Report Number: FEP-06-10

Exodermic Bridge Deck Performance Evaluation

FINAL REPORT

July 2010

Exodermic Bridge Deck Performance Evaluation

Research Study # FEP-96-02

FINAL REPORT

Report # FEP-06-10

Prepared by:
Irene K. Battaglia, M.S.
Engineering Research Consultant
Construction and Materials Support Center, UW-Madison

Deb Bischoff, P.E.
Pavement Policy and Design Engineer
Wisconsin Department of Transportation

Wisconsin Department of Transportation
Division of Transportation System Development
Bureau of Technical Services
Materials Management Section
Foundation and Pavements Engineering Unit
3502 Kinsman Blvd, Madison, WI 53704

July 2010

This study was conducted by the Materials Management Section, Bureau of Technical Services, Division of Transportation System Development, of the Wisconsin Department of Transportation. The Federal Highway Administration provided financial and technical assistance for this research activity. This publication does not endorse or approve any commercial product even though trade names may be cited, does not necessarily reflect official views or policies of the agency, and does not constitute a standard, specification or regulation.

Technical Documentation Page

1. Report No. FEP-06-10	**2. Government Accession No.**	**3. Recipients Catalog No.**
4. Title and Subtitle Exodermic Bridge Deck Performance Evaluation		**5. Report Date** July 2010 **6. Performing Organization Code** WisDOT Research Study # FEP-96-02
7. Authors Irene Battaglia, Deb Bischoff		**8. Performing Organization Report** WisDOT Research Report FEP-06-10
9. Performing Organization Name and Address Wisconsin Department of Transportation Division of Transportation System Development, Bureau of Technical Services Materials Management Section, Foundation and Pavements Engineering Unit 3502 Kinsman Blvd., Madison, WI 53704		**10. Work Unit No. (TRAIS)**
12. Sponsoring Agency Name and Address Wisconsin Department of Transportation Division of Transportation System Development, Bureau of Technical Services Materials Management Section, Foundation and Pavements Engineering Unit 3502 Kinsman Blvd., Madison, WI 53704		**13. Type of Report and Period Covered** Final Report, 1998-2010 **14. Sponsoring Agency Code** WisDOT Research Study # FEP-96-02
15. Supplementary Notes Visit http://on.dot.wi.gov/wisdotresearch/compresprojs.htm for a PDF file of this and other research reports.		

16. Abstract

In 1998, the Wisconsin DOT completed a two-leaf bascule bridge in Green Bay with an exodermic deck system. The exodermic deck consisted of 4.5-in thick cast-in-place reinforced concrete supported by a 5.19-in tall unfilled steel grid. The concrete and steel grid were made composite via shear stud connectors. The bridge deck was evaluated several times during its first 12 years in service. During and immediately following the 7-day wet cure of the concrete, shrinkage cracks formed. The cracking stabilized after several months and has not increased. The cracks were sealed with an epoxy-based material. In 2003, a white substance was noted on the underside of the exodermic deck. This leached material was sampled, and its primary component was determined to be zinc oxide. It is likely that deicing solution leached through the cracks in the deck and caused sacrificial corrosion of the galvanized steel grid. The white material was still present in 2010, and at that time, isolated areas of corroded steel were noted as well. City maintenance personnel have not noted any additional problems with the exodermic bridge deck system. A comparison of the exodermic bridge deck system to a similar bridge with an open grid steel deck indicated that the initial cost of the two systems were within ten percent of each other.

It is recommended that the exodermic bridge deck system be considered for future use in Wisconsin. However, care should be taken in the design of the concrete mixture and reinforcement layout so that cracking in the deck is minimized.

17. Key Words Exodermic bridge deck, open grid steel bridge deck, bascule bridge		**18. Distribution Statement** Distribution unlimited, approved for public release	
19. Security Classification (of this report) Unclassified	**20. Security Classification (of this page)** Unclassified	**21. No. of Pages** 20	**22. Price**

Table of Contents

List of Figures

List of Tables

1. Introduction

In 1995, the existing Main Street bascule bridge (drawbridge) in Green Bay was closed due to shifting of piers that supported the steel grid bascule span. The four-lane bridge, originally constructed in 1929, was not operating properly, and safety of the traveling public was a major concern.

The bascule spans of the original bridge deck were constructed with an open grid steel deck. This type of lightweight deck is common for drawbridge applications, but it results in a loud, rough ride for motorists. An exodermic deck system is a lightweight alternative that provides a smooth riding surface. This type of bridge deck had not been previously used in Wisconsin, and never before on a bascule bridge.

The exodermic deck design was selected for the lift spans of the new Main Street bridge. The existing open grid steel deck bridge was removed and replaced in 1998 with a new bridge that included an exodermic deck system on the bascule spans. This study documents the construction and performance of the new Main Street bridge.

2. Background

2.1 Exodermic Bridge Deck Description [*1*]

An exodermic bridge deck consists of a fabricated, unfilled steel grid that is 3 to 5 inches deep. The steel grid is topped with a galvanized form pan or sheet, on which a 3- to 5-in thick reinforced concrete slab is placed. The concrete slab can be precast on the steel grid panels or cast-in-place after erection of the steel grid system. This design combines the compressive strength of concrete and the tensile strength of steel, thereby reducing the required concrete deck thickness.

Precast exodermic deck panels come in various sizes and contain formed blockouts above stringers and floorbeams and between each concrete module. After placing the panels, these blockouts are filled with rapid setting concrete, which encapsulates the rebar adjoining the concrete modules, the panel grids and headed shear studs that are welded to the tops of stringers and floorbeams. The steel and concrete components are thus bonded together, making them composite.

For the cast-in-place option, the steel grid system is positioned first. Headed shear studs are then welded or bolted to the steel grid, rebar is placed, and the concrete deck is poured. The galvanized pan acts as a stay-in-place form, and little or no additional formwork is required.

In the original exodermic system, which was used for the Main Street bridge project in this study, the steel grid system consisted of main bearing bars, distribution bars and tertiary bars. Short studs were welded to the tertiary bars to provide shear connections and make the steel grid and concrete deck composite (Figure 1). In newer versions of the exodermic design, the tertiary bars and shear studs have been eliminated. To provide shear load transfer and composite action, the main bearing bar is one inch taller, and ¾-in diameter holes are punched at the top of the bearing bar. This portion of the main bearing bar is embedded in the concrete deck (Figure 2). [*2, 3*]

The typical total thickness of an exodermic bridge deck ranges from 6 to 10 inches, with weights ranging from 40 to 80 lb/ft^2. The weight of a standard rectangular open grid steel deck ranges from 15 to 35 lb/ft^2 [*4*], and a standard reinforced concrete bridge deck weighs approximately 100 lb/ft^2.

The exodermic system is a design, rather than a product, and offers several advantages over open grid steel decks and reinforced concrete decks. The exodermic deck provides a smoother and quieter riding surface than that of an open grid steel deck. It uses less concrete than a standard reinforced concrete deck; the dead load is therefore reduced, and the deck is lightweight for lift bridge applications. In addition, the lower dead load typically allows for a reduced amount of structural steel in the bridge framing system. When using precast panels, the exodermic system is ideal for rapid nighttime deck replacement.

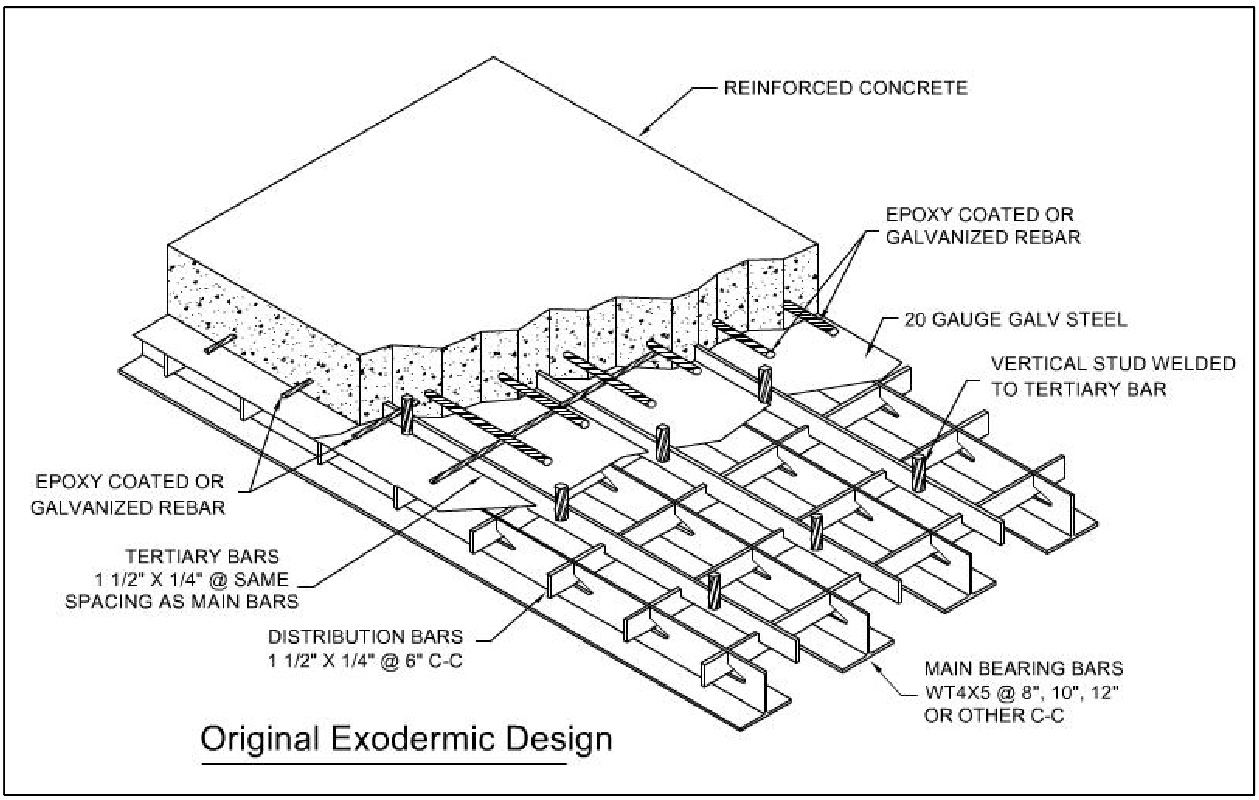

Figure 1. Exodermic deck system used for the Main Street bridge. [*3*]

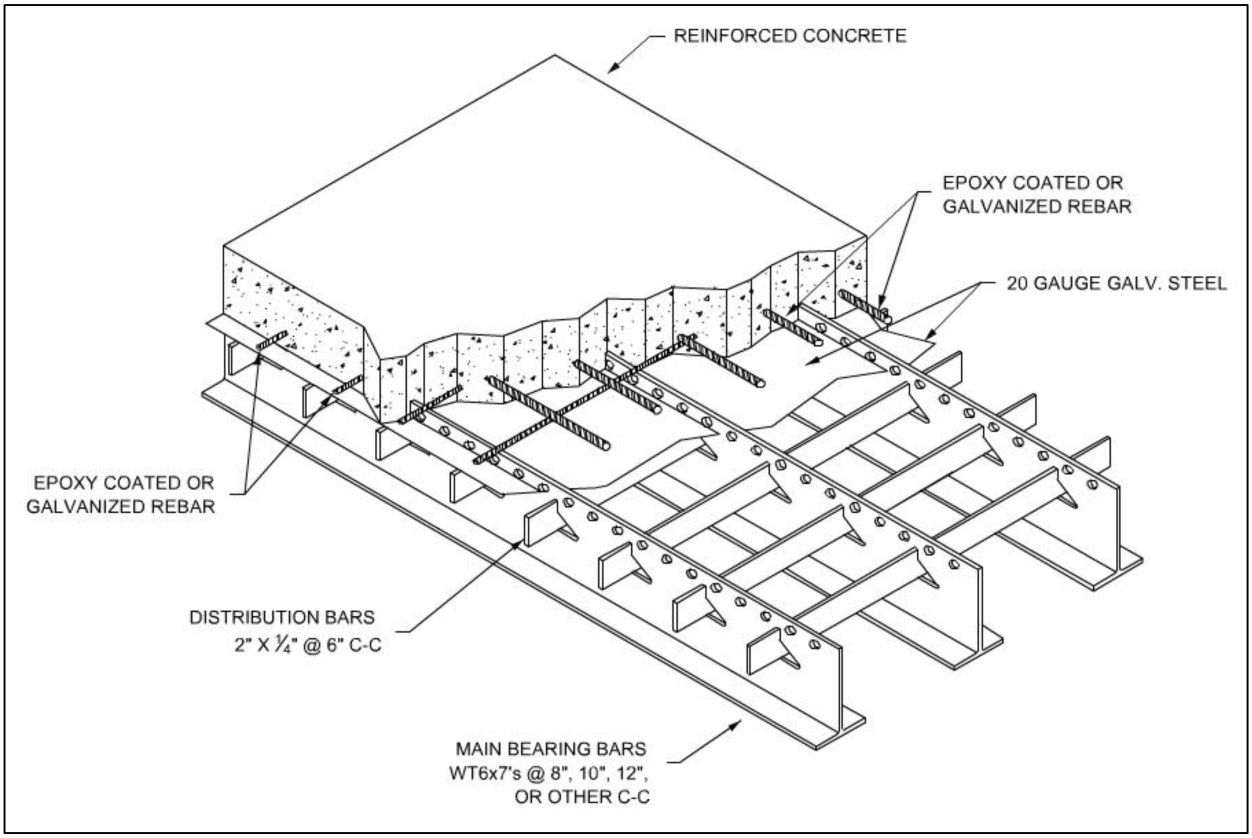

Figure 2. Updated exodermic deck system used in current designs. [*2*]

2.2 Past Performance

There have been well over 100 exodermic bridge deck installations in the U.S., and overall performance has been very good. The most common problem noted has been concrete shrinkage cracking, often when high performance concrete or silica fume concrete mixtures were used. Structural cracking has occasionally been noted but was likely a design issue; for instance, this problem has been noted in negative moment portions of a span for which no additional reinforcing bar was included in the concrete to resist cracking. [*5*]

Precast exodermic deck panels are most commonly used for bridges with high traffic volumes where construction work can only be completed during off-peak travel hours. The precast option has been successful for such bridges as the Tappan Zee Bridge over the Hudson River north of New York City, where work was completed overnight and the bridge remained open during peak travel times. The cast-in-place option is less costly than using precast panels, and this method is typically used for new bridge construction or when a bridge can be taken out of service for an extended period of time. [*5*]

Several exodermic bridge decks have been completed in Florida, most notably on bascule spans. No major problems have been documented, and the Florida Department of Transportation (DOT) has been satisfied with the overall performance. It was noted that installation of exodermic bridge decks can be challenging, and the presence of a manufacturer representative during construction is helpful. [*6*]

The State of New Jersey has also used an exodermic deck system on several bridges, including the Garden State Parkway Driscoll Bridge. This 4,400-foot long structure carries nearly 300,000 vehicles per day and, with its 1984 deck widening, was the first application of the exodermic system. [*7, 3*] In another New Jersey project, the exodermic deck on the East Allendale Avenue bridge, built in 1987, was in good overall condition after 15 years in service. Approximately 5 ft^2 of spalling and 300 linear ft of cracking (1⁄16- to ⅛-in wide) were noted on the 2,660-ft^2 roadway surface. [*8*]

3. Study Description

3.1 Objectives

The purpose of this study was to monitor and evaluate the Main Street bridge exodermic deck system for possible use on other bascule bridges or standard bridges in Wisconsin. Anticipated benefits included cost savings due to reduction in the size of the support structure, less manpower required for the deck installation and accelerated construction. The performance evaluation of the exodermic bridge deck was to be based on constructability, construction duration, appearance, overall costs, deck performance and maintenance.

3.2 Project Location and Description

The Main Street bascule bridge carries traffic on United States Highway (USH) 141 over the Fox River in Green Bay, Brown County. The location of the bridge is shown in Figure 3. Main Street/USH 141 is a principal thoroughfare into downtown Green Bay. The structure is a double lift bridge with a horizontal ship clearance of 95 ft and, when closed, a vertical clearance of 14.9 ft. [*9*] The lifting operations of the structure are shut down annually from December 15th to April 1st.

Parsons Brinckerhoff Quade & Douglas designed the double-leaf rolling lift span bascule bridge system. The steel grid for the exodermic deck is 5.19 in tall, and the concrete deck is 4.5 in thick. The exodermic deck spans 13.5 ft between floor beams and eliminates the need for stringers in the flooring frame. The floor beams are supported by two main bascule girders. Reinforcing bar in the exodermic deck is 0.87 in (22 mm) with 5-in (127-mm) spacing in the longitudinal direction and 0.51 in (13 mm) spaced at 4 in (102 mm) in the transverse direction.[1]

[1] The Main Street bridge plans were developed with metric notation.

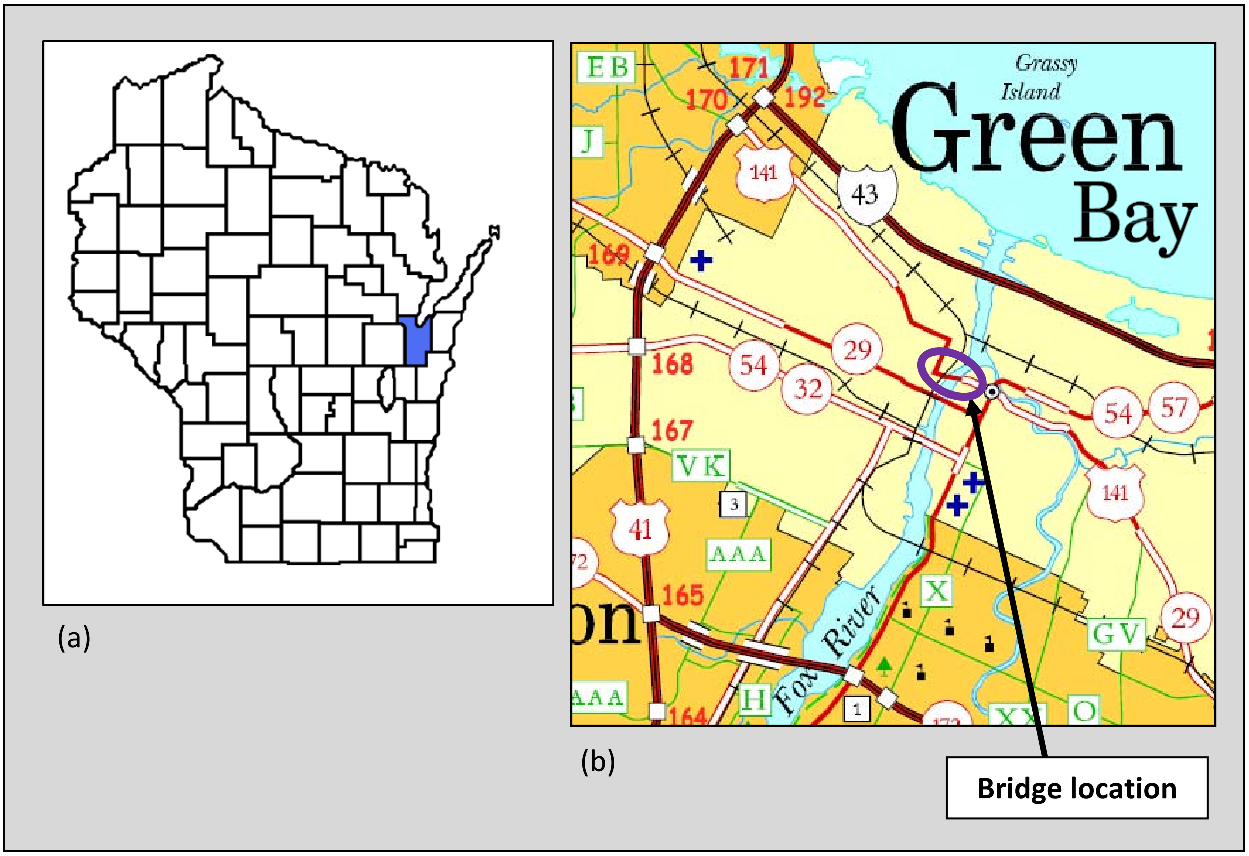

Figure 3. Location of Main Street bridge: (a) Brown County; (b) detail of bridge location.

4. Construction

The new Main Street bridge was constructed under state project I.D. 1451-16-71. The bridge is identified as Wisconsin DOT (WisDOT) structure B-05-0311. Construction began in 1997 with the removal of the old bridge with the open grid steel deck. The new bridge was constructed slightly offset and skewed compared to the old bridge. The bridge was completed and opened to traffic in the fall of 1998. Lunda Construction of Black River Falls, WI was the contractor for bridge construction. Representatives from the Exodermic Bridge Deck Institute visited the site several times during construction.

Construction of the exodermic deck system took place in two stages. In the fall of 1997, the 5.19-in thick, 8-ft wide, 20-ft long steel grid panels were attached to the drawbridge leaves, which were in the down position. The leaves were opened, and other bridge work was completed during the winter months.

In April 1998, construction of the exodermic deck continued. The leaves were closed to the down position, and placement of the deck reinforcing bars and miscellaneous forming were completed. The 4.5-in concrete deck was poured on April 21 using conveyors. The concrete mixture was WisDOT Grade D and included light-weight aggregate. [*10*] The deck was wet-cured for 7 days.

Final construction of the bridge components took place during the summer of 1998, during which time the drawbridge leaves opened and closed for boat traffic on the river. The bridge was opened to traffic in October 1998. The underside of the completed bridge deck is shown in the open position in Figure 4.

Construction of the exodermic deck went well overall. A problem that occurred was that several of the vertical shear studs broke off and had to be re-welded to the tertiary bars. The revised exodermic deck design (Figure 2) does not include welded shear studs and therefore eliminates this problem. Despite several other construction issues that were unrelated to the exodermic deck system, the project was completed on schedule.

Figure 4. Underside of west leaf of Main Street bridge in open position.

5. Exodermic Bridge Deck Performance

Inspections of the Main Street exodermic bridge deck were conducted following construction in 1998, in September 2003 and in June 2010. Overall performance of the bridge deck was evaluated, and distresses (e.g. cracking, surface spalling and delamination) were noted. In June 2010, after nearly 12 years in service, the bridge deck was in good condition. Maintenance personnel and the drawbridge operator had no problems to report and indicated that overall performance of the bridge was good. The exodermic deck system has offered quieter ride and enhanced visual appeal compared to an open grid steel deck. Several specific issues were noted during the site inspections; these are discussed below.

5.1 Cracking

During and immediately following the seven-day wet cure of the concrete deck, random spaced, multidirectional hairline cracks were observed along the entire deck. The number of cracks increased over the next several months and then stabilized. Future site reviews did not note any additional cracking. It is believed that the cracking was due to shrinkage of the concrete and resistance from the steel reinforcement and vertical shear studs. The early cracking could also have been exacerbated by flexure of the concrete during early raising and lowering of the bascule spans. Cracks have been sealed with an epoxy-based material. This material is darker than the concrete deck itself, which reduces the visual appeal of the deck and has resulted in negative feedback from the public. Photographs of the cracking are provided in Figures 5 and 6.

A crack survey was conducted during the September 2003 site review, when the bridge had been in service for five years. The total linear footage of cracking was measured at three random sampling locations. The survey results indicated that an average of 52 linear ft of cracking was present per 100 ft^2 of deck area. The cracks were not deteriorated, and no secondary distress such as spalling, delamination or dislodgement was observed in the concrete deck during this site review.

A final site review was conducted at the Main Street bridge in June 2010, after 12 years in service. The extent of the deck cracking was unchanged from 2003. The cracks were primarily cosmetic and did not appear to be affecting the structural integrity of the bridge deck. Sealant was still present in the cracks, although sealant has not been re-applied since the 2003 site review. Minor cracking was noted in the approach decks (not exodermic in design), but not to the same extent as in the exodermic deck.

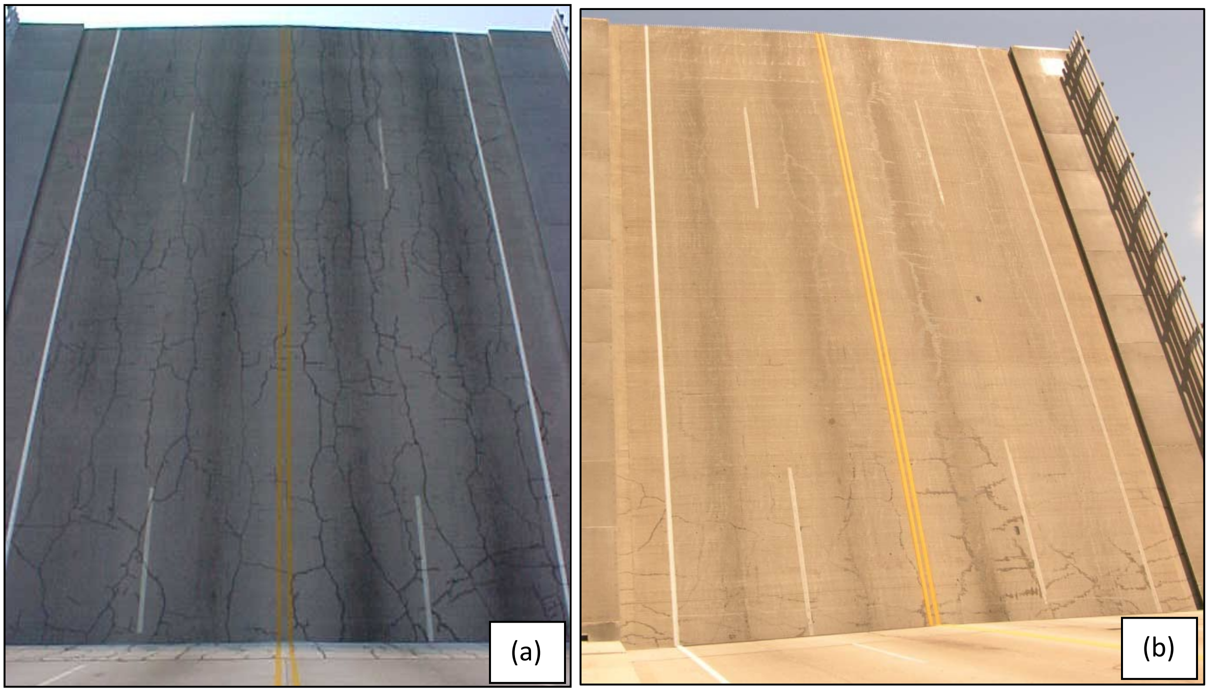

Figure 5. Cracking on exodermic bridge decks: (a) east leaf [September 2003] and (b) west leaf [June 2010].

Figure 6. Cracking of exodermic bridge deck, east leaf (June 2010).

5.2 Concrete Dislodgement

Early site inspections revealed a small piece of concrete missing on the underside of the west leaf, near the tip of the span. The void is located in the channel between steel grid panels, where concrete was cast during construction of the deck (Figure 7). It is believed that the concrete dislodged and fell away during early lifting and lowering of the bascule spans. The void is only partial depth and does not appear to be affecting the structural integrity of the bridge. The June 2010 site review confirmed that the void had not become larger over time.

Figure 7. Void in concrete on underside of west leaf exodermic bridge deck (June 2010).

5.3 Leaching

During the September 2003 site inspection, leaching was noted on the underside of the bridge deck. White deposits were present on the underside of the steel grid panel. This occurrence was consistent with water leaking through the deck and subsequent material precipitation. A sample of the white deposit was collected and analyzed for its chemical composition. The analysis results showed that the deposits were composed primarily of zinc oxide (61 percent by mass). Small amounts of calcium oxide and sodium chloride were also recorded (0.73 and 0.56 percent by mass, respectively). The zinc oxide was likely a residue resulting from sacrificial corrosion of the zinc coating on the upper side of the galvanized steel form pan, which is in direct contact with the concrete deck. Chlorides from deicing salts applied to the bridge deck likely leached through the cracks described in Section 5.1 and came in contact with the galvanized steel.

The leaching process could lead to accelerated corrosion of the steel grid, possibly resulting in increased maintenance costs or a reduced service life of the bridge deck. It is therefore critical that the cracks in the bridge deck remain adequately sealed to keep water out. Some areas of white leached material and small amounts of corrosion were noted on the underside of the exodermic deck during the June 2010 site inspection (Figure 8). It is therefore likely that salts continue to leak through the cracks in the concrete deck. The corrosion indicates that the galvanized layer of the exodermic grid has been depleted in some areas. This condition was not widespread but will worsen over time.

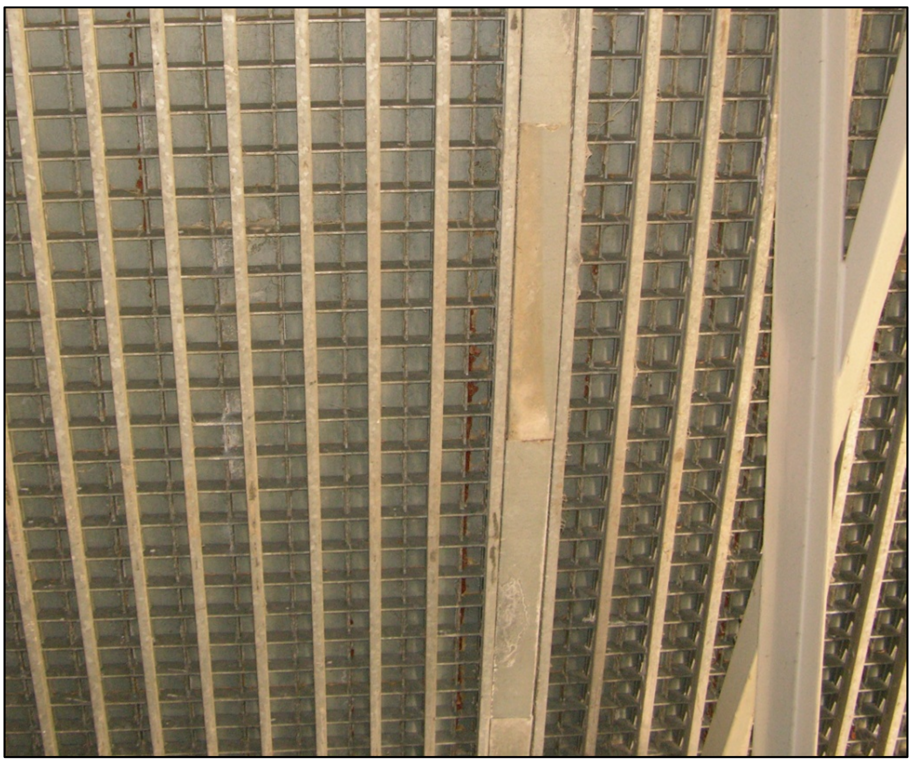

Figure 8. Corrosion and leached material on underside of west leaf exodermic bridge deck (June 2010).

5.4 Maintenance Issues

Sealing of cracks on the deck is the most prominent maintenance activity for the Main Street bridge. This operation is time-consuming and requires lane closures on the bridge. Because the exodermic grid system is made of galvanized steel, painting is not a required maintenance activity, as with open grid steel decks. City maintenance personnel did not have other problems to report regarding maintenance of the exodermic bridge deck when compared to other types of bridge decks.

6. Cost Considerations

To determine whether use of an exodermic bridge deck system is a cost-effective alternative, a comparison was performed with the Kinnickinnick Street bridge, an open grid steel deck bascule bridge. The Kinnickinnick Street bridge carries traffic on STH 32 over the Kinnickinnick River south of downtown Milwaukee, WI. Details for both bridges are provided in Table 1. The structural framing for the Kinnickinnick Street (open grid) bascule span consisted of main bascule girders, floor beams and stringers, while the Main Street (exodermic) bascule bridge deck was supported by main bascule girders and floor beams alone.

Table 1. Comparison Bridge Details

Detail	**Main St Bridge**	**Kinnickinnick St Bridge**
Location	Green Bay, WI	Milwaukee, WI
Bridge Type	Two-leaf bascule	Two-leaf bascule
Bascule Deck Type	Exodermic	Open grid steel
Construction Year	1998	1999
Average Daily Traffic, Construction Year	17,600	12,800
Average Daily Traffic, Design Year	21,500	15,000
Live Load Design Rating	HS-20	HS-20
Design Speed, miles per hour	25	30
Bascule Deck Area, ft^2	8,929	3,408

The cost of each bridge's bascule span was calculated based on plan quantities and bid costs for the bascule span items. A cost per ft^2 was calculated based on the area of the open grid steel and exodermic bridge decks. These costs are detailed in Tables 2 and 3 for the open grid steel and exodermic bridge decks, respectively.

The bascule span costs were calculated to be \$271.53 and \$296.46 per ft^2 for the open grid steel and exodermic bridge decks, respectively. The exodermic bridge deck cost was within ten percent of the open grid steel deck cost. Using this analysis, the exodermic design is a cost-effective alternative to an open grid steel deck design in terms of initial cost of construction. Other factors should be considered, however, when selecting the deck design, such as the potential for unanticipated costs during construction. In addition, fluctuating steel prices can have a significant effect on the cost of both the exodermic steel grid and the open grid steel deck floor.

Table 2. Open Grid Steel Bridge Deck Costs

Item	**Amount**	**Units**	**Unit cost**	**Total Cost**
Concrete masonry, bridges	170	yd^3	$250.00	$42,500
High strength bar steel reinforcing, bridges	10,246	lb	$0.40	$4,098
Coated high strength bar steel reinforcing, bridges	8,730	lb	$0.50	$4,365
Structural carbon steel	451,232	lb	$1.00	$451,232
High strength structural steel	141,172	lb	$2.15	$303,520
Welded stud shear connector	182	each	$2.10	$382
Open steel grid floor, 2.5-inch	3,408	ft^2	$35.00	$119,280
			Total	$925,377
			Cost per ft^2	**$271.53**

Table 3. Exodermic Bridge Deck Costs

Item	**Amount**	**Units**	**Unit cost**	**Total Cost**
Concrete masonry, bridges	29	yd^3	$183.49	$5,280
High strength bar steel reinforcing, bridges	6,173	lb	$0.50	$3,080
Coated high strength bar steel reinforcing, bridges	3,457	lb	$0.54	$1,882
Structural carbon steel	1,062,480	lb	$2.11	$2,245,845
High strength structural steel	205,108	lb	$2.11	$433,552
Welded stud shear connector	928	each	$5.00	$4,640
Steel castings	86,958	lb	$1.59	$138,054
Protective surface treatment	1,678	yd^2	$3.34	$5,612
Exodermic bridge deck	10,398	ft^2	$23.23	$241,500
Exodermic bridge deck leveling plates	1	each	$1,817	$1,817
Misc., Exodermic bridge deck materials	1	each	$1,407	$1,407
			Total	$3,082,669
			Cost per ft^2	**$296.46**

7. Summary and Conclusions

In the fall of 1998, the Main Street bascule bridge over the Fox River in Green Bay, WI opened to traffic. The decks of this bridge's two movable spans were constructed using an exodermic system. This type of bridge deck consists of a reinforced concrete deck supported by an unfilled steel grid. The exodermic deck system rests directly on the bridge's floor beams; stringers are often unnecessary in the steel framing design. The Main Street exodermic bridge deck was the first of its kind in Wisconsin, and one of the first applications of an exodermic system on a bascule bridge in the nation.

A problem noted during construction was that some of the welded shear studs broke off of tertiary bars in the exodermic grid and had to be reattached. Since the time that this study's bridge was constructed, a revised design of the exodermic system has eliminated the vertical shear studs. This modification should lessen similar problems during construction of other bridges.

Performance of the bridge deck was monitored between 1998 and 2010. The most prominent distress noted was shrinkage cracking in the deck that initiated during the 7-day wet cure of the concrete. After the first few months in service, the cracking stabilized and has not increased since then. Approximately 52 linear ft of cracking was noted per 100 ft^2 of bridge deck. The cracks have been sealed with an epoxy-based material, but during the 2010 site survey, it appeared that resealing had not taken place for several years.

Leaching of salt solution, presumably through the cracks described above, was noted on the underside of the exodermic deck. A sample of the white leached substance was collected and analyzed; its composition was primarily zinc oxide, indicating that sacrificial corrosion of the galvanized steel pan had taken place. The 2010 site survey again revealed this white material along with isolated areas of actual steel corrosion on the underside of the exodermic deck.

A void in the concrete channel between exodermic deck panels was noted during the first year after construction. This occurrence is not believed to be related to performance of the exodermic deck and does not appear to affect the structural integrity of the system.

Aside from the problems noted above, the exodermic deck system has provided good performance for the Main Street bridge bascule spans. City maintenance personnel and the bridge lift operator reported overall satisfaction with performance of the bridge deck. The ride on the exodermic spans is smoother and quieter than it would be on an open grid steel deck. The exodermic deck also has greater visual appeal, although the aesthetics are diminished because of the sealed cracks.

A cost comparison between the Main Street bridge and the Kinnickinnick Street bridge, a bascule bridge constructed in Milwaukee, WI in 1999, showed that the costs of an exodermic deck system and an open grid steel deck were similar. However, specific site conditions and fluctuating steel costs must be considered when selecting the appropriate type of bridge deck.

8. Recommendations

It is recommended that the exodermic bridge deck system be considered for use on future bridge decks in Wisconsin. An exodermic deck should be considered when increased visual appeal is a factor, or when tire noise reduction is necessary. This type of bridge deck is appropriate for both fixed and movable spans. A benefit can be realized in the elimination of stringers, as the exodermic deck system can often be supported by floor beams alone. This allows for a reduction in the amount of structural steel necessary in the superstructure.

Care must be taken during the design of the concrete mixture and steel reinforcement layout in the exodermic panels. This will reduce the occurrence of shrinkage cracking, which was a problem on the Main Street bridge. Structural cracking can also be avoided with proper design of the exodermic panels. If cracking does occur, it is critical to routinely seal the cracks to prevent moisture and salts from leaching into the deck system.

It is also recommended that a representative from the exodermic system manufacturer be present during construction of the bridge deck. This will help contractors gain familiarity with the exodermic system, and potential problems can be addressed quickly.

9. References

1. Exodermic Bridge Deck Institute, Inc. "Exodermic Bridge Deck Handbook." 1996.

2. D.S. Brown. "Exodermic Bridge Deck Design." Online. http://www.exodermic.com/design.htm. Accessed June 3, 2010.

3. D.S. Brown. "Exodermic Bridge Decks in Service Since 1984." Online. http://www.exodermic.com/history.htm. Accessed June 3, 2010.

4. Bridge Grid Flooring Manufacturers Association. "Grid Deck Properties - Design and Specification Data." Online. http://www.bgfma.org/grids.htm. Accessed June 3, 2010.

5. Personal conversation with M. Kaczinski, Bridge Grid Flooring Manufacturers Association, The D.S. Brown Company. June 11, 2010.

6. Electronic mail communication with R. Robertson, Florida Department of Transportation. June 4, 2010.

7. New Jersey Turnpike Authority. "Governor Corzine Announces Driscoll Bridge Opening After $225 Million Rehabilitation Project." Online. http://www.state.nj.us/turnpike/documents/Driscoll-Bridge-opening.pdf. Accessed June 15, 2010.

8. Amato, C. "Bridge Re-Evaluation Survey Report of the Bergen County Bridge." Lichtenstein Consulting Engineers, Inc., Paramus, New Jersey. January 30, 2002.

9. Port of Green Bay, Brown County. "Bridges Over the Fox River." Online. http://www.portofgreenbay.com/OneColumn.aspx?id=178. Accessed June 2, 2010.

10. Wisconsin Department of Transportation Standard Specifications for Highway and Structure Construction. Part 5, Section 501.3.2, "Concrete Composition." 2010 Edition.