

*PERFORMANCE OF
MICHIGAN'S CONCRETE BARRIERS*



CONSTRUCTION AND TECHNOLOGY DIVISION

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16. Abstract <p>Modifications to design standards, material specifications, construction methods, and roadway maintenance practices are believed to be major contributing causes for the observed premature deterioration of Michigan's Portland cement concrete bridge railings and barriers.</p> <p>This study documents the history of Michigan's barrier design configurations, provides a synopsis of typical modes of deterioration, and finally, provides recommendations intended to address improvements to the long-term performance of concrete barriers exposed to Michigan's harsh environments.</p>			
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**MICHIGAN DEPARTMENT OF TRANSPORTATION
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Performance of Michigan's Concrete Barriers

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PURPOSE

The purpose of this study is to focus on three primary points of interest of bridge barrier railing.

1. Types of bridge barrier/railing design configurations.
2. Sampling or documenting field performance of bridge barrier/railing design.
3. Potential factors that may contribute to premature deterioration.

BACKGROUND

It is reasonable to expect individual components of a bridge or roadway to age and deteriorate at comparable rates relative to their overall respective parent structure. However, recent field inspections of a representative sampling of bridge barriers and railings in mid-Michigan indicate that this may not be a true-to-life comparison. A freeway corridor or bridge structure may receive one, possibly two, barrier rehabilitation treatments throughout its service life. Many of these barrier/railing retrofits or replacements may have been in response to safety specification upgrades made independent or in conjunction with other construction rehabilitation or maintenance operations, while others may have been prompted by premature deterioration. Markedly, one vivid observation is that many of the current generation barriers in-service on MDOT roadways are deteriorating at a rate much greater than expected compared to 20 years ago.

Modifications to design standards, materials specifications, construction methods, and roadway maintenance practices are believed to be major contributing causes for the observed premature concrete deterioration. Hence, re-evaluation of the anticipated long-term durability for Portland cement concretes exposed to the harsh Michigan freeze-thaw environment may be warranted. Factors considered to be potential causes for reductions in the long-term service life for barrier/railing structures include:

- Design changes away from the open parapet to the solid face “G.M.” and “New Jersey” types configurations trap deicer-latent snow against the interior face of the barrier.
- Construction methods changed from cast-in-place to slipform construction exposing the fresh concrete surfaces to severe early-age plastic and drying shrinkage stresses.
- Use of blast furnace slag and other highly absorptive/low durability coarse aggregates affect water demand and early-age mixture sensitivity, thus further decreasing the concrete’s freeze-thaw durability.
- Increased use of deicing salts on roadways elevates the levels of chloride ingress into the concrete, thus contributing to aggressive corrosion of reinforcing steel and accelerated deterioration of the concrete.

In response to technical concerns related to premature concrete deterioration, modifications adopted by MDOT (prior to 1990) were:

- Adoption of epoxy coated reinforcement standards to provide protection against chloride attack of black reinforcing steel.
- Change from MDOT Grade 35S to 45D Portland cement concrete mixtures to increase concrete density.

Since the rate of decay of these structural units shows that the potential source(s) responsible are very aggressive in nature, surveys were focused on the above contributing factors and the mentioned modifications.

HISTORICAL REVIEW OF RAILINGS AND BARRIERS

Prior to the 1960's, the standard bridge railing types used in Michigan were the Types R-4 and R-5. These railings were constructed of either concrete (R-4) or steel (R-5) posts with metal lattice between posts. Illustrations of these two railing types are shown in Figures 1A and 1B. Depending on the specific application and location, some of these railings, or modifications to them, are still in service today. In addition to the Types R-4 and R-5 railings, other typical railing construction details incorporated extensive use of cast-in-place architectural concrete, and various renditions of rolled and tubular steel designs.



Figure 1A and 1B: Typical R-4 or R-5 standard bridge railing design prior to 1960.



The open parapet concrete railing with aluminum or steel tube (Types R-11 or R-12) was adopted as the standard railing detail in 1961. These railings were used throughout the 1960's and 1970's. Illustrations of a typical open parapet railing with aluminum railing on a structure constructed in 1974 are shown in Figures 2A and 2B. In 1967, the G.M. (Type 1) concrete barrier was approved as the standard barrier detail for trunkline applications. The general shape of this barrier is similar to modern standard details, with exception of the G.M.'s optional tube railing and dimensional modifications. Figure 3 illustrates a typical G.M. (Type 1) detail configuration. The G.M. (Type 1) barrier was shorter in overall height and narrower in cross-sectional width than today's standard design; only 2'-8" high, 6" wide at the top, and 1'-4" wide at the base. According to field inspections, some G.M. barriers are still in service today; many were still observed to be in excellent condition. In 1976, the "New Jersey" (Type 2) concrete barrier design was adopted for use in Michigan.



Figure 2A and 2B: Concrete railing typical of the standard R-11 or R-12 adopted in 1961.





Figure 3: Typical G.M. (Type 1) concrete barrier adopted in 1967.

Figure 4 illustrates a typical New Jersey (Type 2) detail configuration. Differences between the two standard design configurations (G.M. vs. New Jersey) are dimensional modifications to the toe and sloping face of the traffic bearing side. The cross-sectional widths at the top and bottom of the New Jersey (Type 2) barrier were also increased to 1'-0" and 1'-10", respectively. Several revisions to the standard design were adopted during the 1970's, including optional tube railings.



Figure 4: Typical New Jersey (Type 2) concrete barrier adopted in 1976.

In 1977, the New Jersey (Type 3) barrier was adopted. This standard design configuration specified an overall concrete barrier height of 3'-4" with no additional tube railing. Figure 5 illustrates a typical New Jersey (Type 3) detail configuration.



Figure 5: Typical New Jersey (Type 3) concrete barrier adopted in 1977.

On October 14, 1982, the MDOT Engineering Operations Committee (EOC) requested the standard design details for the New Jersey design be further modified. This was based on concerns raised by the Federal Highway Administration (FHWA) that MDOT's current Types 2 and 3 barriers were over-designed. Based on these concerns, the cross-sectional widths were reduced and reinforcement details were modified. Hence, the New Jersey (Types 4 and 5) concrete barriers were developed. These new standard design configurations (Types 4 and 5) resembled the previous standard designs (Types 2 and 3), respectively. However, the detail (Types 4 and 5) modifications reduced the cross-sectional widths to 8" at the top and 1'-6" at the base. Illustrations of these standard barriers types are shown in Figures 6 and 7.



Figure 6: Typical New Jersey (Type 4) concrete barrier adopted in 1982.



Figure 7: Typical New Jersey (Type 5) concrete barrier adopted in 1982.

ADOPTIONS OF CURRENT PRACTICE

In October 1972, the EOC approved the use of “slipform” paving technology for construction of Portland cement concrete barriers for bridge and freeway median applications. This construction technique consists of extruding very low slump (0 to 1-1/2 inch) concrete through a paving machine (commonly known as a “mule”) around the steel reinforcement. The standard design shape is generated by saddling the reinforcement with a moving form, templating the plan cross-sectional shape of the barrier. This method was particularly attractive to industry because of its time- and labor-saving characteristics. Unlike cast-in-place concrete technology (which requires assembly and disassembly of stationary forms for each day’s production), slipform is a continuously moving operation. The mule straddles the reinforcement cage and travels along the bridge deck surface, continually maintaining vertical grade control by means of a survey string-line. The low-slump Portland cement concrete is then charged into the moving form through a discharge hopper. High-frequency external vibrators are used to consolidate the low-slump plastic concrete. As the mule progresses along the bridge, the freshly extruded concrete is hand-floated, broomed, and finally coated with curing compound. A major concern when casting slipform concrete barrier is to maintain a uniform consolidation of the concrete in efforts to minimize voids and “rock pockets” without causing slumping or excessive disfiguration of the extruded concrete mass. This is a particular concern when extruding low-slump concrete around internal obstructions, such as utility conduits, bridge joint end treatments, and joint filler materials. Figures 8A, 8B, and 9 show a typical slipform barrier construction operation.



Figures 8A and 8B: Typical "slipform" concrete barrier operation.





Figure 9: Typical “slipform” concrete barrier operation.

The Portland cement concrete specified for barriers and railings is a typical superstructure grade containing MDOT standard Series 6AA coarse aggregate. The Series 6AA coarse aggregate used in this structural application permits the use of materials originating from either geologically natural or manufactured sources. A common source of manufactured coarse aggregate in Michigan is air-cooled iron blast-furnace slag; a by-product from the steel production industry. Portland cement concrete used in bridge barriers is designated as “superstructure quality” grade concrete. However, MDOT specification requirements prohibiting the use of slag coarse aggregates for superstructure applications are currently limited to the bridge deck only. Many bridge (as well as roadway median) barriers in the metropolitan Detroit area are constructed using air-cooled blast-furnace slag.

In April 1980, the EOC initiated a policy requiring epoxy coating of all steel reinforcement on the traffic face of all future New Jersey type barriers. In December, they expanded the policy to require epoxy coating of steel reinforcement for the entire superstructure. In the field, it is quite easy to identify the pre-1980 bridge barriers containing black reinforcing steel by their brownish colored oxidation leaching from avenues of high porosity in the concrete.

Advanced corrosion of the rusting black reinforcing steel exerts expansive forces within the concrete. The associated stresses generated as a result of corrosion cause the concrete cover over the reinforcement to spall, leaving the exposed corroding steel to further deteriorate. Moisture and chlorides then migrate along the deteriorating interfacial bond surface between the reinforcing steel and concrete further advancing corrosion of the reinforcing steel.

Prior to the 1990 revisions of the MDOT Standard Specifications for Construction, Portland cement concrete specified for bridge barriers was MDOT Grade 35S. This grade specifies 564 lbs./yd³ of Type I Portland cement and a minimum specified 28 day compressive

strength of 3500 psi. Concerns over specifying a substructure Grade 35S concrete mixture for bridge barriers (when all other concretes above the pier caps are superstructure Grade 45D) prompted debate and the ultimate approval of the 1990 Standard Specifications revision specifying Grade 45D superstructure concrete for bridge barriers. From a technical perspective, it was reasonable at that time to justify this change, since the Grade 45D concrete was considered a higher grade mixture consisting of 658 lbs./yd³ of Portland cement, a water reducing admixture, and 1000 psi increase in the specified 28-day compressive strength compared to the Grade 35S. These mix design modifications were initiated in efforts to decrease the permeability of the concrete paste matrix.

FIELD INSPECTION

Field Investigations - In 1997 and 1998, field inspections of a representative population of barriers were conducted to document the condition of Portland cement concrete bridge railings and barriers in Michigan. Each barrier was visually inspected. When possible, samples were collected for laboratory petrographic evaluation. The approximate age of the structural unit, construction method, type of coarse aggregate and overall condition of the concrete were recorded. Photographs were taken at each site for visual documentation. Table 1 summarizes the Portland cement concrete barriers included in this field survey.

Core samples were extracted from the I-69/US-127 interchange barriers for laboratory evaluation. This project was of particular interest since it was constructed in the mid-1980's using a mix of both cast-in-place and slipform construction methods. Further, these barriers were constructed under the same contract using same sources of materials with the same directional average daily traffic (ADT) volumes.

The concrete cores from these two barrier locations at the I-69/US-127 interchange (S01 and S02 of 19042) were examined in the laboratory for hardened air content according to ASTM C-457 "Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete" and rapid chloride permeability according to AASHTO T-277 "Rapid Determination of the Chloride Permeability of Concrete". In addition, several samples were studied petrographically to investigate their physical characteristics compared with what would be considered good quality durable concretes. Field specimens were analyzed for possible alkali-silica reactivity (ASR) according to the "Handbook for the Identification of Alkali-Silica Reactivity in Highway Structures, Handbook", SHRP-C-315 protocol. Petrographic laboratory findings from these specimens will be presented later in this report.

TABLE 1
Summary of Portland Cement Concrete Barriers

Structure No.	Location	Year Built	Construction Method	Coarse Aggregate Type	Condition
B01 - 13082	I-94/Kalamazoo River	N/A	Cast-in-place	Natural Gravel	Poor
S02 - 13082	I-94/Beadle Lake Rd.	1976	Cast-in-place	Natural Gravel	Poor
S05 - 19022	I-96/Wacousta Rd.	1980	Cast-in-place	Natural Gravel	Good
S01 - 19042	EB I-69 at US-127	1985	Slipform	Natural Gravel	Fair
S02 - 19042	WB I-69 at US-127	1985	Cast-in-place	Natural Gravel	Good
S03 - 19043	I-69/Wood Rd.	1973	Cast-in-place	Natural Gravel	Good
S12 - 19043	SB I-69 at I-96	1981	Slipform	Natural Gravel	Fair
S13 - 19043	NB I-69 at I-96	1981	Slipform	Natural Gravel	Fair
R01 - 19081	SB US-127 at R.R.	1973	Cast-in-place	Natural Gravel	Good
S14 - 23063	I-69/I-96 Connector	1990	Slipform	Natural Gravel	Fair
S09 - 23081	I-69/I-496 Connector	1990	Slipform	Natural Gravel	Fair
B03 - 23092	SB M-99/Grand River	1978	Cast-in-place	Natural Gravel	Good
B01 - 23152	EB I-96/Grand River	1980	Cast-in-place	Natural Gravel	Good
R02 - 23152	EB I-96 at R.R.	1982	Slipform	Natural Gravel	Poor
S05 - 23152	I-96/I-496 Connector	1981	Slipform	Natural Gravel	Fair
S08 - 23152	EB I-96/Canal Rd.	1982	Slipform	Natural Gravel	Poor
S13 - 23152	I-96/Eaton Highway	1981	Slipform	Natural Gravel	Fair
S01 - 33084	I-96/Aurelius Rd.	1977	Slipform	Natural Gravel	Poor
R03 - 39022	I-94/R.R.	N/A	Cast-in-place	Natural Gravel	Fair
533 - 50061	I-696/Mound Rd.	1976	Slipform	Slag	Poor
R01 - 81062	I-94/State St. Median	1975	Slipform	Slag	Poor
S01 - 81062	I-94/BL I-94	1974	Cast-in-place	Natural Gravel	Fair
S12 - 81062	I-94/US-12	1975	Slipform	Slag	Poor
R01 - 81074	SB US-23/Huron River	1988	Slipform	Slag	Poor
R02 - 81075	US-23/R.R.	1975	Slipform	Slag	Poor
S04 - 81104	I-94/M-52	1981	Slipform	Crushed Limestone	Fair

DETERIORATION

Freeze Thaw - Based on field investigations, it is evident that accelerated deterioration of Michigan's Portland cement concrete bridge railings and barriers is primarily a result of their exposure to very aggressive freeze thaw environments. Freeze thaw deterioration is progressive in the sense that as the surface is sacrificed to environmental erosion, the interior concrete is exposed. This progressive deterioration eventually reduces the concrete to rubble leaving it structurally unsound. The dislodged pieces of deteriorated concrete run the risk of being cast into traffic from the roadway shoulder, and onto vehicles or open waterways below. Modifications to design, materials specifications, construction, and roadway maintenance practices could all be contributors to changes in the rate of deterioration of these concrete structures. Some are shown to promote enhancements to longevity while others clearly provoke deterioration.

Deicers - Perhaps the most destructive assault on Portland cement concretes exposed to harsh Michigan freeze thaw environments occurs as a result of heavy applications of deicers. The osmotic and hydraulic pore pressures developed during internal expansions and movements of freezing liquids throughout the hardened concrete matrix induce localized tensile stresses ultimately causing micro-fracturing of the concrete paste. These micro-cracks eventually conglomerate to form macro-cracks which then provide wider avenues for further deicing chemicals and moisture intrusion. Osmotic pressures generated within the pore structure of concrete from water/deicer solutions are estimated to be approximately twice the magnitude of those generated by deicer-free pore waters. In addition, since the freezing point of deicer latent water is lower than that of water, the number of freeze thaw cycles experienced by the concrete over a given period of time may be greatly increased. In other words, the cyclic transformation of the pore fluids from a liquid state to a frozen state could compress the deterioration time-frame from decades to years. This, in turn, results in accelerated deterioration of the concrete structure. Further, as the concrete interior matrix is progressively eroded and exposed, carbonation and other complex chemical reactions manifest leaching of soluble calcium hydroxide from the concrete paste, and deposition of harmful mineral compound precipitate into the entrained air voids. This, in turn, reduces the concrete's resistance to future freeze thaw and chemical attack. Figures 10A and 10B show the accelerated deterioration of a concrete barrier caused by aggressive freezing and thawing.



Figures 10A and 10B: Typical deterioration caused by freeze thaw attack.



An interesting observation noted that further underscores freeze thaw attack as a common baseline deterioration mechanism is that many barriers with their traffic-bearing face exposed to the southerly direction tend to be more aggressively deteriorated than their counterpart barrier structures with northerly facing traffic-bearing surfaces. The logic being that as the winter solar radiation warms the southerly facing surface face (of the north-fascia barrier), the deicer latent

snow, built-up against the barrier from highway snow removal operations, melts and freezes daily. Thawing snow concentrated against the lower face of these barriers feed moisture into the concrete surface contributing to induced hydraulic and osmotic pore pressures, which were discussed earlier. The snow build-up against the northerly faced traffic-bearing surfaces experiences very little solar warming and, therefore, remains in a cryonic state for a longer period. As long as the snow remains frozen, the accelerated cyclic fatigue brought on by the movement of pore fluids is temporarily stabilized. This can be seen in Figures 11 and 12.



Figure 11: Example of snow build-up on northerly facing traffic-bearing barrier surface.



Figure 12: Example of snow build-up on southerly faced traffic-bearing concrete surface.

It is evident by field observations that since open parapet railing systems do not trap a significant quantity of deicer contaminated snow against their traffic bearing face, accelerated deterioration effects are not pronounced. However, with increased use of anti-icing/deicing agents, observations show some brush blocks and curb faces on older open parapet railing having been in-service since the late 1960's, are only now showing signs of aggressive deterioration. Some older railings are also experiencing similar signs of deterioration on their exposed vertical

faces. However, many are still in excellent condition. One method to retrofit the open parapet railings still in-service on main trunkline routes is to face it with beam guardrail across the structure, attaching it to the bridge railing. To a certain extent, facing the bridge railing with guardrail could aid toward protecting the concrete from aggressive deterioration. An example of an open parapet concrete railing retrofitted with beam guardrail is shown in Figures 13A and 13B.



Figure 13A and 13B: Example of open parapet concrete railing retrofitted with beam guardrail.



PETROGRAPHIC LABORATORY FINDINGS

Laboratory evaluation of loose rubble fragments collected from a barrier site containing natural gravel coarse aggregate shows the detectible quantities of alkali-silica gel formations within the concrete matrix to be minimal, hence, not necessarily considered to be a controlling factor toward the internal decay of the concrete. The SHRP-C-315 uranyl acetate indicator solution flagged a blue-green fluorescence under ultraviolet lighting. However, MDOT laboratory investigations have shown this blue-green hue to represent sodium chloride (typical rock salt). The SHRP-C-315 flags alkali-silica gel formations as yellow-blue colored fluorescence. Evaluations of these specimens noted only isolated areas of yellow-blue fluorescence, thus, ruling out ASR as the controlling deterioration mechanism for the barrier samples analyzed. Figure 14 shows photographs of barrier concrete fragments examined in accordance with the SHRP-C-315 test method.

According to laboratory inspection of concrete specimens extracted from both slipform and cast-in-place concrete barriers, the rapid-chloride permeability (ASTM C 1202 Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration) for the two concretes are quite low, relative to normal quality concrete. However, an interesting observation was that the surface of the slipform specimen, to a depth of approximately 1/8-inch, was very porous and of very low quality. Sand streaks and a very porous matrix were noted within this thin cover layer. Visual evidence indicates that potential causes could likely be the result of improper mixing, handling, finishing and/or curing during construction. Figure 15 shows the lens of sand detected in the outer 1/8-inch of the slipform barrier traffic-bearing surface. In any case, the laboratory sample was taken at random and considered to be representative of normal slipform barrier concrete. Petrographic evaluation of concrete slices representing the surface of the cast-in-place concrete barrier was consistent and homogeneous in appearance with interior.

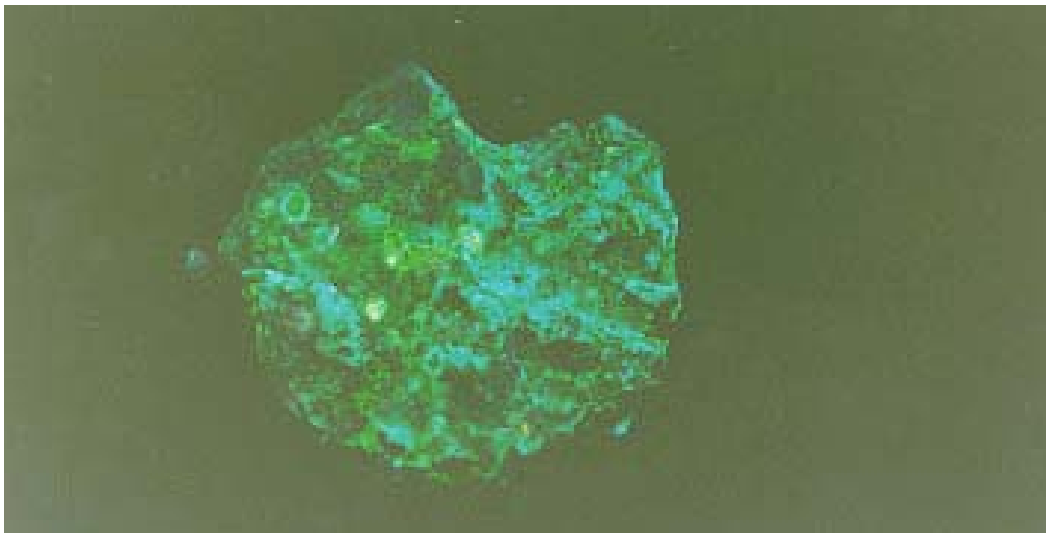


Figure 14: Photos of a concrete barrier specimen examined according to SHRP-315. Note the blue-green colored predominant fluorescence indicating sodium-chlorides presence.



Figure 15: Lens of sand detected in concrete core specimen sampled from slipform barrier. The lens was observed to be located within approximately 6 mm from the traffic-bearing surface.

SLIPFORM CONSTRUCTION

It is interesting to observe the divergence in performance between the conventional cast-in-place Portland cement concrete barriers and ones constructed using slipform technology. In particular, slipform barriers constructed without epoxy coated reinforcement show the highest level of premature deterioration than others (excluding blast-furnace slag coarse aggregate concretes), regardless of their exposures to aggressive deicer chemicals. An example of this was observed at the I-69/US-127 interchange located north of Lansing in Ingham County, shown in Figures 16 and 17. One characteristic mode of deterioration noted with slipform barriers without epoxy coated reinforcement is cracking of the concrete cover directly over the surface steel. These avenues for ingress expose the black reinforcing steel to corrosive environments; initially observed as a brownish oxidation staining, followed by spalling of the concrete cover from expanding oxides.



Figure 16: S02 of 19042, WB I-69 over US-127 near Lansing, MI. Constructed in 1985, this concrete barrier is a typical example of cast-in-place construction. This barrier is nearly crack-free.



Figures 17A and 17B: S01 of 19042, EB I-69 over US-127 near Lansing, MI. Constructed in 1985, this slipform concrete barrier was constructed at the same time, using the same materials as the cast-in-place barrier described in Figure 16. The type and magnitude of distress is typical of slipform barriers in Michigan.



One location of particular interest is near the top of the barrier structure. Many barriers (particularly slipform) experience distinct continuous longitudinal/horizontal cracking and staining approximately 4 inches below the top surface of the barrier. These cracks are believed to originate during the concrete's early-age semi-hardened state. As the concrete slumps under its own weight (often the case when the uniformity of the concrete slump is poorly maintained),

the top 4 inches of the barrier supported by the top longitudinal reinforcement is restrained from settlement as its parent the lower mass slumps downward. The early-age tensile stresses experienced at the interface between the supported top concrete and the slumping lower concrete mass produce longitudinal micro-cracks not noticeable to the naked eye. Over time, the top 4 inches of the barrier breaks away, either as a result of corrosion of the reinforcing steel, thermal stresses, or from deterioration caused by freezing and thawing of the moisture within the concrete. This mode of deterioration is a noted concern especially at structures where falling concrete is a safety hazard. This can be seen in Figures 18A and 18B.



Figure 18A and 18B: Typical advanced deterioration of horizontal crack. Note the oxidation staining from the black reinforcing steel, further leading to expansion and ultimate failure of the concrete due to corrosion expansion.



Observations supporting even early-age potential problems at this interface were noted on two newly constructed barriers at Walker Road and Alward Road over US-27 in Clinton County. At these locations, approximately 18 inches longitudinally along the top surface of two of the barriers delaminated to the depth exposing the top longitudinal No. 4 reinforcing bar and stirrup. Voids were noted under the steel at the exposed locations which also are believed to have contributed to suspected stress concentrations and eventual breakaway spalling of concrete surface at these locations. Figure 19 shows the early-age surface failure of the barrier at Alward Road just six weeks after barrier construction.



Figure 19: Early-age surface failure of barrier at Alward Road over US-27 in Clinton County.

Spalling of these barrier tops was reported during a distinct warming period in late spring. Another barrier located on westbound I-496 over the Red Cedar River in Lansing, as seen in Figure 20, shows longitudinal cracking within three years after construction. Laboratory technical staff was on-site during construction in 1995 to observe slipform barrier construction. As observed, the ambient weather conditions were hot and windy. This contributed to excessive loss of moisture from the fresh concrete surface due to the typical time that the fresh concrete was exposed to the environment prior to application of curing compound. The result was an unwarranted need for excessive hand-finishing after concrete placement of the concrete barrier surfaces in attempts to restore its visual appearance. Many concrete barriers visually noted but not documented in this study exhibit similar premature deterioration characteristics.



Figure 20: Typical horizontal crack deterioration noted within three years after barrier construction (WB I-496 over the Red Cedar River in Lansing). These tensile stress cracks in slipform barriers are a result of early-age stresses developed from slumping plastic concrete.

A concern that contributes to poor performance of slipform barriers is the lack of the ability to conduct thorough quality control construction inspections to assure minimum protective concrete cover over reinforcing steel prior to slipform concrete placement. Figures 21A and 21B show typical deterioration due to insufficient concrete cover over black reinforcing steel. Further aggressive concrete deterioration and corrosion of black reinforcing steel as a result of inadequate protective concrete cover at the toe of the barrier may be further aggravated by impact and abrasion brought on by highway snow removal equipment.



Figures 21A and 21B: Examples of corrosion of black reinforcing steel due to insufficient concrete cover.



One point most often overlooked when constructing slipform concrete barriers is the fact that these structural units receive very little, if any, consideration related to proper curing of the fresh concrete. Many times, this concrete is extruded from the paving machine only to be exposed to high ambient temperatures, low surrounding humidity, and drying winds for extended periods prior to application of curing compound.

COARSE AGGREGATES

Regardless of the method of construction, concrete barriers constructed using blast-furnace slag coarse aggregate show significantly higher levels of premature decay than barriers constructed with higher quality quarried or natural gravel coarse aggregates. A characteristic indicator of a barrier constructed using blast-furnace slag coarse aggregate is one possessing a massive amount of surface drying shrinkage cracks. Many are clustered representing a “turtle shell” pattern initially noticeable only shortly after rainfall when the surface has dried, but moisture is still observed weeping from these fine surface cracks. Eventually, the thin platelets encompassed by the turtle shell cracking patterns spall. The spalling then exposes the interior concrete to the harsh environment. One other characteristic indicative of barriers constructed using blast-furnace slag coarse aggregate is severe longitudinal deep cracks propagating along the top concrete surface. Over time, aggressive environmental stresses from moisture absorption widen and deepen the longitudinal cracks, eventually causing the barrier top to crumble and fall away. It is evident by field observations that slipform barriers constructed using blast-furnace slag coarse aggregate show the highest level of premature decay. Figures 22 through 24 show characteristic deterioration of the median barrier on I-94 west of State Street in Ann Arbor, and a fascia barrier on US-23 over the Huron River in Washtenaw County, both constructed using blast-furnace slag coarse aggregates.



Figure 22A and 22B: Median barrier on I-94 west of State Road in Ann Arbor.





Figure 23A and 23B: Barrier on SB US-23 over the Huron River in Washtenaw County constructed in 1988.





Figure 24A and 24B: Barrier on SB US-23 over the Huron River in Washtenaw County constructed in 1988.



EPOXY COATED REINFORCEMENT

Adoption of epoxy coated reinforcement as a standard design detail has contributed toward increased longevity of Portland cement concrete barriers. Although vertical cracks can still be seen over reinforcement stirrups, the epoxy coating provides a barrier over the black steel reducing the likelihood that moisture and chlorides will propagate the early-age corrosion, often observed with the prior vintage barriers.

PORTLAND CEMENT CONCRETE (CONCRETE MIXTURE TYPE)

The 1990 Standard Specification change focused on upgrading the concrete mixture from substructure Grade 35S to superstructure Grade 45D with the belief that a denser paste matrix could be expected if the Portland cement content were increased from 564- to 658 lbs./yd³. The negative consequence of increasing the volume of cement paste within the unit volume of concrete is increased shrinkage potential of the paste component of the concrete mixture. Field observations alone, however, do not provide conclusive evidence that increased cracking of newer concrete bridge barriers is a result of using the higher cement content concrete mixture, nor supports evidence that increased durability is achieved. The lack of performance related appraisal could also be due to the fact that insufficient time has lapsed since incorporation of this specification change. However, further efforts should be made to acknowledge lower total volumes of cement paste per unit volume of concrete will ultimately decrease overall concrete shrinkages.

ENVIRONMENTAL PROTECTION

The lack of proper early-age protection against the environment strips the “already moisture-deficient” exposed concrete surface of desperately needed water required for proper hydration. This, in turn, produces a very weak and porous barrier surface, unable to endure the aggressive elements during harsh Michigan winters. The characteristic weak and porous surfaces can be documented in the laboratory by concrete core specimens sampled from the slipform barrier. This fact can be further verified in the field by observing the extensive quantities of shallow plastic and drying shrinkage cracks throughout the exposed surfaces of the slipform barriers.

RECOMMENDATIONS

The following are recommendations to assure the long term service life of Portland cement concrete bridge and median barriers in Michigan:

- Conduct thorough candidate surveys by region to assess barriers for programmed replacement.
- Discontinue the use of blast-furnace slag and other highly absorptive/low durability coarse aggregates in Portland cement concretes used for all barrier/railing applications.
- Discontinue the use of slipform construction method for barrier construction applications.

- Specify a minimum seven day continuous wet curing requirement for all surfaces of all newly placed exposed barrier/railing concretes.
- Maintain standard specification requirements for the use of epoxy coated reinforcement for all barrier/railing reinforcing steel.
- Explore opportunities to improve the overall quality of the concrete. Reductions in the cement paste volume in the concrete could be achieved by incorporating optimization of well-graded aggregate blends. This will further facilitate reductions in the Portland cement content for the concrete mixture. Reductions in the paste volume will reduce the likelihood of shrinkage related cracks.
- Explore the potential feasibility for application of protective concrete coatings or sealers for protection against aggressive chemical deicer attack.