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16. Abstract


An experimental study was conducted to determine if the use of stay-in-place metal forms (SIPMF) resulted in reduced bridge deck concrete quality over the life of the bridge compared to bridge decks formed conventionally without SIPMF. A corollary problem addressed was to determine the potential for using ground penetrating radar (GPR) to inspect the bridge deck concrete quality immediately above the SIPMF.

Experimental studies were carried out on three Northern Ohio bridges that were partially constructed approximately 40 years ago using SIPMF. All these bridges had regions where there was no SIPMF. Cores were extracted from these bridges. The deck concrete quality in regions with SIPMF was compared to the concrete quality in regions without SIPMF. Visual inspections and compression, chloride, permeability and ultrasound tests were performed. Ultrasound is is a very discriminating technique to use for comparison. Analysis of the inspection and test data showed no significant difference between the concrete quality in regions with and without SIPMF. This is consistent with the literature.

An experimental study was carried out that compared the predicted concrete quality from a GPR survey to the concrete quality measured by testing verification cores. A GPR signal attenuation map was developed to predict the quality of the concrete in the bridge. This attenuation map was used to select the locations of the verification (ground truth) cores to be harvested. Visual inspections and compression and ultrasound tests were carried out on the ground truth cores. Ultrasound, when coupled with compression testing, is a well established technique to assess concrete condition. Analyses of the inspections and test data showed that GPR was not effective in predicting concrete quality between the bottom layer of rebar and the top of the SIPMF.

The implementation potential for SIPMF in Ohio was considered. Nothing in the present research indicates that implementation of SIMPF in Ohio will be less successful than in the neighboring northern states. Reaping the full benefits will require some time as Ohio contractors and bridge inspectors become familiar with SIMPF. Important aspects of implementation are inspection, materials, repair and specifications.


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The water soluble chloride ion test also indicated that the area located two inches below the surface exhibited the highest chloride ion content. This was expected due to the cracks present in the bridge decks. Chlorides propagated through these cracks, increasing the chloride levels throughout the top two inches of the bridge deck. A major concern of SIPMF is that they prevent visual inspection of the underside of the bridge deck. Engineers are worried that foreign substances, mainly chlorides, will erode the bottom of the deck. From our test results, it was also evident that in most cases, the bottom portion of the deck exhibited the lowest level of chloride ion content. This should help alleviate this concern. Table 5.5 shows the amount of chlorides present at each two-inch (51 mm) interval.

**Table 5.5: Chloride Concentration at Each Two-Inch Interval**

| | **Average Chloride Concentration for Each Bridge** *(Lbs $Cl^-$ per cubic yard)* *(Lbs $Cl^-$ per cubic yard = 5.82 $N/m^3$)* | | | |
|---|---|---|---|---|
| **Bridge** | *2" (51 mm)* | *4" (102 mm)* | *6" (152 mm)* | *8" (203 mm)* |
| **LOR-57-18.18** | 2.64 | 1.74 | 1.00 | 0.71 |
| **OTT-2-28.41** | 4.84 | 2.64 | 1.24 | 0.66 |
| **LAK-90-23.42** | 8.48 | 4.24 | 1.82 | 0.91 |

As stated earlier, the main problem associated with a high level of chloride ion concentration is the corrosion of the reinforcing steel. Sprinkel and Ozyildirim (2000) have stated that a content of 1.3 pounds of chloride per cubic yard (7.66 $N/m^3$) is significant to cause corrosion of the reinforcing steel. They also state that the limit placed by most state departments of transportation is 2.0 pounds of chlorine per cubic yards (11.64 $N/m^3$). Once this threshold is passed, Sprinkel and Ozyildirim state that the reinforcing steel will begin to corrode, and the deck will not function as intended. From our tests results, it was evident that only LOR-57-18.18 possessed a chloride ion concentration lower than the limit placed by most state departments of transportation. However, the chloride ion concentration of this bridge was still higher than the 1.3 limit stated by Sprinkel and Ozyildirim. Therefore, the reinforcing steel has already started to corrode. The main reason for this corrosion of the reinforcing steel is due to the fact that the reinforcing steel in all three of the bridges tested lacked epoxy coating. The epoxy coating has been shown to drastically decrease the corrosion of the reinforcing steel by limiting the amount of chlorides that come in contact with the steel. Since all bridges today require epoxy coating of the reinforcement steel, the problem of rebar corrosion has been greatly reduced.

The test results show that SIPMF do not significantly affect the penetration of chlorides throughout a bridge deck. Similar to the other tests performed, there was no major difference in the areas of SIPMF and areas where no permanent forms are present. The complete chloride test results are in Appendix E: Chloride Ion Test Result.

# Chapter 8: Comparison of Test Results

After completing the compression, permeability, chloride ion and ultrasound tests an overall evaluation was done to compare the areas where there were SIPMF and areas where there was no SIPMF.  this overall comparison study was done by taking an average for each test result in the areas where SIPMF were present comparing it to the average for areas were the deck was formed by the conventional plywood forming method.  Table 8.1 and Figure 8.1 summarize the results from this comparison study.  From the table, it is evident that the concrete from the areas of SIPMF was of better overall quality than the concrete from areas where no SIPMF were present.  Bridge by bridge details of this comparison are presented in Tables 8.2 – 8.4 and Figures 7.98 – 7.100.

The overall finding is that there is no significant difference in deck concrete condition between regions with SIPMF and regions without SIPMF.

## Table 8.1: Comparison Summary of Test Results

| Bridge | Compression Test | | Permeability Test | | Chloride Ion Test | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *AASHTO: T 22* | | *AASHTO: T 277* | | *AASHTO: T 260* | | | | | | | |
| | *(Psi)* | | *(Coulombs)* | | *(Lbs Cl / yd$^3$)* | | | | | | | |
| | *1 Psi = 0.006895 MPa* | | | | *1 inch = 25.4 mm,* | | | | *1 lb/yd$^3$ = 5.89 N/m$^3$* | | | |
| | **No SIPMF** | **SIPMF** | **No SIPMF** | **SIPMF** | **No SIPMF** | | | | **SIPMF** | | | |
| | | | *w/ temp. correction* | | *2"* | *4"* | *6"* | *8"* | *2"* | *4"* | *6"* | *8"* |
| LOR-57-18.18 | 7163 | 7685 | 1777 | 1577 | 3.34 | 2.42 | 1.51 | 0.72 | 2.43 | 1.55 | 0.85 | 0.71 |
| OTT-2-28.41 | 6300 | 6372 | 1990 | 2188 | 4.01 | 2.34 | 1.26 | 0.82 | 5.5 | 2.88 | 1.23 | 0.53 |
| LAK-90-23.42 | 7146 | 6918 | 3136 | 2128 | 9.85 | 4.5 | 2.79 | 1.31 | 7.11 | 4 | 0.85 | 0.52 |
| | | | | | | | | | | | | |
| Average | 6870 | 6992 | 2301 | 1964 | 5.73 | 3.09 | 1.85 | 0.95 | 5.01 | 2.81 | 0.98 | 0.59 |

Compression Test: SIPMF > No SIPMF by 1.74%

Permeability Test: SIPMF > No SIPMF by 14.63%

Chloride Ion Test:

2": SIPMF > No SIPMF by 12.56%

4": SIPMF > No SIPMF by 9.06%

6": SIPMF > No SIPMF by 47.3%

8": SIPMF > No SIPMF by 37.89%

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16. Abstract

A comprehensive research investigation was conducted to evaluate the use of Stay-in-Place Metal Forms (SIPMFs) in construction of concrete bridge decks. The objectives of this research project were to establish the state-of-the-practice for use and performance of SIPMFs for bridge decks, to evaluate the field performance of bridge decks with and without SIPMFs, and to investigate the behavior of environmentally conditioned large-scale laboratory bridge deck specimens with and without SIPMFs.

A survey was developed and administered to all DOTs to examine the state-of-the-practice of using SIPMFs for concrete bridge deck construction. Additionally, a field investigation was conducted to evaluate the performance of existing concrete bridge decks constructed with and without SIPMFs. This field investigation included visual inspection of 10 bridge decks and laboratory investigation of full-depth cores obtained from the inspected bridge decks. The cores were investigated using visual inspection, compressive strength tests, and ultrasonic tests.

A laboratory durability investigation was conducted on 24 large-scale bridge deck slab specimens with and without SIPMF. Four specimens were used as control specimens, and the remaining 20 specimens were subjected to either freeze/thaw exposure and repeated load cycles or salt-water exposure and repeated load cycles. All specimens were constructed using epoxy-coated steel reinforcing. At various stages before, during, and after the environmental exposures, ultrasonic pulse-echo testing was used to determine the quality of contact between the SIPMFs and concrete for specimens with SIPMFs. Furthermore, after the completion of the environmental exposure, ultrasonic through-transmission testing was used to assess the condition of the concrete for all specimens.

Overall, a statistical bias was present in the results of the survey as a function of climate region. Apparent equivalency of deck performance was observed using field inspection as well as visual inspection, compressive strength, and pulse-velocity profiles of the cores. Small changes in the performance of bridge deck specimens with and without SIPMF were measured during the structural and ultrasonic laboratory test programs.


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# CHAPTER 7 : SUMMARY AND CONCLUSIONS

A comprehensive research investigation was conducted to evaluate the use of SIPMFs in construction of concrete bridge decks. A survey was developed and administered to all DOTs to examine the state of the practice of using SIPMFs for concrete bridge deck construction. Additionally, a field investigation was conducted to evaluate the performance of existing concrete bridge decks constructed with and without SIPMFs. This field investigation included visual inspection of 10 bridge decks and laboratory investigation of full-depth cores obtained from the inspected bridge decks. The cores were investigated using visual inspection, compressive strength tests, and ultrasonic tests. The compressive strength tests provided overall strength for the concrete used in the inspected bridges. The ultrasonic tests provided means for evaluating the quality of concrete through the depth of bridge deck. A laboratory durability investigation was conducted on 24 large-scale bridge deck slab specimens with and without SIPMF. Four specimens were used as control specimens, and the remaining 20 specimens were subjected to either freeze/thaw exposure and repeated load cycles or salt-water exposure and repeated load cycles. At various stages before, during, and after the environmental exposure, ultrasonic pulse-echo testing was used to determine the quality of contact between the SIPMFs and concrete for specimens with SIPMF. Furthermore, after the completion of the environmental exposure, ultrasonic through-transmission testing was used to assess the condition of the concrete for all specimens. These tests were followed by the ultimate load tests. Conclusions from each phase of the research investigation are outlined below.

Based on the survey responses provided by 39 DOTs, the following conclusions were drawn:

1) Two-thirds of responding DOTs allow the use and one-third of responding DOTs do not allow the use of SIPMFs in concrete bridge deck construction. Most of the DOTs that use SIPMFs are satisfied with the performance of this bridge deck system.
2) The majority of DOTs that do not use SIPMFs are concerned with the inability to visually examine and access the bottom of the deck slabs.
3) The majority of DOTs use conventional inspection approaches such as visual inspection, and hammer sounding for periodic examination of their SIPMF bridge decks.

4) Most of the DOTs do not believe that the SIPMF increases the long-term durability of bridge decks. The majority of DOTs reported that the use of SIPMFs is not linked to any deck deterioration.
5) Statistical bias is present in the data with regard to climatic region. The overall acceptance of use of SIPMFs and satisfaction with performance of SIPMF decks is generally higher for the Southern region compared to the Northern region of the country.
6) By comparing results of the survey to a similar survey administered in 1974, an increase in the overall use of SIPMFs is observed. However, some DOTs remain hesitant to adopt widespread use of SIPMFs for concrete bridge deck construction.

Based on the field inspection and coring of bridge deck slabs, the following conclusions were drawn:

1) From the visual field inspection and visual inspection of cores, it was determined that the two bridge deck systems were similar. Statistical analysis of compressive strength and ultrasonic pulse velocity tests also indicated similarity of the bridge deck systems for all of the decks as well as for direct comparison decks (for which traffic and environmental loads were identical).
2) The ultrasonic test results through the depth of the cores did not indicate specifically beneficial or adverse effects of the presence of SIPMF on the bridge decks.
3) Overall, the performance of concrete bridge decks constructed with SIPMFs was determined to be similar to the performance of concrete bridge decks constructed without SIPMFs.

Based on results of the laboratory structural test program, the following conclusions were drawn:

1) The average compressive strength of the cylinders that were cured under controlled conditions increased for curing periods up to 28 days, and decreased slightly for further curing times. The average compressive strength of the cylinders decreased with freeze/thaw exposure, and several cylinders deteriorated entirely. The average compressive strength of the cylinders for salt-water exposure increased with increasing time of exposure.

2) Generally, a reduction in the ultimate load carrying capacity was observed for all freeze/thaw specimens with and without SIPMFs except for specimen WO-F-3-2. After 300 cycles of freeze/thaw exposure, greater reduction in the ultimate load carrying capacity was observed for specimens with SIPMF than for specimens without SIPMF (approximately 5%). After further freeze/thaw exposure (600 total cycles), similar reduction in the ultimate load carrying capacity for all specimens with and without SIPMF was observed. This reduction was attributed to the deterioration of specimens with and without SIPMF due to freeze/thaw exposure.
3) An initial increase in ultimate load carrying capacity was observed after 1,000 hours of salt-water exposure for specimens with and without SIPMF. For further salt-water exposure, a relative decrease in ultimate load was obsereved for specimens with and without SIPMF. A larger decrease in ultimate load between 1,000 and 3,000 hours of salt-water exposure was observed for specimens with SIPMF than specimens without SIPMF. The average change in ultimate load carrying capacity for specimens with and without SIPMF between 3,000 and 10,000 hours of salt-water exposure was not significant. After 10,000 hours of salt-water exposure, the ultimate loads for specimens with SIPMF were less than baseline values, whereas ultimate loads for specimens without SIPMF were greater than baseline values.

Based on the ultrasonic pulse-echo tests on laboratory specimens the following conclusions were drawn:

1) The regions of consistent contact rating (good, fair, and poor) were generally well distributed over the entire area of SIPMF.
2) The overall trend of quality of contact between SIPMF and concrete was generally consistent for all freeze/thaw exposure specimens. The initial contact (before cracking) was consistently good, whereas a significant loss of contact occurred upon service load cracking. Essentially all contact was lost after 300 freeze/thaw cycles, and an apparent improvement of contact was observed after 600 freeze/thaw cycles. The apparent improvement in contact was attributed to accumulation of mineral precipitate between the SIPMF and concrete, which was traced to concrete/cement origin.

3) A similar trend of quality of contact between SIPMF and concrete was generally observed for all salt-water exposure specimens. The initial contact (before cracking) was consistently good, a significant loss of contact occurred upon service load cracking, and an apparent improvement of contact was observed with continued salt-water exposure (1,000, 3000, and 10,000 hours of salt-water exposure). The apparent improvement in contact was attributed to accumulation of mineral precipitate on the top and bottom surfaces of the SIPMF, which was traced to cement and salt origin.

Based on the ultrasonic through-transmission tests on laboratory specimens the following conclusions were drawn:

1) With the exception of generally lower pulse-velocities in regions containing cracks, the pulse-velocities were generally well distributed over the entire longitudinal cross section of the specimens. Average pulse-velocity for perimeter, interior, bottom, and total regions were generally similar.
2) An increase in the average pulse-velocity was observed for all freeze/thaw specimens with and without SIPMFs compared to the average pulse-velocity of the respective control specimens with and without SIPMFs. For specimens without SIPMFs, a continual increase in pulse-velocity was observed for freeze/thaw exposure. For specimens with SIPMFs, an increase in pulse-velocity was observed after 300 freeze/thaw cycles. A decreasing trend of pulse-velocity was observed for specimens with SIPMFs after further freeze/thaw exposure (600 total cycles), although the average pulse-velocity remained greater than the average control pulse-velocity (approximately 6%).
3) Relatively small changes in pulse-velocity were observed in response to salt-water exposure. Measured average pulse-velocities after 1,000 hours of salt-water exposure were close to values determined using control specimens. In all cases, the average pulse-velocity increased with further duration of salt-water exposure (3,000 and 10,000 hours total exposure). After 10,000 hours of salt-water exposure, the average pulse-velocity for specimens with SIPMF was higher than the average pulse-velocity for specimens without SIPMF (approximately 3%).

Overall, apparent equivalency of deck performance was observed using field inspection, visual inspection of cores, compressive strength of cores, and pulse-velocity profile of the cores. Small changes in the performance of bridge deck specimens with and without SIPMFs were measured during the structural and ultrasonic laboratory test programs.