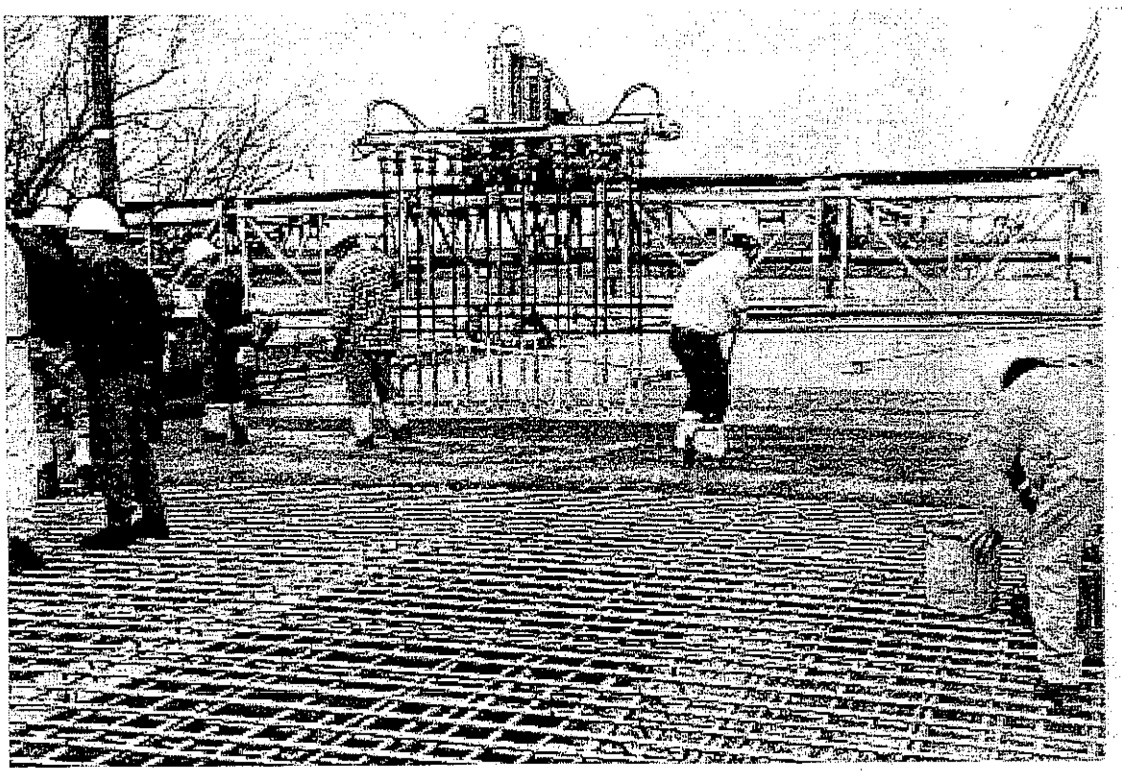
131

Evaluation of Mechanized Consolidation of Bridge Deck Concrete in Illinois

Final Report



Physical Research Report No. 131

August 1999

Illinois Department of Transportation

Bureau of Materials and Physical Research
126 East Ash Street / Springfield, Illinois / 62704-4766

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IL/PR-131		

4. Title and Subtitle **EVALUATION OF MECHANIZED CONSOLIDATION OF BRIDGE DECK CONCRETE IN ILLINOIS**	5. Report Date August 1999 6. Performing Organization Code
7. Author(s) Jeffrey M. South, PE	8. Performing Organization Report No. PRR-131
9. Performing Organization Name and Address Illinois Department of Transportation Bureau of Materials and Physical Research 126 E. Ash Street Springfield, Illinois 62704-4766	10. Work Unit (TRAIS) 11. Contract or Grant No. 13. Type of Report and Period Covered Final Report 1995-1998
12. Sponsoring Agency Name and Address Same	14. Sponsoring Agency Code

15. Supplementary Notes
Study conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

Mechanized methods of vibratory concrete consolidation were used on all or part of fourteen bridge decks in Illinois from 1996 to 1998. The method used on twelve decks consisted of vertical insertion of vibrators in a grid pattern. A transverse drag-through process was used on two decks. Cores were analyzed from decks of both types and compared with cores from conventionally poured decks in order to measure differences in entrapped air voids and in-place density. Based on statistical analysis, the grid pattern method was found to be significantly better than both the drag-through and conventional methods for reducing entrapments per square inch and increasing in-place density. The drag-through method was found to be better than the conventional method for reducing entrapments, but no difference was found for density. Segregation was found in the drag-through cores, but not for either the grid pattern or the conventional method. Some problems were noted on construction sites, mainly having to do with increased weight of the finishing machine and the effect of greater vibration intensity on superplasticized concrete. Costs associated with use of the grid pattern method were approximately $5.50 per square yard of bridge deck. A revised specification and guidelines for use are presented.

17. Key Words	18. Distribution Statement
Bridge deck concrete, gang vibration, grid vibration, concrete consolidation, drag-through vibration, quality improvement.	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	39	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

EVALUATION OF MECHANIZED CONSOLIDATION OF BRIDGE DECK CONCRETE IN ILLINOIS

By:

Jeffrey M. South, PE

Engineer of Technical Services

Illinois Department of Transportation

Bureau of Materials and Physical Research

Springfield, Illinois 62704

August 17, 1999

TABLE OF CONTENTS

Foreword

This report should be of interest to engineers involved in construction of bridge decks, concrete materials, inspection, and quality assurance; contractors; manufacturers of bridge deck paving machinery; and other technical personnel concerned with building bridges and structures.

Notice

Acknowledgments

The author gratefully acknowledges the kind assistance and support of many IDOT District Construction and Materials personnel, Professor Tom Parsons of Arkansas State University, and the late Mr. Harry Horn.

List of Figures

List of Tables

EXECUTIVE SUMMARY

A mechanized method for consolidating concrete after placement and before finishing was used on all or part of fourteen bridge decks built in Illinois from 1996 to 1998. Twelve of these decks were paved using a grid pattern with vertical insertion of the vibrators placed at approximately twelve inch spacing. Two decks were built using a method whereby the vibrators were attached in a horizontal orientation to the finishing carriage and were dragged transversely through the concrete above the top layer of reinforcing steel. These processes were evaluated as quality improvement tools.

Cores were cut from two grid pattern decks, two conventional decks, and the two drag-through decks for petrographic examination. Differences in air entrapments per square inch and concrete unit weight were noted, as was evidence of mixture segregation. The data were analyzed in order to make relative comparisons between the methods with statistical confidence.

Only a few issues pertain to the mechanized vibration processes evaluated in Illinois; superelevated decks, variable width decks, added paver weight, vibration of superplasticized concrete, stage construction, and the experimental special provision. These issues can be resolved with guidelines for use and revision of the special provision from an experimental application to an inserted special provision.

As with any new construction practice, acceptance differed among contractors. Some contractors embraced the concept almost immediately. Others seemed ready to oppose the idea at any cost. The same could be said for Department personnel. Some were supportive of the idea, others were skeptical.

The estimated added cost of the grid pattern method is about $9,500 for an average bridge project, or about $5.50 per square yard of bridge deck. This is based on estimated and actual costs of leasing grid vibration machinery and the average quantity of Concrete Superstructure placed in Illinois between 1996 and 1998.

Illinois is implementing QC/QA specifications for concrete. Under this program contractors must take more responsibility for the quality and testing of their product. End result specifications and warranties are future probabilities. Contractors will need to develop methods, processes, and attitudes that incorporate the active addition of concepts that improve the quality of their end product. Although it is not clear which in-

place properties might be required in an end result specification, fundamental properties such as in-place unit weight and minimized entrapped air content are reasonably related to long term performance and are possible candidates for measurement. Uniformity of a given property is also a likely measurement for an end result specification. Grid pattern vibration is a straightforward construction process that achieves both improvement and uniformity of these fundamental properties. Given that the grid pattern method is a quality enhancement tool, with both the owner and the contractor having an interest in better quality bridge decks, grid pattern consolidation of bridge deck concrete is a method that should be adopted and encouraged.

The special provision for grid pattern vibration was revised. Changes to the special provision include allowing for contractor-built devices with IDOT approval, a separate pay item, and method of measurement for payment. Using careful engineering judgment, the Department can allow contractors to develop effective grid pattern devices. This encourages contractors to think about grid pattern vibration as a standard construction practice. A contractor would be motivated to use an approved device. Addition of a separate pay item for grid pattern vibration will allow the Department to set a unit price and should reduce the incidence of missing the item in the bidding process. A defined method of measurement ensures that the Department pays only for the deck area that was actually grid vibrated.

The following conclusions were made based on the observations and data collected in this study:

1. The grid pattern method was a statistically significant improvement over the conventional method in terms of both reduced air entrapments per square inch and increased unit weight. Uniformity improved for both properties.
2. The drag-through method was a statistically significant improvement over the conventional method in terms of entrapments per square inch. Uniformity was also improved. There was no statistical difference found between drag-through and conventional methods in terms of unit weight.
3. The grid pattern method was significantly more effective in removing entrapments per square inch and improving unit weight than the drag-through method. The grid pattern method also provided better uniformity.

4. Segregation of grid vibrated concrete was not found in the analysis of the cores cut from the District 1 bridge decks, nor was the conventionally vibrated concrete in District 1 segregated. However, the analysis of cores from the drag-through vibrated decks did show signs of segregation.
5. The grid pattern method is applicable to a wide range of construction scenarios, given proper attention to issues related to superplasticized concrete and paver weight.
6. The cost of the grid pattern method was a minor addition to the total cost of the bid item for Concrete Superstructure.

The following are recommendations and guidelines for use:

1. The grid pattern method should be the preferred IDOT method for consolidation of bridge deck concrete in the absence of practical limits. The method should be implemented as an inserted special provision at the discretion of the District design offices. Practical considerations for limiting use include deck superelevation, variable deck width, and effect of finishing machine weight on beam deflection during paving. Grid pattern vibration and high dosages of superplasticizer should be discussed and accounted for in the pre-pour meeting.
2. Grid pattern vibration is a construction process that adds value to the end product. This value is in the form of reduced air entrapments and improved concrete unit weight. As a result of the process, IDOT has more assurance that the concrete has been both better and more uniformly consolidated. Both IDOT as the owner and the contractor have an interest in placement of a higher quality bridge deck. IDOT has been willing to pay for improved quality, and should be willing to pay something for mechanized grid pattern vibration.
3. The drag-through vibration method should not be used for bridge deck paving because of segregation problems.
4. The unit price for mechanized vibration of bridge decks should be $3-4 per square yard. This is a minimal price addition to an average contract, and shares the lease, purchase, or development cost of a device between the Department and the contractor.

INTRODUCTION

This report discusses mechanized methods used to provide uniform vibratory consolidation of bridge deck concrete on several bridges in Illinois. The main topics are constructibility; that is, how well could the device(s) be used on a typical/normal deck paving job, were there special problems or needs, and so on; and discussion of data regarding entrapped air and unit weight and the effect of the methods on improving those properties. The terms 'gang vibration' and 'grid vibration' are used interchangeably and refer to the process of vertical insertion of several vibrators in a matrix pattern. 'Drag-through vibration' refers to a process by which one or two vibrators were dragged transversely through the deck concrete just above the top reinforcement layer. These vibrators were attached to the finishing carriage. The term 'conventional vibration' refers to the standard practice of a laborer consolidating the concrete with a backpack vibrator.

The original purpose of this experimental feature was to determine the effect of improved/uniform concrete consolidation on premature deck cracking. It became evident, however, that given the number of factors contributing to deck cracking [Ref. 1], it would be very difficult to establish a reliable correlation between improved consolidation and early cracking based on the limited original number of test bridges and the inability to control many other influential variables. The focus of the investigation shifted to constructibility issues and the enhancement of certain concrete properties needed for improved performance and durability.

Contractors in Illinois built all or part of twelve bridge decks using mechanized grid pattern consolidation equipment. Two other decks were built using a drag-through vibration process. Initially, the study involved three sets of twin interstate structures built in the Chicago area (IDOT District 1). Two of the grid pattern decks and two conventionally vibrated decks built in District 1 were cored in order to ascertain differences in as-built concrete properties such as air entrapments, segregation, specific surface, mean void diameter, and unit weight. The effects of the new method on concrete placement rate and deck cracking were also measured [Ref. 2]. Both decks built with the drag-through process were cored. Those data were compared to the grid pattern method and conventional method results [Ref. 3].

The early experience in District 1 indicated that contractor experience and comfort level would be major factors for potential statewide implementation of this process. In order to get more contractor experience, and to have the downstate districts get involved, the study was extended to include several other bridges. The remaining eight districts were solicited for prospective projects in which to try this process. Little or no criteria for the prospective projects were required. In fact, two bridge decks and approach pavements were grid vibrated in District 1 at the same time and just after the original District 1 projects. The special provision was apparently inserted into the contract by the district design office. These decks were not part of the project scope.

The decks included in the study were a wide assortment of interstate and primary, 2- and 4-lane, stage and full width construction, skewed and normal, and superelevated and normally crowned structures. The decks built in Illinois using mechanized vibration methods are identified in Table 1.

The remainder of the report includes a short discussion on the benefits of improved concrete consolidation, a description and discussion of the bridges and consolidation methods used, problems encountered during construction, core data analysis, a discussion of cost, a summary discussion, and conclusions and recommendations resulting from the research project.

TABLE 1
List of Bridge Decks Paved Using Mechanical Methods

<u>Grid Pattern Vertical Insertion</u>

I-57 Southbound over EJ&E Railroad near Matteson (District 1)
I-80 Eastbound over NS Railroad near Mokena (District 1)
I-80 Westbound over US 30 near Joliet (District 1)
IL 1 over Little Calumet River (District 1) *
IL 1 over Cal Sag & Ashland Avenue (District 1) *
OR 66 over Rooks Creek (District 3)
OR 66 over Turtle Creek (District 3)
US 67 over Edwards Creek (District 4)
I-70 Eastbound over Camp Creek (District 7)
IL 4 over Little Silver Creek (District 8)
IL 4 over Tributary to Little Silver Creek (District 8)
OR 5 over Chain-of-Rocks Canal (District 8)

<u>Drag-Through Vibration</u>

Brighton TWP 467 over Girder Brook (District 6)
Monroe Street (Southbound) over Spring Creek in Decatur (District 5)

* The grid vibration special provision was independently inserted into the contract by District 1.

EFFECT OF CONSOLIDATION ON CONCRETE MATERIAL PROPERTIES

The objective of improved bridge deck concrete consolidation is to remove entrapped air bubbles in plastic concrete with the goal of producing a deck with better, more uniform properties. An entrapped air void is defined by the Portland Cement Association (PCA) as a void larger than 1/25 inch (1mm) in diameter. Better consolidation has the effect of increasing the unit weight (density) of in-place concrete. Previous research by Whiting and Tayabji [Ref. 4] shows that improved unit weight is highly correlated to improvements in compressive strength, impermeability, and bond strength to reinforcing steel. Improvements in these properties are all desirable. Whiting and Tayabji found that:

- "There is a loss of approximately 30 percent in compressive strength for every 5 percent decrease in consolidation. Mixtures having higher cement contents show a somewhat greater sensitivity to strength loss for a given percentage decrease in consolidation. Type of aggregate used and (entrained) air content have little effect on this relationship.
- Bond stress is reduced by more than 50 percent for a 5 percent decrease in consolidation. The predominant effect is evidently a loss in bond due to increasing void space in the vicinity of the reinforcing steel.
- Permeability to chloride ions, as measured by the rapid AASHTO test, increases with a decrease in percent consolidation. The effect is greater in limestone mixtures and in mixtures with high levels of entrained air. The effect becomes more pronounced below 96 percent consolidation.
- In the majority of cases, overconsolidation to the point of incipient segregation results in improvements in all properties tested."

Even a minimal improvement in consolidation can result in concrete with better properties without the need for costly changes in cement content, admixtures, or other mix design parameters. Reduction of entrapped air also reduces subsidence of plastic concrete which can affect deck smoothness and ride quality.

It was not the intent of this study to try to verify or reproduce the results noted above. For the purposes of this study, it was assumed that real improvements in compressive strength, bond strength, and permeability to chloride ions can be inferred when statistically significant differences in base measurements such as either increased unit weight or removal of entrapped air voids are found.

It was also of interest to note the variability of the data between conventionally poured, grid pattern, and drag-through vibration methods. The reasoning was that because Illinois is on a path of increased contractor responsibility and end result specifications, a contractor would have a definite interest in making sure that the concrete placed on the deck had uniform properties.

The project perspective was that of evaluating a potential quality enhancement tool. Although in-place bridge deck compressive strength is rarely measured in Illinois, there is general agreement that achieving design concrete compressive strength is not a problem. Lack of adhesive bond strength between concrete and epoxy coated reinforcement emphasizes the importance of improving mechanical bond strength. Limiting permeability to chloride ions makes sense as a prudent general improvement to concrete mixtures in civil engineering structures.

CONSTRUCTION

Three sets of bridges in District 1 were initially selected in 1995 for this study. These sets were composed of twin interstate structures. The plan was to build one deck using grid vibration and the other conventionally for comparison purposes.
The structures involved were:

- I-57 over the EJ&E Railroad near Matteson,
- I-80 over the NS Railroad near Mokena, and
- I-80 over US 30 near Joliet.

At the time, two companies provided mechanized grid pattern consolidation devices. In order to foster competition and to keep the scope of the study fairly narrow, a special provision was developed that allowed either of the two devices identified by the two manufacturers, but also kept contractors from building a device that was "put together with duct tape and baling wire." The intent of the special provision was to require the use of the best available equipment. The version of the special provision used for most of the projects is contained in Appendix A. The special provision outlines requirements for the vibrators and allows the grid vibration device to be either mounted to the paver or a stand alone machine on a separate bridge. It was left up to the contractor to contact the manufacturers and arrange for acquisition of a device. One company instituted a leasing arrangement early in the research project as a method to encourage contractors to use the device without requiring them to purchase an expensive piece of equipment. The other manufacturer started a lease program later in the study.

The drag-through process was included later in the study as an adjunct issue at the request of an interested contractor. Also later in the study, one district approved a contractor-built mechanized grid vibration device as an equivalent to those commercially available.

I-57 over the EJ&E Railroad near Matteson

The I-57 bridges over the EJ&E Railroad near Matteson are comprised of two six span structures, each 415 feet long. The decks are 43 feet 2 inches wide. These bridges were redecked using stage construction techniques. Southbound I-57 (SN 016-0048) was redecked using grid vibration methods, northbound I-57 (SN 016-0049) was redecked conventionally. First stage pour width was 20 feet 1 inch. These decks were built in the 1996 construction season.

The two grid pattern devices used on I-57 Southbound were stand alone machines built by Allen Engineering of Paragould, Arkansas. These devices were prototypes. The Stage I device had some problems during a dry run. The contractor kept a spare deck finisher and a crane on site to lift the device off the bridge in case it had problems. Concrete was delivered via conveyor belt. The Stage I device used a 2 by 4 vibrator pattern and is shown in Figure 1. No construction problems were encountered during the pour. The device in no way slowed the paving operation. It was noticed, however, that laborers routinely walked in the consolidated concrete between the vibration device and the paver. While this would not affect the concrete below the top reinforcement layer, the benefits of better consolidation could be lost in the top of the slab. There were some scheduling and agreement problems between the contractor and the manufacturer, who acted as a sub-contractor. The Stage II pour used a 4 by 4 grid pattern.

I-80 over the NS Railroad near Mokena

The I-80 bridges over the NS Railroad near Mokena are 211 feet-4 inch, three span structures. These bridges were redecked as part of an I-80 reconstruction project. They were both poured full width. The eastbound structure (SN 099-0070) was built in 1996 using the grid vibration device. Westbound I-80 (SN 099-0071) was conventionally built in the 1997 construction season.

The machine used here was a stand alone device built by Allen Engineering. The vibrators used were arranged in a 4x4 grid pattern. The previous prototype was reworked and expanded to extend full deck width. This device is shown in Figure 2. Concrete was delivered by pump. There was less laborer traffic between the two devices because they were held closer together than for the I-57 pour. The device caused no delays during paving. There was a significant skew on this bridge, so the device was not used until it was past the skew. The only problem of note related

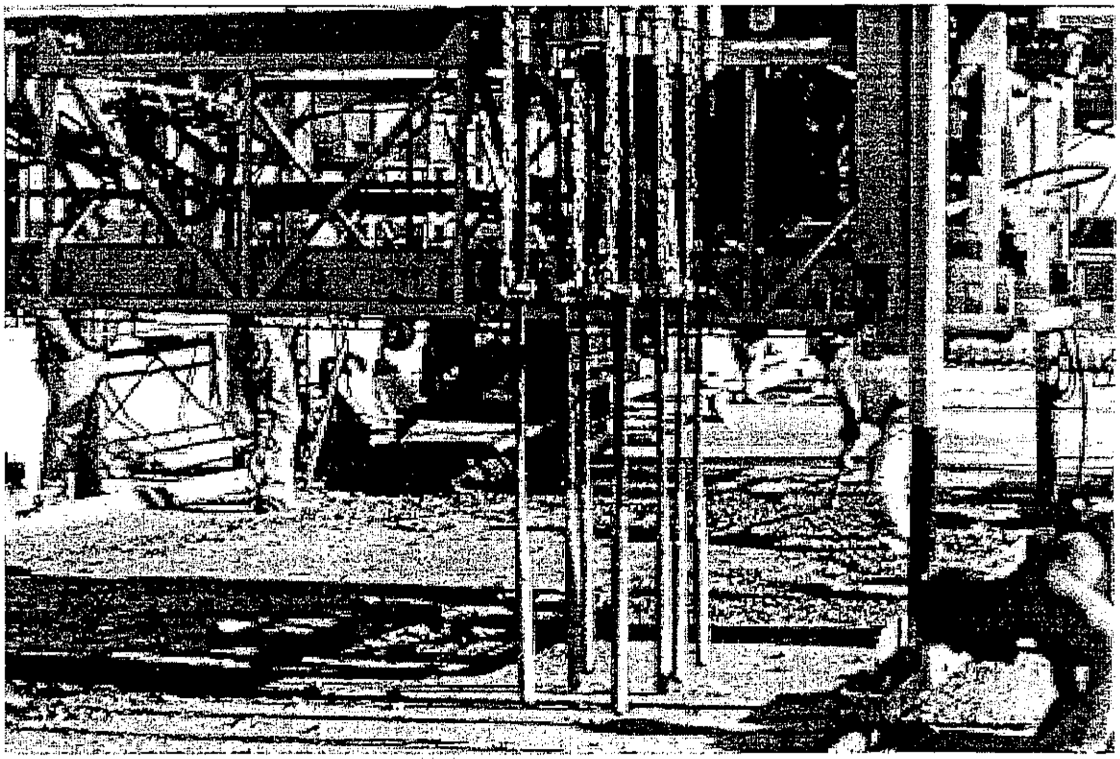


Figure 1. Two by four grid pattern vibration machine used for Stage I on I-57 southbound over EJ&E RR in District 1.

to grid vibration on this bridge was related to the slight superelevation. The contractor commented that the concrete was moving downhill and resulted in more waste concrete than expected. This was attributed to the 4x4 grid pattern which seemed to concentrate the vibration effort. Later versions of the Allen device tended to use a 2x8 grid.

I-80 over US 30 near Joliet

The I-80 bridges over US 30 near Joliet are 629 feet long, 9 span structures. These bridges were also redecked as part of the I-80 reconstruction project. Both were poured full width. The eastbound structure (SN 099-0069) was built conventionally in 1996. The westbound structure (SN 099-0068) was built in 1997 using the grid vibration device for approximately two-thirds of the structure. Both structures are slightly superelevated. The remaining portion was paved conventionally because ramp proximity resulted in variable structure width. The device used on this bridge was a

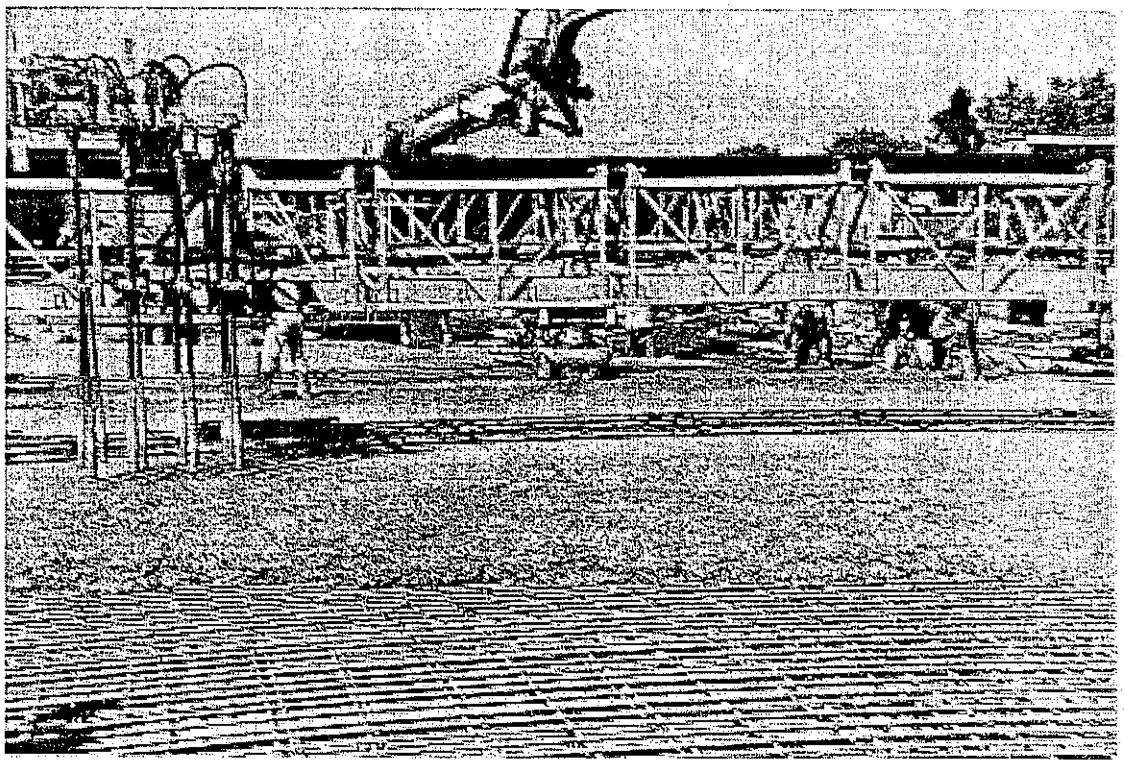


Figure 2. Four by four grid pattern device used on I-80 EB over NS RR in District 1.

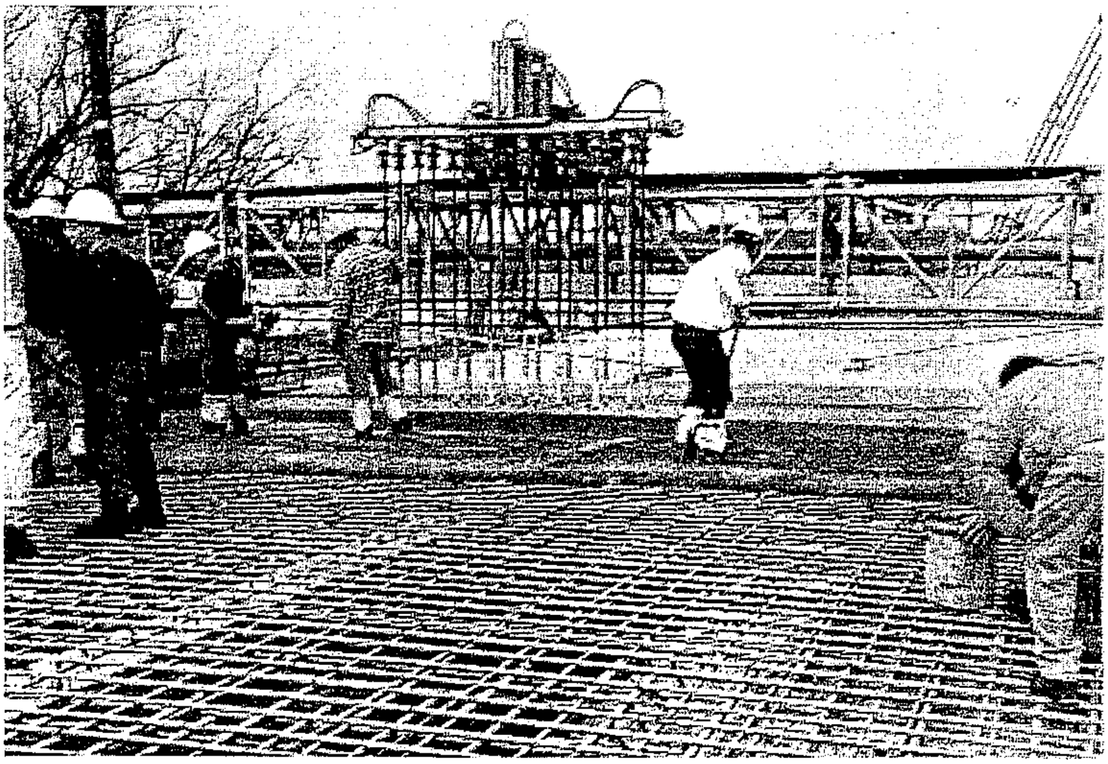


Figure 3. Two by eight grid pattern device with finishing carriage on same machine. This device was typically used for most subsequent grid vibration. Photo is actually from OR 66 bridge in District 3.

combination finishing machine/grid vibrator built by Allen Engineering. This device is shown in Figure 3.

The eastbound structure was originally intended to be grid vibrated. However, the contractor had significant problems when performing a dry run. The paver came off the support rails more than once. Initially it was believed that the extra weight of the grid device was to blame, but the same problem occurred with a conventional paver. Part of the problem was related to the variable width structure. Both pavers had to be adjusted for width, and also had to contend with a superelevation. During a personal inspection it was noted that the adhesive used to bond the rail support stands to the steel stringers in the positive moment areas was still soft and tacky more than 24 hours after the dry run. The rail supports were also bonded to the painted surface, not the steel beam substrate. The failure of both pavers to complete the dry runs was likely a result of the combination of poor bond, variable paving width, and side thrust from the superelevation. The district required the deck to be conventionally paved and the westbound structure to be grid vibrated.

The westbound pour occurred over two days. The first day was the conventional pour to accommodate the variable width, the second pour was grid vibrated using a 2x8 pattern. Early shrinkage cracks occurred in the grid vibrated portion of the deck and the mechanized process was initially suspected of being a contributing factor. However, core analysis, evaporation rate data, and the presence of similar cracking on the I-80 WB structure over the NS Railroad (conventionally paved) indicated the early cracking was a result of plastic shrinkage. Plastic shrinkage cracking is associated with curing practices, not improved consolidation. Core analysis clearly showed the initial crack depth to be related to plastic shrinkage, followed by continued crack growth from drying shrinkage. This type of cracking has been found on other bridges throughout Illinois.

Other Bridge Decks Built in District 1

The decks on IL 1 over the Little Calumet River and over the Cal Sag Canal and Ashland Avenue in District 1 were paved in the 1996 construction season using the Allen device available at the time. No other information was collected on these structures.

OR 66 over Rooks Creek and Turtle Creek

These bridges are located south of Pontiac in District 3. Rooks Creek (SN 053-0003) is a four span continuous steel structure and was redecked full width. Turtle Creek (SN 053-0005) is a two span continuous steel structure and was also redecked full width. Both bridges were on the same contract and were redecked in 1997. The combination device manufactured by Allen Engineering was used. On one of these bridges it was attempted to skew the paver to consolidate the concrete in the skew triangle area. This required the device to be manually operated in that area and resulted in significant extra effort. Other problems noted by the Resident Engineer were that the rollers did not smooth the surface as expected and that consolidation might not have been as uniform as hoped and was related to the forward advance of the paver. It was thought that increased operator skill was needed and that certain adjustments to the machinery could have addressed the apparent problems.

US 67 over Edwards River

This bridge is located north of Viola in Mercer County, District 4. The Edwards River bridge (SN 066-0017) is a new, six span, simply supported structure with PPC I-beams. It was paved full width in the 1997 and 1998 construction seasons.

The approach span for the Edwards River bridge was poured in late 1997 and was grid vibrated using the Allen device with a 2x8 grid pattern. It was noted that the concrete used for this pour was heavily superplasticized for pumping purposes. The visual effect of the grid vibration process on the superplasticized mixture caused a great deal of concern for overvibration and possible segregation. The vibration process was suspended after paving about 40 feet and the pour continued with conventional consolidation methods. The deck was not cored in order to either confirm or refute the perception of segregation.

The remaining spans over Edwards River were poured in 1998. The same grid vibration pattern was used. There were no problems with overvibration, but the concrete temperature exceeded specifications about two hours after the pour began, and paving was suspended. The rest of the deck was poured conventionally later.

I-70 over Camp Creek

The I-70 eastbound bridge over Camp Creek (SN 026-0019) is located just east of Vandalia in District 7. This is a 14 span structure on steel beams. Part of the structure is continuous and there are also two simply supported spans. The total length of the structure is 600 feet. There was no skew or superelevation. The structure was paved full width in 1998 using the Allen device with a 2x8 grid pattern. This project was also an experimental A+B contract with significant awards and penalties for early or late completion. The contractor planned to pave the entire structure length in a day-long pour.

There were three problems of note during this pour. First, the paver dropped off the support rails as a result of one side of the paver advancing too far ahead of the other. This resulted in a delay of about 30 minutes while the paver was lifted and the rail supports reset. Second, at least one plywood form failed under the weight of the newly placed concrete. These areas had to be shored up and refinished. This delay was approximately 30 to 45 minutes. Even with this delay of an hour or more the pour was completed that day. Third, the operator had some problems early in the day with his generator. The problem was cleared up quickly and did not result in excessive delay.

Illinois 4 over Little Silver Creek and Tributary to Little Silver Creek

The IL 4 bridges over Little Silver Creek and Tributary to Little Silver Creek are located in St. Clair County in District 8. The Little Silver Creek bridge (SN 082-0300) is a three span continuous structure with a 15 degree skew and integral abutments. It is a two lane facility that was reconstructed in stages. IL 4 over the Tributary to Little Silver Creek is a two span continuous structure, also with integral abutments, but no skew. It is also a two lane bridge and was reconstructed in stages under the same contract as the Little Silver Creek bridge. Both bridges were built in the 1997 and 1998 construction seasons.

No construction problems were noted, although there was some concern about the weight of the paver and the number of rail supports needed.

OR 5 over Chain-of-Rocks Canal

OR 5 over Chain-of-Rocks Canal (SN 060-0068) is located just south of I-270 over the Chain-of-Rocks Canal in Madison County, District 8. It is a sixteen span facility with a truss structure over the canal. It is a two lane structure that was redecked in two stages in 1998.

The district approved a contractor-built vibration device for this project. The device used a 1x12 grid pattern. This device is shown in Figure 4. The vibrators were attached to a frame connected to the finishing machine. Since this was a one lane pour, the twelve vibrators span the width of the pour and did not move transversely. The insertion was apparently controlled manually. No problems were identified in the use of this device.

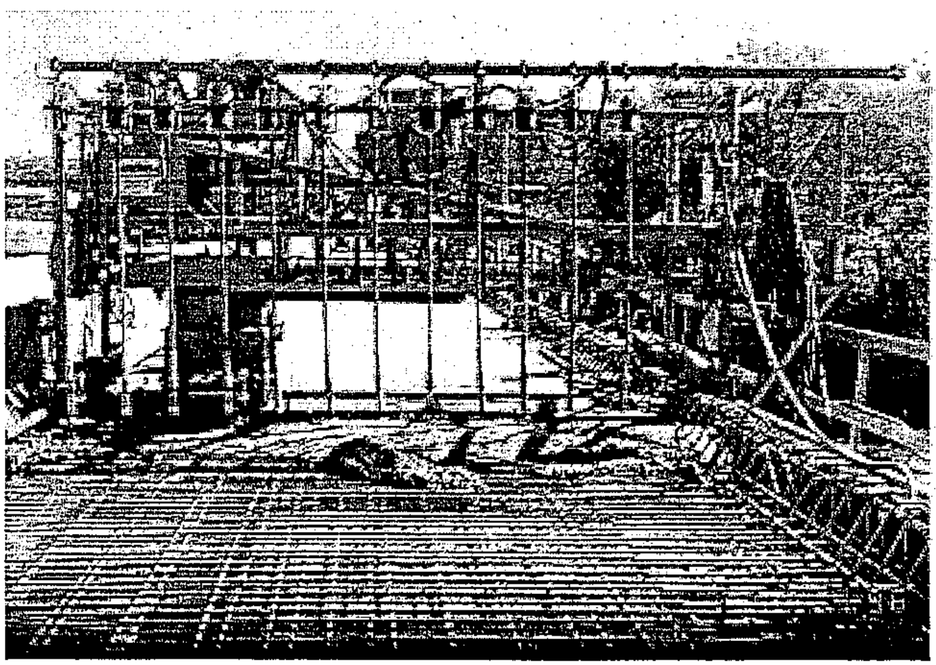


Figure 4. One by twelve grid pattern used in District 8.

Brighton TWP 467 over Girder Brook

Brighton TWP 467 over Girder Brook (SN 059-3504) is located in southern Macoupin County, District 6. It is a two lane 120 foot long, three span structure that was poured full width in late 1997.

The drag-through process was used on this bridge. In this case, the contractor used two vibrators mounted on the finishing carriage. See Figure 5. The vibrator fixture was rotated 180 degrees at the end of each traverse to keep the vibrator tip from catching on the top reinforcement layer. The vibrator frequency was reported to be about 8,000 rpm. The paver advanced 3-4 inches per pass. The concrete delivered was 'wet' and the vibrators raised considerable 'cream' to the top. The contractor was concerned about possible overvibration. Given the rate of paver advance, the radius of action and spacing of the vibrators, it is evident that the same 'particle' of concrete could be vibrated at least six times. Based on the wet condition of the concrete and the concern of overvibration, the contractor wanted to try the process on a second project in order to better control the slump.

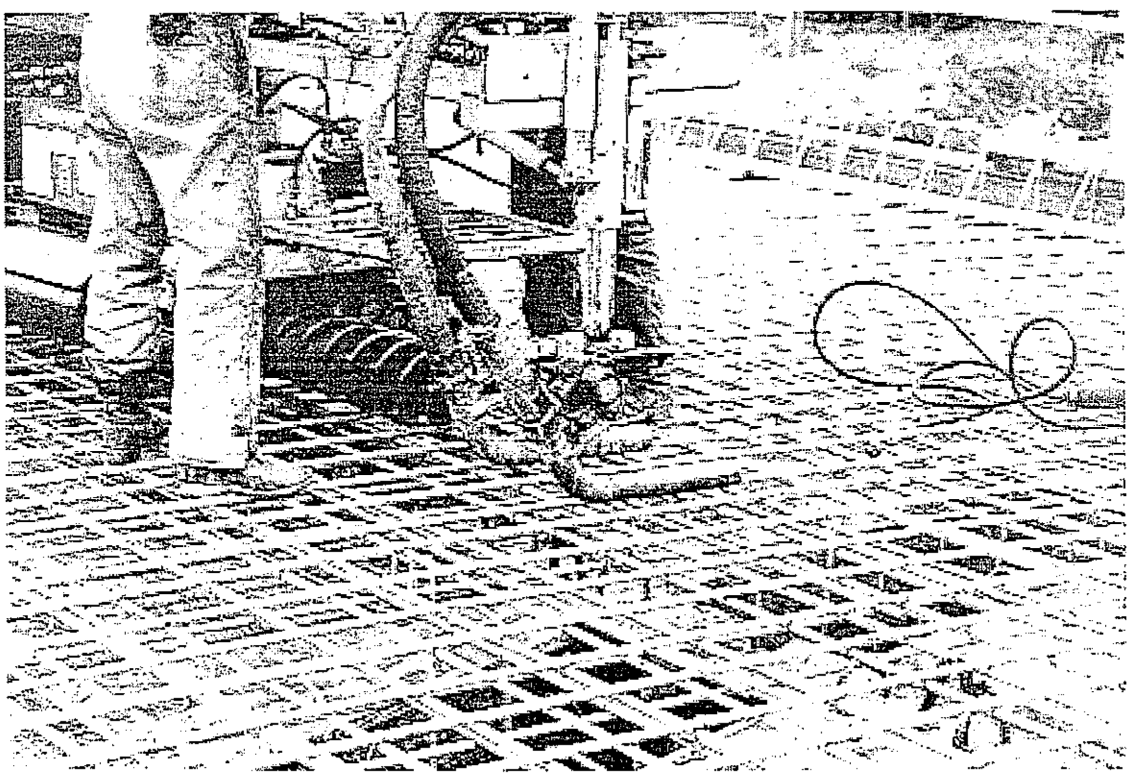


Figure 5. Drag-through vibration device used in Districts 5 & 6.

Monroe Street over Spring Creek

Monroe Street over Spring Creek (SN 058-3040) is located in Decatur, District 5. This is a four lane, 100 foot long, three span structure. The bridge was built in two stages. The northbound lanes were paved conventionally. The southbound lanes were paved using the drag-through process in 1998.

The first half (about 50 feet) of the pour consisted of two vibrators running at approximately 9,000 rpm. The remainder had one vibrator operating at about 7,000 rpm. There were no material or construction problems noted.

Construction Summary

The following is a summary and discussion of the construction experiences using mechanized vibration processes in Illinois.

The devices and procedures were new, so contractors were sometimes reluctant to use them. Subcontractual arrangements were often delayed when contractors were reluctant about using the device. This sometimes resulted in scheduling problems and misunderstandings between the equipment manufacturer and the contractor.

For a staged construction process, the weight of the device required that either the finishing machine rails be mounted on the fascia and the last interior beams, or that the rail support system be redesigned to accommodate the increased weight. The implications of mounting rails on the beams meant that sometimes a significant amount of hand work was still required outside the area of grid vibration. Thus the narrower the bridge, the less width that was actually being grid vibrated. This led to debate that the use of the device on stage jobs was not economical.

The issue of use on four-lane divided stage construction was also sometimes complicated by the lease agreements. As a worst case example, the contractor would almost never pour both sides of a four-lane divided facility at the same time. This lag time was naturally charged by the lease agreement as 'time on the job' and could easily be one to two weeks. Also, paving of the second stages could typically be months later. This delay necessitated returning the device to the manufacturer and then paying for shipping, handling and setup again for the second stage pours.

Some problems were encountered with superelevated bridge decks. First, the vibration effort caused the plastic concrete to flow downhill. If not accounted for, this could result in excessive waste at the low side. Second, if the resultant overturning moment of the combined paver and vibration machinery was not accounted for, the capacity of supports for the finishing rails might not be adequate. This problem was encountered on I-80 eastbound over US 30, which was originally intended to be grid vibrated. The machine came off the rails in the dry runs. However, this problem also occurred with the normal paver. The bridge was of variable width and was also superelevated. A personal inspection of the adhesive used to fasten the rail supports to the beam flanges indicated that it was not completely set even a day after the dry run with the gang vibration machinery. The rail supports were bonded to a painted surface, not the steel beams. The combination of factors proved problematic for both new and conventional pavers. The special provision was revised at that time to reiterate that adequate support rails were the responsibility of the contractor. One manufacturer offered analysis services to ensure adequate rail support.

A large percentage of the bridge deck concrete used in Illinois is pumped. Also, most of the mix designs used in Illinois consist of one coarse aggregate and one fine aggregate. The resultant gap-graded mix design is sometimes difficult to pump. To improve pumpability, producers often add superplasticizer at the jobsite. The resulting concrete delivered on the deck has higher slump. Grid vibration of highly superplasticized concrete occurred on part of one deck in District 4, and the process was halted due to the visual assertion that the concrete was being segregated. That something already so flowable should need to be vibrated to remove entrapped air was difficult to rationalize, and the operation continued without the grid vibration process. Segregation was neither proven nor refuted for that case.

The special provision was written as an addition to a section of the Standard Specifications for Road and Bridge Construction and was included in the bidding documents. A separate pay item was not developed, however, and the cost was included in the bid price for Concrete Superstructure. It is often the case that contractors do not closely read the inserted special provisions and an addition that could be a significant cost item might be missed..

The vibration devices were subject to breakdown, as is any other mechanical device on a construction site. There were apparently few mechanical difficulties after the prototype 2x4 grid device. Placement times were apparently as good as or better than conventional work.

One contractor attempted to grid vibrate the concrete in the skew triangle of one bridge by rotating the device to match the skew. This was probably more trouble than it was worth.

DATA ANALYSIS

Consultant Study of Grid Process

Nine (9) cores were collected from both I-57 bridges and both I-80 WB bridges. These 36 cores were analyzed by a consultant for entrapped and entrained air contents and unit weight (and other petrographic data) as part of a contract through FHWA [Ref. 3]. In addition to the material properties issues, the effect of the grid vibration process on both placement time and deck cracking were investigated. The conclusions reached in that study were:

- "The automated [i.e. grid] system of consolidation produced a more uniform concrete deck. That is, the variation in concrete densities was reduced when the automated system was used. The automated consolidation system reduced the entrapped air in the concrete without affecting the entrained air.
- The automated system of consolidation had no effect on placement rates. A major advantage of the automated system was when the workers became accustomed to the machine, they did not walk in the concrete after it was consolidated. This is a common practice when the deck is placed by conventional methods.
- The automated system machine weighs more than present concrete finishers without the vibrators. When consolidating concrete on super-elevation care needs to be exercised since the automated system applied vibration to more of the concrete than normal hand held vibration practices.
- Important findings of the study were that 1) the automated system produced a more uniform deck, 2) reduced the amount of entrapment air by half, 3) did not reduce the amount of entrained air, 4) did not segregate the concrete and 5) did not effect placement rates."

The effect on deck cracking was inconclusive:

..."The analysis showed that on the I-57 bridges transverse cracking occurred within a few weeks after the placement of the decks. It should be noted that the decks were replaced by the stage construction technique which subjected them to continuous vibrations from traffic. The number of cracks increased when the lanes were open to traffic, but the cracks were at a minimum near the abutments and expansion joints. The Norfolk Southern eastbound bridge showed a few signs of cracking in the areas where the deck was consolidated by the automated system before it was opened to traffic. The number of transverse cracks increased after traffic was on the bridge.

A few cracks were observed in the I-80 US 30 eastbound bridge after the placement of the deck. Follow-up visits revealed several areas of transverse and longitudinal cracking. After six months of traffic, the westbound bridge was visited and transverse and longitudinal cracking was observed from the bottom side of the deck.

The cracking appeared to be most severe in the areas where the concrete was consolidated by conventional means.

The automated consolidation method did not eliminate cracking, but in some cases, appeared to reduce the severity of the cracking. It should be noted that cracking is a complex problem with many variables. As shown by the petrographic analysis, the concrete has over 34 percent paste and at this percentage the mix is susceptible to shrinkage problems.

The I-80 US 30 westbound bridge showed a large number of plastic shrinkage cracking in the area where the concrete was consolidated by the automated system. However, evaporation rates played a major role with this problem."

Consultant Study of Drag-Through Process

To evaluate the drag-through process, six (6) cores were cut from the Brighton TWP bridge and eight (8) cores were cut from the Decatur bridge. These cores were analyzed by the same consultant as for the District 1 cores. The cores were evaluated for entrapments per square inch, unit weight, and evidence of segregation [Refs. 5&6]. In both cases, the consultant made the following statement:

"The drag method appears to segregate the concrete. Three patterns appear to exist. First, the top two inches of concrete generally has smaller aggregate and a large amount of paste around the aggregate. Second, the area between the top layer of steel and bottom of decks appears to have a good blend of aggregate and limited amount of paste between aggregate. Third, either a paste line or aggregate line forms near the top layer of steel. Rectangular aggregate appears to lay flat and small aggregate will concentrate in this area in horizontal lines or parallel to the surface of the deck."

This evidence of segregation is significant because no segregation was found in either the conventionally vibrated or grid pattern cores.

Entrapped Air and Unit Weight Data

Summary statistics for entrapments per square inch and unit weight data from the core studies were developed for the current study and are presented in Table 2. These statistics were used to test hypotheses and develop statements of significance for the relative effectiveness of the three methods. The first hypothesis tested in each comparison was the null case; the assumption that the averages of the two samples are equal. One-tailed tests were used. The z-statistic was used for the entrapments per square inch. The t-statistic was used for the unit weight comparisons due to smaller sample sizes [Ref. 7].

TABLE 2
Grid, Drag-Through, and Conventional Vibration
Summary Data

	Entrapments/in^2	Unit Weight (lb./ft^3)
Grid Pattern	Average = 2.94 Std. Dev. = 1.47 n = 208	Average = 146.88 Std. Dev. = 1.74 n = 19
Drag-Through	Average = 3.98 Std. Dev. = 1.75 n = 162	Average = 143.56 Std. Dev. = 4.12 n =15
Conventional Method	Average = 5.65 Std. Dev. = 2.23 n = 208	Average = 143.67 Std. Dev. = 3.62 n = 25

An entrapped air void is defined by the Portland Cement Association (PCA) as a void larger than 1/25 inch (1mm) in diameter. Comparison of concrete mix designs used in different contracts was considered reasonable based on similarities of aggregates, paste percentages and aggregate percentages.

Grid versus Conventional

Observation shows that entrapments per square inch for the grid pattern method were nearly half (52 percent) of those found for the conventional method. The standard deviation is also smaller for the grid method. This indicates better uniformity. A comparison of means statistical analysis indicates that the difference in average entrapments is significant with 99 percent confidence.

The grid vibration data for unit weight show a 2.2 percent improvement over the conventional method. Better uniformity is indicated by the fact that the standard deviation is less than half that for the conventional method. A comparison of means test indicates that the difference in average unit weights is significant with 95 percent confidence. The analysis indicates that the grid process is an improvement over the conventional method in terms of both reduced air entrapments per square inch and increased unit weight.

One could question the physical significance of a seemingly small 2.2 percent improvement. Whiting and Tayabji tried to manufacture specimens with 85 and 92 percent consolidation by careful volume control, hand placement, and no vibration. Even so, these target values were difficult to achieve. Hand-placed, unvibrated concrete is apparently at least 90 to 95 percent consolidated (expressed as a percentage of maximum theoretical density). The remaining available consolidation potential is that sought by both conventional and grid pattern vibration methods. A small increase in consolidation is physically significant, since the degree of consolidation left available is also small.

Drag-Through versus Conventional

Entrapments per square inch found for the drag-through method were 70 percent of those found in the conventionally poured cores. The standard deviation was lower for the drag-through method. With 95 percent confidence, one can say that the drag-through process is an improvement compared to the conventional method in terms of removing entrapments per square inch. There was no statistical difference found between the drag-through and conventional methods in terms of improved unit weight.

Grid versus Drag-Through

Entrapments per square inch for the grid pattern method were 74 percent of those found for the drag-through method. The standard deviation of the data was also lower for the grid pattern. Statistical testing indicates that the reduction of entrapments per square inch between grid pattern and drag-through is significant with 95 percent confidence. Comparison of unit weights shows a 2.3 percent improvement for the grid pattern over drag-through. The grid method showed better improvement in concrete unit weight than the drag through method with 95 percent confidence.

COST ANALYSIS

A lease estimate for the I-80 bridge over US 30 itemized the costs for a grid pattern device. The total estimate was $17,526 and included travel to and from the jobsite, setup, dry run, two technicians, and three days of paving. The I-80 over US 30 bridge consisted of about 700 cubic yards of concrete for the entire deck. Based on that estimate, the cost of the grid vibration process was $25.04 per cubic yard. The estimated cost per square yard (8-inch deck) is $5.56 per square yard.

The actual cost of the grid vibration process on the I-70 bridge over Camp Creek was $15,911. For 603 cubic yards of deck concrete, the unit cost was $26.38 per cubic yard. For a 7.5-inch deck, the actual square yard cost was $5.50 per square yard.

The average quantity of Concrete Superstructure (deck and parapet, in-place) placed in Illinois from 1996-1998 was 368.4 cubic yards. The statewide average cost for Concrete Superstructure for 1996-1998 was $667.79 per cubic yard. Using the above prices, the estimated cost of the grid vibration process for an average structure is between 3.75 and 3.95 percent of the average cost of Concrete Superstructure. For an average project, the cost increase would be $9,471.53. Given that the average bridge superstructure cost is just over $246,000, it appears that grid vibration adds very little to the cost of the finished deck. Since Concrete Superstructure is only part of the total cost of a project, the impact on a typical bridge rehabilitation project is low.

The Illinois Department of Transportation administered an average of 125 bridge contracts incorporating Concrete Superstructure per year between 1996 and 1998. Assuming that 25 percent of the contracts contained work for two decks, the grid vibration process would increase the total program cost by about $1.5 million per year.

SUMMARY

A mechanized method for consolidating the concrete after placement and before finishing was used on all or part of fourteen bridge decks built in Illinois. Twelve of these decks were paved using a grid pattern with vertical insertion of the vibrators placed at approximately twelve inch spacing. Two decks were built using a method whereby the vibrators were attached in a horizontal orientation to the finishing carriage and were dragged transversely through the concrete above the top layer of reinforcing steel.

Cores were cut from two grid pattern decks, two conventional decks and the two drag-through decks for petrographic examination. It was of particular interest to note differences in air entrapments per square inch, concrete unit weight, and evidence of mixture segregation. The data were analyzed in order to make relative comparisons between the methods with statistical confidence. The grid pattern method was found to be an improvement over both the drag-through and conventional methods in terms of both reducing entrapments per square inch and increased unit weight. The drag-through method was found to be an improvement over the conventional method only in terms of reducing entrapments. The petrographic analysis also indicated that neither the grid pattern nor the conventional methods caused segregation of the concrete. However, the drag-through method did cause segregation. Based on the statistical analysis and the evidence of segregation, the drag-through process is not equivalent to the grid pattern method.

When condensing the construction experiences down to issues unique to mechanized vibration and issues common to any new process evaluated on a construction site, it is apparent that only a few issues really pertain to the mechanized vibration processes evaluated in Illinois:

- superelevated decks,
- variable width decks,
- added paver weight,
- vibration of superplasticized concrete,
- stage construction, and
- the special provision.

Excessive waste concrete and extra machine weight are issues for the case of superelevated decks. Excessive waste concrete was probably caused by the 4x4 grid pattern. Changing to the 2x8 pattern seems to have minimized the problem.

The overturning moment on the rail supports resulting from deck superelevation must be accounted for. The combination of variable width and superelevation causes problems for bridge deck paving in general, but the added weight of the grid method seemed to exacerbate the problem. Closer spacing of rail supports, increased plate bond area, bonding to the steel beam instead of to a coat of paint, and improved adhesive are positive steps toward reducing this problem for any bridge deck finishing machine used. Contractors must be made aware of this issue when using mechanized vibration devices. Alternative manufacturers' devices may be lighter than those used in this study.

Extra machine weight might be an issue with shallow girders on simple supports. If the weight were too much, significant centerspan deflections could result in problems keeping the deck thickness true. Smoothness could also be affected. This should be resolved before the contract is let.. Other devices might weigh less.

Concerns regarding concrete pumpability and use of highly superplasticized concrete must be addressed in a pre-pour meeting. .Options include using less supeplasticizer or waiting until the chemical effect is dissipated before mechanically vibrating.

Mechanized vibration devices were used on stage construction projects, so there is no question of being able to do it. Modification of the special provision to allow acceptable devices built by contractors should reduce logistical concerns.

Modification of the special provision to include a separate pay item for grid pattern vibration would allow contractors to include the item in their bid process.

As with any new construction practice, acceptance differed among contractors. Some contractors embraced the concept almost immediately. Others seemed ready to oppose the idea at any cost. The same could be said for Department personnel. Some were supportive of the idea, others skeptical. The most common observation seemed to be related to the perception of too much vibration. However, evidence of segregation was not found in any of the cores cut from decks which used the grid pattern process.

The estimated added cost of the grid pattern method was about $9,500 for an average bridge deck, or about $5.50 per square yard.

Illinois is implementing QC/QA specifications for concrete. Under this program contractors must take more responsibility for the quality and testing of their product. End result specifications and warranties are future probabilities. Contractors will need to develop methods, processes, and attitudes that incorporate the active addition of concepts that improve the quality of their end product. Although it is not clear which in-place properties might be required in an end result specification, fundamental properties such as in-place unit weight and minimized entrapped air content are reasonably related to long term performance and are possible candidates for measurement. Uniformity of a given property is also a likely measurement for an end result specification. Grid pattern vibration is a straightforward construction process that achieves both improvement and uniformity of these fundamental properties. Given that the grid pattern method is a quality enhancement tool, with both the department and the contractor having an interest in better quality bridge decks, grid pattern consolidation of bridge deck concrete is a method that should be adopted and encouraged.

A revised special provision for grid pattern vibration is shown in Appendix B. Changes to the special provision include allowing for contractor-built devices with IDOT approval, a separate pay item, and method of measurement. Using careful engineering judgment, the Department can allow contractors to develop effective grid pattern devices. This encourages contractors to think about grid pattern vibration as a standard construction practice. Addition of a separate pay item for grid pattern vibration will allow the Department to set a unit price and should reduce the incidence of missing the item in the bidding process. A defined method of measurement ensures that the Department pays only for the deck area that was actually grid vibrated.

CONCLUSIONS AND GUIDELINES FOR USE

The following conclusions are made based on the observations and data collected in this study:

1. The grid pattern method was a statistically significant improvement over the conventional method in terms of both reduced air entrapments per square inch and increased unit weight. Entrapments per square inch were reduced by approximately half and unit weight was increased by 2.2 percent. Uniformity improved for both properties.
2. The drag-through method was a statistically significant improvement over the conventional method in terms of entrapments per square inch. The drag-through method reduced entrapments by approximately 30 percent. Uniformity was improved, also. There was no statistical difference found between drag-through and conventional methods in terms of unit weight.
3. The grid pattern method was significantly more effective in removing entrapments per square inch and improving unit weight than the drag-through method. The grid pattern method also provided better uniformity.
4. Segregation of grid vibrated concrete was not found in the analysis of the cores cut from the District 1 bridge decks, nor was the conventionally vibrated concrete in District 1 segregated. However, the analysis of cores from the drag-through vibrated decks did show signs of segregation.
5. The grid pattern method is applicable to a wide range of construction scenarios, given proper attention to issues related to superplasticized concrete and paver weight.
6. The cost of the grid pattern method was a minor addition to the total cost of the bid item for Concrete Superstructure.

The following recommendations and guidelines for use are made:

1. The grid pattern method should be the preferred IDOT method for consolidation of bridge deck concrete in the absence of practical limits. The method should be implemented as an inserted special provision at the discretion of the District design

offices. Practical considerations for limiting use include deck superelevation, variable deck width, and effect of finishing machine weight on beam deflection during paving. Grid pattern vibration and high dosages of superplasticizer should be discussed and accounted for in the pre-pour meeting.

2. Grid pattern vibration is a construction process that adds value to the end product. This value is in the form of reduced air entrapments and improved concrete unit weight. As a result of the process, IDOT has more assurance that the concrete has been both better and more uniformly consolidated. Both IDOT as the owner and the contractor have an interest in placement of a higher quality bridge deck. IDOT has shown a willingness to pay for improved quality, and should be willing to pay something for mechanized grid pattern vibration.
3. The drag-through vibration method should not be used for bridge deck paving because of segregation problems.
4. The unit price for mechanized vibration of bridge decks should be $3-4 per square yard. This is a minimal price addition to an average contract, and shares the lease, purchase, or development cost of a device between the Department and the contractor.

REFERENCES

1. "Transverse Cracking in Newly Constructed Bridge Decks," NCHRP 380, Krauss, Paul D., and Rogalla, Ernest A., Transportation Research Board, 1996.

2. "Evaluation of an Automated Bridge Deck Vibration System," Parsons, Thomas J., Project Number DTFH71-PTP-AR-33, Arkansas State University, June 1998.

3. "Evaluation of a Drag-Through Vibration Process for Consolidation of Bridge Deck Concrete," South, Jeffrey M., Illinois Department of Transportation, September 1998.

4. "Relationship of Consolidation to Performance of Concrete Pavement," Whiting, D. A. and Tayabji, S. D., FHWA/RD-87/095, February 1988.

5. "Analysis of Bridge Deck Cores from Macoupin County Bridge," Parsons, Thomas J., Report to the Illinois Department of Transportation, July 1998.

6. "Analysis of Bridge Deck Cores from Monroe Street Over Spring Creek, Decatur, Illinois," Parsons, Thomas J., Report to the Illinois Department of Transportation, July 1998.

7. "Theory and Problems of Statistics," Spiegel, Murray R., Schaum's Outline Series, McGraw-Hill, New York, 1961.

APPENDIX A

SPECIAL PROVISION
FOR
BRIDGE FLOORS
(Revised 9/30/96)

Revise the first paragraph of Article 503.17 (c) to read as follows:

"Bridge Floors. After the concrete is placed, the consolidation of the concrete shall be accomplished by means of an automated mechanical device on which internal concrete vibrators of the same type and size are mounted. The vibrators shall be mounted so as to provide a maximum insertion spacing of 12 inch centers. This spacing shall not be changed without the permission of the Engineer.

The device shall be manufactured by either the Bidwell Division of the CMI Corporation or the Allen Engineering Corporation. The vibrators shall meet the following requirements:

Diameter of Head (mm)(inches)..45 to 65 (1.75 to 2.5)
Frequency of Vibration (vib./min)(under load)...............................8,000 to 14,000
Average Amplitude (mm)(inches)..................................0.6 to 1.3 (0.025 to 0.05)
Radius of Action (mm)(inches)..180 (7)

The vibrators shall be mounted on the mechanical device in such a manner that they will enter the concrete in a vertical position under the influence of their own weight. The penetration of the vibrator shall be to a depth of 20 +/- 5 mm (0.75 +/- 0.25 inch) above the bottom of floor formwork. The time of insertion shall be from 7 to 10 seconds. The removal shall be accomplished in not less than 3 seconds and shall raise the vibrators above the surface of the concrete. The location of insertions shall be spaced to miss reinforcement where possible.

The mechanical device shall be mounted on the finishing machine or upon an independent self-propelled framework operated on the finishing rails. If an independent self-propelled framework is used, the Contractor shall provide adequate increased support for the finishing rails. The device shall progress longitudinally in 300 mm (1 ft.) increments and shall come to a complete stop while the vibrators traverse the width of the pour.

After the concrete is placed and consolidated, the concrete floor of bridges 30 m (100 ft.) or more in length shall be struck off and screeded with a power driven finishing machine. The finishing machine will not be required for that portion of the deck outside the outer construction joints shown on the plans, when the distance from the construction joint to the parapet flow line is less than 2m (6 ft.)."

Revise Article 503.22 Basis of Payment to include the following:

"Payment for bridge deck consolidation will be included in the contract unit price per cubic meter (cubic yard) for CONCRETE SUPERSTRUCTURE."

APPENDIX B

SPECIAL PROVISION
FOR
MECHANIZED VIBRATION OF BRIDGE FLOORS
(Revised 4/15/99)

Revise the first paragraph of Article 503.17 (c)(1)a. to read as follows:

"Finishing. After the concrete is placed, the consolidation of the concrete shall be accomplished by means of an automated mechanical device on which internal concrete vibrators of the same type and size are mounted. The vibrators shall be mounted so as to provide a maximum insertion spacing of 12 inch centers. This spacing shall not be changed without the permission of the Engineer.

Commercially available devices are manufactured by the Bidwell Division of the CMI Corporation and the Allen Engineering Corporation. Other devices must be approved by the Engineer before use. The vibrators shall meet the following requirements:

Diameter of Head (inches)	1.75 to 2.5
Frequency of Vibration (vib./min)(under load)	8,000 to 14,000
Average Amplitude (inches)	0.025 to 0.05
Radius of Action (inches)	7

The vibrators shall be mounted on the mechanical device in such a manner that they will enter the concrete in a vertical position under the influence of their own weight. The penetration of the vibrator shall be to a depth of 0.75 +/- 0.25 inch above the bottom of floor formwork. The time of insertion shall be from 7 to 10 seconds. The removal shall be accomplished in not less than 3 seconds and shall raise the vibrators above the surface of the concrete. The location of insertions shall be spaced to miss reinforcement where possible.

The mechanical device shall be mounted on the finishing machine framework or upon an independent self-propelled framework operated on the finishing rails. The Contractor shall provide adequate increased support for the finishing rails. The device shall come to a complete stop while the vibrators consolidate the width of the pour. The longitudinal vibration spacing as the device progresses forward shall be at 12 inch increments.

After the concrete is placed and consolidated, the concrete floor shall be struck off and screeded with a power driven finishing machine."

Revise Article 503.21 Method of Measurement to include the following:

"Mechanized vibration will be measured for payment in square yards of bridge floor area. In computing the area for payment, deductions will be made for omissions in skews and other areas left unvibrated by the mechanical vibration process."

Revise Article 503.22 Basis of Payment to include the following:

"Payment for mechanized vibration of bridge floors will be paid for at the contract unit price per square yard for MECHANIZED VIBRATION OF BRIDGE DECK CONCRETE."

August 17, 1999
GRDRPRT3.DOC