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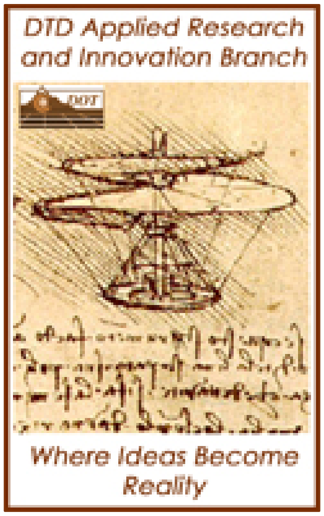

STUDY ON THE USE OF SELF-CONSOLIDATING CONCRETE FOR THE REPAIR OF THE MEAD BRIDGES ON I-25

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16. Abstract

Self-consolidating concrete (SCC) is a stable and highly flowable concrete that consolidates without the help of external vibration and can flow through heavy reinforcement and around corners in complex formwork under its own weight. The exceptional performance of this remarkable material has attracted the attention of construction firms and DOTs in the United States interested in using SCC on new bridge construction and bridge repair projects. CSM has been granted a CDOT research project to participate in two SCC demonstration projects in the state of Colorado. The first project is part of the construction of structures P-18-BK and P-18-BM on I-25 in Trinidad, CO. The second project is the repair of abutment supports of structures D-17-DA and DB on I-25 in Mead, CO. This report presents the study and recommendations for the repairs in Mead. The Mead project addresses the problem of locking the ends of a non-composite steel-girder bridge to its abutments.

SCC will be placed at the bridge end, to encapsulate the ends of the steel girders, the space between them, and the abutment. The SCC will be placed through holes at the deck into an encased area. Casting will take place one traffic-lane at a time, while the other lane is open to traffic. The concern is that a “gapped” and weakened bond between the new concrete and the existing structure may develop due to traffic vibrations. A stable, early-high-strength SCC mix has been developed by CSM for this project. Bridge vibrations due to traffic were recorded capturing all reasonable combinations of traffic flow and loads. Small-scale experiments were designed and performed that simulated the effects of vibrating steel girders within freshly mixed SCC as expected in the field. The effects of such action on the interface quality between the steel girders and the encasing concrete were evaluated. The SCC developed at CSM is characterized by high static and dynamic stability. It has a slump flow of at least 26 inches, a 24-hour compressive strength of 4,000 psi, and a 28-day compressive strength of 8,000 psi. Small-scale steel beams were placed within freshly mixed SCC and were subjected to the recorded traffic vibrations for 24 hours. At the end of this process, the bond strength of vibrated and un-vibrated specimens was measured by pull-out or push-through tests. It was concluded that the CSM-developed SCC mix design performed well for the purposes of this project and the loss of bond strength due to vibrations was moderate.

Implementation:
The CSM developed SCC mix, or a similarly performing concrete, can be used in the bridge abutment-locking construction. The construction should be performed at a time of reduced traffic loads, such as the early morning hours between 1:00 a.m. and 6:00 a.m. The commercial heavy trucks should be diverted to the frontage road for this period in order to reduce the impact to the fresh SCC. At the end of the 28-day curing process the girder-concrete interface must be inspected and resulting gaps should be sealed with epoxy resins to extend the life of the construction.

17. Keywords
SCC, mix design, stability, slump flow, bond strength, traffic vibrations

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The gracious offer of Pinkard Construction and Aggregate Industries to perform a field demonstration of SCC placement for CDOT affiliates and the CSM researchers is greatly appreciated. Specifically David Lemon of Pinkard Construction was willing to allow the change of construction plans to facilitate the use of SCC, and Monty Nieman of Aggregate Industries offered the SCC mix that was used in the demonstration. Mike Bowker from CSM was also willing to approve the change of construction plans for the use of SCC. His willingness to help the writers achieve their research goals is very much appreciated.

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Executive Summary

Self-consolidating concrete (SCC) is a stable and highly flowable concrete that consolidates without the help of external vibration and can flow through heavy reinforcement and around corners in complex formwork under its own weight. The exceptional performance of this remarkable material has attracted the attention of construction firms and DOTs in the United States interested in using SCC on new bridge construction and bridge repair projects. The Colorado Department of Transportation (CDOT) has several projects that can greatly benefit from the properties of SCC. However, there is only limited experience in the state of Colorado with SCC. CSM has been granted a CDOT research project to participate in two SCC demonstration projects in the state of Colorado. The first project is part of the construction of structures P-18-BK and P-18-BM on I-25 in Trinidad, CO. The second project is the repair of abutment supports of structures D-17-DA and DB on I-25 in Mead, CO. This report presents the study and recommendations for the repairs in Mead.

The Mead project addresses the problem of locking the ends of a non-composite steel-girder bridge to its abutments. SCC will be placed at the bridge end, to encapsulate the ends of the steel girders, the space between them, and the abutment. The SCC will be placed through holes in the deck into an encased area. Casting will take place one traffic-lane at a time, while the other lane is open to traffic. The concern is that a “gapped” and weakened bond between the new concrete and the existing structure may develop due to traffic vibrations. A stable, early-high-strength SCC mix has been developed by CSM for this project. Bridge vibrations due to traffic were recorded capturing all reasonable combinations of traffic flow and loads. Small-scale experiments were designed and performed that simulated the effects of vibrating steel girders within freshly mixed SCC as expected in the field. The effects of such action on the interface quality between the steel girders and the encasing concrete were evaluated.

The concrete abutments at the Mead Bridges on I-25 are deteriorating due to unexpected freeway embankment movements. In many places the concrete has spalled off and exposed the steel reinforcement. The north abutments are especially affected by the embankment movement towards the bridge. This movement has forced the steel girders against the abutment that has stopped at the plane of the abutment reinforcement. The movement has also lifted the concrete deck off of the girders, resulting in a gap between the deck and the girders. CDOT plans to “lock” the girders to the abutments with the use of SCC. Due to the volume of traffic on I-25, the bridges must have at least one lane open at all times during the repair. SCC will be placed at the bridge end to encapsulate the ends of the steel girders, the space between them, and the abutment. Casting will be through holes at the deck into an encased area and will take place one traffic-lane at a time, while the other lane is open to traffic. The concern is that a “gapped” and weakened bond between the new concrete and the existing structure may develop due to traffic vibrations. A properly designed and stable SCC is ideal for this type of repair due to the ease of casting and the ability to consolidate without vibration and to encapsulate of the steel girders.

A mix specifically designed for this application has been developed at CSM. The goals for this mix included: a) compressive strength of 3000 psi at 24 hours; b) compressive strength of 7000 psi at 28 days; c) minimum slump flow of 26 inches; and d) high static and dynamic stability. The final product met or exceeded these goals. The mix is characterized by high static and dynamic stability; it has a slump flow that ranges from 26 to 30 inches, a 24-hour compressive strength of 4,000 psi and a 28-day compressive strength of 8,000 psi.

The Mead Bridge traffic vibrations were recorded with the help of accelerometers and Linear Variable Displacement Transducers (LVDT) that were attached to the bridge girders. The recordings included all reasonable combinations of traffic load and flow. Small-scale steel beams were placed within freshly mixed SCC and were subjected to the recorded Mead Bridge traffic vibrations for 24 hours. At the end of this process, the bond strength of vibrated and un-vibrated specimens was measured by pull-out or push-through tests. The results of the experiments showed that the loss in bond strength of the vibrated beams was in the order of 20% compared to the un-vibrated specimens. The CSM SCC mix design performed well for the purposes of this project and the loss of bond strength due to vibrations was moderate.

It is recommended that the CSM mix presented in this study, or another mix that can be proven to perform as well under similar testing be used for the Mead bridge repairs. The concrete placement of the proposed SCC mix should take place at night, with a temperature that exceeds 50^{o} Fahrenheit. Heavy truck traffic should be diverted to the frontage road for at least four hours after placement. The night casting is recommended to avoid heavy traffic, and the temperature restriction placed to assure at least moderate strength development of the SCC.

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Introduction

Repair and construction projects throughout the United States are beginning to take advantage of the strength and fluidity of self-consolidating concrete (SCC). The Colorado School of Mines (CSM) has been granted a CDOT research project to participate in two SCC demonstration projects in the state of Colorado. The first project is part of the construction of structures P-18-BK and P-18-BM on I-25 in Trinidad, CO. The second project is the repair of abutment supports of structures D-17-DA and DB on I-25 at Mead, CO. This report presents the study and recommendations for the repairs at Mead.

Due to the age of the Mead Bridges, there are signs of degradation to the concrete on all four abutments at the site. Both northbound and southbound bridges are comprised of concrete slabs that were cast with no-composite action with the supporting steel girders. The north end of the freeway embankment has moved into the bridge, as shown in Figure 1. This has resulted in abutment movement toward the bridge and has caused penetration of the steel girders into the abutments up to the plane of the steel reinforcement. The movement has also caused the concrete deck to buckle and lift off of the girders. The deck flattens and strikes the supporting girders whenever a heavy truck drives over it, causing added fatigue concerns.

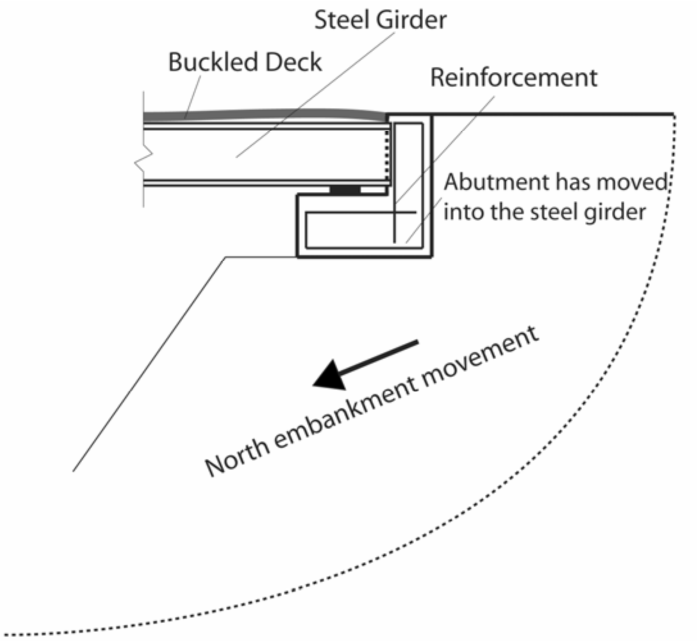

Figure 1: Mead Bridge abutment

CDOT engineers intend to "lock" the girders to the abutments with concrete, in order to prevent further damage caused by the girder-abutment relative movements and to eliminate the effects of the deck separation from the supporting girders. A properly designed SCC is the ideal material for this type of bridge repair. SCC can be pumped to fill complex spaces, including voids on the surface of the abutments. It can also consolidate and fully encapsulate the girders without any external vibration. Figure 2 shows how the placed SCC would encapsulate the ends of the girders the space between them and the abutment.

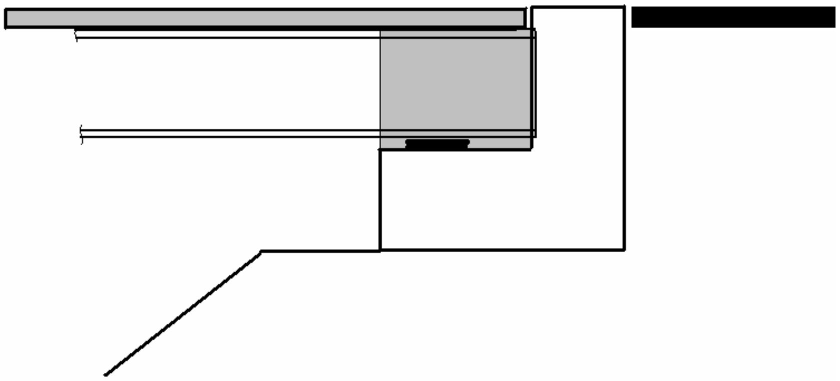

Figure 2: Proposed repair to bridge abutments

A number of challenges must be addressed for this repair. The main concern is the traffic on the bridge. Although there is an available frontage road by the interstate, CDOT does not wish to divert all traffic during construction. One lane may be closed for several hours to perform the repair. Large commercial trucks may be diverted to the frontage road for a few hours if it is deemed necessary. Thus, traffic and associated vibration are expected on the bridge as the SCC cures raising the concern that a "gapped" and weakened bond between the new concrete and the existing structure may develop due to traffic vibrations. A study was conducted to evaluate the effects of traffic induced vibrations on the bridge as the SCC cures.

Several milestones were required in order to achieve the goals of this study.

1) Instrument and record the vibratory deflections of the bridge girders under various traffic loads in the area of locking, where concrete will be placed.

2) Develop a stable SCC mix design with a slump flow between 26 and 30 inches.
3) Instrument and record the deflections of the bridge girders under various traffic loads in the area of locking, where concrete will be placed.
4) Develop and perform small-scale experiments where beams vibrate within freshly mixed SCC blocks.
5) Compare the bond strength between the SCC and the embedded vibrated beams to similar specimens where the embedded beams have not been subjected to vibrations.

The following sections provide a detail description of each of the above assignments and conclude with recommendations of how the objective repair can be achieved.

Instrumentation of the Mead Bridge

In order to determine the anticipated vibrations on site during concrete curing at the Mead Bridge, measurements of the magnitudes and frequency of the traffic vibrations were required. Accelerometers and Linear Variable Displacement Transducers (LVDT) were attached to the girders of the North bound bridge to record the response of the bridge under traffic loading. The North bound bridge was chosen for data collection because it visually has the greatest displacements. During the data collection, a video of the traffic was recorded for cross-reference with the data. The video, when compared to the data, allowed the association of the recorded deflections with the traffic conditions. Loading combinations of interest included large trucks moving in the left lane, large trucks moving in the right lane, large trucks moving simultaneously in both lanes, small vehicles next to large trucks, small vehicles only in one lane at a time and finally small vehicles in both lanes.

Data was collected on four steel girders for all combinations of the loading conditions listed above. Figure 3 illustrates a sub-sample of the recorded accelerations of the most severely loaded girder. Note that the peaks at 20 and 40 seconds in Figure 3 correspond to large commercial trucks directly over the instrumented girder.

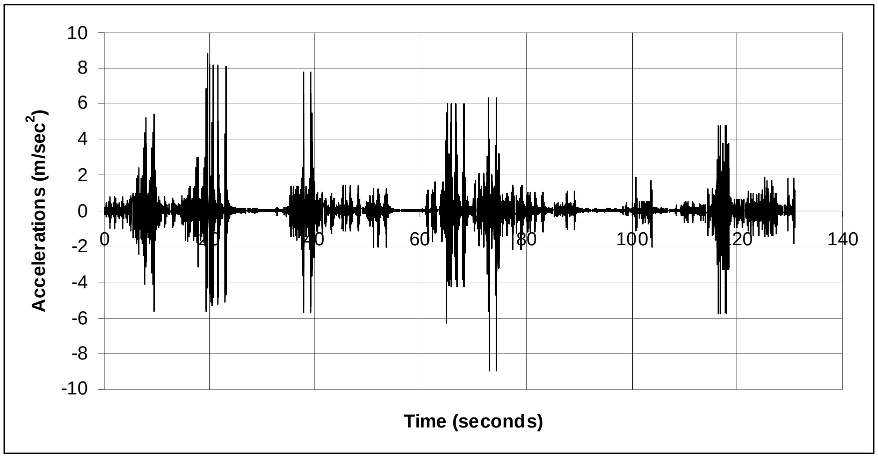

Figure 3: Recorded accelerations at Mead Bridge

The sensors were placed seven feet from the girder supports. Placing the accelerometers and LVDTs away from the supports allowed for larger and less noisy deflections to be recorded. Through interpolation, the displacements at the location of maximum deflection within the repair concrete (three feet from the support) could be reasonably obtained with less noise. The calculated displacements that correspond to the most stressed girder at this location were used for experimental analysis.

SCC Mix Design

Proper use of chemical admixtures and fly ash in SCC mixture development allows it to be sufficiently workable and fluid in order to flow under its own weight around formwork corners and congested reinforcement, consolidate without external vibration, and encapsulate reinforcement and other enclosures without segregation, first due to the dynamic action of placement and subsequently due to the static action of curing. Typically, SCC mixtures are characterized by increased amounts of cement, some replacement of cement with type F fly ash (up to 40% by weight), larger than usual fine to coarse aggregate ratio, smaller coarse aggregate sizes, and low water to cementitious ratios (w/cm). The most important admixture for SCC is a

High Range Water Reducing Admixture (HRWRA), also known as superplasticizer. A second admixture that is often used in SCC is a type of Viscosity Modifying Admixture (VMA). Traditional HRWRAs, such as sulphonated melamine and naphthalene-based products, form a chemical bond with the cement particles, and give them a negative charge, leading to repulsion and thus deflocculation. Newer polycarboxylate ether superplasticizers are fundamentally different, in that they work through steric hindrance rather that electrostatic repulsion [1,2,3,4]. This is a process that also leads to cement particle deflocculation, but is based on the formation of electron clouds around the cement particles rather than electrostatic repulsion. The use of VMA increases the viscosity of the water, which stabilizes the mix and prevents bleeding and segregation. VMAs are quite costly and are at times replaced by alternative approaches such as increased cementitious materials content in the mix.

Several standard tests are available to measure the fluidity and stability of SCC mixes. The most common test for both laboratory and field testing is the slump flow test (ASTM test method C1621). The test uses a standard Abrams cone. However, the intent is to measure the amount of lateral spread rather than the slump. The cone is filled in the upright or inverted position in one lift without rodding and is then picked-up, allowing the SCC to flow though the cone end and spread under its own weight. The diameter of the concrete spread is the slump flow. In addition to the cone, a J-ring is often used in combination with the slump test. A J-ring is a circular device with vertical bars to simulate reinforcement. The SCC is allowed to flow through the bars during the slump flow test and provides an indication of the stability and workability of the SCC. Whereas some engineers use the combination of slump flow and J-ring to measure the difference in spread between free (without the J-ring) and hindered (with the J-ring) flow, others use the J-ring as a measure of flow stability by examining the difference in the spread height at the inner/outer interface of the J-ring. An unstable mix segregates during flow through the gap of the J-Ring resulting in higher aggregate content inside the ring and thus an abrupt change in spread height at the location of the J-ring. Figure 4 demonstrates the ASTM C1621 slump flow test of a stable SCC mix.

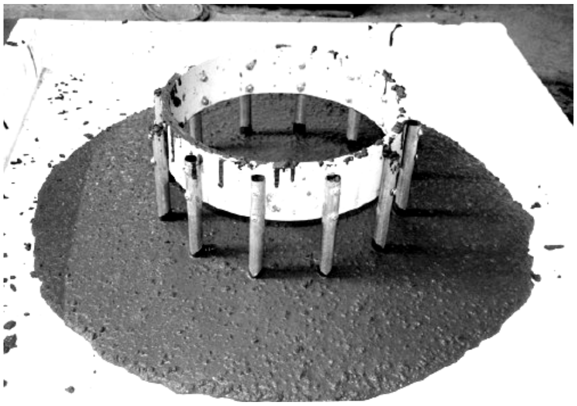

Figure 4: Slump flow test with J-ring

Based on the required workability for SCC placement for the Mead Bridge repair, it is concluded that the SCC mix must have a minimum slump flow of 26 inches. The early strength of the mix (24 hour compressive strength) must at least 3000 psi. The 28-day strength development for such SCC mixtures developed at CSM typically exceeds 7000 psi. Finally, given the *bulk* nature of the concrete required in this project, static and dynamic stability of the mix are very important. A fairly significant amount of class F fly ash replacement of cement (20%-30% by weight) was considered necessary to help with the workability and stability restrictions as well as to reduced shrinkage, which if not properly considered, can be excessive. The mixes use Type III cement to obtain a higher early strength. Table 1 below details the mix proportions tested.

Table 1: CSM SCC mix proportions

	Sand	3/8" Agg	Type III Cement	Class F Fly Ash	Water	w/cm	HRWR (1)	VMA (2)
	lbs per cu. yd.						oz per cu. yd.	
20% Fly Ash	1234	1507	640	159	273	0.341	109.6	14.6
30% Fly Ash	1642	1339	605	259	281	0.325	116.9	7.3
1) Glenium 3400 2) UW 450 (provided by BASF Chemical Admixtures)								

Note in Table 1 that the amount of fine aggregate is greater than the coarse aggregate. This has been shown to provide for a more stable mix during pumping and placement. The addition of Class F fly ash in the mix improves workability, pumping, stabilizes the particles, reduces heat generation during curing and reduces shrinkage [5]. The ratio of water to cementitious materials was maintained below 0.35 to improve the shrinkage characteristics of the mix, and naturally resulted in fairly high strength concretes. The measured air content for the mixes ranged between 3.0% an 8.0%, with an average value of 5.6%. Although no chemical air entraining admixtures were added, the volume of entrained air is attributed to the HRWRA which entrains air into the mix. Figure 5 demonstrates the compressive strength development in time for all successful mixes. Note that all specimens exceeded the minimum requirements with an average 24 hour and 28 day compressive strengths of 4000 psi and 8050 psi respectively.

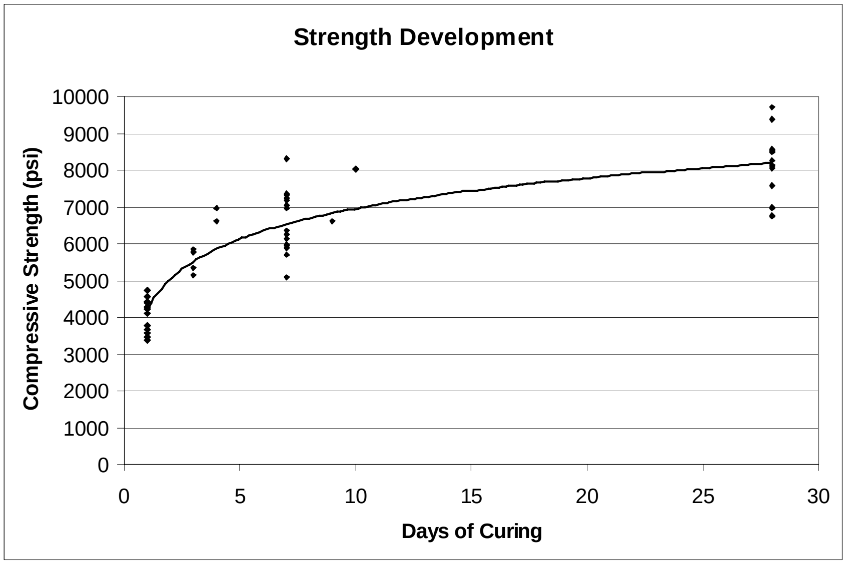

Figure 5: Compressive strength chart for CSM SCC mixes

Shrinkage tests (ASTM C157) performed for the SCC mix designs found that normal autogenous and drying shrinkage was present. The measured average shrinkage strain was 400x10^{-6} at 28 days, ranging from 300 x10^{-6} to 550 x10^{-6}. Although the shrinkage strain for SCC may be higher than normal concrete because of the increased binder content [6], and the smaller coarse aggregate size, the SCC tested in this study produced shrinkage, which was similar to that of normal concrete (400x10^{-6} to 500x10^{-6} after 28 days [6]). The fairly low shrinkage strain, of this SCC mix, is attributed to the high content of fly ash and the low water content.

Pinkard Construction was gracious to perform a 7.0 cubic yard field demonstration of SCC placement for CDOT affiliates at the construction of the new CSM Recreation Center in May 2006. A SCC mix, which was developed by Aggregate Industries Inc. and had similar characteristics to the CSM mix, was placed in an 8.0-inch thick wall that was five feet tall, and 25 feet long with several corners. The Aggregate Industry mix design is proprietary and cannot be published in this report. Nevertheless, the mix was somewhat similar to the CSM mixes that have been described here. The specified 28-day strength was 7000 psi. The average tested 28-day compressive strength was 10,080 psi.

Despite the loss of slump flow due to high ambient temperatures (≈90°F), placement of the SCC at the CSM Recreation Center was overall successful. The measured slump flow was 22.0 inches after approximately 1.0 cubic yard of pumping, however the slump flow measured at approximately 5.0 cubic yards was 19.0 inches. There were no significant problems pumping the SCC and the mix was able to flow around corners in the forms and the reinforcement without external vibration. This was especially the case at the early stages when the slump flow was 22 inches. At that time, the end of the pump hose was kept at the center of the forms and the SCC flowed and spread laterally without difficulty. However, as the slump flow reduced, the end of the pump was moved along the length of the forms to complete the casting. The loss of slump flow was attributed to the high ambient temperature, which was close to 90 degrees Fahrenheit. CSM studies concur with the European practice, which recommends SCC placement at temperatures that do not exceed 80°F [7].

Experimental Program

A series of experiments were developed to simulate the vibrations of the steel bridge girders in wet concrete under normal traffic conditions. These experiments are used to quantify the deterioration of bonding strength between the girder and the concrete that result from the vibratory motion of the girders in the freshly mixed SCC. The experiments consisted of steel channel sections of various sizes placed vertically in rectangular forms as shown in Figure 6. SCC was placed around the steel channels to a depth of seven inches. For each experiment, two blocks were cast. Each block had identical channels and depths of SCC. The channel in one block was vibrated for 24 hours, starting immediately after the concrete placement, while the channel in the second block remains perfectly still for the same period. Figure 6 presents a picture of a pair of tests with channels in fresh SCC.

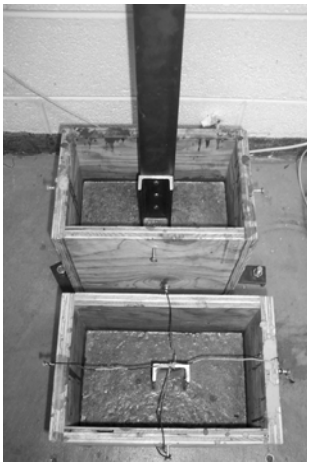

Figure 6: Steel channels in fresh SCC

To simulate the vibration of the steel girders, the measured Mead bridge displacement history was applied to the top of the channel using a small shake table. The vibrations were proportioned as necessary and applied as shown in Figure 7. The movement of the shake table is transferred to the channel in the fresh SCC, therefore vibrating the channel as the SCC cures. The steel channels pivot about the bottom of the form, where a 1/8 inch deep grove was cut to prevent the channels from moving laterally during casting and testing. Figure 7(a) demonstrates the configuration used to vibrate the 1.25in channels and Figure 7(b) demonstrates the configuration used to vibrate the 2.0in and 3.0in channels.

A wider steel blade was used for the larger channels to avoid deflection in the connecting arm and assure movement of the channels as the concrete sets. A smaller bar was sufficient to vibrate the 1.25in channels because their 0.5in flanges do not produce significant bearing pressures. To better simulate the actual bridge girders, channels with larger flanges were tested. The Mead vibration record was placed in a continuous loop for 24 hours. After that time, the concrete has sufficiently hardened and the specimens were removed from their forms and tested for bond strength.

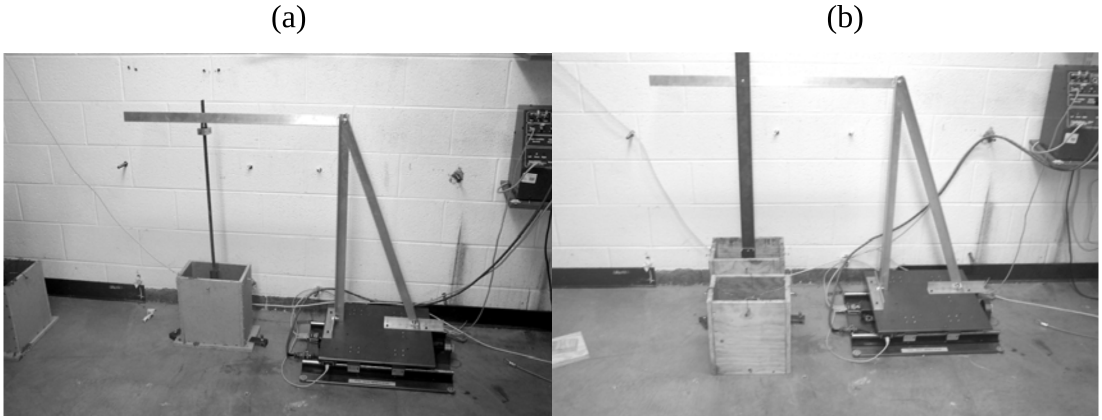
(a)
(b)

Figure 7: Shake table connected to steel channel in fresh SCC

Figure 8 illustrates the effects of the vibrating channels in fresh SCC as it cures. The pivot point of the vibration is located at the bottom of the channel to simulate the rotation of the girders at the abutment. Although the movement creates a defect at the top surface of the concrete, there were no visible defects at the bottom of the channel. The minimal amount of movement at the bottom of the channels did not contribute to the loss in bond strength as much as the movement at the top of the channels.

Figure 9 demonstrates a short time interval of the displacement data applied by the shake table. This signal is a modification of the recorded data. It has been filtered to reduce the electrical noise and it has also been shortened to remove periods of no traffic.

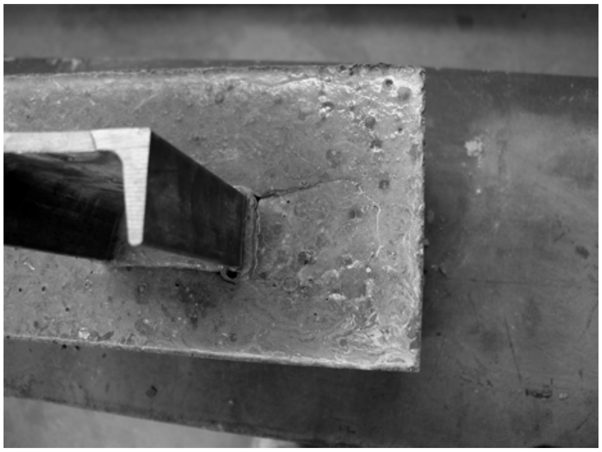

Figure 8: Effects of vibration on SCC

Both pull-out and push-through experiments were performed to evaluate the beam-concrete bond strength. Pull-out tests with the use of a 100-ton capacity hydraulic ram were convenient for the smaller channels. However, push-through configurations proved more effective for the larger channels.

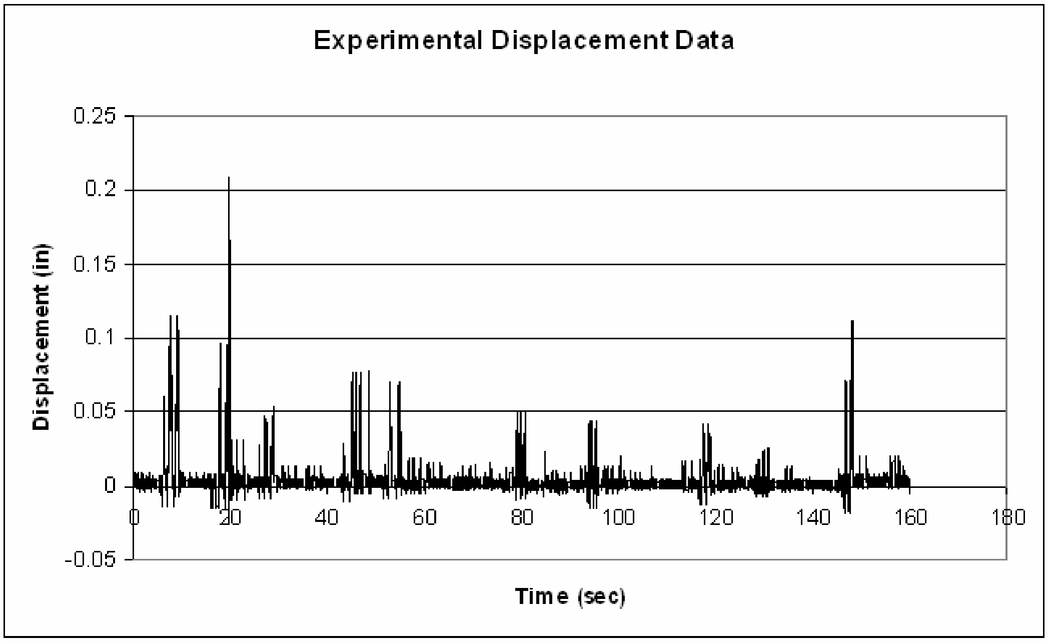

Figure 9: Displacement data for vibration experiments

Figure 10 presents a schematic of the push-through test, while Figure 11 shows a picture of the pull-out hydraulic ram as it pulls a channel from its concrete block.

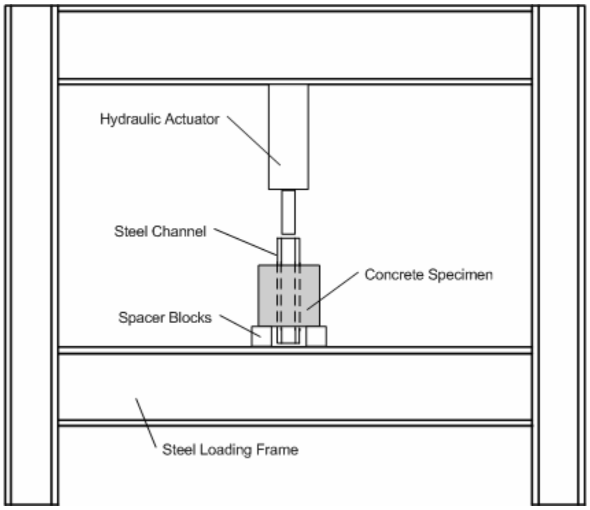

Figure 10: Push-through test schematic

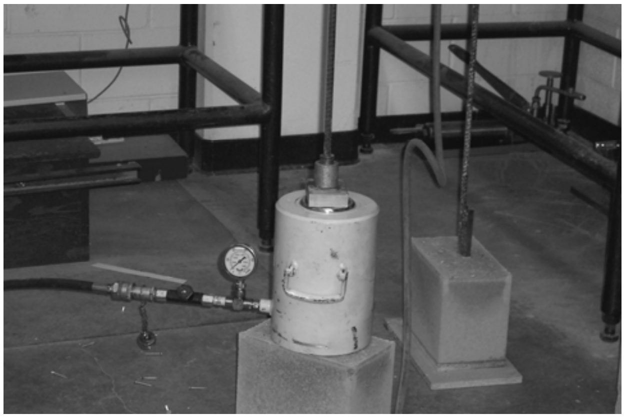

Figure 11: 100-ton hydraulic ram pulling out #5 bar and channel

Although the pullout experiments obtained reliable results for comparison of bond strength between the vibrated and un-vibrated specimens with small channels (1.25 inch depth), it was concluded that more reliable data could be obtained by pushing the channels through the concrete. Push-through tests were conducted for channels with depths of 1.25, 2.0, and 3.0 inches. Table 2 summarizes the results of the push-through experiments.

Table 2: Push-through test summary

A	B	C	D	E	F
Experiment	**Bar Size**	**Average Cylinder Strength at Test (psi)**	**Max Vibrated Load (lbs)**	**Max UnVibrated Load (lbs)**	**% Reduction**
P03	1.25in Chan	3813	12680	14821	14.4%
P04	1.25in Chan	4106	10557	12785	17.4%
P05	1.25in Chan	4288	12737	14563	12.5%
P06	2in Chan	3674	10040	15259	34.2%
P07	2in Chan	4421	11549	13718	15.8%
PT2	2in Chan	4722	12390	17640	29.8%
PT3*	2in Chan	5335	14744	29860	50.6%
PT4	2in Chan	3781	15862	18227	13.0%
PT5	2in Chan	4563	13266	16620	20.2%
PT6*	2in Chan	5768	18902	21006	10.0%
PT7*	2in Chan	5775	17197	21874	21.4%
PT8	3in Chan	2634	14630	17325	15.6%
PT9*	3in Chan	5140	21301	**N/A**	**N/A**
PT10	3in Chan	3372	**N/A**	17685	**N/A**
PT11	3in Chan	3456	25334	17469	-45.0%
PT12*	3in Chan	5858	21176	24159	12.3%
PT13	3in Chan	4387	23060	19251	-19.8%
* test conducted after 3 days of curing					

Several conclusions can be drawn from Table 2. First, the percent reduction given in Column F indicates the amount of bond strength lost between the vibrated and un-vibrated specimens. For most of the experiments a bond strength loss that was less than 25% was recorded. Specimen PT3 recorded a much larger loss (50%) while specimens PT11 and PT13 recorded increase in bond strength for the vibrated channels! Specimen PT3 was performed after three days of curing, rather than the standard 24-hour experiments due to scheduling conflicts.

Four additional push-through tests were performed after three days of curing to examine potential time-dependent effects, due to a concern that was sparked by the unexpectedly large loss of strength that was observed in specimen PT3. These results do not indicate any significant change in loss of bond strength compared to the other experiments. The cells in Table 2 with a "N/A" listed were failed experiments, caused by equipment malfunction.

All specimens were visually examined after the push-through tests were performed. The examinations revealed that in all experiments the SCC was able to fully encapsulate the channels.

Figures 12 through 20 present the experimental load versus displacement plots for various push-through experiments. The push-through load in the plots is normalized to the bond strength of the un-vibrated channel. Note in Figures 17 and 19 that the bond strength of the vibrated specimens was greater than that of the un-vibrated specimens. Also note the fairly significant (all frictional) residual strength after the initial failure even for large deformations indicating the excellent encapsulation of the channels by the SCC blocks. During the residual loading, unload-reload cycles were applied to separate the elastic and frictional response of the bond.

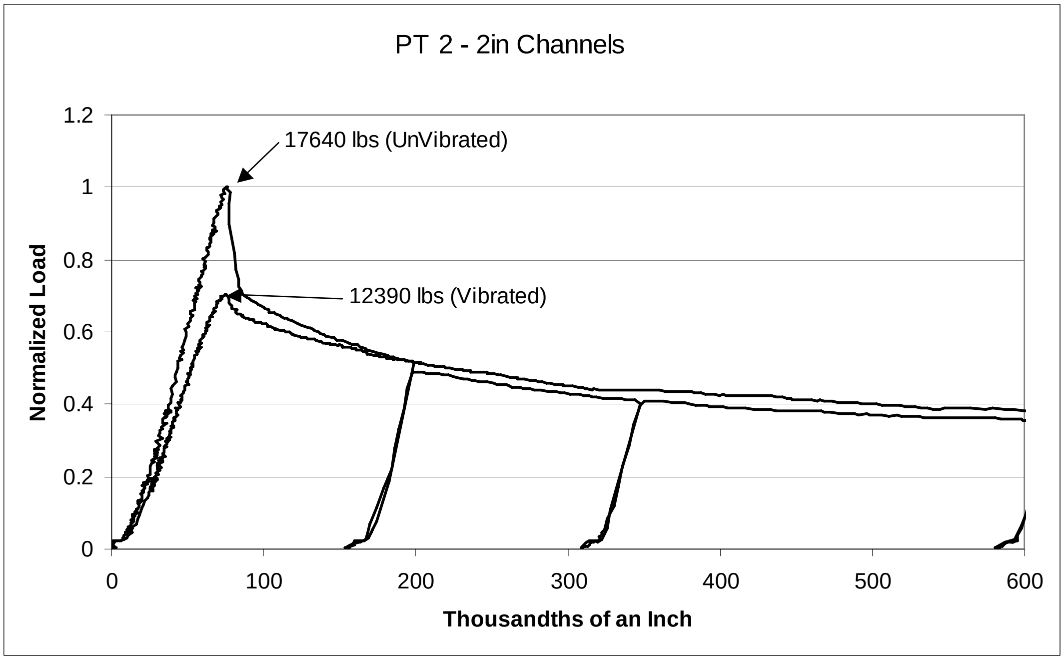

Figure 12: Push-through data for PT 2

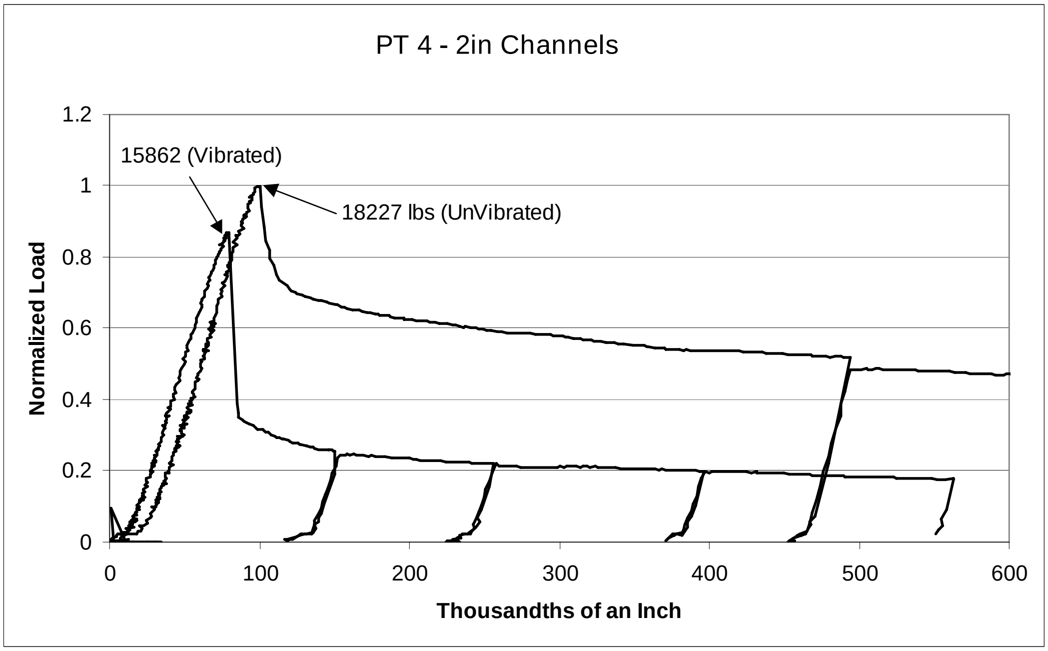

Figure 13: Push-through data for PT 4

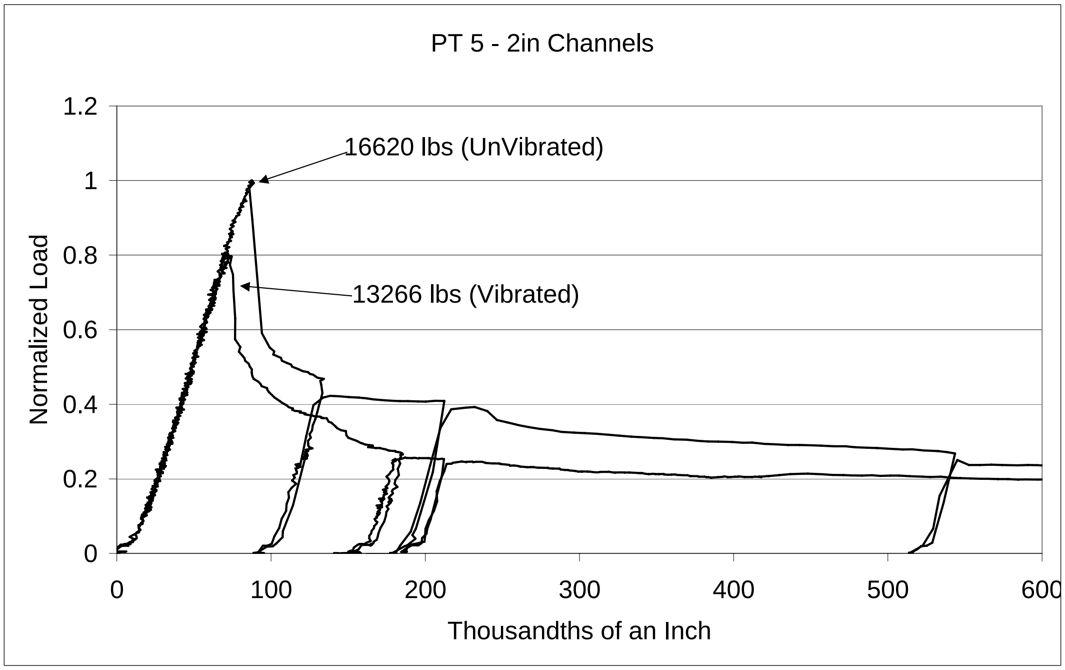

Figure 14: Push-through data for PT 5

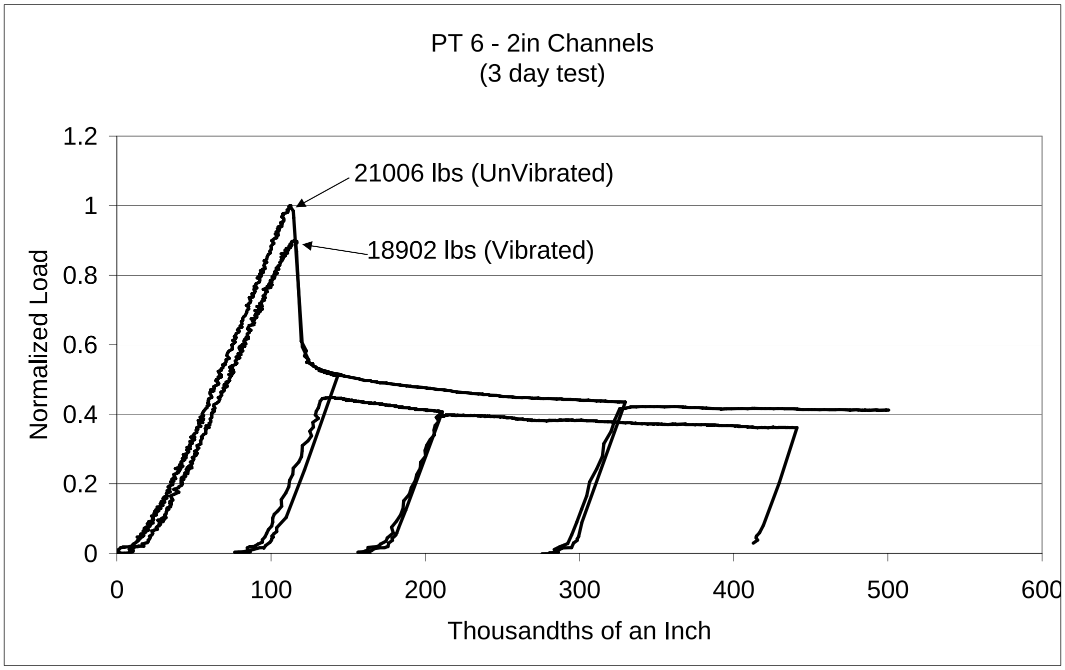

Figure 15: Push-through data for PT 6

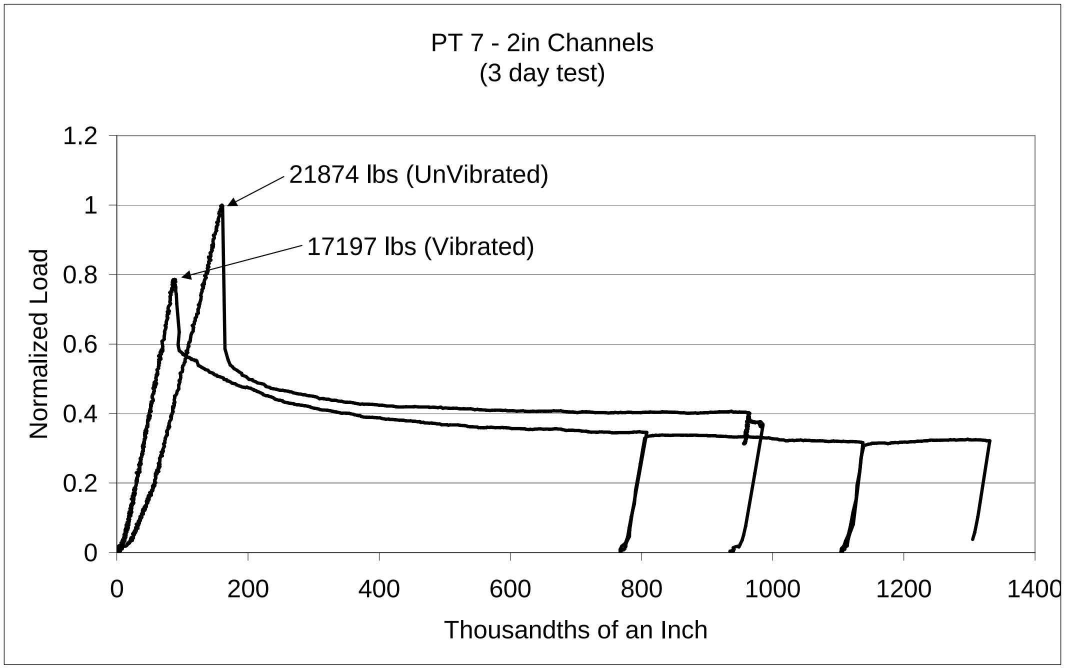

Figure 16: Push-through data for PT 7

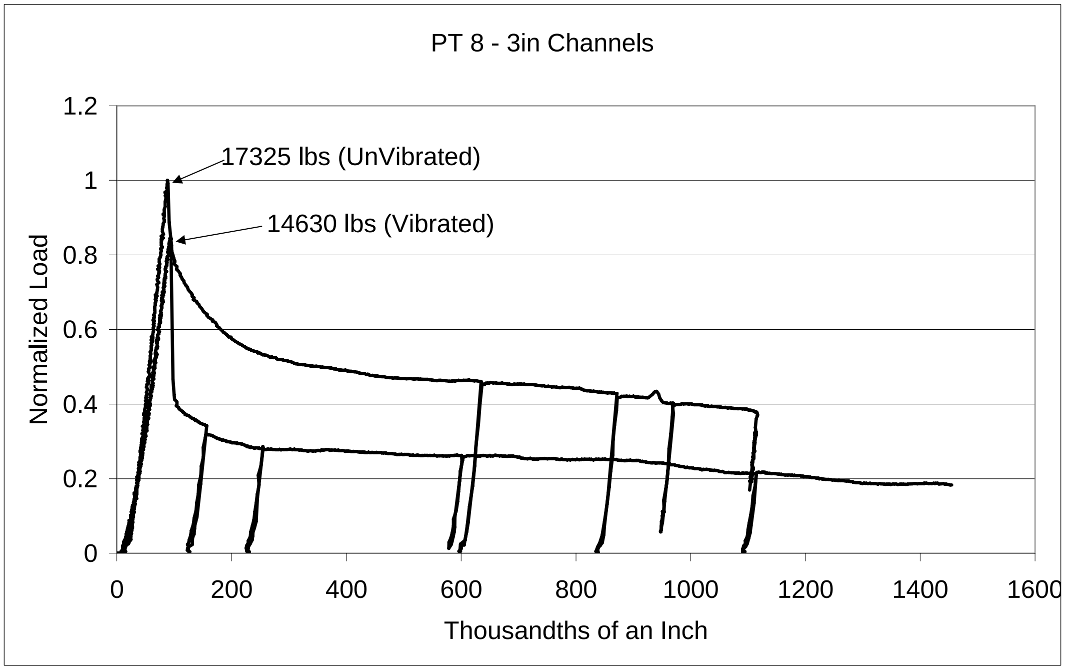

Figure 17: Push-through data for PT 8

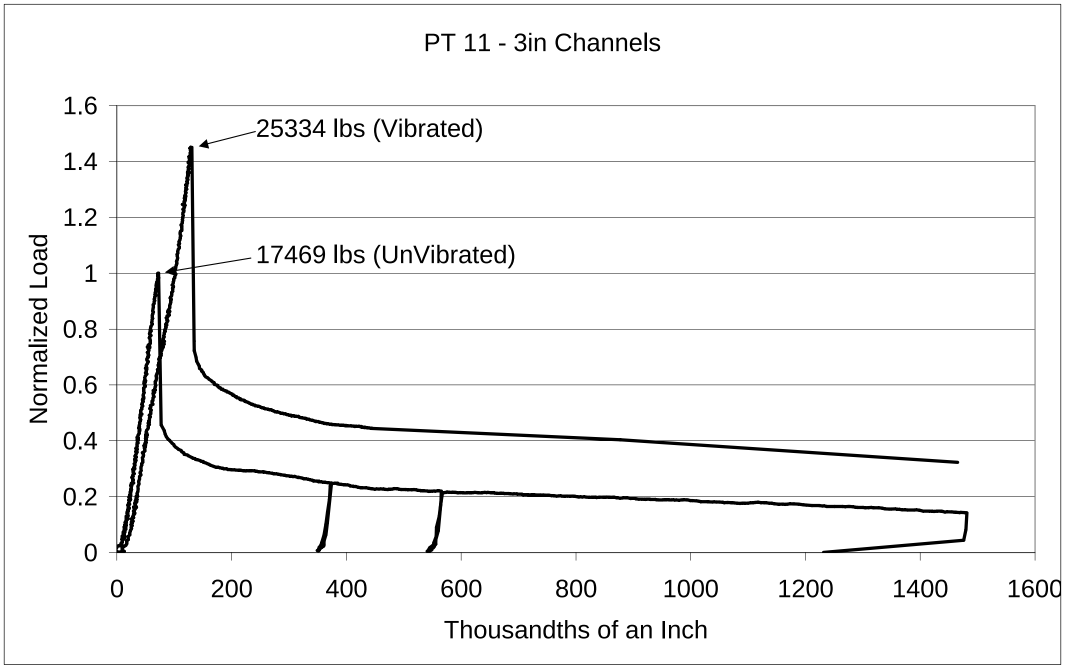

Figure 18: Push-through data for PT 11

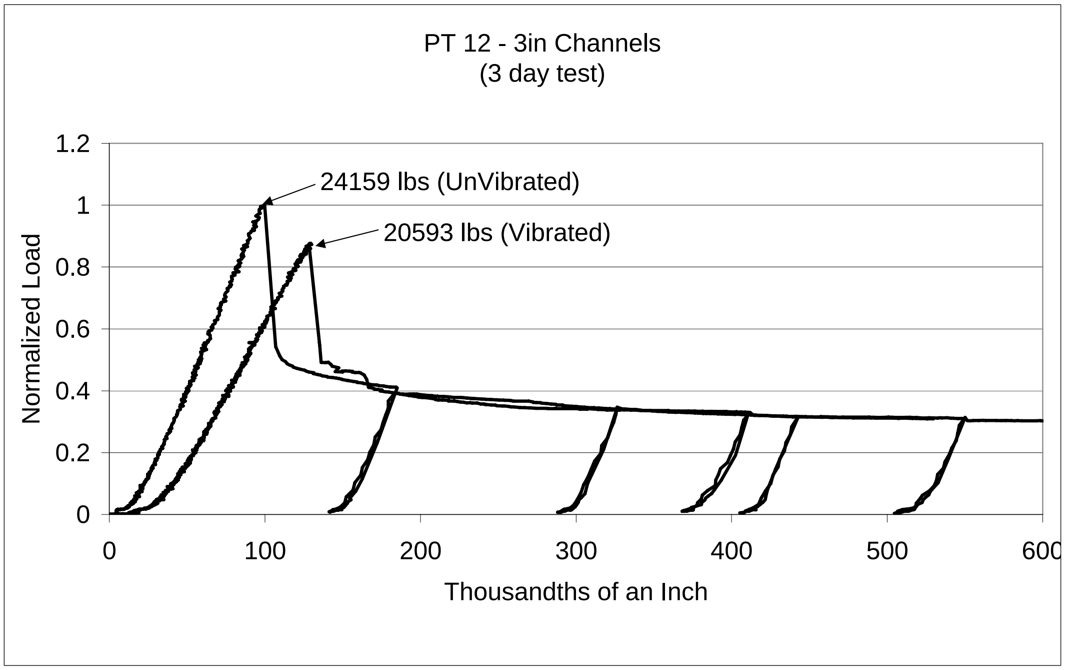

Figure 19: Push-through data for PT 12

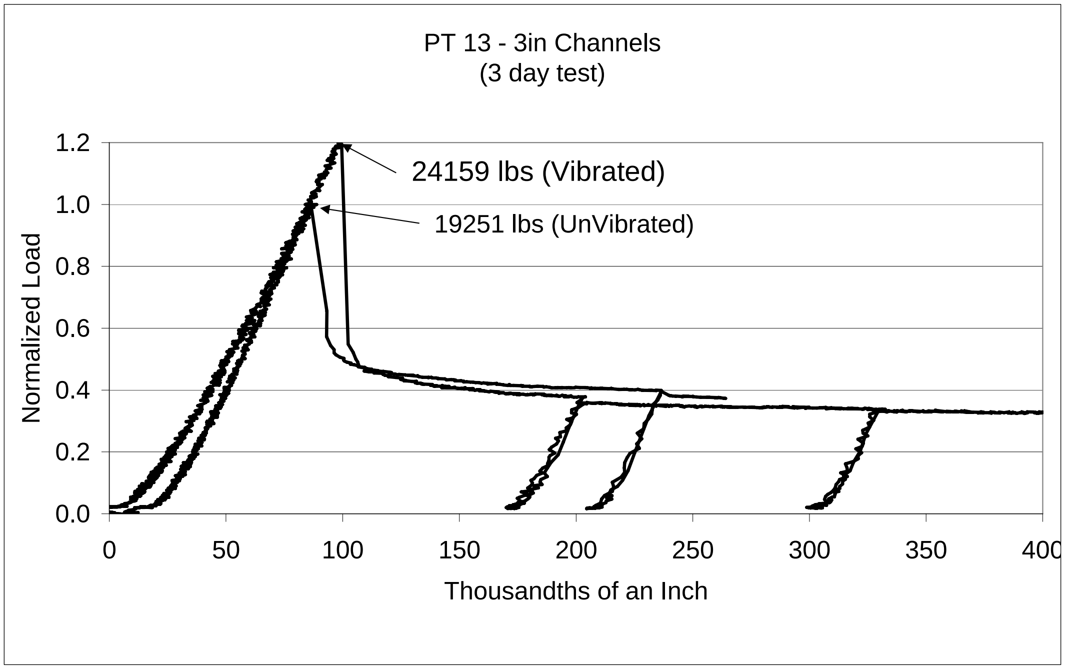

Figure 20: Push-through data for PT 13

Conclusions and Recommendations

The study performed by CSM to determine the feasibility of using SCC to repair the Mead Bridge on I-25 found that under normal traffic conditions, a properly proportioned SCC mix could provide adequate encapsulation of the steel girder without excessive loss of interface bond strength. The CSM SCC mixture developed significant early strength with adequate stability and fluidity to consolidate around obstacles under its own weight without segregating. A slump flow ranging between 26 and 30 inches is recommended to secure proper placement with complete girder encapsulation.

It was also found that steel channels vibrated in freshly mixed SCC can obtain suitable bond strength with the concrete. Comparing vibrated channels versus un-vibrated channels embedded in freshly mixed SCC showed little loss in bond strength.

Due to the size of the concrete mass required to lock the girders to the abutments, CSM recommends that reinforcement be installed to control temperature and shrinkage cracking as per ACI or AASHTO requirements. Expansion joints are also recommended between the consecutive construction concrete blocks to further control the temperature and shrinkage cracking.

It is also recommended that the Mead Bridge repair occur at the early morning hours, with temperatures above 50 degrees Fahrenheit. The reduced early morning traffic will result in less inconvenience to the travelers and will apply reduced loads to the freshly mixed SCC during the critical early curing time. The minimum temperature requirement assures workability of the SCC as well as proper curing. Finally, it is recommended that all large commercial trucks be diverted to the frontage road during the critical curing time. Diverting the large trucks during this time will decrease the impact of the girders on the curing concrete and will result in a stronger and longer lasting bond between the girder and the concrete. Gaps at the concrete-steel girder interface are inevitable due to the traffic vibrations, and must be repaired by injecting epoxy resigns to help extend the life of the structure.

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