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**CENTER FOR STRUCTURAL DURABILITY  
AT MICHIGAN TECH**

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**Assessment of ODOT Culvert Load Rating  
Spreadsheets for use in Michigan  
FINAL REPORT**

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## **DISCLAIMER**

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## ***Background***

The project “Assessment of ODOT Culvert Load Rating Spreadsheets for use in Michigan” was a short time-frame project funded by the Michigan Department of Transportation (MDOT) through the Center for Structural Durability (CSD) at Michigan Tech. The objective of the project was to assess existing spreadsheets developed by the Ohio Department of Transportation (ODOT) for performing load rating calculations on corrugated metal pipe culverts using both Load Factor Rating (LFR) and Load and Resistance Factor Rating (LRFR) methods. The spreadsheets were assessed for their adherence to reference guides and then modified as required to function with Michigan legal and overload truck descriptions. The project did not investigate the suitability of the technical process used in the ODOT spreadsheets to produce reasonable load rating calculations. Significant structural and programming changes to the spreadsheets were considered outside the project scope. Details on the work performed for this project are described in the following sections of the report.

### ***Task 1 – Literature Review***

The technical basis of the ODOT spreadsheets references “Load Rating and Structural Evaluation of In-Service, Corrugated Steel Structures” (NCSPA 1995) and the AASHTO Standard (AASHTO 2002) and LRFD (AASHTO 2010) specifications. The spreadsheets were developed around these references and have been tested through finite element and field testing as described in “Verification of ODOT’s Load Rating Analysis Programs for Metal Pipe and Arch Culverts” (Sezen, H. et. al. 2009).

ODOT and The Ohio State University conducted a detailed assessment on the culvert spreadsheets through finite element model comparisons and field testing (Sezen, H. et.al. 2009). 39 in-service culverts were assessed as part of the project. Both static and dynamic loads were applied to the culverts, and deflection and strain gage measurements were taken at several locations within each culvert. Loading was accomplished with a heavily loaded truck representative of an HS20-44 at 10 static load points and 6 dynamic load speeds ranging from 5 to 40 mph or the maximum legal speed. Each test was conducted twice with the load applied once from each direction. An instrument frame was setup inside the culverts to measure the displacement at 5 locations along the upper circumference of the culvert and 14 strain gages were installed (Sezen, H. et. al. 2009).

Numerical modeling of the culverts was performed using CANDE, a two-dimensional finite element program typically used for corrugated culvert analysis. A Level 3 analysis was performed in the study which allowed for user defined geometrical shapes, soil material zones, and structural properties (Sezen, H. et. al. 2009).

Results of the field testing showed that a significant decrease in deflection and strain measurements was found when the culverts contained more than 6.5 feet of cover. Maximum deflections caused by dynamic loading were found to be 10 to 30% less than the corresponding static loading. Soil type is generally not considered when conducting a load rating on a culvert, the effect of soil type on thrust forces was found to be negligible (Sezen, H. et. al. 2009). Specifically with regards to the spreadsheets, the researchers found:

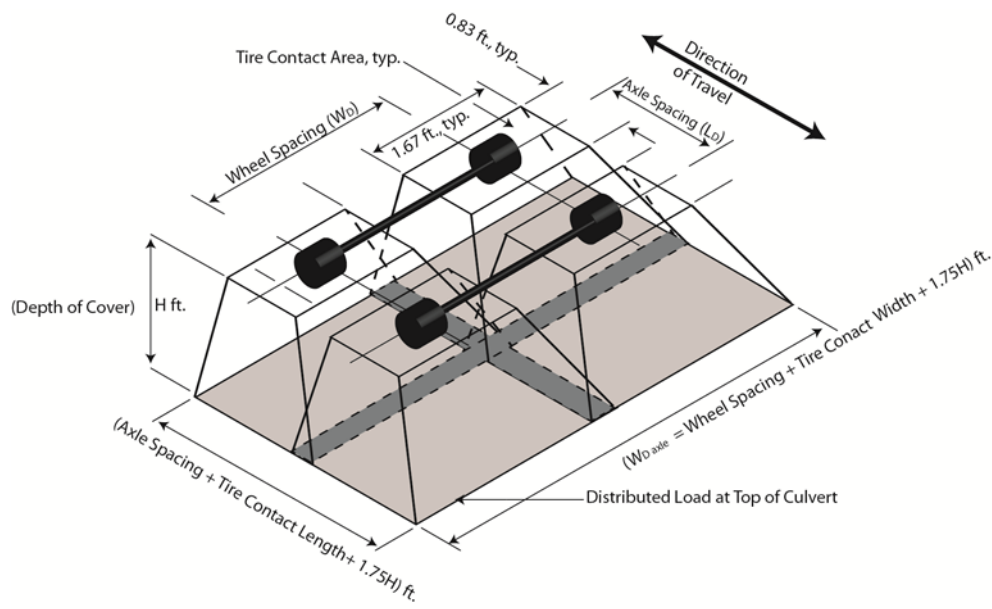
For the worst possible culvert condition (i.e., the reduction factors have the minimum possible values for each culvert), proposed rating factors (RF) are smaller than ODOT's RFs and are also less than 1.0 for most culverts. This suggests that the research-proposed load rating procedure is less conservative and more effective in evaluation of the existing condition of culverts.

It was suggested that the ODOT spreadsheets be improved by incorporating condition factors, based on inspection reports, to reduce the seam and buckling strengths and wall area when determining the thrust capacity of the culvert. The ODOT spreadsheets do not contain version numbers or build dates and information was not available to identify if recommendations for change to the spreadsheets were incorporated.

### ***Task 2 – Spreadsheet Assessment and Adherence to Reference Guides***

The ODOT culvert load rating spreadsheets were compared to the AASHTO Standard and LRFD Specifications and the Michigan Bridge Analysis Guide (2009). The basic principles of load rating were met along with the load factors. The general procedure used by the ODOT spreadsheet is that described by the NSCPA (1995) report.

The ODOT spreadsheets consider loading from one vehicle on the culvert and limit the width of the loaded area (transverse to the direction of travel) to the length of the culvert. Individual wheel loads are distributed from the tire contact area downward in a pyramid shape with side slopes of 1.75 times the depth of cover for the LFR method and 1.15 times the cover for the LRFR method. When these pyramids overlap the distributed area of the combined loading becomes the total area enveloped by the parameter of the pyramids as shown in Figure 1.



**Figure 1 Distributed load (LFR) determined from axle weight**

The ODOT spreadsheets use this area, however, the calculations used to determine the distributed load were based on one heavy axle and up to two adjacent axles placed within 4-feet of the heavy axle. The algorithm used to determine the distributed load from this description (up to three axle weights and spacing) was appropriate for the load configurations of ODOT trucks. However, for Michigan trucks this process would not have been appropriate and an alternative method had to be used.

The ODOT spreadsheets also do not account for the case where trucks are present in adjacent lanes. In this case, the distributed area could be further restricted depending upon the depth of cover. Modifications, explained in the next section of this report, were performed to determine the distributed load attributed to the controlling Michigan vehicle for the given depth of cover and allow for multiple loaded lanes in the Michigan modified spreadsheet. The ODOT spreadsheets were found to meet the reference guidelines. The general procedure follows the NSCPA (1995) guidelines and AASHTO Standard and LRFD load and condition factors are utilized.

As per the project proposal, MDOT was contacted and a teleconference meeting was conducted to review the outcome of the first two project tasks prior to proceeding with Tasks 3 and 4 to modify the spreadsheets for Michigan vehicles and perform trial runs of the spreadsheet for quality control and quality assurance. Discussion with MDOT led to the decision to go

forward with the project. A process was discussed for determining the controlling Michigan vehicle for each truck type at various depths which would greatly improve the functionality of the spreadsheet. This was determined to be outside the original scope of work and as such these calculations were conducted by MDOT and incorporated into the Michigan modified spreadsheets.

### ***Task 3 – Michigan Modifications***

The original spreadsheet developed by ODOT contained the analysis for Federal Trucks (HS20-44 or HL-93 Truck/Tandem) and the four Ohio Legal Trucks. This spreadsheet analyzed the heavy axle load and up to two adjacent axles provided they were located within 4-feet of the heavy axle. These axle loads were then used to calculate the average distributed load applied to the top of the culvert. The height of cover above the culvert was used to determine whether loading was based on the distributed area of an individual wheel, or one, two, or three axles. This approach worked well for the four Ohio Legal Trucks due to the legal axle configurations. However, the complexity of the Michigan trucks allowed for cases in which this approach would not have adequately represented the loading. To solve this problem, MDOT developed a spreadsheet to calculate the distributed load caused by the controlling truck for each vehicle classification (one, two, or three unit) at 0.25 foot increments from 0.25 to 2.0-feet of cover (LRFR), 0.5 foot increments from 2.0 to 4.0-feet, and 1.0 foot increments from 4.0 to 20.0 feet. Data was produced for the LRFR method for depths less than 2.0 feet because of the spreadsheet for modified minimum cover is only available for LRFR. The distributed loading was summarized in the form of a line load that represented the weight of the vehicle distributed along the length of the vehicle but not the width. The distribution of the line load over the width was handled by the Michigan modifications to the load rating spreadsheets due to the need to consider the individual properties of each culvert. A sample of the summary table for controlling trucks with the LFR method is shown in Table 1.



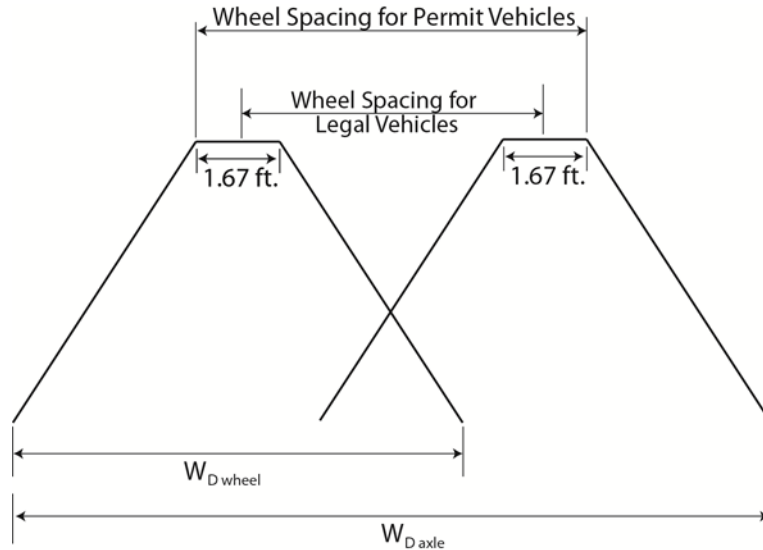
**Table 1 Sample of MDOT controlling vehicle summary table**

<b>FEDERAL - UNFACTORED!!!</b>							
Depth (ft)	1	1.5	2	2.5	3	3.5	4
HS-20 (k/ft)	12.39	9.25	7.38	6.14	5.26	4.60	4.09
Controlling Axles	1-Axle	1-Axle	1-Axle	1-Axle	1-Axle	1-Axle	1-Axle
<b>MICHIGAN LEGAL - FACTORED</b>							
Depth (ft)	1	1.5	2	2.5	3	3.5	4
1 Unit (k/ft)	9.06	6.77	5.40	4.78	4.34	3.98	3.69
Controlling Truck	Truck 1	Truck 1	Truck 1	Truck 2	Truck 2	Truck 2	Truck 4
2 Unit (k/ft)	9.06	6.77	5.40	4.78	4.42	4.30	4.18
Controlling Truck	Truck 6	Truck 6	Truck 6	Truck 6	Truck 17	Truck 17	Truck 17
3 Unit (k/ft)	9.06	6.77	5.40	4.78	4.34	3.98	3.69
Controlling Truck	Truck 19	Truck 19	Truck 19	Truck 19	Truck 19	Truck 19	Truck 22
<b>MICHIGAN OVERLOAD Class A - FACTORED</b>							
Depth (ft)	1	1.5	2	2.5	3	3.5	4
OverLoad (k/ft)	30.19	22.55	18.00	14.98	12.82	11.21	9.96
Controlling Truck	Truck 1	Truck 1	Truck 1	Truck 1	Truck 1	Truck 1	Truck 1
<b>MICHIGAN OVERLOAD Class B - FACTORED</b>							
Depth (ft)	1	1.5	2	2.5	3	3.5	4
OverLoad (k/ft)	30.19	22.55	18.00	14.98	12.82	11.21	9.96
Controlling Truck	Truck 1	Truck 1	Truck 1	Truck 1	Truck 1	Truck 1	Truck 1
<b>MICHIGAN OVERLOAD Class C - FACTORED</b>							
Depth (ft)	1	1.5	2	2.5	3	3.5	4
OverLoad (k/ft)	30.19	22.55	18.00	14.98	12.82	11.21	9.96
Controlling Truck	Truck 1	Truck 1	Truck 1	Truck 1	Truck 1	Truck 1	Truck 1
Note: All loads are in k/ft along the length of the truck							

The tire contact area is specified by AASHTO for the HS20-44 and HL-93 trucks as being 10 inches in the direction of travel by 20 inches wide. The same tire contact area was used for the Michigan Legal Vehicles. Michigan Overload Vehicles could have many more tires associated with each axle, therefore, the tire contact area was assumed to be contained within the 8-foot wheel spacing.

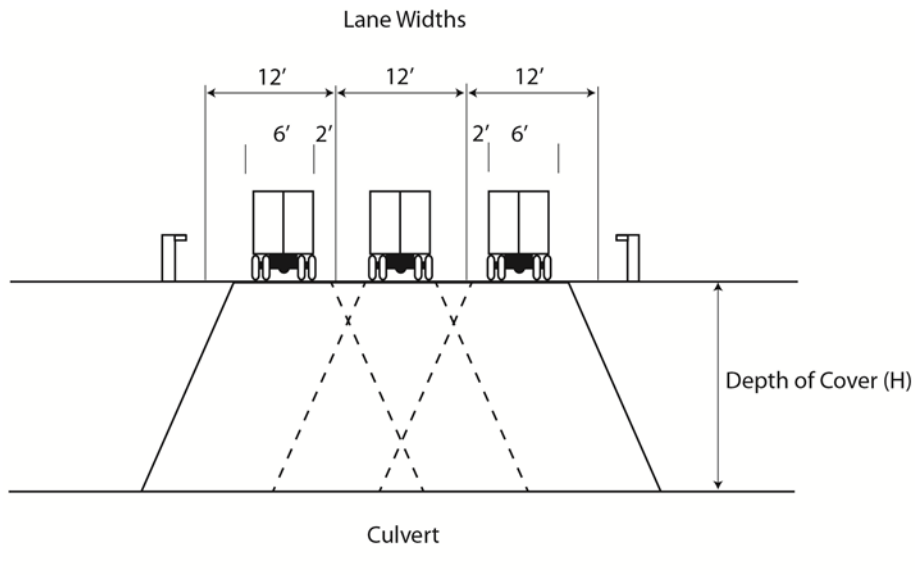
The distributed load at the depth of the culvert was computed by using an Excel lookup function to determine the controlling truck line load from the summary table of controlling Federal and Michigan loads. This line load was distributed across the appropriate loading width. The width for each truck was determined by taking the wheel spacing on each axle (6-feet plus the tire contact area for legal vehicles and 8-feet for overload vehicles) and adding the soil

distribution factor multiplied by the depth of cover. Figure 2 shows how the distributed width of each wheel was used to determine the width for an axle.



**Figure 2 Distributed width from wheel spacing**

The axle width was then limited by the width per lane provided by the structure which was found by taking the minimum of the structure length divided by the number of lanes and the distribution caused by a vehicle placed in each traffic lane with the outer vehicles located the minimum 2-feet from the inner lanes. Figure 3 shows a diagram of loading from multiple lanes and how it was used to determine the maximum allowable distributed width of vehicular loading.



**Figure 3 Distributed width limited by multiple loaded lanes**

Michigan has modified live load factors for the LRFR method. Each vehicle has its own live load factor which changes with the average daily truck traffic (ADTT) of the roadway. Live load factors are determined at ADTT of 100, 1000, and 5000. The live load factors for each vehicle at an ADTT of 5000 were incorporated into the controlling vehicle spreadsheet to determine the controlling truck at each depth. For consistency, the summary table (Table 1) for the LFR controlling trucks also included factored values for the legal and overload vehicles. The Federal vehicles were left unfactored due to the need to have different live load factors for the inventory and operating ratings.

Formatting modifications were made to the Michigan modified spreadsheets to achieve consistency with other MDOT spreadsheets. Drawings showing loading details were redone and labels were updated to agree with the values contained within the spreadsheet. Several new figures were added to show how the axle loads were used to determine the distributed load applied to the top of the culvert (Figures 1-3).

The NCSPA Design Data Sheet No. 19 had been scanned and included within the ODOT spreadsheet. The scanned copy was out of focus and hard to read. This worksheet was redone for the MDOT Modified version of the spreadsheets.

#### ***Task 4 – Trial Runs***

The modified spreadsheets (Appendix A) were run through several validation processes during QA/QC. Two researchers reviewed the spreadsheets; one focused on an analysis of the programing within the spreadsheet and checked cell references and functions. The other researcher checked the technical content and verified the spreadsheet calculations with hand calculations and then performed analysis on a variety of in-service culverts.

Results of the QA/QC are included in Appendix B. No errors were found in the programing; however, some suggestions were noted for improvement on the programing under a future project. Analysis of the technical content also found no errors but proved to be a good source for comments on updates that could be made to the program in the future under another project.

### ***Task 5 – Final Report and Deliverables***

Deliverables for this project consist of the following three Excel 2010 files along with this report:

- Michigan modified load factor rating method for corrugated metal pipe, Version 1.0
  - MDOT\_CMP\_LFR.xlsx
- Michigan modified load and resistance rating method for corrugated metal pipe, Version 1.0
  - MDOT\_CMP\_LRFR.xlsx
- Michigan modified load and resistance rating method for corrugated metal pipe with a modification for minimum cover requirements, Version 1.0
  - MDOT\_CMP\_LRFR\_modified\_minimum\_cover.xlsx

### ***Future Work***

- As with any program, future updates will be required to keep the spreadsheet up to date on changes in the specifications and to make improvements on the usability and to meet the needs of those using the spreadsheets. Attempts were made to increase the efficiency of the programing and improve the layout within the spreadsheets. However, more work could be done to further improve efficiency, usability, and reporting format although a complete rewrite was out of the scope of this project.
- These Excel spreadsheets meet the immediate needs for the load rating of culverts through both the LFR and LRFR methods. However, the ability to store culvert data in a database that could be accessed through a standalone culvert program or web application would allow for updates to the programing without the need to re-input large amounts of data into individual spreadsheets. A standalone program would also eliminate the likelihood of users accidently making changes to the program, however, it could be written to include user defined values where engineers may desire to allow their own calculations to be used instead of those within the program. Database storage would also allow for better organization of the culvert files for agencies with large numbers of culverts in their inventory.

## ***References***

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