PERFORMANCE OF THIN BONDED CONCRETE IN HIGH VOLUME ROADS: REVIEW

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Abstract

Due to the poor economic outlook faced by transportation authorities, the demand for maximising preservation and rehabilitation procedures employed to maintain highway concrete and asphalt pavements has never been stronger. Many of the techniques for using conventional bonded and unbonded concrete overlays to protect and restore concrete and asphalt pavements have a long history of success. Techniques that employ thinner concrete coverings with closer joint spacing, however, are more recent. Both bonded and unbonded (directly applied) overlays are applied using these methods. These thinner bonded and unbonded concrete overlays have been used in the USA for more than 15 years, and field testing has shown their usefulness as a cost-effective way to prolong the life of concrete. life of damaged concrete, asphalt, and composite pavements. Typically, thin concrete overlays range in thickness from 4 to 7 in (100 to 175 mm). The overlay panels generally measure 6 by 6 feet (1.8 by 1.8 metres) or less. In order to give extended performance lifetimes of 15 to 20 years and to satisfy individual objectives, thin concrete overlays can be developed for a variety of traffic loads. Thin concrete overlays that are well-designed and built can require little maintenance and have low life-cycle costs. This essay offers an analysis of thin concrete overlay usage and experience in the US. Additionally, a number of recent case studies are provided to show the broad range of uses for thin concrete overlays.

Keywords: - Bonded concrete overlays, concrete, concrete inlays, concrete overlays, concrete pavements, pavement rehabilitation, unbonded concrete overlays

1. INTRODUCTION

Concrete is a very common material used in construction. It has been in use for over a century now and there is no shortage of structures that have been built using concrete. The biggest challenge with concrete rehabilitation is the fact that it requires strengthening and repair, which often requires a lot of effort and money. Among different approaches that can be considered for concrete rehabilitation, overlays are often the most economical alternative. Overlays are used to extend the life of a concrete structure by restoring a smooth sound surface and/or its original load-carrying capacity. In some cases, they can also help to improve the load-carrying capacity of a concrete structure by increasing its thickness.

Overlays are particularly suitable in the case of structures with large surface areas, where it can be either poured or sprayed, example pavements, bridge decks, walls and tunnels. Overlaying slabs is a common method for restoring worn out concrete. Overlaying a slab or pavement can be done to match the level of an adjacent slab, replace deteriorated or contaminated concrete, improve the frictional characteristics of the surface for pavements or bridge decks, and restore architectural features such as colour or texture.

2. BACKGROUND

Applications of concrete overlays include the following:

- Over existing asphalt pavements
  - Bonded overlay of asphalt pavements
  - Unbonded (directly placed) overlay of asphalt pavements
- Over existing concrete pavements
  - Bonded overlay of concrete pavements
  - Unbonded (separated) overlay of concrete pavements
- Over existing composite pavements
  - Bonded overlay of composite pavements
  - Unbonded (directly placed) overlay of composite pavements

Figure 1 depicts the family of concrete overlays. Figure 2 provides a summary of the concrete overlays' application. As seen in Figure 2, existing pavements that are not substantially damaged can be effectively covered with thin concrete overlays. Unbonded concrete overlays are increasingly acceptable when the quality of the old pavement deteriorates since they require relatively minimal pre-overlay rehabilitation. Unbonded concrete overlays are normally thicker than about 6 in. while bonded overlays are typically 4 to 7 in. (100 to 175 mm) thick (150 mm). However, as discussed in more detail below, good experience is being gained with the use of thinner, unbonded overlays that are 5 to 7 in. (125 to 175 mm) thick.

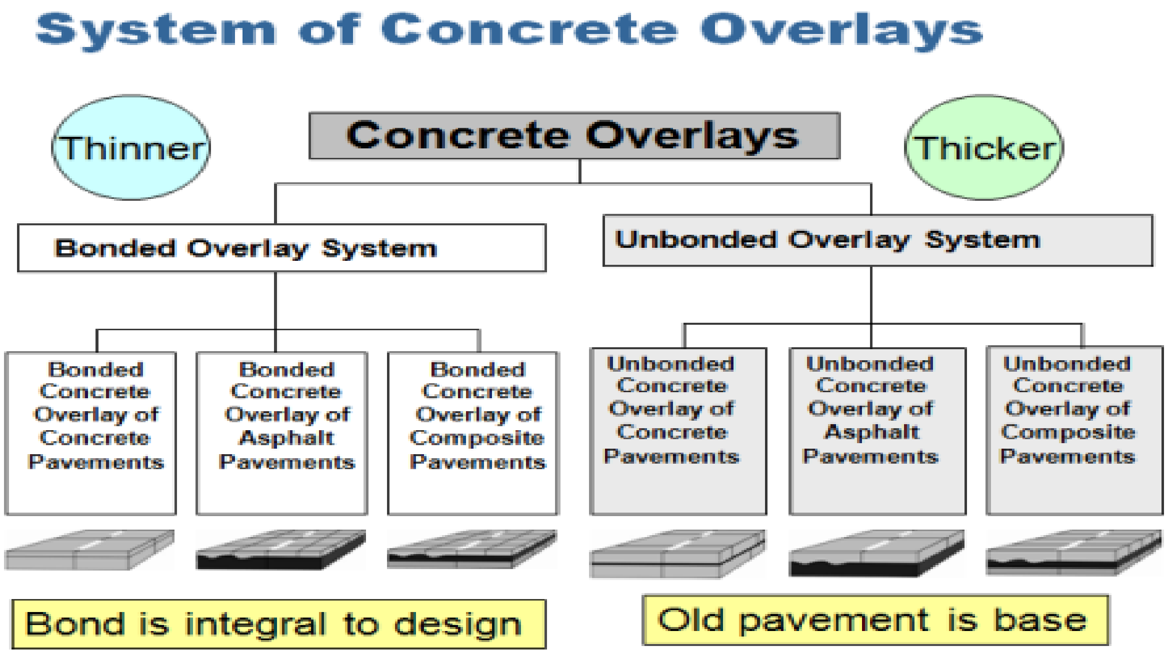

Figure 1 – Family of Concrete Overlays

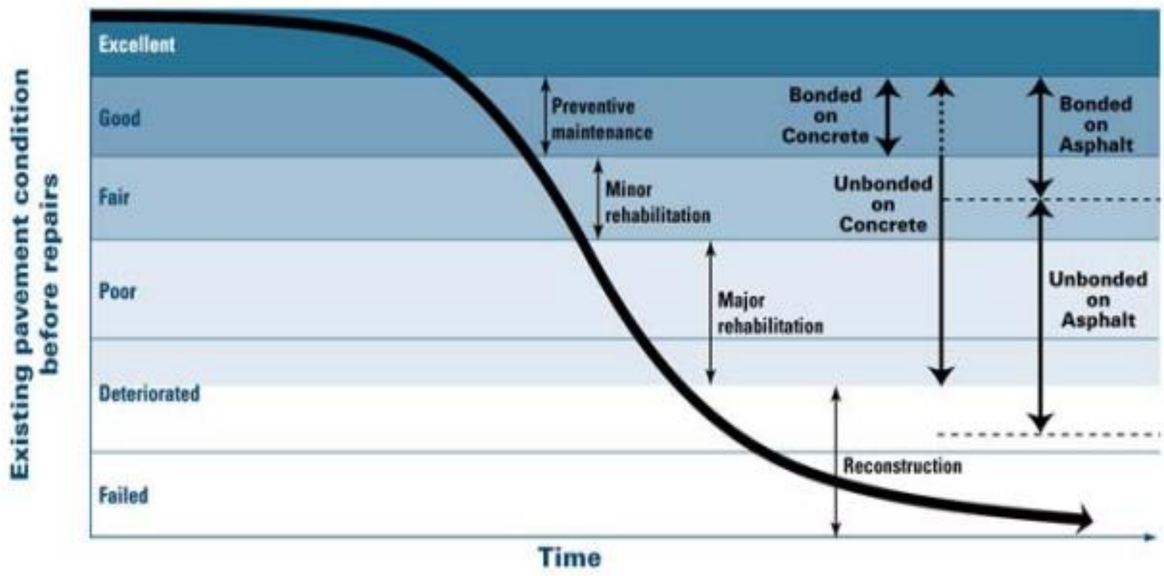

Figure 2 – Applicability of Concrete Overlays

3 APPLICABILITY OF THIN CONCRETE OVERLAYS

3.1 Bonded Overlays of Existing Asphalt Pavements

The normal thickness of bonded overlays is 4 to 6 in (100 to 150 mm). The overlay panels are generally 6 by 6 ft (1.8 by 1.8 m) or smaller when bonded to a milled asphalt surface. Thin bonded AC pavement overlays are a more recent development. Even though several early test installations were built in the 1990s, it wasn't until the late 1990s that the method started to gain wider acceptance. The average in-service time for thin bonded overlays on AC pavement is therefore less than 15 years. However, the performance of the several miles of thin bonded overlays in numerous US States suggests that they may have a service life of at least ten years if designed and installed appropriately.

3.2 Bonded Overlays of Existing Composite Pavements

A composite pavement's use of thin bonded overlays must be carefully considered. Original concrete pavements with an asphalt concrete (AC) overlay are referred to as composite pavements. Over time, the original concrete pavement's seams and cracks tend to be covered by reflection cracking in the AC overlay. Therefore, if there is severe reflection cracking in the composite pavement and there is a significant volume of truck traffic, there is a strong possibility for the development of reflection cracking in the concrete overlay of the composite pavement. A bonded overlay may still be an option if the reflection cracking in the composite pavement is not severe by employing bent steel bars to cover the cracks.

3.3 Bonded Overlays of Existing Concrete Pavements

The results of thin bonded overlays applied to existing concrete pavements have been inconsistent. These overlays are intended to cover any surface flaws in an existing concrete pavement, boost structural strength, and enhance surface friction, noise, and rideability for highway applications. Their thickness ranges from 2 to 4 in. (50 to 100 mm). The bonded concrete overlay's joint spacing is the same as the overlay's joint spacing. When existing concrete pavements are still in good structural condition with just little surface deterioration, bonded overlays are typically employed to improve the structural capacity of those pavements. When properly built, these overlays last 15 to 20 years and offer good service. These overlays can, however, display early failures, often joint corner delamination leading to cracking in the overlay, since they are so sensitive to existing pavement surface preparation, curing, and joint sawing procedures. The state of the existing pavement was restored in one of the case studies in this study by applying a novel thin bonded concrete overlay inlay style over a deteriorated concrete pavement.

3.4 Unbonded Overlays of Existing Asphalt, Concrete and Composite Pavements

Unbonded overlays, referred to also as directly placed overlays, are of two types:

- Conventionally thick overlays, 6 in. (150 mm) or thicker, are full-width and have transverse joint spacing of 12 to 15 ft. (3.7 to 4.6 m).
- Thinner overlays are 4 to 6 in. The overlay panels are generally 6 by 6 foot (1.8 by 1.8 m) in size and (100 to 150 mm) thick. This use is a modification of AC pavements' thin bonded concrete overlays. The use of an unbonded overlay over a composite pavement in Michigan is described in one of the case studies in this study.
- Unbonded overlays are often installed over an asphalt concrete surface, either over an existing asphalt pavement, over an asphalt interlayer installed over an existing concrete pavement, or over the AC surface of a composite pavement, depending on the kind and thickness of the existing pavement. An interlayer is necessary for effective utilisation when utilised over pre-existing concrete or composite pavements.

The interlayer's function is to isolate overlay from existing pavement

- — Prevent reflection cracking
- — Prevent bonding/mechanical interlocking
- Provide level surface for overlay construction
- Provide a softer interlayer – fewer curling stresses

Typically, a 1 to 2 in. (25 to 50 mm) thick layer of densely graded hot mix asphalt concrete is utilised as the interlayer (HMAC). Studies are being conducted to assess the usage of thicker geotextile fabric as the interlayer material, as was addressed in this study. This application is based on the German custom of separating a cement-treated foundation from the concrete slab for new building with a 0.2 in. (5 mm) thick geo-fabric. This idea is being used by US researchers to study thin, unbonded concrete coverings. A project that employed a thin geo-fabric as a separating layer for a thin unbonded overlay was built in Missouri in 2008 5. One of the case examples in this study is this undertaking.

3.5 Thin Concrete Overlay Design and Construction Considerations

The following are key design and construction considerations for use of thin concrete overlays:

- Overlay type: Plain concrete
- Jointing:
  - Except for bonded overlays of pre-existing concrete pavements, the suggested joint spacing is 6 by 6 ft (1.8 by 1.8 m) for overlay thicknesses of 4 to 6 in (100 to 150 mm). The overlay joint spacing for bonded overlays of jointed concrete pavements must match the joint spacing of the existing concrete pavement. The longitudinal joints in bonded overlays of continuously reinforced concrete pavement (CRCP) must match the longitudinal joints in the CRCP. However, bonded concrete overlays of CRCP do not offer transverse joints.
  - To guarantee that the overlay concrete won't prevent the bonded overlay system from expanding during warm days, joint sawing for bonded overlays of jointed concrete pavement must be full depth of the as-constructed overlay plus 12 in. (12 mm).
  - For overlays that are less than 8 in. (200 mm) thick, dowel bars are not utilised at transverse joints.
  - Along external longitudinal joints, tie-bars are an option. The longitudinal joints must have ties-bars, according to the Colorado DOT. The custom in Michigan is not to employ tie bars.

- Concrete mixture
  - Concrete used is similar to that used for conventional concrete paving.
  - Use of smaller maximum aggregate size for thin overlays.
  - Rapid setting concrete may be used if needed.
- Concrete placement
  - Similar to conventional concrete paving - slipform or fixed-form construction may be used
  - Proper curing and joint sawing are very critical for thin overlays
  - Surface requirements (ride and texture): similar to conventional concrete pavement.

3.6 Performance of Concrete Overlays

As was mentioned, thin concrete overlays that were properly planned and built have worked effectively in the US. This is based on observations made over the course of the past 15 years in the US. Early implementations of this technique saw certain difficulties, particularly when so-called ultra-thin concrete overlays were used, as the design and construction criteria were not clearly specified or understood. The following distresses may be present in thin concrete overlay failure:

- Panel cracking, as shown in Figure 3.
- Panel delamination (and subsequent cracking) for bonded overlays
- Panel rocking
- AC stripping and loss of support under the overlay
- Panel settlement, also shown in Figure 3.
- Roughness

For concrete overlays that are 4 to 6 in. (100 to 150 mm) thick, the expected service life is 15 to 20 years. It is anticipated that the thin concrete overlays will be made to have a longer service life as more performance data becomes available.

Figure 3 – Thin Bonded Concrete Overlay Panel Cracking and Settlement

4. RECENT INNOVATIVE THIN CONCRETE OVERLAY PROJECTS

In order to increase the service life of current concrete and asphalt pavements, thicker unbonded concrete overlays have been applied often. Although thinner bonded concrete overlays of concrete pavements have a long history, the technology has traditionally been utilised to reinforce pavements that are in good condition. The design and construction processes are being improved upon and becoming more well-established, and the thin bonded overlays of AC pavements are establishing strong service records. Case studies of the following creative projects are provided to demonstrate how thin concrete overlays can be used in a variety of settings.

- Thin bonded inlay of a deteriorated concrete pavement in Kansas.
- Missouri's deteriorating concrete pavement with a thin, unbonded overlay. Instead of a typical AC interlayer, a geotextile interlayer was employed in this project.
- Thin unbonded overlay of a deteriorated composite pavement in Michigan.
- Bonded Overlay on 15th Street in Del City, Oklahoma
- Bonded Overlay on Iowa 3 East of Hampton, Iowa

4.1 Thin Bonded Concrete Inlay – Kansas

In 2008, a thin bonded inlay was built beside I-35 in Johnson County, Kansas. The current concrete pavement was built in 1985 and is made up of a 4 in. (100 mm) thick cement treated foundation and a jointed reinforced concrete pavement (JRCP) that is 9 in. (225 mm) thick. JRCP joints were separated by 30 feet (9.1 m). Joint distress was visible in the JRCP as surface spalls that were several inches broad and about 2 inches (20 mm) deep. The sand/cement mortar in the concrete was failing due to a weak entrained air system, as can be seen visually from the spalls. Figure 4 depicts the state of the existing pavement. Only an infrequent limestone aggregate appeared to be impacted by "D-cracking," and the coarse limestone aggregate was discovered to remain intact. Wire mesh was used to strengthen the JRCP, and it was positioned 2.25 to 4.5 inches (57 to 114 mm) below the surface. The predicted concrete flexural strength was 680 psi (4.7 MPa). Full-depth repair of certain seams was done before the surface was milled for 2 inches, shot-blasted, and then a cement slurry (3 parts water to 1 part cement) was used before a 2 inch (50 mm) thick plain concrete inlay was applied. Figure 5 depicts the application of the slurry and the placing of the concrete. Over the already-existing joints, joints were sawed into the inlay. Full depth + 0.5 inches was the sawcut depth (12.5 mm). The entire job had to be finished in 10 weeks by the contractor. The inlay implantation was permitted across four weekends. The pavement may be opened to construction traffic at 340 psi (2.3 MPa) flexural strength or 1800 psi (12.4 MPa) compressive strength, according to the construction standard. The inlay was ground with diamonds. The concrete inlay is functioning effectively about 18 months after construction. There were no failures at young ages. According to the Kansas DOT, the inlay will at least add 15 years to the current pavement's useful life.

Figure 4 – Condition of Existing Concrete Pavement

Figure 5 – Slurry Application and Concrete Placement

4.2 Thin Unbonded Overlay – Missouri

In Missouri in 2008, a geotextile cloth was used as an interlayer in a thin, revolutionary unbonded concrete overlay. The 3.13-mile (5-kilometer) long project is situated between Routes 150 and 58 along a stretch of Route D in Jackson County. The current jointed concrete pavement, which is 30 feet (9.1 metres) apart and 8 inches (200 mm) thick, was built in 1986. At transverse joints, one-inch (25 mm) dowel bars were employed. The Missouri DOT (MoDOT) anticipated that up to 25% of the pavement area would need full-depth repair prior to a typical AC overlay as of 2008 since the pavement section was showing severe D-cracking along both transverse and longitudinal joints. Figure 6 depicts the state of the pavement as it stands right now.

Figure 6 – Condition of Existing Concrete Pavement

The MoDOT looked at a number of options for repairing the Route D pavement. These options included new construction utilising AC and PCC, traditional unbonded overlay that was 8 in. thick (200 mm), and rubble with a 12 in. (300 mm) AC overlay. Considering an experimental thin unbonded concrete overlay using a non-woven geotextile fabric as an interlayer in place of a typical AC interlayer was determined after negotiations between MoDOT and the industry. The concrete overlay design that was created called for the usage of 6 ft by 6 ft (1.8 by 1.8 m) panels with an unbonded concrete overlay that was 5 in. (12.5 mm) thick. The shoulders were chosen to have the same design. The German practise of employing a geotextile cloth as an interlayer is expanded upon by this method of using one. The shoulders were chosen to have the same design. This method of employing a geotextile fabric as an interlayer is an expansion of the German practise of separating concrete from a foundation that has been treated with cement using a geotextile fabric that is 0.2 in. (5 mm) thick. Due to the cushioning effect of the 0.2 in. (5 mm) thick fabric, the Germans have successfully employed this application to minimise curling strains and remove bonding between the concrete and cement treated substrate. For this project, two nonwoven geotextiles were used. These were produced by Propex under the names Geotex 1201 and Geotex 1601. These geotextiles were somewhat thinner than the 0.2 in. (5 mm) geotextile fabric used in Germany for new concrete construction.

The overlay construction steps included the following:

- Pre-overlay repairs – some of the severely deteriorate joint areas were patched using flowable concrete.
- Fabric placement - As seen in Figure 6, the geotextile material was delivered to the project in 300 ft (90 m) rolls. The cloth was 4.6 metres (15 feet) wide. The cloth was positioned using a telescoping forklift, as seen in Figure 7. The pavement was covered with two rolls of geotextile.
- Fabric fastening – a Hilti gas powered fastening system was used to fasten the fabric onto the underlying concrete pavement.
- Concrete placement - Before the concrete was placed, the geotextile material was damp. As indicated in Figure 8, concrete was laid using a typical slipform paver that was supported by the cloth directly. During the laying of concrete, there were no issues with the geotextile noted.
- Concrete curing – A curing compound was used and applied at a higher rate that typically used for new concrete pavement construction.
- Concrete joint sawing – Joints were sawed in a timely manner and no early age problems were observed.

Figure 7 – Geotextile Fabric Placement

Figure 8 – Slipform Paver over the Fabric and Completed Unbonded Overlay

The MoDOT is pleased with the initial project results and will continue to assess the overlay's effectiveness in the coming years. After around 16 months of use, the thin unbonded overlay is still functioning effectively.

4.3 Thin Unbonded Overlay of a Composite Pavement – Michigan

In the city of Detroit, on M-3 (Gratiot Avenue) between I-75 and I-94, the Michigan Department of Transportation (MDOT) Metro Region opted to undertake a thin concrete overlay demonstration project. The project was 3.17 miles long and used around 198,000 square yards (165,000 square metres) of pavement. The hot mix asphalt concrete had been applied multiple times over the original concrete pavement, which was put down in the early 1900s. A parking lane, three through lanes going in each direction, and a shared centre turn lane make up the pavement's nine lanes. The presence of underlying brick pavers along the outside parking lane was found after a check of the available blueprints. The composite pavement's surface quality had gotten worse. The composite pavement's surface condition has substantially declined, necessitating the renovation of the road. Visual examination of the composite pavement revealed a few isolated locations with suspect foundation support. An AC overlay will often conform to the contour of the foundation below, making it simple to spot weak spots. The magnitude of any possible support issues was immediately assessed when the surface AC milling was finished. The state of the composite pavement is seen in Figure 9. It was agreed to build a thin unbonded concrete overlay over the composite pavement with smaller 6 by 6 ft (1.8 by 1.8 m) panels after negotiations between MDOT and the industry. Very few composite pavements nationwide have undergone this kind of restoration. A cross-functional team held six working meetings from October 2003 to April 2004 to create plans and guidelines for the deployment of this pavement treatment.

Figure 9 – Condition of Existing Composite Pavement

In August 2004 the project was put out to bid. The lowest offer was $7,17,000,000. Full depth patches were used to repair places with the weakest foundation support, which are generally near inlets, whereas partial depth removal of concrete with hand-patched asphalt or replacement of concrete was used to restore regions with less severe degradation. In order to preserve curb depth and cross-slope, an asphalt milling depth of 5 in. (12.5 mm) was developed. 350 manhole structures were present in the composite pavement, and they were separated from the pavement using a 5 ft (1.5 m) diameter core drill. Each step of the core holding the manhole casting was removed before machining the AC surface layer. Before placing the concrete, the castings were modified to the new pavement grade. A 4 in. (100 mm) concrete overlay is applied after the AC surface layer has been cold milled. A 4 in. (100 mm) concrete overlay was put over a 1 in. (25 mm) asphalt separator layer after cold milling the AC top layer. This project also included the construction of experimental sections with two different asphalt separator mixtures and sealed vs unsealed seams. The slab panels had a maximum dimension of 6 by 6 ft (1.8 by 1.8 m) and were 6 in. (150 mm) thick. The majority of the work was started in 2005 and finished in the late fall or early part of that year. Full-depth repair and median strengthening are shown in Figure 10 as pre-overlay actions. Figure 11 illustrates how to lay an AC interlayer to provide a level and consistent surface for pouring concrete. As seen in Figure 11, concrete was poured using slipform paving. The MDOT Metro Region has planned future demonstration projects since it is pleased with the results of the inaugural initiative. After more than three years of operation, the unbonded overlay is still operating well.

Figure 10 – Pre-Overlay Repairs

Figure 11 – AC Interlayer and Concrete Placement

Figure 12 – Completed Thin Unbonded Overlay

4.4 Thin Unbonded Inlay of an Asphalt Pavement – Delaware

In Felton, Delaware, a portion of US 13 was built using a thin, bonded inlay of an existing AC pavement in November 2009. The job entailed putting a 6 in. (150 mm) thick bonded inlay after machining a 6 in. (150 mm) section of the outer lane. A small number of pre-overlay tasks were completed to patch up holes and fill fractures in the existing AC pavement. The overlay concrete had to reach compressive strength of 2,000 psi (13.8 MPa) in 12 hours to allow opening to traffic the following day. The panel measurements for the inlay were 6 by 6 foot (1.8 by 1.8 m). Figure 13 depicts the milled AC pavement prior to the application of an overlay. the location of the concrete inlay and the inlay joint sawing are shown in Figure 14.

Figure 13 – Milled AC Pavement (Outside Lane)

Figure 14 – Bonded Concrete Inlay Placement and Inlay Joint Sawing

4.5 Bonded Overlay on 15th Street in Del City, Oklahoma

As a result of the opening of a liquid fertiliser factory near the western edge of Hampton, the Iowa Department of Transportation (Iowa DOT) built a 3 in. thick, 1.8 mi. long COC-B overlay on Iowa 3, a state major route, in September 1994. Iowa DOT-sponsored research with the goals of measuring the rate of bond strength development between concrete overlays and existing pavements and evaluating non-destructive testing techniques for estimating concrete strength includes documentation of this project (Cable 1995). The original 10 in. thick concrete pavement with 10 ft wide granular shoulders had been built in 1969. Before applying the overlay, there was some mild spalling at the centre line joint (Figure 15). In 1994, the overlay was built one lane at a time while being driven on by pilot vehicles. Utilizing 36-inch-long, epoxy-coated, deformed No. 5 reinforcing bars to delay reflection cracking of mid-slab nonworking transverse fractures was a novel element of the overlay. Prior to the installation of the overlay, the bars were fastened to 42 crack areas in the existing pavement surface, as illustrated in Figure 16. Even though reflective cracking did happen, these fissures were just hair-thin. Figure 17 shows that as of 2021, the COC-B overlay is in good shape after 27 years of operation, with the exception of a 0.25 mi portion Figure 18 . The mild spalling that was first seen in the centreline joint of the old pavement in 1994 has now been mirrored into the overlay and has become more severe at the west end of the overlay.

Figure 15 Existing concrete pavement in 1994 prior to overlay placement, with a shotblasted in operation and some spot spalling evident at the centreline joint

Figure 16 Reinforcement over transverse cracks in the existing concrete pavement prior to overlay placement 1994

Figure 17 East end of the COC–B overlay on Iowa 3 in August 2021, showing pavement in fair to good condition

Figure 18 West end of the COC–B overlay on Iowa 3 in August 2021

4.6 Bonded Overlay on Iowa 3 East of Hampton, Iowa

Del City, Oklahoma built a 3 in. thick bonded asphalt overlay over an existing 7 in. thick concrete pavement that was built in the 1970s in the fall of 1994. The project was located on a 1.25 mi long section of commuter route 15th Street. The 3 in. thick asphalt overlay was cold-milled and replaced with a 3 in. thick COC-B overlay by the city in 2003. At that time, 15th Street saw about 7,500 daily vehicles, with 5% of them being trucks. Figure 19 depicts the existing asphalt surface before milling, and Figure 20 depicts the existing concrete pavement following the milling of the asphalt surface. Asphalt was also milled in the curb and gutter portions to match the slope of the existing gutters Figure 20 Any residual asphalt was manually removed after the cold-milling of the asphalt, and non-stable panels were removed by doing full-depth concrete patch repairs at certain spots. Shot blasting was used to considerably roughen the surface of the milled concrete in order to remove any microcracking that may have resulted from the milling process and to improve bonding. As illustrated in Figure 21, many No. 5 reinforcing bars with U-shaped bends were secured over nonworking longitudinal fissures in the pre-existing concrete. After 15 years, the fracture areas were examined, and tight cracks in the overlay were noted. Figure 22 depicts the COC-B overlay's state in 2020.

Figure 19 Existing 3 in. thick asphalt overlay on 15th Street prior to milling

Figure 20 Existing concrete on 15th Street after milling the 3 in. thick asphalt overlay

Figure 21 U-shaped No. 5 tied bars fastened over longitudinal cracks in the existing concrete

Figure 22 Condition of 15th Street in September 2020

Conclusion

The restoration of old asphalt, concrete, and composite pavements can be accomplished cost-effectively by using thin concrete overlays, as was detailed in this work. The case studies that are provided show the wide range of uses for thin concrete overlays. These applications are the result of wise engineering choices and a drive to keep looking for new ways to develop and enhance current technology. The success of these cutting-edge applications will provide pavement engineers additional resources they can rely on to efficiently and affordably renovate old pavements. Thin concrete overlays have the major benefit of preserving the existing pavement, which drastically cuts down on construction time for the restoration activity and encourages sustainable rehabilitation methods.

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