with better equipment.
7. To prevent premature setting of the SCC mix after addition of the accelerator, it is very important to maintain the truck mixer in a continuous agitation mode and at a slightly higher speed than conventional agitation.

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