DESIGN CONSIDERATIONS

Roads, Rivers, and Rail: Structural Culvert Rehabilitation

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Failing culverts pose serious hazards to drivers, businesses, and rail traffic. It is incumbent upon design engineers and owner-managers to ensure structures are sound and reliable. DOT, county, municipal, and railway maintenance and engineering divisions play a critical role in conducting routine inspections and repairs. Many repairs must be accomplished with zero to minimal impact on businesses, residents, and traffic – whether military, interstate commerce, county and municipal, or rail. And further complicating some repairs is the need for environmental sensitivity, for instance, when fish passages are involved.

This design guide will feature two separate projects requiring heavy load rating repairs, without closures to above ground road and rail. One of these cases also illustrates precautions implemented to protect a recognized trout stream.

ROAD AND RIVER

Fort Drum, in Jefferson County NY, is home to the Army's 10th Mountain Division. Roadways, culverts, and bridges here must support heavy military equipment—tanks are common sights on Fort Drum, as are Mine-Resistant Ambush Protected vehicles (MRAPs), weighing between 14 and 18 tons. Like many municipalities, Fort Drum is faced with aging infrastructure. And being in Upstate New York, near the Canadian border, Fort Drum experiences some of the highest levels of snow-fall in the world. This directly translates to the corresponding stresses and strains of freeze-thaw cycles and road-salt damage.

Figure 2: Fort Drum, NY

Cities with the Highest Snow Accumulation

1 Aomori City, Japan
2 Sapporo, Japan
3 Toyama, Japan
4 Newfoundland, Canada
5 Syracuse, NY
8 Rochester, NY
9 Buffalo NY

Source: Accuweather.com

Figure 2: Snowfall Rankings

In July 2016, all these factors came together when a 56-foot wide, road-supporting culvert needed rehabilitation—the culvert, laid in a trout stream, consisted of four 142” by 91” corrugated metal pipe (CMP) arches laid parallel to one another with a separation of three feet between each barrel and only three feet of cover over the barrel crowns.

Figure 3: Parallel 142" by 91" CMP Road-Supporting Arches, Fort Drum, NY

“This was a very good example of what I call a ‘buried bridge’,” says Norman (Ed) Kampbell, P.E., President of Rehabilitation Resources Solutions. “With relatively little cover, the CMP barrels really had to do a lot of structural work, so any rehabilitation technique used had to be structural itself which, along with the big diameters of these culverts, ruled out cured in place pipe (CIPP) and most of the other techniques usually used in culvert rehabilitation.” This was especially true given the military loading classification that applied here—the existing buried bridge structure was classified for wheeled traffic of 41 tons for one direction traffic and 27 tons for two direction traffic; for tracked vehicles it was classified as 37 tons and 25 tons, respectively.

Figure 4: Wheeled military load in Fort Drum, NY

Figure 5: Fort Drum 10th Mountain Division

Two other complications applied; the buried bridge is set in the Black River, a recognized trout stream, and the military roadway needed to stay open. So the structure couldn’t simply be torn out and replaced, and river diversions had to be limited and carefully managed.

Design Consideration: Solution Evaluation and Assessment

In any rehabilitation project, critical factors in evaluating solutions include: site accessibility, space availability required for equipment associated with repair solution options, activity level of the road or rail line and associated cost/business impact of closure, and temperature considerations relevant to various repair solutions.

Kampbell has been working with both manufacturers and suppliers of various rehabilitation solutions for many years, developing rehabilitation approaches for challenging situations like this. And in this case, specifying and applying a centrifugally cast, fine aggregate composite concrete was an ideal, structural solution. The application method, and the selected material, are both critical to a successful, structural rehabilitation.

"Here in Fort Drum, CentriPipe, a solution from AP/M Permaform, was a natural fit," he says. "CentriPipe is a centrifugally cast concrete pipe (CCCP) technology that uses a spincaster to apply thin layers of concrete to pipe interiors. The spincaster is great in itself because it casts a very smooth and even pipe. And the material used, PL-8000, was just what this project needed—completely structural, and it adheres well to most surfaces, including CMP."

Design Consideration: Material Properties

When specifying centrifugally cast concrete, the material used should have ASTM C1609 testing, exhibit strain hardening, have quantifiable amount of toughness, and minimal residual stress after initial cracking.

PL-8000 is a fine aggregate composite concrete (FACC), distributed by AP/M Permaform and used with the CentriPipe process. It relies on precisely graded quartz sands, non-metallic fibers, and other complex admixtures to achieve a unique blend of strength and other desirable properties that make it an excellent choice for horizontal pipe and sewer rehabilitation.

"The sophistication of this fine aggregate concrete should not be taken lightly by the design engineering community," says Kampbell. "And it's not just its strength characteristics, which dramatically exceed those of most concrete products. Low permeability, good freeze/thaw characteristics, the right thixotropy and thin shell toughness—AP/M Permaform has really got all these right with PL-8000, and that makes it a great choice for culverts and buried bridges like this one."

In a technical paper prepared for AP/M Permaform, Kampbell examined some of these properties in detail.

• **Thixotropy:** “PL-8000 has the ability to become fluid—i.e. experience a viscosity decrease—when it’s stirred or shaken,” Kampbell explains. “That produces a flowable mixture that can then be pumped long distances. And once it’s cast into position onto the wall of a structure it thickens up quickly, providing sufficient "hang-time" for the wet concrete applied to take its initial set. Getting the thixotropy right is so important—it helps the contractor apply consistent layer thicknesses, it enables good flow into low areas like corrugations and open joints, and it means the initial layers stick well to substrates, providing a dense foundation for the new concrete liner with the host pipe structure.”

• **Permeability:** “Obviously, a very low permeability is a design parameter needed in a sanitary and storm sewer pipe application,” Kampbell points out. “One of the commonly employed qualifications-based tests cited for judging this parameter is ASTM C-1202, the Rapid Chloride Permeability Test, and PL-8000 does very well on this test. And low permeability is also associated with better freeze/thaw performance.”

• **Thin-shell Toughness:** “The use of fibers in PL-8000 is one factor that increases the ductility of the hardened liner’s overall in place performance,” Kampbell says. “This gives the rehabilitation outstanding abrasion, impact, and shatter resistance, lengthening the service life of rehabilitated sewers and pipes.”

Design Consideration: Environmental Requirements
Because the Black River is a trout stream, great care had to be taken with dewatering and diverting the stream. The project also called for a fish ladder to be installed.

To handle diversion efficiently and safely, Arold Construction Company, the regional licensed CentriPipe applicator based in Kingston NY, decided to work on two culverts at a time—that is, water was diverted from two of the arched CMP culverts and these two were completely rehabilitated before the process was repeated with the final two. Diversion was accomplished with cofferdams and bypass pumping, and diverted water was filtered through large bio bags before being reintroduced to the river. Dewatering also required some CMP repair before lining began.

Design Consideration: Liner Thickness

Many considerations must be accounted for when calculating proper design thickness for centrifugally casting fully structural rehabilitated pipe. These factors include weight load, soil compression, water table, freeze-thaw cycles, and host pipe materials, condition, and diameter.

The load response behavior of the liner is found by calculating the arch rise parameter of the proposed liner. The arch rise parameter is a function of the angle of the arc element that is taking the load multiplied by the radius of the arc element squared divided by the proposed thickness of the liner. If the value of this relationship is equal to or above 4.0, the response behavior will be that of axial compression; and when the value is below 4.0, the response behavior will be that of a simple beam in bending.

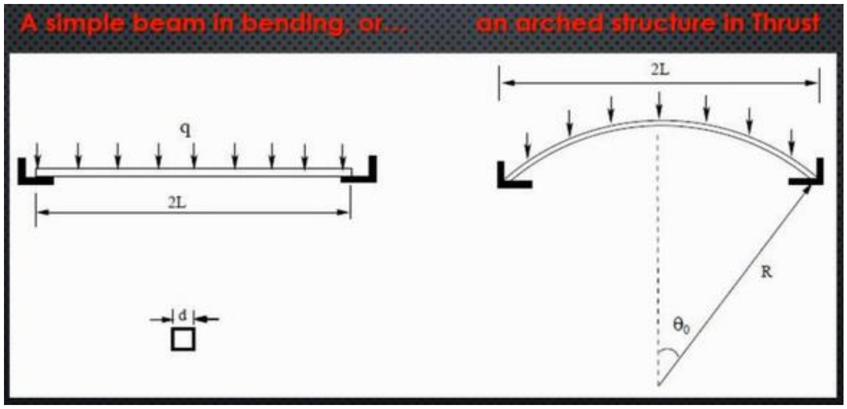

Figure 6: Determining the likely load-response mode of the liner

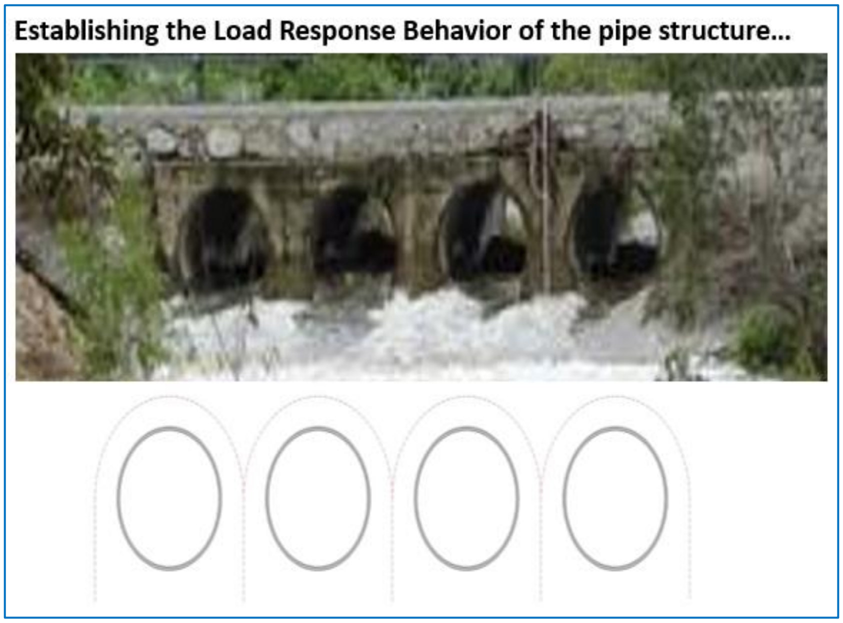

Figure 7: Use of the Arch Rise Parameter: λ= 〖α^2 R〗/h

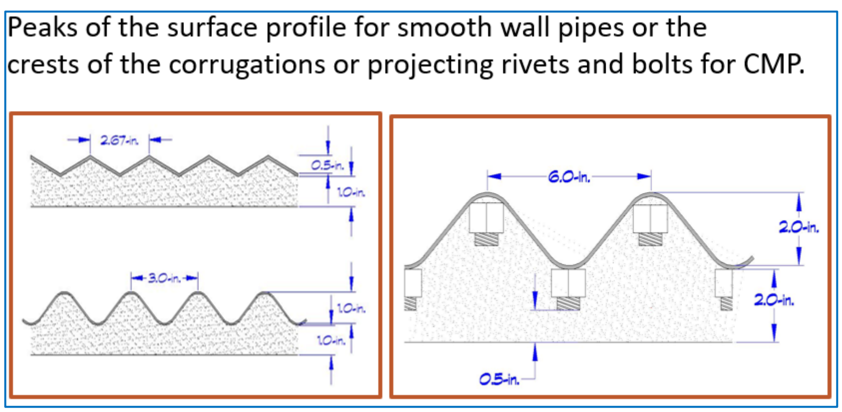

Figure 8: Basis for calculating best design thickness

In the case of Fort Drum, a total thickness of a little more than two inches over the corrugations was calculated to be the best design thickness. As a testament to PL-8000's strength characteristics, this thickness was enough to meet the military loading requirements.

RAIL

Canadian National Railway (CN), is Canada's largest railway and only transcontinental railway, with a rail network spanning three coasts and over 21,000 miles of track throughout Canada as well as the central United States (CN, 2015). This amounts to a substantial amount of track to maintain, along with the culverts that run underneath them. Much of this maintenance and rehabilitation must be performed in remote areas, under active track, with limited accessibility, and varying weather conditions.

CN has installed two projects in Winnipeg, Manitoba, both running directly under high-traffic rail, and each presenting their own challenges, with weather a primary variation.

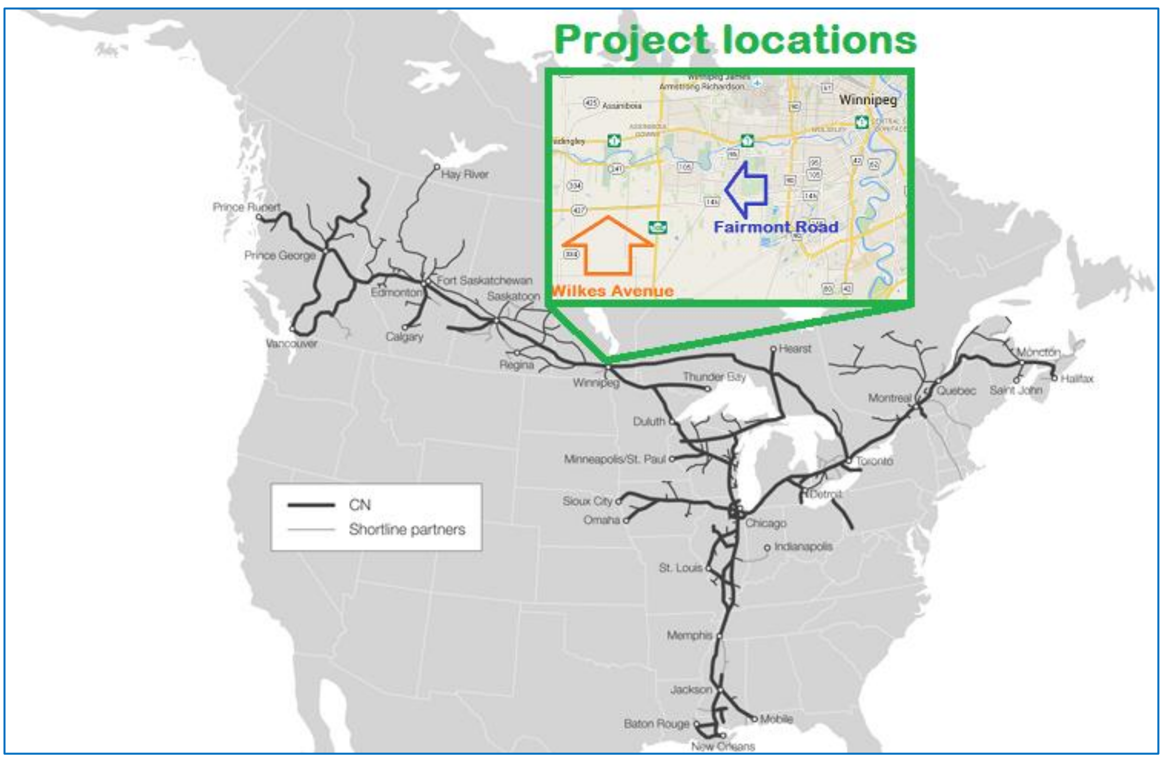

Figure 9: CN Rail Network and Manitoba Project Locations

The summer project, near Wilkes Avenue, was completed first and rehabilitated a considerably deteriorated 42" diameter pipe, 85 feet in length, running underneath the track and several miles from the nearest railroad crossing. After dewatering and repairing the invert, two passes on consecutive days applied a total thickness of one inch to structurally repair the failing culvert.

The winter project, near Fairmont Road, was completed in January 2015, with temperatures of -20ºC (-4ºF). Heaters were installed to thaw ice for dewatering and for successful application and curing of the centrifugally cast concrete within the twin 36" diameter CMP culverts, 62 feet long, running parallel underneath the rail, and trains passing over nearly every hour.

Safety Initiatives

CN is committed to safety, with a multi-faceted safety plan in place. This plan covers all aspects of safety, and includes specific details, technologies, and investment plans for above- and below-ground infrastructure maintenance and improvements.

CN's 2011-2012 WinterREADY Program published in November 2011, states that, "Standing and flowing water are the greatest hazards to track stability. Drainage systems are designed to channel water away from the track structure. Blocked culverts, water undercutting the track or standing pools of water adjacent to any track must be reported immediately to CN's 24-hour emergency line at 1-800-661-3963." (CN 2011-2012 WinterREADY Program, 2011)

In one initiative exemplifying this commitment, CN launched a $35-million project to restore nearly 40 miles of track between Ladysmith and Barron, Wis in August 2012, with a news brief stating "CN will upgrade rail and replace railroad ties, repair culverts and bridges, and restore rail service along the line."

Figure 10: CN Rail 2015 Leadership in Safety Report

CN's safety program is further documented in the company's publication entitled "Leadership in Safety - Looking out for each other 2015: An Overview of CN's Safety". In an excerpt from the document, CN's President and Chief Executive Officer states "CN continues to make significant investments to maintain a safe operation, through our top-notch training and technology and infrastructure improvements. In 2015, CN plans to invest approximately C$2.6 billion on capital programs, of which more than C$1.3 billion is targeted towards track infrastructure to continue operating a safe railway and to improve the quality and fluidity of the network." (CN Leadership in Safety - Looking out for each other, 2015)

In another extension of this on-going commitment, CN worked closely with Martech, Inc., the Western Canada distributor for AP/M Permaform, and MuddRuckers, Inc., based in Winnipeg, Manitoba, to conduct the two pilot culvert repair projects that were implemented without disrupting rail traffic and applied in remote areas.

Design Considerations

Based on site considerations, load requirements, and the necessity of repairing under active rail lines, CN Rail specified the application of a structurally sound centrifugally cast concrete pipe, well suited to situations requiring limited staging, no-dig culvert repairs. In making this assessment, CentriPipe was selected as the application method, with PL-8000, from AP/M Permaform, as the specified fine aggregate composite concrete.

Figure 11: Rehabilitating under active rail lines in remote areas

The same attributes that made CentriPipe with PL-8000 a natural fit for Fort Drum – strength of material; ability to apply in remote areas with limited accessibility and without disrupting overhead traffic/trains; and smooth, seamless, structural, watertight application – all applied to the CN Rail project as well.

Situational Considerations

As in any project, implementation challenges are often unique to the situation. In addition to active rail traffic overhead, the summer project, for instance, addressed dewatering and muddy conditions, while cold weather was the challenge with the winter project. To ensure proper curing in the sub-zero temperatures, MuddRuckers utilized 4’x6’ and 4’x8’ plywood panels and rigid insulation to build walls around the culvert ends, and then covered the walls with insulated tarps to create large hoardings. Once end enclosures were in place, ground thaw heaters and hoses were introduced and left in place for a few days; bringing temperatures up in the existing culvert, and melting ice so that dewatering could take place.

Figure 12: Enclosed, heated work space

CONCLUSION

While the projects featured in this paper support extremely differing classes of traffic, all require ability to support high weight classifications. Additionally, each of these projects posed their own significant site-related challenges and constraints.

The flexibility in adapting to these varying conditions, while providing a tested and sound structural solution, made the CentriPipe with PL-8000 an ideal fit for each of these scenarios.

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