MONTANA DEPARTMENT OF TRANSPORTATION
In cooperation with the U.S. Department of Transportation - Federal Highway Administration

Project Number MDT- 313265
(WJE Project No. 2019.5465)

Evaluation of Thin Polymer Overlays for Bridge Decks

Wiss, Janney, Elstner Associates
330 Pfingsten Road
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ITEM 1: SUMMARY PAGE

MDT - 313265 - Evaluation of Thin Polymer Overlays for Bridge Decks

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Proposal Written by:	Paul Krauss, P.E. (Montana), Project Manager and Principal Todd Nelson, P.E. (Illinois), Materials Engineer and Associate Principal Mohamed ElBatanouny, Ph.D., S.E. (Illinois), Structural Engineer and Associate Elizabeth Nadelman, Ph.D., Materials Scientist and Associate Kate Hawkins, Materials Scientist and Associate Terry McGovern, P.E. (Colorado), Project Engineer and Associate
Proposal Date:	September 23, 2019
Principal Investigator:	Paul Krauss, P.E. (Montana) 330 Pfingsten Road Northbrook, Illinois 60062 847-753-6583 tnelson@wje.com
Administrative Officer:	Paul Krauss (same as above)
Proposed Contract Period:	36 Months
Total Contract Amount:	$75,000
Proposed Contract Type:	Cost plus Fixed Fee
Fixed-fee Portion at 15%	$9,287.49

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TABLE OF CONTENTS

ITEM 2: BACKGROUND AND PROBLEM STATEMENT

Overlays are routinely used by DOT's throughout the United States for maintenance and rehabilitation of bridge decks. These overlays are desirable in that they act as both a barrier to chlorides and moisture from external sources and provide a new wearing surface for the bridge deck. Common overlay materials include portland cement concrete mixtures, membranes with asphalt concrete, and polymer concrete. A survey by Fowler and Whitney (2011) indicates that through 2011, approximately 2,400 overlays installed in the United States were polymer concrete overlays. These overlays are used primarily to extend service life; restore surface friction and uniform deck surface appearance; repair spalled and cracked surfaces; and provide waterproofing and chloride penetration resistance to the deck (Fowler and Whitney 2011). Polymer concrete overlays have the advantage of being much faster to install than conventional concrete overlays, a significant advantage in urban areas, and being thinner, they also add less dead load to the structure (ACI 548.5R-16).

The use of polymer overlays dates back to the 1950s, with the first systems consisting of single layers of coal tar epoxy broomed onto concrete bridge decks, with fine aggregates broadcast over the surface (ACI 548.5R-16). Oil-extended epoxy overlays were introduced in the 1960s, and polymer concrete overlays were being used by the mid-1970s (Fowler and Whitney 2011). As demand for these materials increased through the 1980s and 1990s, additional materials and construction practices were advanced. Significant work using polymer concrete for protection of bridge decks occurred during the mid-1980s with California and Virginia DOT's being primary investigators. To date, various polymer binder materials have been used for overlays. Epoxy overlays are the most common polymer overlay materials nationwide (Fowler and Whitney 2011); however, polyester-styrene polymer concrete has been successfully used in California and other states since the 1980s (Krauss 1988).

Organic polymer resins used in polymer concrete deck overlays are typically within the polyester-styrene, epoxy, methacrylate, and urethane families, each with different curing and performance characteristics. Depending on the base polymer, polymer concrete performance can vary. In general, polyester-styrene (fiberglass, cultured resin countertops, and automotive Bondo) has shrinkage during curing and a strong odor, but epoxy resins (adhesives and coatings) typically have very low shrinkage and less odor. However, epoxies cure more slowly and come in a wide range of formulations, many of which are cheapened with high volumes of fillers or co-polymers. Methacrylates cure very well in cold temperature (sometimes used for in-service freezer floors), tend to be thin (low viscosity) such that they usually penetrate fine cracks, but are highly volatile and tend to be brittle (high modulus) making them prone to cracking or delamination. Polyurethane (used in foam seating, foam insulation, gaskets, skateboard wheels, coatings, and Spandex) typically provides flexibility but may be moisture sensitive during cure resulting in foaming and can be toxic (isocyanides). Polyurethane coatings are often applied as top coats over epoxy coatings to protect the epoxy from UV degradation. However, since polymers are routinely formulated and blended with co-polymers, generalizations concerning performance are not always accurate.

Polymer overlays are composite materials of organic polymer resins combined with aggregates. Advantages include rapid curing and strength gain, excellent mechanical strength, and polymers can be easily formulated for a variety of applications. Disadvantages can include a high thermal coefficient of expansion, high modulus, moisture sensitivity, safety and flammability considerations, resin shelf life, high cost, and risks for poor polymerization, shrinkage, or improper formulations. Some resin formulations have low glass transition temperature, so polymer concrete properties, including shear modulus, can vary greatly with small changes in temperature.

Polymers have been used in a wide variety of ways to treat bridge decks including resin impregnation (sometimes assisted by vacuum) with post polymerization, crack repair by injection or gravity, broom and seed overlays, mortar overlays, concrete overlays, and high friction surface treatments (HFST). The

American Concrete Institute, Committee 548, *Polymers in Concrete*, has developed numerous documents and guides on the use of polymer concrete for a wide range of bridge applications. Documents of particular interest to this project might include: ACI 548.5R-16, *Guide for Polymer Concrete Overlays*; ACI 548.8-19, *Construction Spec for Type EM (Epoxy Multi-Layer) Polymer Overlay for Bridge and Parking Garage Decks*; ACI 548.10-10, *Specification for Type MMS (Methyl Methacrylate Slurry) Polymer Overlays for Bridge and Parking Garage Decks*; and ACI 548.9-08, *Specification for Type ES (Epoxy Slurry) Polymer Overlays for Bridge and Parking Garage Decks.*

Challenges

One of the main challenges of early polymer overlay was cracking and delamination due to thermal incompatibility between the overlay material and the bridge deck substrate, especially for more thickly applied overlay layers. However, as polymer overlay materials grew in popularity through the 1980s and 1990s, research and development into new materials and construction methods led to improvements in the performance of these overlay systems. More specifically, resins that permitted greater elongations and had lower elastic moduli were developed to reduce problems associated with thermal incompatibility (Fowler and Whitney 2011), while aggregate shapes and gradations were also optimized to reduce resin contents.

Review of the literature indicates that when installed properly, polymer overlay systems can achieve service lives up to 25 years or longer. The majority of premature failures of polymer concrete overlay systems have been encountered when the condition of the bridge deck is poor at the time of overlay application (i.e., deck has excessive cracking and delamination), or when construction is not performed in accordance with best practices (e.g., issues with surface preparation, quality control, and contractor inexperience) (Fowler and Whitney 2011). Carter (1997) and Sprinkel (2003) have reported that some polymers may lose flexibility, bond strength, and skid resistance over time due to exposure to ultraviolet radiation, thermal cycling, and wear. In cold climates, thermal compatibility remains a major factor for a number of failures (Carter 1997). No matter how well the overlay is constructed, it the resin formulation or polymer concrete is thermally incompatible, failure will occur. This is of particular relevance to the thin polymer overlays in Montana, where not only do temperatures routinely drop below freezing in the winter time, but large diurnal variations in temperature in the summer months induce additional thermal cycles on the bridge deck overlay. Besides incorrect resin formulations and constructions defects; such as poor curing or poor surface finishing and ride, defects can include cracking, delamination, excessive wear, and loss of skid resistance. Cracking and delaminations are often caused by high thermal-induced stresses since the resin has a high thermal coefficient of expansion and often a high (brittle) modulus. Inadequate surface preparation, excessive moisture in the deck, resin saponification due to the high pH of the concrete are also potential causes of delaminations.

Another consideration is that thin polymer mortar overlays and broom and seed overlays typically are not as impermeable to water and deicers; as advertised ,since they are thin, highly aggregate filled systems that contain interconnectivity between aggregates and therefore paths for deicer migration and diffusion. Furthermore, as some resin formulations age under UV exposure, they crack and can allow increased deicer diffusion. Thicker (1-inch thick) mixer blended and screeded polymer concrete overlays (polyester-styrene) are likely to provide superior resistance to moisture and deicers compared to 3/8-inch thick broom and seed overlays.

Recent Montana Experience

Montana Department of Transportation (MDT) has initiated an experimental research project to evaluate the friction and durability of high friction surface treatments (HFSTs) applied to four bridge decks in the state. These HFSTs are a form of thin polymer concrete overlay, which incorporates a high-friction aggregate topping. As part of this project, two HFST systems were installed in 2014 and 2015 on four bridges (two bridges each system). A Dayton Superior-Unitex system (epoxy) was installed on bridges in Bigfork and Big Timber, while a Poly-Carb system (co-polymer) was installed on bridges in Kalispell and Roundup. Friction resistance (skid) was evaluated after installation and three times between 2015 and 2018.

The most recent (2018) friction resistance test results for the Bigfork and Kalispell bridges indicate average skid numbers of approximately 36 and 17, respectively, reduced from initial skid numbers of approximately 80.[1] By comparison, the Big Timber and Roundup bridges had average skid numbers of approximately 53 and 55, respectively, also reduced from initial skid numbers of approximately 80. A skid number of 30 to 35 is typically considered to be the minimum acceptable skid number for highway structures.

Based on a cursory review of the data provided by MDT, several possible sources for the low skid resistance observed at Bigfork and Kalispell have been identified. These include:

- ***Thermal stresses*:** Bigfork and Kalispell are located in the northern Missoula area, which is subject to wide daily temperature variations, especially in the summer months. Due to the different thermal expansion properties of polymer overlays, aggregates, and concrete, large temperature fluctuations may cause a mismatch in the stresses in each of these components, leading to eventual delaminations and overlay failures caused by thermal fatigue.
- ***Abrasion due to chain wear and heavier traffic loads*:** Bigfork and Kalispell both average more than 10,000 vehicles daily, while Big Timber and Roundup average between 1,500 and 2,600 vehicles daily. These heavier traffic loads, especially in areas with heavy truck traffic and tire chains, may cause premature wearing of the bridge deck surfaces.
- ***Original bridge deck condition*:** The nature of pre-existing cracks and other distress in the bridge decks is currently unknown. Pre-existing cracks that are not well-sealed prior to overlay installation, or are moving cracks that reflect through the overlay, will disrupt bond and cause premature delamination and failure of the bridge deck overlay.

Additional sources, such as variations in UV exposure or environmental exposures, will also be considered based on further evaluation of the bridge decks and bridge deck overlays.

ITEM 3: BENEFITS OF RESEARCH

The objective of this research is to assess the factors that influence the long-term performance of polymer overlay systems in Montana, specifically with respect to friction resistance and durability, and to provide guidance and recommendations to MDT regarding appropriate polymer systems for use across Montana's varying geographic regions. In support of this objective, the proposed research will consist of the following:

- A literature review and survey of thin polymer overlay systems used across the United States and Canada, with particular emphasis on factors that affect surface friction and durability in colder climates similar to Montana's.
- A focused field investigation of select bridge decks with thin polymer overlays to assess the present condition of the bridge decks and overlay systems, and continued monitoring of these bridges over a minimum three-year period to evaluate long-term performance of the overlays.
- Development of strategies to evaluate the effectiveness of polymer overlays with respect to sealing the deck from water and chloride intrusion.
- The four bridge decks described above, as well as twelve additional bridge decks located throughout the state (as identified by MDT), will be evaluated. Many of these bridge decks have been previously evaluated by WJE as part of research project 2016.3598 (WJE Job Number).

[1] Initial skid number was not provided for Bigfork Bridge.

A key outcome of this research effort will be recommendations for incorporation into the MDT current special provisions and specifications related to polymer systems, considering the varying traffic volumes, climates, geographic features, and bridge deck conditions for which certain polymer overlay systems may be appropriate.

ITEM 4: RESEARCH PLAN

Item 4.1 - Literature Review

This task will consist of literature review to compile reported performance of different thin polymer overlay systems used in the United States in terms of surface friction and durability on concrete bridge decks. To facilitate this literature search, WJE will use its library capabilities to identify pertinent reports sponsored by FHWA, state DOTs, NCHRP, and other groups. Many include observed service life and performance evaluation for thin polymer overlays. Qualitative observations of the advantages and disadvantages of different overlays, such as ease of construction and sensitivity of surface preparation, will be included in the literature search as well. The effect of environmental exposure and traffic conditions on the performance of the overlays will also be assessed, if available.

The information collected in this section will aid in the assessment of the appropriateness of using thin polymer overlays for the bridges selected for the high friction surface treatment (HFST) experimental research project, especially for the bridges where below-standard skid resistance was measured after two years. The literature search will be updated as appropriate during the project duration.

At the completion of the literature review, a survey will be developed and issued to DOTs that have utilized thin polymer overlays in recent history. The survey will focus on collecting information on surface preparation procedures, applications procedures, materials used, skid resistance, and performance history.

Item 4.2 - Field Investigation

WJE will implement a focused field effort to investigate the performance of selected bridge decks with thin polymer overlays. Due to limited funding and to maximize the benefits of this research for MDT, WJE will choose four (4) of the bridges currently included in the skid resistance testing program. The bridge decks will be selected in coordination with MDT and will represent geographic locations, traffic volumes, and deck conditions that have been reported in the literature to be most closely related to the performance of thin polymer overlay systems.

The bridge deck assessment work will include visual inspection, delamination surveys, bond strength testing, concrete core extraction for laboratory evaluation, and skid resistance testing as detailed below:

- A visual survey of the top side and under side (when accessible) of each deck will be performed. This survey will focus on locating and documenting the extent, nature, and location of deterioration. Types of visually, identifiable deterioration include cracking, spalling, corrosion staining, scaling, abrasion, spalling, efflorescence, and other distress will be documented. Field microscopes will be used to examine microscopic features such as resin cracking and aging effects, aggregate loss and fractures, and resin to aggregate adhesion. Photographs of representative distress will be taken. Detailed crack mapping will also be performed on the top side of representative areas, documenting the location and size of cracks.
- A delamination survey will be performed on representative areas on the top side of the deck, using chain dragging and hammer tapping. The location and size of any delaminations will be documented.
- If cracks are found, WJE will identify core locations for concrete sampling for subsequent laboratory studies. These cores will be located strategically to capture the crack or distress mechanisms and be

representative of the findings of the visual and delamination surveys. The core locations will be patched using a quick-setting concrete repair mortar.

- Skid resistance measurements performed in general conformance with ASTM E274, using a single tire skid unit as has been performed by MDT on their previous bridges. WJE has assumed MDT will perform this testing alongside WJE during the bridge investigations.
- Bond strength testing will be performed in accordance with ASTM C1583, *Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method) and* using the guidelines of ICRI 210.3R-2013, *Using In-Situ Tensile Pulloff Tests to Evaluate Bond of Concrete Surface Materials*.
- Laboratory evaluations of cores will be performed to qualitatively assess bond of the polymer, general characteristics of the cracks, substrate surface preparation, resin quality, aggregate durability, and quality of the substrate concrete using the procedures in ASTM C856, *Standard Practice for Petrographic Examination of Hardened Concrete*.

Item 4.3 - Evaluation Options for Sealing and Chloride Resistance

Experimental methods anticipated to be used on the extracted field cores for evaluation include ASTM C1202 / AASHTO T277, *Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration,* and AASHTO T357, *Standard Method of Test for Predicting Chloride Penetration of Hydraulic Cement Concrete by the Rapid Migration Procedure*. These test methods are electrical methods that can provide an indicator of concrete's ability to resist chloride and moisture penetration. In this case, the methods will be modified to provide an indicator of the ability of the overlay to resist chloride and moisture penetration. Tests will be performed on approximately 2-inch thick slices taken from the top of 4-inch diameter cores sampled through the overlay and substrate concrete. The effectiveness of the polymer overlay to resist moisture and chloride ingress will be evaluated based on the total charged passed after 6 hours by ASTM C1202 / AASHTO T277 (with a target of less than 100 coulombs) or on the rate of penetration after 18 hours by AASHTO T357 (with a target to be determined based on laboratory testing). WJE has performed similar modified tests to evaluate the sealing effectiveness of polymer overlay systems in California, Texas, and Iowa. Pending the results of these laboratory studies, a modified testing procedure will be proposed for use by MDT.

Item 4.4 - Monitoring of Decks for Three Years

WJE will monitor the performance of the selected bridge decks for a period of three years. Our monitoring efforts will include observations of the decks during annual site visits, where the evaluations include the protocol in **Item 4.2,** Page 7, with the exception of core extraction and any additional laboratory evaluations as noted.

Similar to investigations and observations WJE has made on structures for MDT in the past, all of the field measurements, observations, and photographs will be documented and collected on WJE's Plannotate software. WJE has developed general field inspection and bridge-specific software using the Plannotate software. Field use has demonstrated the system to be an efficient platform for collection and review of field inspection data. Frequent uploads of the collected information to WJE's servers help prevent any loss of the inspection data. The basis of the inspection process is to tie the inspection notes and photographic documentation spatially to the relevant bridge documents using WJE Plannotate iPad software. The inspection data is then accessible during each visit in real time to ensure that all previous areas of distress are fully documented during each annual visit.

In addition to the on-site based monitoring efforts listed above, we will use weather data from NOAA, to track temperature and precipitation events at the station(s) nearest to the bridges to better inform our recommendations on performance under different exposure conditions found around the state. Similarly, as with any bridge wearing surface, the performance of the overlays will be heavily dependent on the traffic volume over the bridge. To monitor traffic volume during the three year period, WJE proposes to use data generated by MDT on how many vehicles travel the highways on the selected bridges.

Item 4.5 - Recommendations

At the conclusion of our literature review, site observations, testing and monitoring, we will develop recommendations on an overlay system, or systems, for use at various exposure conditions found around the state. Our recommendations will be focused on addressing the two main concerns of MDT, which are maintaining friction or skid resistance, and durability. We anticipate that our recommendations of system(s) may vary depending on the traffic volumes and types of vehicles traveling over the bridges, as well as environmental exposure factors such as sun exposure, temperatures, and amount of precipitation. In addition, we will take into account the location of the bridges relative to mountain passes which may indicate if vehicles are likely to be using chains or studded tires which can impact the wearing characteristics of the overlay. The recommendations will provide MDT with a sound evidence based selection of overlay systems for use at various locations around the state which will provide improved service life and increased safety.

Item 4.6 - Reporting

During the duration of the project, monthly progress and Task reports will be delivered to MDT, as further described in (**Item 7**, Page 10). At the conclusion of the investigative work proposed above, WJE will compile a comprehensive report including the completed scope of work, findings, recommendations, and implementation. The details of the reporting are further discussed in the deliverable portion of this proposal (**Item 7**, Page 10).

ITEM 5: DATA

The provided data will be compiled in an organized, electronic format, and the source of each document will be clearly identified. All data will be provided to MDT via a secured source at the completion of the project.

In addition to WJE's report being inclusive of all the data from this study, the field investigation data will be preserved in WJE's Plannotate software. Collection of field data has always been a core component of WJE's project work. In an effort to enhance data collection techniques, as previously discussed, WJE developed Plannotate, a software application to annotate inspection data onto PDF's using the Apple iPad. The inspectors' data is stored in an open mapping data format that allows for simple aggregation and analysis in programs like Excel. This mapping provides information on the appearance and spatial position of the annotation, as well as inspection data and photographs collected by the inspector. This data will always be available to MDT and can be used for future inspection documentation.

ITEM 6: MDT INVOLVEMENT

From the scope of work presented above, WJE anticipates MDT's involvement to include the following:

1. **Item 4.2,** Page 7 - Collection of documentation related to the bridges to be investigated.
2. **Item 4.2 and Item 4.3,** Pages 7 and 8 - Traffic control and skid resistance testing during the initial overlay investigations and subsequent monitoring.
3. **Item 4.2 and Item 4.3,** Pages 7 and 8 - Coordination with a coring contractor for extraction of concrete cores during the initial overlay investigation and potentially during subsequent monitoring.
4. **Item 4.4,** Page 8 - MDT will provide WJE with the traffic volumes for the selected bridges for the three year monitoring period.

ITEM 7: MEETINGS AND DELIVERABLES

Meetings

WJE proposes an initial Kick-Off meeting with MDT prior to initiation of **Item 4.1,** Page 7, of the proposed scope of work. This meeting is proposed to be held via web meeting/conference call, and the goal of this meeting will be to introduce WJE's team to MDT's technical panel; discuss the proposed scope of work and schedule; and discuss documentation related requests. Prior to **Item 4.2,** Page 7, WJE proposes to have a meeting to discuss the bridges to be inspected and associated inspection protocol.

After completion of the laboratory portion of **Item 4.3,** Page 8, and completion of the survey as part of **Item 4.1**, Page 7, a meeting will be held with MDT and WJE to discuss the evaluations performed in the laboratory to assess the effectiveness of the field overlays in preventing moisture and chloride ingress and discuss the results of the DOT survey. WJE also proposes meeting during the overlay monitoring period of **Item 4.4**; Page 8, during the Implementation phase, and during the Final Reporting process. The Implementation meeting has been planned to coincide with the Oral Presentation. The project manager and additional appropriate WJE staff will attend each of these meetings, and meeting minutes will be provided for review within two weeks after completion of the meeting.

Deliverables

Monthly Reports

Monthly progress reports are proposed to be delivered to MDT prior to the 15th of every month. These progress reports will include updates on scope completion; upcoming schedule; requests for MDT involvement; overall percentage completion (% of overall budget) and current invoice; and any upcoming concerns and resolutions.

Task Reports

Task reports will be issued at the completion of each Item. When these Task reports coincide with a monthly report, only one Task report is proposed. These reports will be written in a fashion to be easily included in the Final Report, and will include all the information in the monthly progress reports and include the following: task summary, major findings, and any associated implementation opportunities. WJE anticipates these Task reports will be brief in nature; approximately 2 to 3 pages in length.

Final and Implementation Report

The Final Report will be submitted in Microsoft Word and Adobe Acrobat format and prepared in accordance with Montana Department of Transportation's Report Writing requirements. All data will be presented in metric units with the English units in parentheses. The final reporting for this project will be delivered to MDT in Draft form for review and comments. After comments are addressed by WJE's project manager and appropriate staff, a second draft will be delivered to MDT within two weeks of receiving MDT's comments. Any additional revisions will be delivered within a week of MDT's comments. After the completion and approval of WJE's Final Report, WJE plans to provide an Implementation report (two weeks after the Implementation meeting), Project Summary Report and Oral presentation. WJE has assumed the Oral presentation will be held in Helena, MT.

ITEM 8: SCHEDULE

The time required to complete the proposed scope of work is 36 months, with specific Item durations outlined in the following tables. WJE has assumed the proposed work will be initiated in 2020, and the overlay evaluations will extend into 2022. WJE anticipates providing monthly progress and Task reports during each Item and completing a Final report, Implementation report, and Oral presentation at the completion of the project.

	2020				2021				2022			
Items	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
4.1 Literature Review and DOT Survey	X	X	X	X						X	X	
4.2 Field Investigation			X									
4.3 Evaluation Options for Sealing and Chloirde Resistance				X	X							
4.4 Monitoring of Decks for Three years			X			X				X		
4.5 Recommendations										X	X	
4.6 Reporting											X	X

	2020				2021				2022			
Deliverables	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Kick Off Meeting	X											
Meeting prior to Item 4.2 and after 4.3		X			X							
Meetings during 4.4			X				X			X		
Monthly and Task Reports	X	X	X	X	X	X	X	X	X	X	X	X
Final, Project Summary, and Implementation Report											X	X
Presentation												X

ITEM 9: STAFFING - RESEARCH TEAM

The Research Team has carefully selected the following relevant experts for our proposed research and have attached selected resumes in the appendices, which will lend more detail to their background and experience.

Paul Krauss, PE | Primary Investigator | *330 Pfingsten Road, Northbrook, IL* | *847.753.6517*

Mr. Krauss will serve as the primary investigator and project manager for this project. He is a Principal with WJE and is nationally known for providing practical experience in solving problems related to bridge rehabilitation, concrete cracking, deterioration and reinforcing corrosion. Mr. Krauss joined WJE in 1988 after 8½ years with the California Department of Transportation (Caltrans). He received the Caltrans "Excellence in Research Award" in recognition of outstanding research in developing new and improved materials and techniques for the rehabilitation of portland cement concrete structures. Since joining WJE, Mr. Krauss has performed several landmark research projects including National Cooperative Highway Research Program (NCHRP) Report 380 "*Transverse Cracking in Newly Constructed Bridge Decks*", Project 20-07, Task 234 "*Guidelines for Selection of Bridge Deck Overlays, Sealers, and Treatments*", and Project 20-07, Task 235 "*Testing Protocols for Surface Applied Concrete Sealers*".

Todd Nelson, PE | Materials Engineer | *330 Pfingsten Road, Northbrook, IL* | *847.753.6583*

Mr. Nelson has over twenty years of experience in a wide variety of field, laboratory, and analytical investigations of new and existing structures. His experience includes construction materials evaluation, durability assessments, litigation support, laboratory test programs, repair and rehabilitation, and research and development of construction materials. Mr. Nelson's project work has included investigations of concrete slab-on-ground and pavement distress; concrete durability and deterioration; low and variable concrete strength; alkali silica reactivity (ASR); chemical and environmental attack of concrete; and utilization of petrographic, chemical, and analytical diagnostic methods.

Elizabeth Nadelman, PhD | Material Scientist | *330 Pfingsten Road, Northbrook, IL* | *847.753.6320*

Dr. Nadelman will serve as a materials consultant on this project and perform document review, laboratory evaluations, and reporting. Since joining WJE in 2016, Dr. Nadelman has been involved in a variety of projects involving the field, laboratory, and analytical investigation of reinforced concrete materials and structures. Her background and interests include durability of concrete materials, service life analysis of reinforced concrete structures, and development and testing of construction materials. In addition to concrete, Dr. Nadelman's experience also includes evaluation of grout, mortar, masonry, and polymeric construction materials. Prior to joining WJE, Dr. Nadelman conducted research at the Georgia Institute of Technology focused on the early-age properties and long-term durability of concrete made with portland limestone cement. She has presented, published, and lectured on her work relating to chemical and autogenous shrinkage, physical salt attack, and transport properties of cement-based materials.

Mohamed ElBatanouny, PhD, PE, SE | Structural Engineer | *330 Pfingsten Road, Northbrook, IL* | *847.753.6395*

Since joining WJE in 2015, Dr. ElBatanouny has worked on a variety of projects, including field investigations, vibration analysis, and structural health monitoring and instrumentation. He has background and interest in condition assessment of existing structures, nondestructive evaluation, concrete material degradation, load testing, and experimental characterization. Dr. ElBatanouny has managed and served on numerous sponsored research projects. He has authored over 60 publications including two book chapters and has presented numerous lectures. Dr. ElBatanouny is an active member in several other technical committees in ACI and TRB.

Terry McGovern, PE | Project Engineer | *3609 South Wadsworth Blvd, Lakewood, CO* | *303-914-4342*

Mr. McGovern has participated in the investigation and rehabilitation of multiple concrete, steel, and wood structures. Mr. McGovern's focus lies in the area of existing structures, with an emphasis on concrete structures. He has participated and led the evaluation of many cast-in-place, precast, prestressed, and post-tensioned concrete structures. These evaluations have included assessment of structures to develop long-term maintenance plans as well as to address current failures or distress. He also serves on ACI Committee 546, *Repair of Concrete*, and ACI Committee 563, *Specifications for Repair of Structural Concrete*.

Kathleen Hawkins | Material Scientist | *330 Pfingsten Road, Northbrook, IL* | *847.753.6446*

Since joining WJE in 2018, Ms. Hawkins has worked on projects involving bridge condition assessment and maintenance, service life assessment, and development and quality testing of construction materials. She has background and interest in concrete and steel degradation, preservation of reinforced concrete structures, and development of construction materials. Prior to joining WJE, Ms. Hawkins conducted research at the University of Illinois at Urbana-Champaign focused on measuring and manipulating the rheological properties of fresh concrete.

ITEM 10: COMMUNCIATION AND QUALITY CONTROL

The project manager will maintain day-to-day contact with team members and with MDT. During the initial stages of this project, WJE will work closely with MDT to develop the project objectives, stay on schedule, and to help MDT implement recommendations. The project manager will be responsible for organizing the work in the most cost-effective manner and seeing to those agreed-upon budgets and schedules being maintained.

WJE has a long and proven track record of accomplishing projects on time, within stated budget limitation, and with effective quality assurance. Our record on previous projects for Federal, State, municipal agencies, and the private industry has been and remains excellent. WJE has developed working knowledge of basic and complex investigation or rehabilitation procedures for bridges and uses this knowledge when establishing investigations, scheduling, reporting and implementation of related services.

Quality Control of WJE work product is assured through a consistent technical review and checking process which is applied to every project. This is standard practice on all WJE projects. All work product will be reviewed by at least to staff members associated with this project, consistent with WJE's standard practice. The assigned project manager will be responsible, in consultation with MDT's manager, for setting up a formal project / task assignment performance review, and reporting procedures. All work will be reviewed and reported on a regular, periodic basis to avoid pitfalls and to make certain that the objectives of the given effort are met in a timely and cost-effective manner.

ITEM 11: COMPANY/INDIVIDUAL PROFILE AND EXPERIENCE

Wiss, Janney, Elstner Associates, Inc. (WJE) is a professional firm providing practical, innovative, and technically sound solutions to structural, architectural, and materials problems. WJE specializes in the investigation, analysis, and design of repairs for distressed conditions in bridges and other structures. Since 1956, WJE has served more than 70,000 clients around the world from individuals to large corporations and governmental agencies. WJE employs more than 700 experts and support personnel experienced in structural, architectural and civil engineering, as well as petrography, testing and instrumentation. Besides breadth of experience, WJE staff members offer a strong track record of accomplishment in their fields. More than half of the WJE professional staff have over fifteen years of experience, both on-site and in the laboratory. WJE is routinely called upon by state DOTs to provide expert services in the area of bridge inspection, repair, concrete corrosion, and materials investigation. WJE has conducted investigations on a variety of bridge structures in nearly every state in the union.

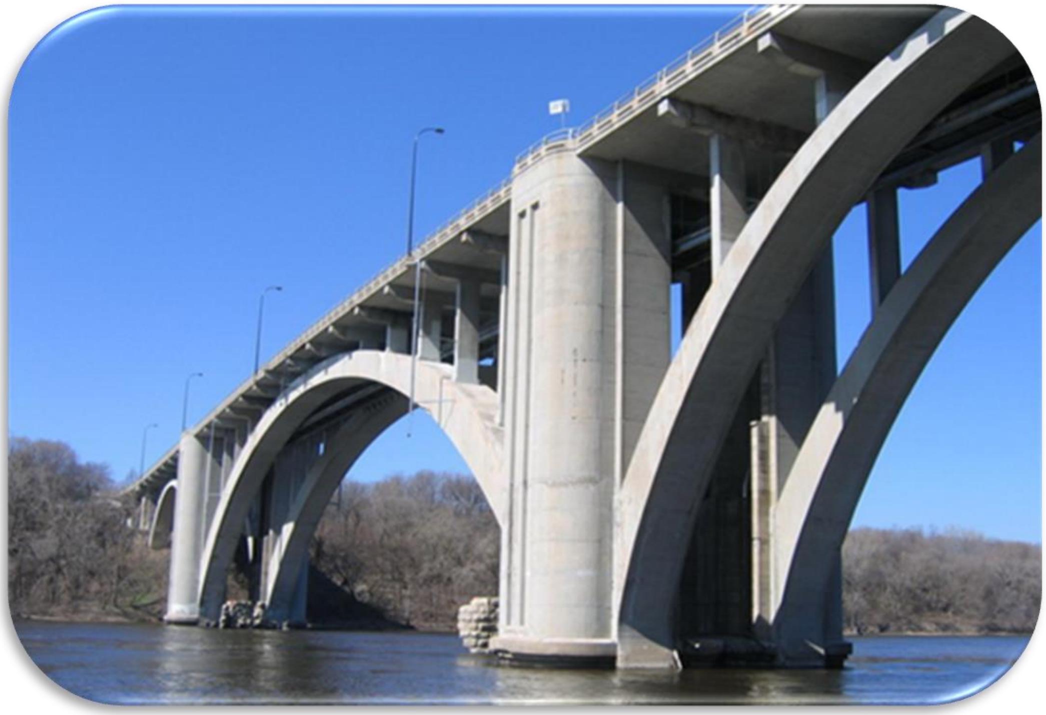


Figure 1. WJE developed the repair and rehabilitation procedures for the historic preservation of the Franklin Avenue Bridge in Minneapolis, MN.

Specialized bridge services include:

- Investigations of failed or distressed structural systems
- In-depth inspection of corrosion damage and general conditions in reinforced concrete structures
- Material evaluation durability, performance, and for service life modeling
- Nondestructive testing concrete bridge sub- and super-structure
- Field instrumentation and testing of structural systems
- Laboratory testing of structural models, components, and materials used in bridge construction
- Structural analyses and load rating
- Structural repair design and preparation of drawings and specifications for rehabilitation and repair
- Corrosion protection recommendations for concrete structures
- Laboratory evaluation of concrete of utilizing petrography, chemistry, and other analytical tools
- Installation and field testing of repair details and procedures to assess their constructability and performance

WJE is uniquely qualified to provide MDT with engineering solutions of these polymer concrete overlay bridge structures. Knowledge of the material performance is supported by technical expertise in testing and instrumentation. The office and laboratory headquarters complex in Northbrook, Illinois, offers 80,000 square feet of state-of-the-art structural and materials test facilities (constructed in 2018) and equipment for construction-related investigations, instrumentation, and research. Clients rely on WJE's more than 60 years of investigation experience to solve problems that arise during and after construction. WJE has demonstrated that research knowledge and laboratory techniques can be put to practical economical use to solve our client's problems. In this way, WJE has earned a reputation for functional, durable, and cost-effective designs.

Bridge Inspection, Evaluation and Rehabilitation Experience

WJE staff members have extensive experience conducting field investigations of bridge deck, superstructure and substructure problems, as well as performing laboratory studies of a wide range of bridge materials. WJE has evaluated problems on bridge types ranging from archaic concrete arch bridges and steel bridge structures to historic bridges to modern high performance steel bridges and long span precast, segmental concrete bridges, as examples. WJE has investigated problems in all types of bridge construction.

WJE has the in-house personnel and expertise to respond to the unique requirements of each bridge investigation. Services include visual inspections, nondestructive and destructive field evaluations, instrumentation and data acquisition, full-scale load testing, laboratory analyses and testing of materials and members, computer analysis of the original design and the as-built structures, design of repairs, field evaluation of trial repairs, and, in some instances, the actual installation of the repairs.

Annually, WJE staff perform more than 250 bridge projects, nearly all dealing with distress and deterioration of critical bridge components, systems and subsystems. Work is conducted for state departments of transportation, local government agencies, and private bridge owners.

WJE is the industry leader in concrete technology, having completed numerous research and training projects on concrete deterioration, repair, preservation for the American Concrete Institute, Federal Highway Administration, National Highway Cooperative Research Project, Concrete Reinforcing Steel Institute and others. This work has positioned WJE at the forefront of bridge deck rehabilitation.

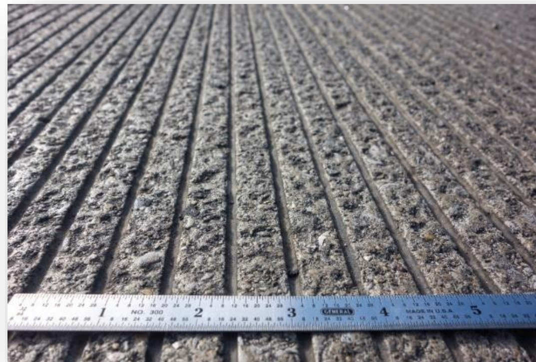
Through a better understanding of the causes of concrete deterioration, WJE has developed repair and rehabilitation solutions that range from sealers and surface treatments that inhibit the ingress of corrosion chemicals such as chlorides; partial and full depth patching using specialized mortars that maximize the effectiveness of these materials to improve long term durability of concrete repairs; passive and active cathodic protection to counter the effects of corrosion; corrosion protection coatings of embedded reinforcing to limit future interactions between the metal and a corrosive environment, and others.

Plans and specifications have been prepared for hundreds of concrete structures using state-of-the-art materials and construction methods. WJE’s research and practical application of cathodic protection systems and experimental laboratory experience regarding specialty concretes, penetrating sealers, coatings, epoxy-coated bars, epoxy-coated prestressing strand, and admixtures sets WJE apart from other firms in the development of construction, rehabilitation, and maintenance procedures for new and older reinforced and prestressed concrete structures. Two noteworthy polymer overlay bridge projects are highlighted below:

Iowa Department of Transportation - Performance Evaluation of Polymer Overlays

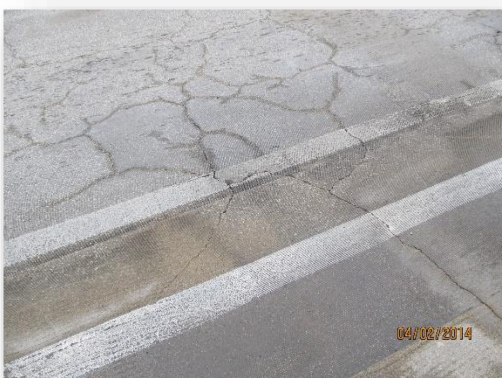
WJE is currently working with Iowa DOT in conjunction with the Iowa Highway Research Board (IHRB) to evaluate the performance of polyester polymer concrete (PPC) overlays as an alternate overlay material. WJE previously researched the optimum timing to apply polymer overlays and/or sealers on bridge decks to extend the service life and achieve the best cost-benefit ratio from the application. As a follow up to this previous research, WJE is currently evaluating the performance of PPC overlays to be applied on two older bridge decks in Iowa and develop guidelines for Iowa DOT that can aid in the implementation, design, and construction of PPC overlays based on challenges and successes observed in the two case studies. This project will aid in future bridge deck overlay decision making and provide design, construction, and QA/QC guidance for future practice.

The overlay field evaluation of the two bridge decks includes visual inspection, delamination surveys using chain dragging, steel reinforcement surveys using ground-penetrating radar (GPR), half-cell potential deck survey per ASTM C876, concrete core extraction for laboratory evaluation, and crack mapping. The laboratory evaluation portion of this research includes testing the bond strength of the PPC overlay at varying ages and measurement of the chloride diffusion coefficient of the PPC overlay. This information will be utilized for service life modeling for each bridge deck to determine the effect of the overlay on the remaining service life of the bridge deck. A life cycle cost analysis will then be conducted based on the estimated service life for each of the bridges.



Kwik Bond - Investigation into Cracking and Delamination of Polymer Overlay

In 2014, WJE performed a detailed investigation for a polymer manufacturer (Kwik Bond) that was used in an overlay applied to a 300 foot long bridge deck, 40 feet wide; which cracked and delaminated shortly after constructed. WJE's investigation included document review, field investigations, laboratory evaluations, and analytical modeling. A detailed field investigation was performed on the entire length of the bridge, including a delamination survey, crack mapping, tensile bond strength testing, and core extraction (for subsequent laboratory studies). During the field investigations, WJE found the cracking occurred only at the delaminated areas, and delaminations were consistently within the substrate concrete. Tensile bond strength testing found the polymer overlay was well bonded to the substrate concrete, but failure in the substrate concrete was observed and due to near surface cracking conditions (resulting from the surface preparation procedures). Laboratory studies included determination of the resin content of the polymer overlay for consistency to approved mixture proportions and petrographic analyses (ASTM C856) to assess bond of the polymer, general characteristics of the cracks, aggregate durability, substrate surface preparation, and quality of the substrate concrete. The polymer resin content was found to vary through the overlay placement, and polymer cracks were found to have likely occurred very early. Analytical stress modeling found that there was significant potential to crack and delaminate the overlay within the first 24 hours primarily due to thermal changes and associated strains. From these findings, WJE provided recommendations for repairs to the applied polymer and improvement to specifications and installation procedures.



WJE's Northbrook Laboratories - Janney Technical Center

WJE's Janney Technical Center (JTC) is named after WJE founder Jack Janney. Composed of both engineers and scientists, the JTC provides advanced testing and forensic capabilities to solve the most technically challenging problems in connection with structures, construction materials, and manufactured components. After half a century and more than 125,000 assignments, JTC engineers and materials scientists have successfully completed investigative, testing, and repair projects involving virtually every type of construction material, structural system, and architectural component. The JTC's 70,000-square-foot state-of-the-art testing and applied research facility (built in 2018) includes wet chemical, petrographic, metallurgy, concrete and mortar, structural testing, and analytical chemistry laboratories as well as environmental exposure chambers.

JTC personnel are recognized leaders in their fields and are active participants in standards development and industry organizations. The multi-disciplinary nature of our team of experienced scientists and engineers enables WJE to offer extensive testing and investigation capabilities to characterize materials, determine root causes of problems, and evaluate performance. The JTC performs tests to determine specification compliance, simulate performance under field conditions, understand failure mechanisms, generate fundamental engineering properties, and assess service life to meet the needs of various types of clients. Our services extend beyond our laboratories, and it is common for JTC personnel to take our expertise to the field and conduct specialized testing on site. From the laboratory to the job site, from engineering to chemistry to physical sciences, JTC professionals develop and test new approaches and create innovative solutions for the built world.

The JTC maintains an International Accreditation Service (IAS) laboratory accreditation. The IAS is a subsidiary of the International Code Council-Evaluation Service (ICC-ES). The ICC is responsible for producing the International Building Code (IBC) and the International Residential Code (IRC). The ICC-ES, a subsidiary of ICC, is a nonprofit, public-benefit corporation that performs technical evaluations of building products, components, methods, and materials. The JTC operates the laboratory and testing using a quality system and manual written following the ISO 17025, "General requirements for the competence of testing and calibration laboratories".

JTC's laboratory is also accredited by the American Association of State Highway and Transportation Officials (AASHTO) for testing concrete, cement, and aggregates (www.aashtoresource.org). The AASHTO accreditation program utilizes onsite assessments and proficiency sample testing to evaluate laboratories. The laboratory meets the requirements of AASHTO Standard Practice R18 "*Standard Practice for Establishing and Implementing a Quality System for Construction Materials Testing Laboratories*". The laboratory also performs concrete and cement proficiency sample testing through the Cement and Concrete Reference Laboratory (CCRL) and performs aggregate proficiency sample testing through the Aggregate Materials Reference Laboratory (AMRL).

Reference Materials

WJE maintains a comprehensive physical and online library, with nearly 35,000 items in the library collections of the Main Library and the unit libraries. The collection consists of periodicals, books, codes, standards, CD-ROMs, DVDs, and WJE company reports. A number of electronic resources available through the Library's intranet page provide immediate access to particular items, such as WJE authored articles and a wide variety of online subscriptions.

ITEM 12: COST ESTIMATE

The following two tables depict 1) the estimated total number of hours for each Item and 2) the hourly and expense costs for each Item. Costs for WJE staff are determined using staff-specific direct costs, combined with company-average overhead, general and administrative costs, and salary benefits computed in accordance with our standard accounting procedures. WJE overhead rates have been audited by the public accounting firm of FGMK, LLC, and are based upon actual expenses of fiscal year 2018 (the most recent available). These documented rates were submitted on Montana's eMACs for this project. A fixed fee of 15% is included in the hourly rate for WJE staff. The selected fixed fee is equal to the fixed fee used during WJE's previous work with MDT.

Effort By Tasks (Hours) - MDT - 313265
Evaluation of Thin Polymer Overlays

Principal Staff Members	Role in Study	% Time over Contract Period	Hours						
			Item 4.1	Item 4.2	Item 4.3	Item 4.4	Item 4.5	Item 4.6	Total Hours
P. Krauss	Primary Investigator	0.4%	2	4	2	6	4	8	26
T. Nelson	Materials Engineer	0.6%	2	6	6	12	4	8	38
M. ElBatanouny	Structural Engineer	0.3%	2	0	0	12	2	4	20
E. Nadelman	Material Scientist	1.1%	2	8	16	8	20	12	66
T. McGovern	Project Engineer	1.7%	4	28	2	56	4	12	106
D. Mauro	Project Petrographer	0.8%	0	0	24	24	0	2	50
K. Hawkins	Project Scientist	0.8%	16	2	2	6	16	8	50
L. Zegler	Laboratory Technician	0.2%	0	0	8	0	4	0	12
M.Haddad	Laboratory Technician	0.2%	0	0	8	0	4	0	12
Project Totals			28	48	68	124	58	54	380

Budget Detail - MDT - 313265

			Item 4.1		Item 4.2		Item 4.3		Item 4.4		Item 4.5		Item 4.6		Total	
(a) Salaries and Wages																
Name	*Role in Study*	*Direct Hourly Rate**	*Hours*	*Cost*	*Hours*	*Cost*	*Hours*	*Cost*	*Hours*	*Cost*	*Hours*	*Cost*	*Hours*	*Cost*	*Hours*	*Cost*
P. Krauss	Primary Investigator															
T. Nelson	Materials Engineer															
M. ElBatanouny	Structural Engineer															
E. Nadelman	Material Scientist															
T. McGovern	Project Engineer															
D. Mauro	Project Petrographer															
K. Hawkins	Project Scientist															
L. Zegler	Laboratory Technician															
M.Haddad	Laboratory Technician															
Subtotal			28	$ 1,249.78	48	$ 2,732.90	68	$ 3,325.48	124	$ 6,872.26	58	$ 2,667.40	54	$ 2,978.82	380	$ 19,826.64
(b) Borrowed Personnel - None Anticipated																
Subtotal				$ -		$ -		$ -		$ -		$ -		$ -		$ -
(c) Consultants - None Anticipated																
Subtotal				$ -		$ -		$ -		$ -		$ -		$ -		$ -
(d) Subcontracts - None Anticipated																
				$ -								$ -		$ -		$ -
Subtotal				$ -		$ -		$ -		$ -		$ -		$ -		$ -
(e) Capital Equipment - None Anticipated																
Subtotal				$ -		$ -		$ -		$ -		$ -		$ -		$ -
(f) Materials and Services																
				$ -								$ -		$ -		$ -
Subtotal				$ -		$ -		$ -		$ -		$ -		$ -		$ -
(g) Communications and Shipping - None Anticipated																
																$ -
Subtotal				$ -		$ -		$ -		$ -		$ -		$ -		$ -
(h) Travel																
Item 4.4 - Travel for Overlay Inspection				$ -		$ 850.00		$ -				$ -		$ -		$ 850.00
Item 4.5 - Travel for Overlay Monitoring x 2										$ 1,700.00						$ 1,700.00
Item 4.6 - Travel for Presentation				$ -		$ -						$ -		$ 850.00		$ 850.00
Subtotal				$ -		$ 850.00		$ -		$ 1,700.00		$ -		$ 850.00		$ 3,400.00
(i) Employee Benefit Plan & Payroll Taxes				$ 843.23		$ 1,843.89		$ 2,243.70		$ 4,636.71		$ 1,799.69		$ 2,009.81		$ 13,377.03
	Rate:	67.47%														
(j) General Overhead & FCCM				$ 1,809.93		$ 3,957.79		$ 4,815.96		$ 9,952.41		$ 3,862.93		$ 4,313.93		$ 28,712.94
	Rate:	144.82%														
(k) Fixed Fee				$ 585.44		$ 1,280.19		$ 1,557.77		$ 3,219.21		$ 1,249.50		$ 1,395.38		$ 9,287.49
	Rate:	15.00%														
PROJECT GRAND TOTALS			**28**	**$ 4,488.38**	**48**	**$ 10,664.76**	**68**	**$ 11,942.91**	**124**	**$ 26,380.59**	**58**	**$ 9,579.53**	**54**	**$ 11,547.94**	**380**	**$ 74,604.11**

ITEM 13: BIBLIOGRAPHY

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