OHIO DEPARTMENT OF TRANSPORTATION'S LRFR PRACTICE FOR EXISTING SHORT SPAN BRIDGES AND CULVERTS

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Abstract

Bridges in Ohio are crucial components that make up one of the largest transportation systems in the United States. Ohio's economy is directly linked to its ability to move goods and services through the 5th largest interstate highway system, 2nd largest inventory of bridges, and 10th largest highway network in the nation. This paper provides an overview of Ohio Department of Transportation's Load & Resistance Factor Rating (LRFR) practice for existing short span bridges and culverts. It also highlights great team efforts of the Department of Transportation, County Engineers and Municipality officials to get Ohio's bridge inspection program in compliance with National Bridge Standards (NBIS.)

Introduction

In 1967, the Silver Bridge & carrying U.S. 35 & spanning between West Virginia and Ohio over the Ohio River collapsed. 46 unfortunate motorists were killed in this disaster. This brought attention to the need for establishment of National Bridge Inspection Standards (NBIS). Ohio was instrumental in establishing its own standards in the wake of this catastrophe. NBIS states that a bridge, defined as a structure with a length of at least 20 feet (6.10 m), needs to be inspected at least once every two years. The Ohio Revised Code (ORC) defines a bridge as a structure going over or under a public road and having a length of at least 10 feet (3.05 m). All bridges in Ohio are required to be inspected annually. The US Department of Transportation (Federal Highway Administration, FHWA) defines a bridge as a structure having a length of more than 20 feet (6.10 m) and requiring every bridge to be inspected every other year.

Based on the ORC definition of a bridge, the inventory of the Ohio Department of Transportation (ODOT) Bridge Management System had 44,609 bridges as of March 2008. Based on the FHWA, NBIS definition of a bridge and 2008 data, Ohio had 29,274 bridges. Ohio's bridge inventory is the second largest inventory in the United States. These structures are owned and maintained by the state, counties, municipalities, townships, and other agencies.

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The US Highway Bridge Network contains over 600,000 structures. The management of these structures is a big challenge for public and private owners. After the 2007 collapse of bridge carrying Interstate 35 over Mississippi River in Minnesota, bridge inspection process and the federal enforcement of the current NBIS were discussed at various hearings at both the US Senate and US House. The resulting initiative named "the 23 metrics" demands full compliance with the NBIS.

Among the over 29,000 NBIS bridges ODOT has inventory, inspection and load rating responsibility of 10,494, Ohio Turnpike Commission has all three responsibilities of 488, Counties have all three responsibilities of 15,768 and the municipality or cities have all three responsibilities of 1,429 highway bridges. Generally an agency that owns the bridge is responsible for having the structure inventoried, inspected and load rated by a professional engineer.

Table 1: Total Number of Bridges in the State of Ohio as of March, 2008

Inspection Responsibility	**NBIS Bridge Count [longer than 20'(6.10 m)]**	**Bridge Count based on ORC [10'(3.05 m) & longer]**
Ohio DOT	10,494	14,061
Ohio Turnpike	488	568
County	15,768	26,173
Municipality	1,429	2,335
Others	1,095	1,472
TOTAL	**29,274**	**44,609**

Challenges Faced and ODOT's Strategic Plan

The FHWA requires all highway bridges be load rated by some method other than "Engineering Judgment" and report to them. As of March 2008, counties were reporting more than 11,200 bridges have not been load rated.

First and far most important step to achieve load rating goals were to bring all key players (County and City Engineers, FHWA, ODOT Engineers) on board. Several presentations and meetings were held and communication channels were established. Efforts were started with the detailed scrutiny of the bridge inventory data and making efforts to have the bridge data accurate, consistent and up to date with the help from the county engineers. Bridges open to highway traffic were identified. Next important step was to locate bridge plans, inspection reports and field information essential to perform load rating.

FHWA met with officials at the Ohio Department of Transportation to stress compliance with the FHWA Bridge Inspection Program.

As of March 2008 when FHWA met with Ohio DOT,

1. Approximately 4% of bridges on Ohio DOT system had not been load rated.
2. About 71% of bridges on Ohio County system had not been load rated.
3. Approximately 65% of bridges on the Municipal system had not been load rated.

Table 2: Approximate Number of NBIS Bridges Load Rated As of March, 2008

Inspection Responsibility	NBIS Bridge Count	NBIS Bridges have been load rated	Percent of NBIS Bridges have been load rated
Ohio DOT	10,494	10,114	96%
County	15,768	4,557	29%
Municipality	1,429	502	35%

Ohio DOT, FHWA and County Engineers Association of Ohio (CEAO) entered into an agreement in January 2009 to get Ohio counties into compliance with NBIS. The agreement included:

1. 20% of the County bridges are to be load rated per year for next 5 years completing the load rating by October 2013.
2. Sour evaluations and plan of actions to be completed by 2010.
3. All deck trusses to be analyzed and gusset plates load rated by the end of 2011
4. Ohio DOT to provide training, & guidance on load rating.

In September, 2011 Ohio DOT Municipality Bridge Inspection Program was kicked off. A three-year agreement was entered between Ohio DOT and 251 Ohio Municipalities. The agreement included:

1. 100% of the Municipality bridges are to be load rated within the next 3 years ending in October 2013.
2. Ohio DOT to provide training & guidance on load rating.

Right after the FHWA/ODOT/CEAO agreement was entered, Ohio DOT started a series of multi-day bridge load rating hand calculation trainings to counties, cities and consultants. We traveled across the state of Ohio, provided hands on trainings to county engineers, city engineers and engineers from consultants.

Since about 75% of the bridges in county and municipal system are simple span structures, the load rating analyses are doable with hand calculations or Excel Spreadsheets. Ohio DOT developed a series of load rating spreadsheets for simple span structures.

We also made funding available through County Engineers Association of Ohio (CEAO) program and Municipality Bridge Inspection Program:

For CEAO program:

Round 1, Fracture Critical Bridges: $5.3 million
Round 2, Fracture Critical & Conti. Multi-Span Bridge: $1.3 million
Round 3, Fracture Critical, Conti. Multi-Span, and Culverts: $1.5 million

For Municipality Bridge Inspection Program: 6 rounds, total of $1.8 million

Progress

After As of September, 2012:

1. More than 99% of Ohio DOT bridges have been load rated.
2. All 88 Counties have met their goals of 20% bridges load rated by October, 2009, 40% by October, 2010 & 60% by October 2011. More than 87% of bridges on the Ohio County system have been load rated.
3. More than 68% of Municipality bridges have been load rated.

Table 3: NBIS Highway Bridges (as of September, 2012)

Inspection Responsibility	**NBIS Bridge Count**	**NBIS Bridges have been load rated**	**Percent of NBIS Bridges have been load rated**
Ohio DOT	10,359	10,296	99.4%
Ohio Turnpike	477	465	97.5%
County	14,815	12,983	87.6%
Municipality	1,188	816	68.7%
Others	92	39	42.4%
TOTAL	**26,931**	**24,599**	91.3%

The load rating programs are on track. Ohio DOT is very confident that the State will be in full compliance with NBIS by October, 2013.

Ohio DOT's Open Source LRFR Spreadsheets for Single Span Bridges

When load rating trainings started back in 2008, the available load rating tools to Ohio county engineers are:

1. Free but outdated DOS program "Bridge Analysis and Rating System" (BARS).
2. Fee based commercial Design/Load Rating programs.
3. Hand Calculations.

The original BARS program was written and published by the Control Data Corporation (CDC) back in 1971. Over the years several states expressed interest in the BARS program, American Association of State Highway and Transportation Officials (AASHTO) was approached to provide the software as a part of AASHTO software products with more states contributing to its enhancement and maintenance. Around 1988, AASHTO acquired software redistribution rights to the BARS software and began making the software available to more states. AASHTO later has discontinued modification and enhancement of the BARS system in October 1995. The current version of BARS program, last modified by AASHTO in 1996, cannot load rate bridges using LRFR method.

There are quite few commercial design/load rating programs available. Among them the new AASHTOware VIRTIS is the most popular one.

The County engineers were reluctant to use the first two options because of the long learning curve plus no future updating of BARS and the expensive up in front cost of the commercial programs. Since majority of county bridges are single span structures, they are very much doable using the old fashion hand calculations. While the hands on trainings of fundamental knowledge in load rating of bridges in accordance with the AASHTO Manual for Bridge Evaluation were going on, meantime ODOT developed a series of spreadsheets that can load rate all the single span bridge types that were taught during the training classes. At the time county engineers finished the training classes, they were not only equipped with good understanding about the background behind the AASHTO Manual for Bridge Evaluation, good knowledge on how to perform the load rating, they were also given the tools they need to do the load rating more efficiently.

There spreadsheets were written in a format similar to hand calculations. There are no black boxed in the files, all the equations can be viewed and verified. Demonstrative diagrams are embedded for clarification purposes. Reference tables and design data sheets are also included for user conveniences. The input boxes are user friendly and the printout format is good for record keeping and future updating. These spreadsheets are open source, free to download and use.

List of Ohio DOT's Open Source LRFR Spreadsheets for Single Span Bridges:

1. Simple Span Steel Beam w/ Composite Concrete Deck
2. Simple Span Steel Beam w/ Non-Composite Concrete Deck
3. Simple Span Reinforced Concrete Slab
4. Simple Span Precast Pre-stressed Concrete Box Beam w/ Composite Concrete Deck
5. Simple Span Precast Pre-stressed Concrete Box Beam w/ Non-Composite Concrete Deck

There are some limitations for these spreadsheets. All the spreadsheets are for single span structures. Load rating factors are calculated based on moment capacity, shear calculations are not included.

Ohio DOT's Open Source LRFR Spreadsheets for Metal Culverts

NBIS defined a bridge as a structure with a length of at least 20 feet (6.10 m). Based on this criterion, State of Ohio has a bridge count of 29,274. The Ohio Revised Code (ORC) defines a bridge as having a span length of at least 10 feet (3.05 m), and that made State of Ohio has a bridge count of 44,609. Among these 44,609 structures, there were 3,588 of them are metal culverts. And majority of these culverts are on county routes.

Table 4 State of Ohio Total Numbers of Metal Culverts*(as of March, 2008)

Maintenance Responsibility	NBIS Metal Culvert Count [longer than 20'(6.10 m)]	Metal Culvert Count based on ORC [10'(3.05 m) & longer]
Ohio DOT	167	1,044
County	341	2,371
Municipality	51	173
TOTAL	**559**	**3,588**

*Total Numbers of Steel Culverts is included in the Total Number of Bridges

Culverts do not receive much attention, primarily because they are generally hidden from view from the travelling public. Occasionally, however, an incident occurs that serves as a reminder that the failure of a culvert can have serious consequences. Although there is considerable information available on the design and construction of new culverts of many materials, there is little information in the literature on how to load rate existing in-service metal culverts. The National Corrugated Steel Pipe Association (NCSPA) published a design data sheet (NCSPA Design Data Sheet No. 19) back in June 1995 titled "Load Rating and Structural Evaluation of In-Service, Corrugated Steel Structures". In the data sheet, the load rating factors were calculated using LFR method. As of today, this design data sheet still served as the main guideline for the load rating of in-service corrugated metal pipes.

Ohio DOT developed two LRFR spreadsheets to load rate in-service metal culverts based on AASHTO LRFD Bridge Design Specifications and the NCSPA Design Data Sheet No. 19. One is for Corrugated Metal Pipes (Figure 1) and the other one is for Structural Plate Box Culverts (Figure 2). Even though these two types of metal culverts are included in the same section of AASHTO LRFD Bridge Design Specifications, they behave differently. The Corrugated Metal Pipes are ring compression structures while Structural Plate Box Culverts are bending moment resistant structures. Both spreadsheets can load rate steel culverts and aluminum culverts.

Figure 1 Corrugated Metal Pipe


Figure 2 Structural Plate Box Culvert

After the metal culvert spreadsheets have been utilized by Ohio county engineers, questions have been raised. Some of their corrugated metal culverts with shallow covers have been rated low and needed posting by using the corrugated metal culverts (CMP) spreadsheet. Based on the field inspections, majority of these culverts are in very good shape and have been in service without any sign of overstress or structural problems for decades. When using the spreadsheet for corrugated metal culverts with covers do not meet AASHTO minimum cover requirements, the load rating factors dropped dramatically. Ohio Department of Transportation conducted a study to address this concern and proposed another CMP spreadsheet to load rate corrugated metal pipes with shallow covers.

Based on the AASHTO LRFD Bridge Design Specifications and the NCSPA Design Data Sheet No. 19, there are two sets of rating factors are to be calculated for Corrugated Metal Pipes (CMP). One set is the rating factors based on wall strength and the other set of rating factors are rating factors based on AASHTO minimum cover requirements. The controlling load rating factors are the minimums of these two sets of numbers.

Load rating factors calculations from NCSPA Design Data Sheet No. 19:

1. Operating Load Rating Factor based on AASHTO minimum cover requirements:

$$RF_{O-C} = \frac{H^2}{C(h)^2} \qquad \text{(Equation 1)}$$

Where: H = Lowest actual cover over the culvert in a traffic area based on field measurement.
h = AASHTO minimum cover
S = Span length
C = Minimum cover factor of safety adjustment

$$C = 2.36\frac{H}{S} + 0.528 \leq 1.0$$

2. Inventory Load Rating Factor based on AASHTO minimum cover requirements:

$$RF_{I-C} = \frac{H^2}{h^2} \qquad \text{(Equation 2)}$$

The load factors calculated from the above equations are only a function of backfill depth, AASHTO minimum cover and span length. Culverts material properties, section properties, magnitude of applied loads or possible severe damage in culverts do not affect this set of rating factors at all. Furthermore, the AASHTO minimum cover itself is also not related to structural properties of culvert. Thus, in the new spreadsheet a new method is proposed to calculate RF_C. The method provides a relationship between the cover depth, span length, and material properties.

Generally, the external live load effect on the culvert increases as the cover H decreases. If H is very shallow, the surface live load can cause excessive deflection, buckling, or severe damage of the culvert. Therefore, determination of minimum depth of cover is very important. According to AASHTO LRFD Table 12.6.6.3-1, the minimum cover level for corrugated metal pipe shall be span length/8 but not less than 12 inches (305 mm). The surface live load is transferred to the culvert through pavement and soil. The effect of live load on the culvert is based on the truncated pyramid model as shown in Figure 3. The procedures for the calculation of live load pressure on the culvert are based on the assumption that soil is elastic. In Figure 3, the surface load (p) represents a tire contact area of width W_T and length L_T. ϕ_E is the factor for distribution of live load with depth of fill based on backfill type (per AASHTO LRFD 3.6.1.2.6), and is equal 1.15.

The truncated pressure on the culvert due to the tire contact pressure is

$$q = \frac{p}{(W_T + \phi_E H)(L_T + \phi_E H)} \qquad \text{(Equation 3)}$$

Where W_T is 20 inches (508 mm) and L_T is 10 inches (254 mm) for the AASHTO LRFD HL-93 design truck. If p is known and the critical pressure which causes local buckling or excessive deflection of the culvert can be evaluated, the minimum cover depth can be found by solving Equation 3. Thus, the minimum cover can be defined as the cover depth of a safe and stable culvert system subjected to a large number of passes of external live load.

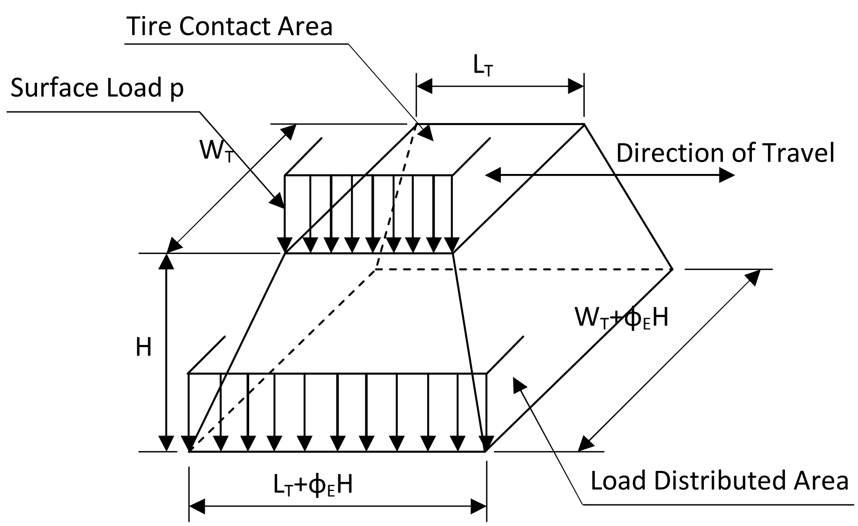

Figure 3 Truncated pyramid showing surface load distribution

The critical location in a culvert where the maximum deflection or maximum moment develops due to external loads is generally near the crown. In order to find the critical pressure near the crown, some researchers (Timoshenko and Gere, 1961; Meyerhof, 1982; and Moore, 1989) investigated when and where the buckling happens. If a parabolic arch structure is subjected to a uniform load (q) distributed along its span as shown in Figure 3, there will be axial compression but no bending in the arch. If the intensity of the uniform load is increased, the arch starts to buckle at a critical load (q_{cr}), which can be calculated from Equation 4 (Timoshenko and Gere, 1961).

$$q_{cr} = \gamma_4 \frac{EI}{S^3} \qquad \text{(Equation 4)}$$

Where E is the elastic modulus, I is moment of inertia, and γ_4 is the critical parameter depending on the culvert rise and span ratio R/S, where R is the rise the arch and S is the span length.

Once the culvert design is completed, q_{cr} in Equation 4 can be calculated because γ_4 , S , E and I are known. The maximum pressure (q_{max}) on the crown due to dead and live load can be determined for the actual cover depth. The calculated maximum pressure q_{max} will be compared to q_{cr} to determine whether the cover depth is adequate for the structure to be considered stable.

$$q_{\max} = \gamma_{EV} H\delta + \gamma_{LL}\rho_{(L+IM)} \qquad \text{(Equation 5)}$$

Where, $\rho_{(L+IM)}$ = pressure at crown due to live load plus dynamic load allowance
δ = Soil density
γ_{EV} = Vertical Earth Pressure for CMP
γ_{LL} = AASHTO LRFD Load factor for live loads

The values of q_{cr} are obtained from book "Guide to Stability Design Criteria for Metal Structures, 5th Edition", Table 17.1, authored by Theodore V. Galambos.

Table 5 Critical Load Parameter γ_4 for circle arches

Rise to Span Ratio R/S	Three-Hinged Arch qS^3/EI	Two-Hinged Arch qS^3/EI	Fixed Arch qS^3/EI
0.10	22.2	28.4	58.9
0.20	33.5	39.3	90.4
0.30	34.9	40.9	93.4
0.40	30.2	32.8	80.7
$\geq$ 0.50	24.0	24.0	64.0

If the calculated q_{max} is larger than q_{cr}, the actual cover depth is not sufficient to support the design load. Then, either the cover needs to be increased to support the design load, or the design live load needs to be reduced until q is smaller than q_{cr}. In the ODOT's shallow cover CMP load rating spreadsheet, when the maximum pressure q_{max} is less than the critical load q_{cr}, the structure is considered to be stable and the cover depth is considered to be adequate. To simplify this approach and to be conservative, instead of further the calculations to find out the actual minimum cover required with the structure, the actual depth of cover will be used in the load rating factor calculations in lieu of AASHTO minimum cover. With this conservative approach, the operating load rating factor will be 1.0 when the $q_{max} \leq q_{cr}$ is satisfied. Full load testing will be performed in the near future to verify this load rating approach.

1. Operating Load Rating Factor based on "Modified AASHTO minimum cover"

$$RF_{O-C} = \frac{H^2}{C(h_{\text{mod}})^2} \quad \text{(Equation 5)}$$

2. Inventory Load Rating Factor based on "Modified AASHTO minimum cover"

$$RF_{i-c} = \frac{H^2}{h_{\text{mod}}^{\ 2}} \quad \text{(Equation 6)}$$

Where, $h_{mod} = H$ if $q_{max} \leq q_{cr}$.

Summary

Partnerships in the implementation of bridge load rating practices are very important. In our case, state agency teamed up with FHWA, CEAO and city engineers to bring mutual understanding of the challenges and forming a roadmap. We targeted the issue together, through mutual discussions, & communication, delivered an effective strategic plan and used all available resources to archive the desired goals. Ohio’s economic future depends on maintaining and improving its aging transportation infrastructure. Great team efforts will not only get us to be in compliance with NBIS, but more importantly will make Ohio’s bridges safe and reliable to drive on.

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