LOAD RATING OF CONCRETE CULVERTS IN TENNESSEE UNDER NEW EMERGENCY VEHICLE LOADS

FINAL REPORT

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Tennessee Department of Transportation
Suite 900, James K. Polk Building
Nashville, Tennessee 37243-0334

By

X. Sharon Huo, Ph.D., P.E.
Professor of Civil Engineering

Noah Stansfield, E.I.
Graduate Research Assistant

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Tennessee Technological University
P.O. Box 5032
Cookeville, Tennessee 38505

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16. Abstract

The Fixing America's Surface Transportation Act changed the existing weight limit restrictions for highway vehicles. The new restrictions allow for emergency vehicles to traverse highways without acquiring permits. The FHWA has now required state transportation departments to load rate all structures within a mile of the interstate system for two new loading configurations. The configurations are named EV2 and EV3 and are evaluated as legal loads per the LRFR method. The FHWA also developed a new load posting procedure based on the rating results of the new emergency vehicle configurations. The main objective of this research project was to compile a database of culvert ratings for new emergency vehicle loading to determine the effects of new emergency vehicle loads on culverts in Tennessee. TDOT provided all pertinent culvert information. Structural computer models for all of the culverts were built using the software program AASHTOWare. The culverts were load rated for different loading configurations. Upon completion of load rating the culverts affected by new emergency vehicles, it was found that all EV3 ratings and some EV2 ratings were less than HL-93 operating ratings. Some culverts' ratings are sufficient for HL-93 loading, but are insufficient for the new emergency vehicle loading. EV2 and EV3 are heavier and shorter than HL-93 loading, and they are not compliant with federal bridge formula B weight restrictions. The new emergency vehicle load posting procedure and the relatively smaller EV2 and EV3 load ratings significantly impact recommended load postings for culverts in Tennessee. The correlations found between HL-93 and emergency vehicle load ratings are strong and can be used to reasonably estimate EV2 and EV3 ratings when HL-93 ratings are available.

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EXECUTIVE SUMMARY

The Fixing America's Surface Transportation Act (FAST act) changed the existing weight limit restrictions for highway vehicles. The new restrictions now allow for emergency vehicles to traverse highways without requiring certain permits or route restrictions. The hope being this change will allow for emergency vehicles to more easily maneuver to locations in emergency situations. In response to the new restrictions, the Federal Highway Administration (FHWA) released a memo that requires state transportation departments to load rate all bridges and structures within a mile of the interstate system for two new loading configurations. The configurations are named EV2 and EV3 and must be evaluated as legal loads per the Load and Resistance Factor Rating (LRFR) method. The memo included a mandate to state departments of transportation requiring the new load rating be completed no later than December 2019. In addition, the FHWA memo defined a new load posting procedure based on the rating results of the new emergency vehicle configurations.

Within Tennessee there are 827 reinforced concrete culverts on a highway or within a mile of the highway and must be load rated per the FHWA memo. The main objectives of this project were to compile a database of ratings for culverts affected by new emergency vehicle loading, conduct a parametric study of the rating results of the emergency vehicle loading with respect to HL-93 ratings, and investigate possible changes that can be made to culvert models to increase accuracy. This report summarizes an investigation into the effects of new emergency vehicle loading configurations on load ratings of concrete culverts in Tennessee.

The Tennessee Department of Transportation funded the project and provided all pertinent information. It was determined that computer models should be constructed for each culvert affected by the FAST act. Based on the information provided by TDOT including original design drawings and bridge inspection reports, structural models of the culverts were built using the software program AASHTOWare. This program was chosen to model the culverts due to its easy to use interface, its comprehensive library of vehicle configurations and structural input se, and its use by TDOT and other state departments of transportation to rate bridge structures.

In order to gain a thorough understanding of the effects of the new emergency vehicle loads, the culverts were load rated with EV2 and EV3 at legal load rating as well as LRFD HL-93 loads at the inventory and operating rating. After all the ratings were compiled, comparisons were made between the results for HL-93 loading and the results from the new emergency vehicle loading. It was found that EV3 ratings were less than HL-93 truck and HL-93 tandem operating ratings for every culvert while EV2 ratings were less than HL-93 operating rating for some culverts. Therefore, there were culverts whose ratings were sufficient for HL-93 truck and tandem loading, but are now insufficient for EV3 emergency vehicle loading. The reason for the decrease in ratings is due to a few factors. First, EV3 truck is heavier in weight and shorter in length compared to HL-93 loading. Second, the EV2 and EV3 vehicles have higher weight to length ratios compared to HL-93 loading which results in higher load effects being developed in a structure. Additionally, per the FHWA memo, a live load factor of 2.0 is required for EV2 and EV3 loads for culvert ratings since they are buried structures, while a live load factor of 1.35 is required for rating culverts for HL-93 loading. Finally, the decreased ratings for the new emergency vehicles result from a lack of compliance of EV2 and EV3 loading to federal bridge formula B weight restrictions.

Based on the rating results determined from this project, recommended posting loads were also determined. Both the new emergency vehicle posting procedure and the LRFR posting procedure were followed. Since the EV3 ratings typically controlled compared to the HL-93 ratings, the recommended posting loads for the existing culverts were greatly impacted. It was observed that, for most culverts, the new emergency vehicle loading configurations will result in more restrictive recommended posting loads.

A parametric study of EV2 and EV3 rating results was conducted to determine the impact that new loading configurations have on culverts compared to existing HL-93 loading evaluated at the operating level. Alternative analysis of culverts with unique structural designs were performed to better reflect the performance of those culverts. It was found that ratings as well as recommended posting loads are improved if those culverts are not modeled as a frame but rather a continuous slab on top of columns. Another way that ratings were improved was by considering culverts with 0’ fill per bridge inspection reports as non-buried structures. This allows the engineer to utilize a live load factor of 1.3, legal load rating factor, instead of 2.0 per LRFR requirements and the FHWA memo.

The following conclusions are made based on the findings of this project. The new emergency vehicle load posting procedure and the relatively low EV3 load ratings will significantly impact recommended load postings for culverts in Tennessee. The correlations found between HL-93 and emergency vehicle loading are strong and can be used to reasonably estimate EV2 and EV3 ratings when HL-93 ratings are available. Engineers should give a careful consideration of culvert design and potential performance when conducting culvert modeling and analyses in order to obtain accurate load ratings.

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CHAPTER 1 INTRODUCTION

The following report outlines the objectives, procedures, results, and findings of an analytical study performed for the Tennessee Department of Transportation's (TDOT) structures division. TDOT requested assistance in re-evaluating the load rating of concrete culverts throughout the state affected by new emergency vehicle loading per a recent memo from the Federal Highway Administration (FHWA). Chapter 2 presents a literature review of culvert rating, current rating procedures, emergency vehicles, and the soil arching phenomenon. The next chapter describes the development of computer models to estimate the load ratings of culverts based on their respective in-situ conditions. The results from the computer models are shown in Chapter 4 and an analytical study that consists of a parametric study of rating results is shown in Chapter 5. Chapter 6 concludes with findings from the study along with recommendations for further analysis and determination of load ratings for reinforced concrete culverts in Tennessee.

1.1 Load Rating

Load rating is defined by the American Association of State Highway and Transportation Officials (AASHTO) Manual for Bride Evaluation (MBE) as, a procedure to evaluate the adequacy of various structural components to carry predetermined live loads. It is "a basis for determining the safe load capacity of a bridge," (AASHTO 2017). In general, it is a process utilized by engineers to determine the live load carrying capacity of a bridge using as-built bridge plans and supplemented by information gathered from the latest field inspection to ensure the overall safety of bridge structures. Load ratings are expressed as a rating factor or as a tonnage for a particular vehicle. The load rating process is governed by the Load and Resistance Factor Rating (LRFR) method. This method was, "developed to provide uniform reliability in bridge load ratings, load postings, and permit decisions," (AASHTO 2017). This methodology consists of three procedures: design load rating, legal load rating, and permit load rating which is discussed further as a part of the literature review.

The end goal of load rating is to determine if any restrictions or modifications to a bridge structure are required. If a bridge structure does not meet all evaluation level requirements of the LRFR method, the bridge may need to be posted or even strengthened. Bridge posting must occur when, according to the MBE, "the maximum legal load under state law exceeds the safe load capacity of a bridge," (AASHTO 2017). The rating factors determined from the LRFR method are used to calculate the required posting load for a structure if necessary. By restricting the maximum truck weight allowed to traverse a bridge with a posted load, the lifespan of the structure will hopefully be maintained or even lengthened. In addition to determining a posting load, the load rating process dictates when structures need to be strengthened or even replaced. Load rating seeks to ensure the safety of the public while minimizing unnecessary economic burden. It is a very important process that has wide-ranging implications.

1.2 Project Background and Necessity

Tennessee Tech has had the privilege of working with TDOT to develop efficient means of load rating reinforced concrete culverts on multiple occasions. Recently, TDOT was tasked with re-evaluating the load ratings for all bridges and culverts affected by new emergency vehicle loading. In order to accomplish this, they reached out to Tennessee Tech for assistance in rating the culverts that would be affected.

In a memo set forth by the FHWA, all, "bridges on the Interstate System and within reasonable access to the Interstate System" (Hartmann 2016) are required to be load rated for two new emergency vehicles, Types EV2 and EV3, by December 31, 2019. This memo was written in response to a provision in a new law that was passed at the end of 2015, Fixing America's Surface Transportation Act (FAST Act). The FAST act was a long-term national transportation spending package passed in nearly a decade. In addition to appropriating funds for highway projects, the bill hoped to simplify the permitting process for emergency vehicles by including a new provision. The provision amended the existing weight restrictions for truck traffic on all major U.S. highways, previously determined by the FHWA Bridge Formula B, and any arterial road within a mile of a highway. Within Tennessee, 827 culverts are located within a mile of the interstate system and need to be load rated for the new emergency vehicles.

1.3 Objectives of the Research

Along with determining a load rating for each culvert based on new loading configurations, this research project aims to achieve the following objectives:

- Compile a database of culvert ratings for new emergency vehicle loading recently specified by the FHWA.
- Conduct a parametric study of the rating results to better understand how different factors affect culvert ratings and what trends can be noted based on the results.
- Investigate possible changes that can be made to culvert models that allow for a more accurate estimation of the structure's capacity and rating.

Upon completion of the research project's objectives, a broader understanding of how emergency vehicle loads affect culvert ratings is reached. This understanding serves to greatly benefit TDOT and the best interests and welfare of the general public.

1.4 Research Procedures

The following steps were taken to achieve the main objectives of this research project: (1) literature review of previous research on related topics; (2) computer modeling of each culvert based on available information provided by TDOT. This information included how much fill is present at each site, the geometry of each culvert, and the structure details per original design drawings; (3) load ratings of culvert models under different loading scenarios, including the new emergency vehicles and HL-93 truck and tandem; (4) parametric studies of obtained rating results to identify trends and patterns based on various design considerations; and, finally, (5) conclusions and recommendations based on the results gathered.

CHAPTER 2 LITERATURE REVIEW

In this chapter, previous research and other literature were reviewed in order to gain a better understanding of various considerations of load rating of concrete culverts as well as the development of the new emergency vehicles.

2.1 Existing Load and Resistance Factor Rating Procedure

The following discussion includes a description of the LRFR procedure, design/rating loads, and related details of LRFR rating process.

2.1.1 LRFR Loading Configurations

In order to account for the potential live loads that a structure may be subjected to, AASHTO has developed a loading configuration to be used based on an envelope of truck sizes. The LRFR procedure requires bridges to be designed based on HL-93 loading. The loading configuration for HL-93 loading consists of a nominal truck, HS20, shown in Figure 2.1 below, paired with a lane load of 0.64 kips per foot or a tandem truck paired with the same lane load. Bridges are then designed based on the worst-case load effects developed by either combination. Figures 2.2 and 2.3, below, show the load diagram for both the truck and lane configuration and the tandem and lane configuration.

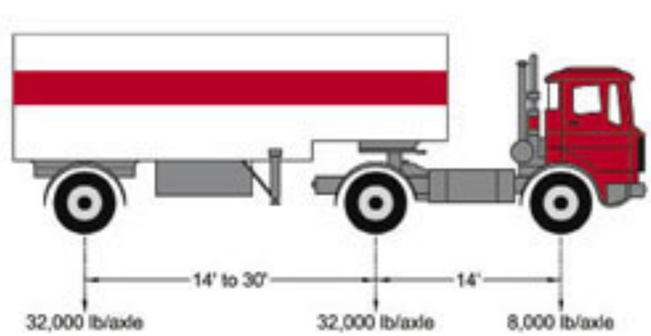


Figure 2.1: HS20 Truck

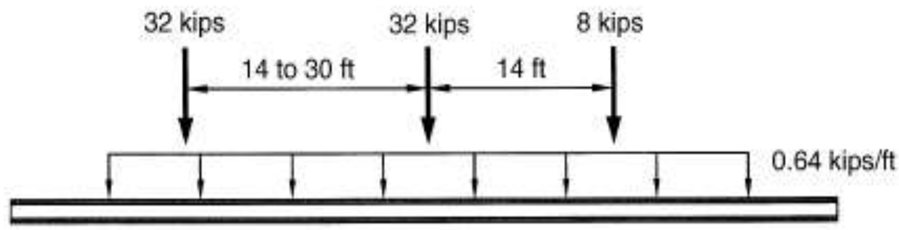


Figure 2.2: Truck and Lane

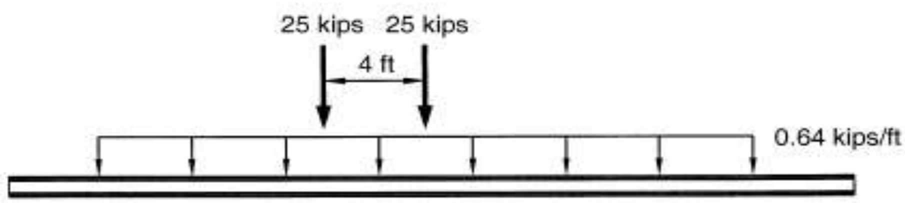


Figure 2.3: Tandem and Lane

The LRFR method requires that the AASHTO Load and Resistance Factor Design Bridge Specifications (LRFD) be used to determine a structure's capacity for load rating.

2.1.2 LRFR Load-Rating Equation

The following equation, known as the general load-rating equation, is used to determine the rating factor (RF) for a given culvert and is defined by the AASHTO MBE as:

$$RF = \frac{C - (\gamma_{DC})(DC) - (\gamma_{DW})(DW) \pm (\gamma_P)(P)}{(\gamma_{LL})(LL + IM)}$$

Where C is the culvert capacity for the strength limit. γ_{DC} is the load factor for the dead load of a bridge structure's components and attachments. γ_{DW} is the load factor for the dead load of a bridge structure's wearing surfaces and utilities. γ_P is the load factor for permanent loads. γ_{LL} is the load factor for live load. DC is the dead load due to a bridge structure's components and attachments. DW is the dead load due to wearing surfaces and utilities. P is the dead load due to permanent loads. LL is the live load present. IM is the dynamic load allowance which is a factor to account for wheel impact. In general, the rating factor is a comparison between the capacity of a given bridge structure to the dead and live loads presented on the bridge. When a bridge was rated with HL-93 truck, a RF $\geq$ 1.0

implies that the bridge satisfies the HL-93 design load rating check and a RF < 1.0 identifies that the bridge is a vulnerable bridge for further evaluations.

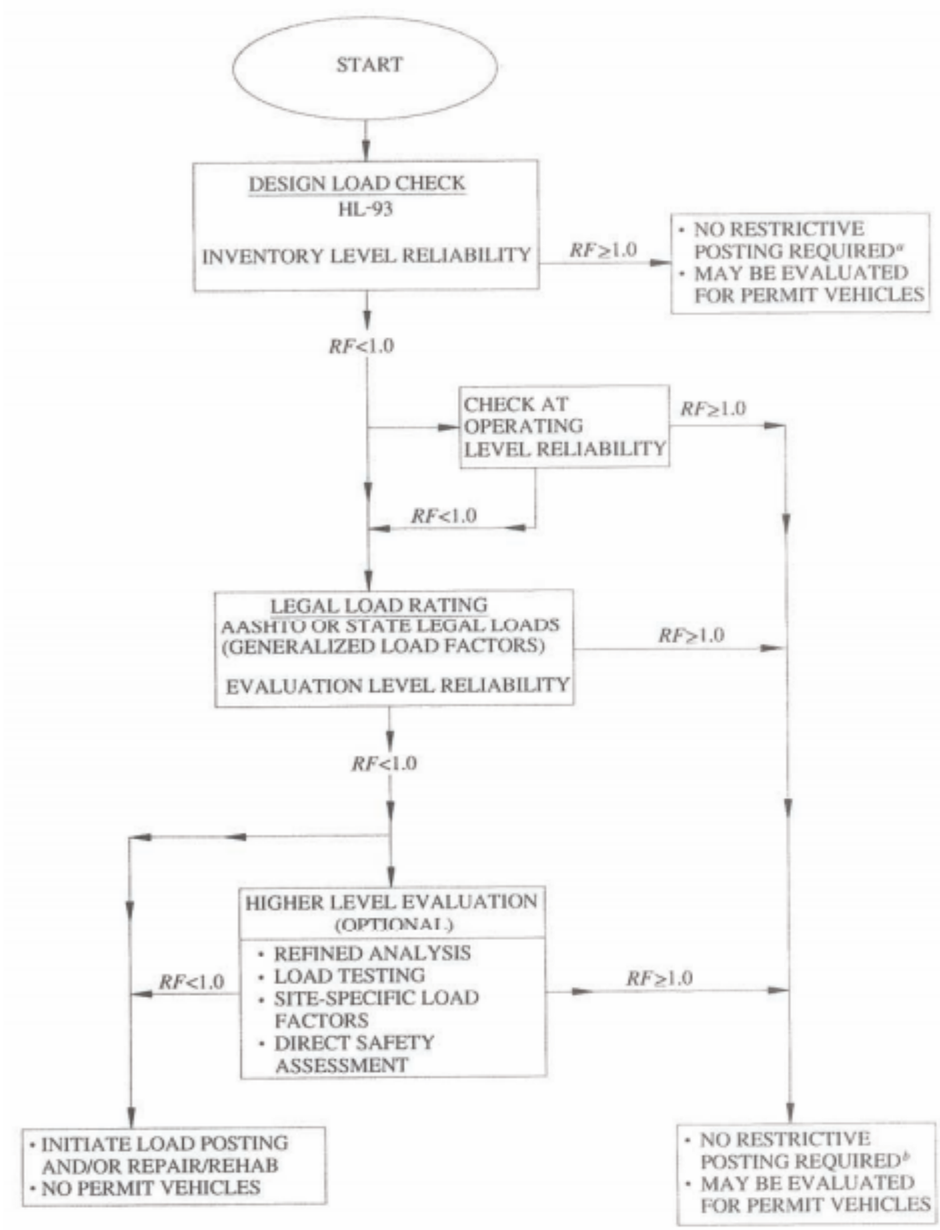
2.1.3 Inventory and Operating Level Rating

There are two rating levels that all structures are evaluated at in the LRFR method. The Inventory Level Rating is defined by the MBE as, "the rating at the design level of reliability for new bridges (in LRFD), but reflects the existing bridge and material conditions with regard to deterioration and loss of section," (AASHTO 2017). This means the inventory level rating for a given structure is determined based on both the original design loads specified in the LRFD bridge spec and the current state of the bridge. The current bridge condition is reported in a bridge inspection report compiled by certified bridge inspectors. The information included in the bridge inspection reports allow engineers to determine the final inventory rating for a given structure. In contrast, the MBE defines the Operating Level Rating as the, "maximum load level to which a structure may be subjected." (AASHTO 2017). This level serves to protect bridges from being overstressed. Any vehicle whose rating at this level is greater than one will be allowed to traverse the structure without any restriction. However, it is important to note that the MBE includes the following note on restriction-less vehicles, "allowing unlimited numbers of vehicles to use the bridge at the Operating level may shorten the life of the bridge," (AASHTO 2017). Care should be taken by engineers when determining the operating level rating to ensure long-term safety and economy for a given bridge structure.

As mentioned in section 1.1, the LRFR method includes three procedures: design load rating, legal load rating, and permit load rating. Design load rating involves rating a structure at the inventory level for HL-93 loading. The MBE explains the design load rating procedure as, "a measure of the performance of existing bridges to current LRFD bridge design standards, "(AASHTO 2017). If a structure passes the inventory level design check, it will be sufficient for all legal loads defined by LRFD exclusion limits. A rating factor of greater than one for a bridge at this level represents a passing rating. However, if the rating factor is less than one, then the structure is evaluated at the operating rating level. A passing rating at this level means the structure is sufficient for all AASHTO legal loads but may not have capacity for heavier state legal loads.

If a structure has a rating factor less than one at the inventory or operating level then the legal load rating procedure must be followed. This procedure is considered an evaluation level of reliability. The legal load rating procedure determines a bridge’s safe load capacity for numerous truck configurations. This is due to the fact that AASHTO and state authorities use a wide variety of legal loads for posting. This research, for the first time, included EV2 and EV3 truck configurations in the legal load rating procedure. If the resulting rating factor for a given truck configuration is greater than one, then the structure is sufficient. If not, then a higher level of evaluation may be undertaken to determine if a structures rating is greater than one. If the engineer determines that a structure’s rating is greater than one based on this higher level, then the structure will have no restrictive posting required.

Once all of these procedures are completed, the structure will either require restrictive posting or it will not. If the structure requires posting, no further steps occur. If not, the final procedure, the permit load rating procedure is checked. This procedure allows for permit vehicles to be evaluated for passage. Figure 2.4, below, summarizes the procedures of the LRFR method.



[a] For routinely permitted on highways of various states under grandfather exclusions to federal weight laws.

[b] For legal loads that comply with federal weight limits and Formula B.

Figure 2.4: LRFR Procedure Flowchart

Table B6A-1, shown below in Figure 2.5, in the MBE governs the applicable load factors for the LRFR method for all three rating procedures as well as the inventory and operating level rating.

Bridge Type	Limit State*	Dead Load *DC*	Dead Load *DW*	Design Load Inventory *LL*	Design Load Operating *LL*	Legal Load *LL*	Permit Load *LL*
Steel	Strength I	1.25	1.50	1.75	1.35	Tables 6A.4.4.2.3a-1 and 6A.4.4.2.3b-1	—
	Strength II	1.25	1.50	—	—	—	Table 6A.4.5.4.2a-1
	Service II	1.00	1.00	1.30	1.00	1.30	1.00
	Fatigue	0.00	0.00	0.75	—	—	—
Reinforced Concrete	Strength I	1.25	1.50	1.75	1.35	Tables 6A.4.4.2.3a-1 and 6A.4.4.2.3b-1	—
	Strength II	1.25	1.50	—	—	—	Table 6A.4.5.4.2a-1
	Service I	1.00	1.00	—	—	—	1.00
Prestressed Concrete	Strength I	1.25	1.50	1.75	1.35	Tables 6A.4.4.2.3a-1 and 6A.4.4.2.3b-1	—
	Strength II	1.25	1.50	—	—	—	Table 6A.4.5.4.2a-1
	Service III	1.00	1.00	0.80	—	1.00	—
	Service I	1.00	1.00	—	—	—	1.00
Wood	Strength I	1.25	1.50	1.75	1.35	Tables 6A.4.4.2.3a-1 and 6A.4.4.2.3b-1	—
	Strength II	1.25	1.50	—	—	–	Table 6A.4.5.4.2a-1

Figure 2.5: Load Factors for Load Rating

Table 2.1 below summarizes the live load factors used for rating based on the required values from Table B6A-1 for reinforced concrete structures.

Table 2.1: Load Factors Used in Modeling

Rating Vehicle	Load Factor
HL-93 Operating	1.35
HL-93 Inventory	1.75

2.2 FHWA Bridge Formula

This formula was developed in 1975 in order to, “limit the weight-to-length ratio of a vehicle crossing a bridge,” (FHWA). The equation is as follows:

$$W = 500 * [\frac{L * N}{N - 1} + 12 * N + 36]$$

Where, W equals the “overall gross weight on any group of two or more consecutive axles to the nearest 500 pounds” L equals the “distance in feet between the outer axles of any group of two or more consecutive axles” and N equals the “number of axles in the group under consideration.” The weight of any two consecutive axles on a truck is a function of the distance between axles, and the number of axles under consideration. In general, a truck that distributes its weight over a long distance will produce lower load effects on a bridge than a truck that weighs the same but distributes the weight over a shorter distance. This trend is depicted in Figure 2.6 below, where the shorter truck is causing more stress in the bridge than the longer truck even though they weigh the same.

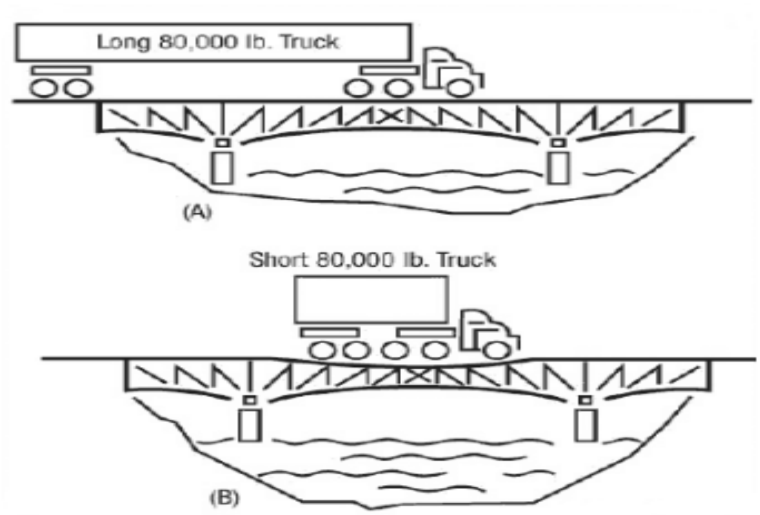


Figure 2.6: Axle Spacing Load Effects

It is important to note that all trucks previously used to rate culverts as legal loads, including HL-93 loading, comply with this formula. However, the new EV2 and EV3 trucks' load distributions are in excess of the limits of the formula and would not be considered as a legal load. Instead, the EV2 and EV3 trucks would need to be permitted as overweight vehicles.

2.3 New Emergency Vehicle Load Rating

There is now a new process for load rating bridge structures based on emergency vehicle loading.

2.3.1 Load Rating for the FAST Act's Emergency Vehicles

New vehicle weight limitations have been defined by the FHWA to account for increasing emergency vehicle sizes. Specifically, the FHWA has defined in a memo regarding the FAST Act transportation bill passed at the end of 2015, two new emergency vehicles that bridges must be rated with. According to the memo, an emergency vehicle, “is designed to be used under emergency conditions to transport personnel and equipment to support the suppression of fires and mitigation of other hazardous situations,” (Hartmann 2016). Due to their importance in emergency situations, the ability for these vehicles to efficiently traverse roadways can quickly become a matter of life and death. With the changes made to weight limitations, the FAST act hopes to increase the efficiency of emergency vehicle travel and decrease overall response time.

The changes made by the FAST act are in regard to the weight limit restrictions of emergency vehicles. The changes intend to reflect the load effects of all typical emergency vehicles. FHWA notes that these vehicles, “can create higher load effects compared to AASHTO legal loads,” (Hartmann 2016) when they traverse bridges. To most accurately replicate these load effects, the FHWA, “has determined that, for the purpose of load rating, two emergency vehicle configurations produce load effects in typical bridges that envelop the effects resulting from the family of typical emergency vehicles,” (Hartmann 2016). These enveloped vehicle configurations have been named Type EV2 and Type EV3. The loading configurations for each are shown below in Figures 2.7 and 2.8.

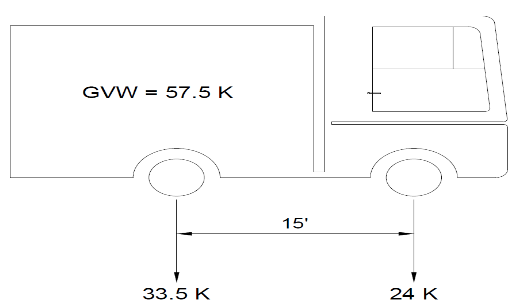


Figure 2.7: EV2 Truck Loading Configuration

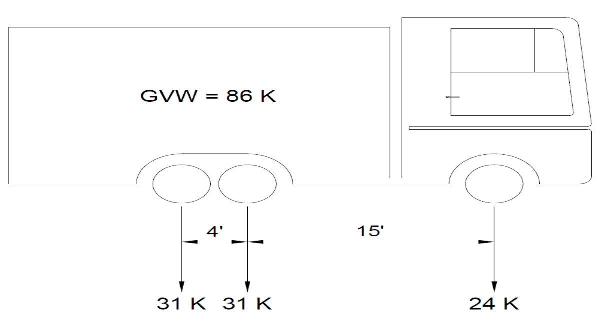


Figure 2.8: EV3 Truck Loading Configuration

Table 2.2, below, summarizes the previous vehicle weight limit restrictions in effect for all bridges and culverts. Table 2.3, below, shows the new limitations imposed on vehicles based on the FAST act.

Table 2.2: Vehicle Weight Limitations Prior to FAST Act

Restriction	Weight Limit (kips)
Gross Vehicle Weight	80
Single Drive Axle	20
Tandem Axle	34

Table 2.3: FAST Act Vehicle Weight Limitations

Restriction	Weight Limit (kips)
Gross Vehicle Weight	86
Single Drive Axle	34
Tandem Axle	62

EV2 and EV3 are significantly different than the vehicles currently used to design bridges per the AASHTO LRFD bridge spec, and the new weight limit restrictions outlined in the FAST act reflect the loading configurations for EV2 and EV3.

According to the FHWA memo, the AASHTO LRFR method, defined by the third edition of the MCE, must be used to rate all bridges and culverts. The LRFR method uses the same HL-93 loading condition as the LRFD method to determine a structure's rating. The only change that is made to the typical LRFR method per the FHWA memo is the inclusion of the new EV2 and EV3 vehicles. These configurations must only be considered for load rating when the bridge structure is, "on the Interstate System (or) within reasonable access to the Interstate System," (Hartmann 2016). The memo further clarifies the definition of "reasonable access" as, "at least one-road-mile from access to and from the National Network of highways," (Hartmann 2016). If a bridge or culvert is located beyond a mile from the nearest highway, then the structure will be rated based on the standard procedures of the LRFR method.

The memo includes the following exception to the MBE LRFR method. It explains that, "a live load factor of 1.3 may be utilized in the LRFR method," (Hartmann 2016) for evaluating structures for the new EV2 and EV3 configurations since they are legal loads. However, the FHWA Office of Bridges and Structures goes on to clarify that, "for buried structures, utilize the appropriate live load factor of

2.0 per MBE Article 6A.5.12.10.3" (Office of Bridges and Structures 2018) when load rating for the new emergency vehicle configurations. The FHWA includes Figure 2.9, below, which shows the relationship between HL-93 inventory rating and the new emergency vehicle rating results based on the LRFR load factor for HL-93 inventory loads and a live load factor of 1.3 for EV2 and EV3 loads.

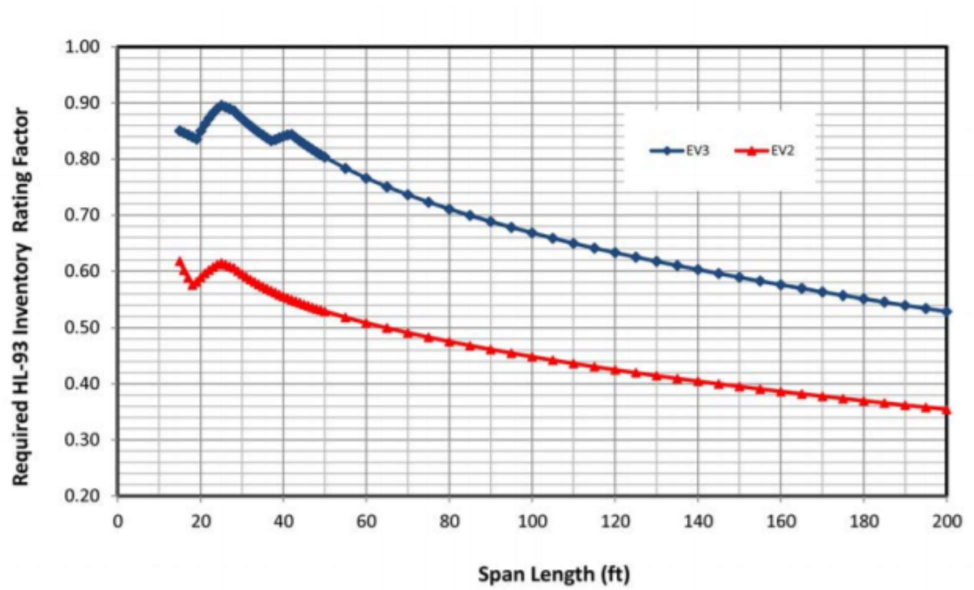


Figure 2.9: Required HL-93 RF to Achieve an Operating RF of 1.0 for EV2 and EV3

The figure above plots out HL-93 inventory rating factors vs. span length for bridges. The data points represent what HL-93 rating factor would be required to obtain an EV2 or EV3 rating of 1.0 for a given bridge span length. It is important to note, that the HL-93 inventory rating would need to be less than 1.0 to achieve an EV2 or EV3 rating of 1.0 for every bridge span length. When FHWA compared emergency rating results to HL-93 inventory rating results for the same structure, they found that the HL-93 inventory rating controls for bridges of any length. This was the case for the LRFD method utilizing a live load factor of 1.3 for EV2 and EV3 loads, while a rating factor of 1.75 was used for HL-93 inventory rating. Table 2.4 below summarizes the live load factors required for the various loading configurations discussed in this report based on the LRFD bridge spec and the LRFR method.

Table 2.4: Live Load Factors Used in Structure Analysis

Loading Configuration	Live Load Factor
HL-93 Inventory Rating	1.75
HL-93 Operating Rating	1.35
EV3 Legal Load Rating for Non-Buried Structures	1.3
EV2 Legal Load Rating for Non-Buried Structures	1.3
EV3 Legal Load Rating for Buried Structures	2.0
EV2 Legal Load Rating for Buried Structures	2.0

Careful consideration must be taken when any adjustments to legal loads are made. This is due to the potentially negative impact new loading can have on bridges' and roadway structures' lifespans. FHWA explains the reasoning behind the addition of the new emergency vehicles is to, "expedite the dispatch and safe movement of firefighters and fire trucks by eliminating the existing permitting and routing process. It may also result in savings, especially when emergency vehicles must move through multiple states," (Office of Bridges and Structures 2018). FHWA suggests the potential for emergency vehicles to be dispatched more efficiently is of greater importance than the potentially negative consequences that new weight limitations will have on the ratings of bridge structures.

Per the requirements of the FAST act, the FHWA memo explains that, "all highway bridges must be load rated and, if necessary, posted in accordance with the MBE," (Hartmann 2016) for the new EV2 and EV3 vehicles. However, due to the time-consuming nature and level of detail required to rate structures, the memo allows transportation departments sufficient time to go and rate all structures affected. The memo requires that the re-rating of structures be completed, "before December 31, 2019" (Hartmann 2016). All bridges and culverts on the interstate system or within a mile of the interstate system must now be rated and, if necessary, posted for the new EV2 and EV3 vehicles based on the posting procedure defined in the next section.

2.3.2 Emergency Vehicle Recommended Posting Loads

The main reason for determining the rating factor for a given culvert is to check whether or not restrictive load posting may be required. The MBE specifies, “when the maximum legal load under State law exceeds the safe load capacity of a bridge calculated at the Operating level, restrictive posting shall be required,” (AASHTO 2017). The new FAST Act defines EV2 and EV3 as legal loads for all bridges and structures. Therefore, if the rating factor for a given culvert is less than one for either the EV2 or EV3 loading configuration, then the culvert may need to be posted. Figure 2.10, below, shows an example of signage recommended by FHWA to be used when posting structures.

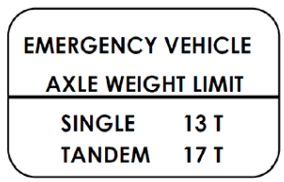


Figure 2.10: FHWA Posting Signage Example

In order to determine what the posting loads should be for a single or tandem axle or the gross vehicle weight, the FHWA developed the following flowchart, shown in Figure 2.11.

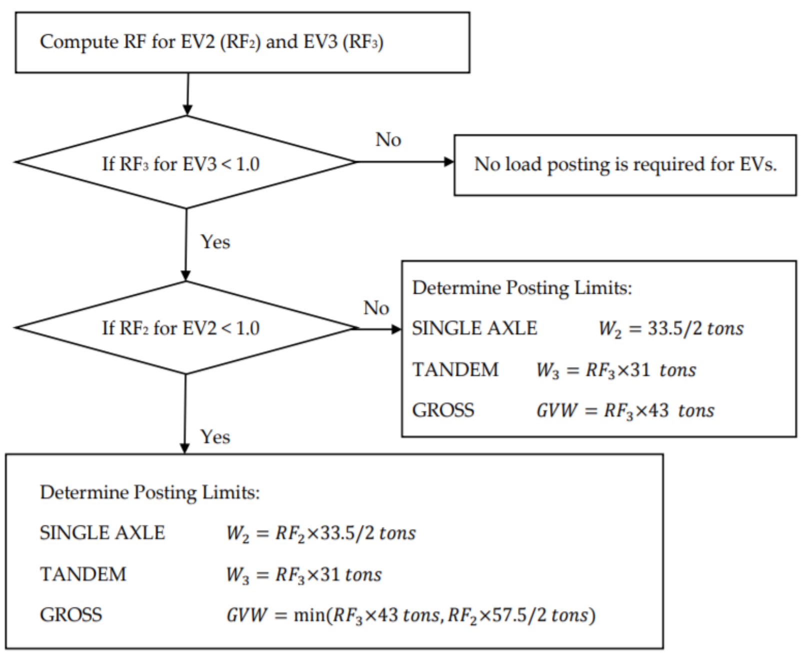


Figure 2.11: Recommended Emergency Vehicle Posting Load Flowchart

Where RF_2 is the rating factor for EV2 load rating and RF_3 is the rating factor for EV3 load rating. This new process is significantly different than the existing process of load posting for HL-93 loading, and serves to protect the lifespan of bridge structures by restricting vehicles of various configurations from traversing without special permits.

2.4 Previous Investigations into Bridge Rating and Posting

Other research on bridge rating, truck loading, and culvert structural analysis were also reviewed and selected ones are listed below.

2.4.1 Bridge Rating Practices and Policies for Overweight Vehicles

A synthesis study was performed to determine differences and commonalities between how state and local entities rate bridges for overweight/oversized vehicles. A questionnaire was sent to multiple state DOT's and municipalities that sought information on a wide variety of bridge rating topics. The questionnaire asked about how an agency approaches bridge rating in general, whether by detailed computer modeling or by engineering judgement, as well as what policies are in place for a given jurisdiction regarding overweight permitting. While the questionnaire was wide-ranging, the study hoped to find common practices and policies in use by most agencies. This would then lend itself to more continuity and safety throughout the bridge rating community, saving tax-payer dollars and minimizing confusion and paperwork for the trucking industry as well as first-responders. Unfortunately, what the study found was that there are many different approaches to permitting heavy vehicles and rating bridges throughout the country. The study even found situations where bordering states have vastly different weight limit restrictions and rating policies.

It is important to note, that of the 38 states that responded to the survey, TN had the 6th most bridges or culverts (almost 20,000) but had the 2nd lowest percentage of bridges electronically modeled and rated. TN agreed with the importance that electronic models have on rating uniformity and are quoted saying, "electronic models provide the data to allow a more rapid analysis of permit vehicle requests. They also allow a more rapid updating of allowable capacity, for permits, when conditions change," (Fu 2006). TN clearly recognizes the importance and usefulness of computer models when it comes to rating bridges and culverts. The relatively low percentage of bridges that TN has currently rated, and the importance that the state puts on electronic modeling shows the necessity of this proposed research which will update the ratings of culverts throughout the state by building electronic models of each culvert.

The general conclusion that was drawn was that there does exist non-uniformity among both state and local agencies in regards to both permitting and bridge rating practices, policies, procedures and requirements. The study concluded with recommendations that would potentially make the process of evaluating which vehicles should be required to be permitted and which vehicles should not be allowed on specific routes more consistent and uniform across the United States.

2.4.2 Legal Truck Loads and AASHTO Legal Loads for Posting

This study examined the effects of special hauling vehicles (SHV's) Examples of SHV's are shown below in Figure 2.12. They are categorized as having relatively short wheelbases and typically produce load effects in bridges in excess of legal loads.

Figure 2.12: Special Hauling Vehicles

It was made very apparent that the trucking industry utilizes many different vehicle configurations for use in a wide range of activities. A questionnaire was sent to all states to gather information regarding which trucks are evaluated for bridge posting and which methods are in place. The study clearly showed how the trucking industry has begun to utilize many trucks that meet the

Federal Bridge Formula B weight restrictions by shortening the overall length of the truck while increasing the overall gross weight to 80 kips. These vehicles were then shown to produce load effects that significantly exceed AASHTO legal loads. It should be noted that while the study detailed many different vehicles and configurations, none of the trucks discovered surpassed the 80-kip gross vehicle weight limitation. It is therefore worthwhile to mention that these SHV’s, which are already causing load effect increases of 50% the current legal loads, will only continue to increase in weight given the new provision by the FHWA to expand the gross vehicle weight for permitting to 86 kips in the coming years. Additionally, no vehicle studied had a maximum tandem axle weight greater than 45 kips which is significantly less than the new EV3 truck which has a tandem axle weight of 62 kips. If the size of trucks, that have no restriction on which bridges and routes they traverse, continue to increase in weight, the lifespan of transportation systems may be negatively impacted due to repeated overstressing.

2.5 Effect of Soil Dead Lead on Buried Structures

An investigation into the distribution of load through fill was previously done to determine if there was a possibility, under the governing AASHTO LRFD bridge spec, to reduce the load applied to buried structures. It was noted that the most influential parameters in determining load for buried structures are the type of construction used when installing the structure and the soil characteristics present. Research was done to determine if any adjustments to the final models could be utilized.

2.5.1 Theoretical Soil Mechanics

Soil arching, or the arching effect, is a phenomenon that has been widely studied by geotechnical engineers. In his book, *Theoretical Soil Mechanics,* Karl Terzaghi defines soil arching as a, “transfer of pressure from a yielding mass of soil onto adjoining stationary parts,” (Terzaghi 1943). Terzaghi used his findings from a simple trap-door soil test, shown in Figure 2.13 below, to describe arching.

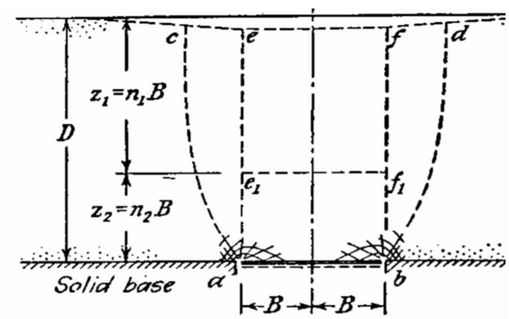


Figure 2.13: Soil Arching Trap-Door Diagram

The dashed lines in the figure above represent the soil deflection after the trap-door is released. In general, if any significant deflection occurs in a mass of soil relative to the surrounding soil, the opposing shearing force present will decrease the vertical pressure over the yielding mass and increase or “arch” the vertical pressure out to the adjacent soil masses.

2.5.2 Load Reduction on Rigid Culverts Beneath High Fills: Long-Term Behavior

In order to measure the amount of soil arching present in a given construction and how it behaves over time, three full-sized tests were conducted. One of the tests included a cast-in-place concrete box culvert buried under roughly 75 feet of fill. The test wanted to see if there was any difference in soil pressure if different construction techniques were used to backfill the same culvert. The two techniques used were the conventional construction method and imperfect ditch method. The conventional construction method includes backfilling solid soil until the necessary elevation is achieved. The imperfect ditch method includes installing a flexible material, relative to the soil, above the culvert and then backfilling solid above the material to the desired elevation. The material chosen for this test was expanded polystyrene (EPS). Figure 2.14, below, shows the setup for the two tests. While tabulated results were not provided, Figures 2.15 and 2.16 below show the pressures measured by load cell 1 and load cell 3 over time. The figures also include the overburden pressure based on the unit weight of soil and the depth of fill. The authors concluded that, “the full-scale tests described show that the imperfect ditch method can be used to reduce vertical earth pressure on rigid culverts,” (Vaselstad 1993). Specifically, in regards to the concrete box culvert, the tests showed that the pressure, “in the section with EPS was reduced to less than 50 percent of the overburden,” (Vaselstad

1993). While the, “section without EPS was 1.24 times the overburden,” (Vaselstad 1993). The rigidity of a concrete box culvert relative to soil causes negative arching and results in a pressure at the top of the culvert in excess of the soil overburden.

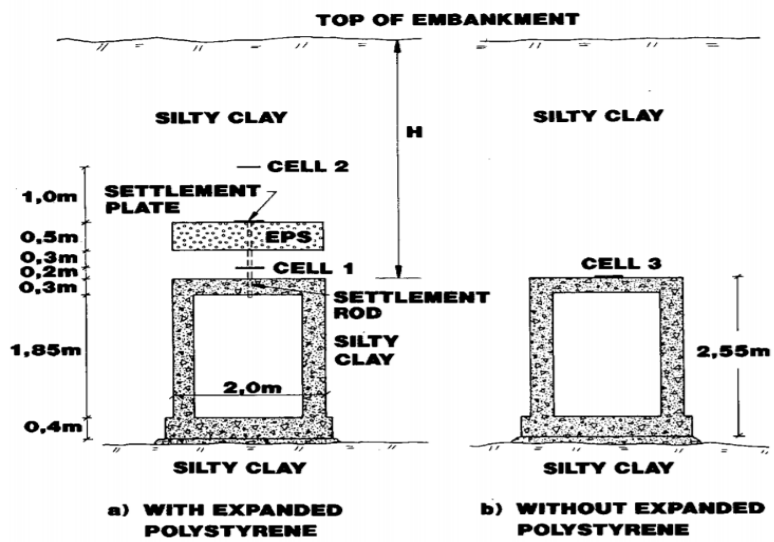


Figure 2.14: Buried Culvert Vertical Pressure Test Setup

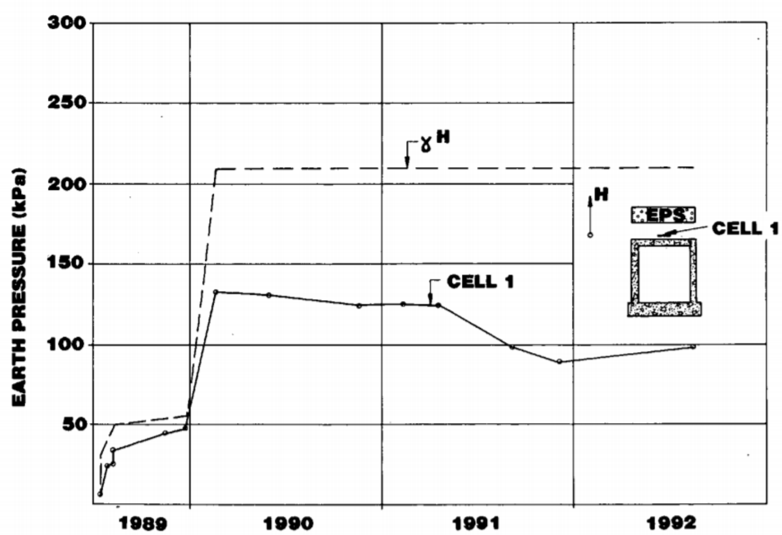


Figure 2.15: Measured Pressures at Cell 1 vs Overburden over Time

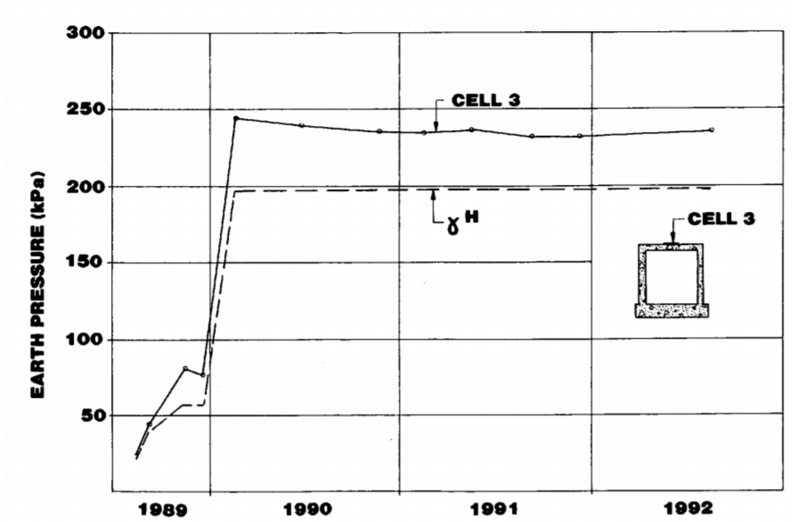


Figure 2.16: Measured Pressures at Cell 3 vs Overburden over Time

2.5.3 Design Loading on Deeply Buried Culverts

Two finite element programs, ABAQUS and ISBUILD, were used to model deeply buried box culverts in order to compare the soil-structure interaction factors for different installation methods, namely embankment, trench, and imperfect trench. The goal was to see whether or not the soil-structure interaction factor, otherwise known as effective density, calculated based on the LRFD bridge spec was representative for the three different installations or if the factor was overly conservative. The study concluded that, generally, "soil–structure interaction factors for deeply buried box culverts are more sensitively affected by the foundation characteristics," than any other parameter (Kim and Yoo 2005). It was also expressed that, for trench installations, "the effective density given by the current AASHTO is conservative compared to the analytically predicted values," (Kim and Yoo 2005). The study also concluded that, "the soil-structure interaction factor may be significantly reduced by properly implementing the imperfect trench method," (Kim and Yoo 2005). For culverts buried under deep fill, the construction techniques used have a great impact on the amount of dead load that is developed into the structure.

2.5.4 Live Load Distribution through Soil

The current AASHTO code requires wheel live load to be distributed through soil based on Article 3.6.1.2.6. This article puts a limit on the depth of fill to where live load may be distributed to the top slab of a buried culvert. If the culvert is single span the maximum depth of fill where live load is still considered is the greater of 8 feet and the span length (AASHTO 2017). For multi-cell culverts, AAHSTO specifies that, “the effects may be neglected where the depth of fill exceeds the distance between inside faces of end walls,” (AASHTO 2017). All culverts modeled checked for the presence of live load based on fill depth and span length of the culvert per this specification. If live load was not neglected the distribution of live load was determined based on the rest of the specifications outlined in Article 3.6.1.2.6.

2.5.5 Dead Load Distribution through Soil

While live load distribution is only permitted based on Article 3.6.1.2.6, AASHTO states that, “in lieu of a more refined analysis, the total unfactored earth load,” (AASHTO 2017) may be determined based on the specifications of Article 12.11.2.2. Within that article, AASHTO includes dead load calculations based on two types of buried structure installation techniques, embankment and trench. Figures 2.17 and 2.18 show examples of each.

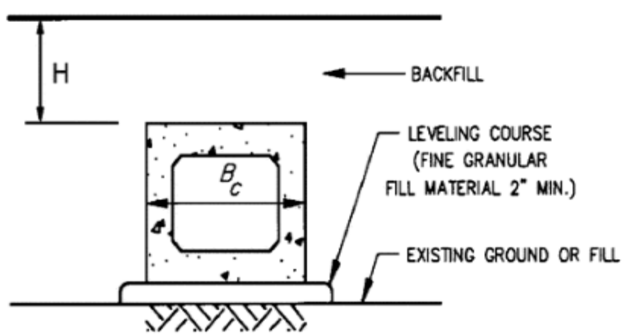


Figure 2.17: Embankment Condition

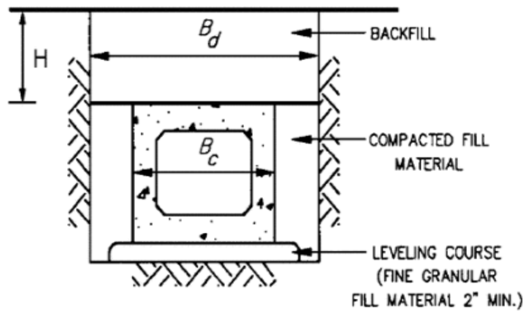


Figure 2.18: Trench Condition

For the embankment condition, the dead load calculated is always greater than the overburden. The equation below is used to calculate the unfactored earth load for embankment installations.

$$W_e = F_e(overburden\ pressure)$$

Where W_e is the unfactored earth load, and F_e is the soil-structure interaction factor. F_e is calculated based on the following equation:

$$F_e = 1 + 0.2(\frac{H}{B_c})$$

Where H is the fill depth and B_c is the width of the structure. The soil-structure interaction factor will always be greater than one and is capped at 1.4. This means that the unfactored earth load will always be greater than the overburden pressure. This reflects the phenomenon of soil arching in that the culvert is assumed to be rigid enough to create relative settlement for the soil columns on either side of the structure. Due to soil settling on either side of the soil column above the structure, the dead load must be increased above overburden. This applies for all culverts that were constructed using the embankment technique.

Due to the fact that the culverts analyzed in this project have been built from many different design specifications over the course of a century and cover the entire state of TN, there is no reasonable way to consistently determine the construction technique utilized when a culvert was first constructed as well as the soil conditions present at a given culvert. Therefore, it was determined that the most conservative dead load calculation be utilized when determining culvert loads. If the embankment installation technique was used when constructing the culvert, then it is likely that the dead load present is greater than the overburden pressure. This negative arching phenomenon was also reflected in the results of the experiment run by Vaslestad that was summarized in section 2.5.2 earlier.

CHAPTER 3 CULVERT MODELING

Computer models were developed for each affected culvert to accommodate the situations that include large number of culverts needing to be rated, the wide range of design drawings used of the affected culverts, and the various truck loading scenarios needing to be analyzed.

3.1 AASHTOWare

For this research, AASHTOWare Bridge Rating software (AASHTOWare) was the primary software program chosen to carry out the rating of the affected culverts. The program determines structure capacity and load ratings based on the LRFD bridge spec. It has many features and controls that allow the user to model many different types of bridge superstructures and substructures including buried box and slab culverts. This program was chosen for three reasons. First it is used by many state departments of transportation across the country to analyze and design/rating bridges including TDOT. Using this program allowed the digital models developed in this research to be directly transferred to TDOT upon project completion for record and documentation. Additionally, the program utilizes a well-developed graphical user interface that was easy to operate and back check. This made the modeling process more streamlined and reliable. Finally, AASHTOWare was selected because it includes a library of vehicles, materials, and other structural inputs that allowed the user to accurately represent the in-situ conditions of a given structure. An example of a typical AASHTOWare culvert input file is shown below in Figure 3.1. Since all culverts analyzed through this project could be used for future load rating, it is very important the structural model used to determine the culvert's rating was as accurate and representative as possible.

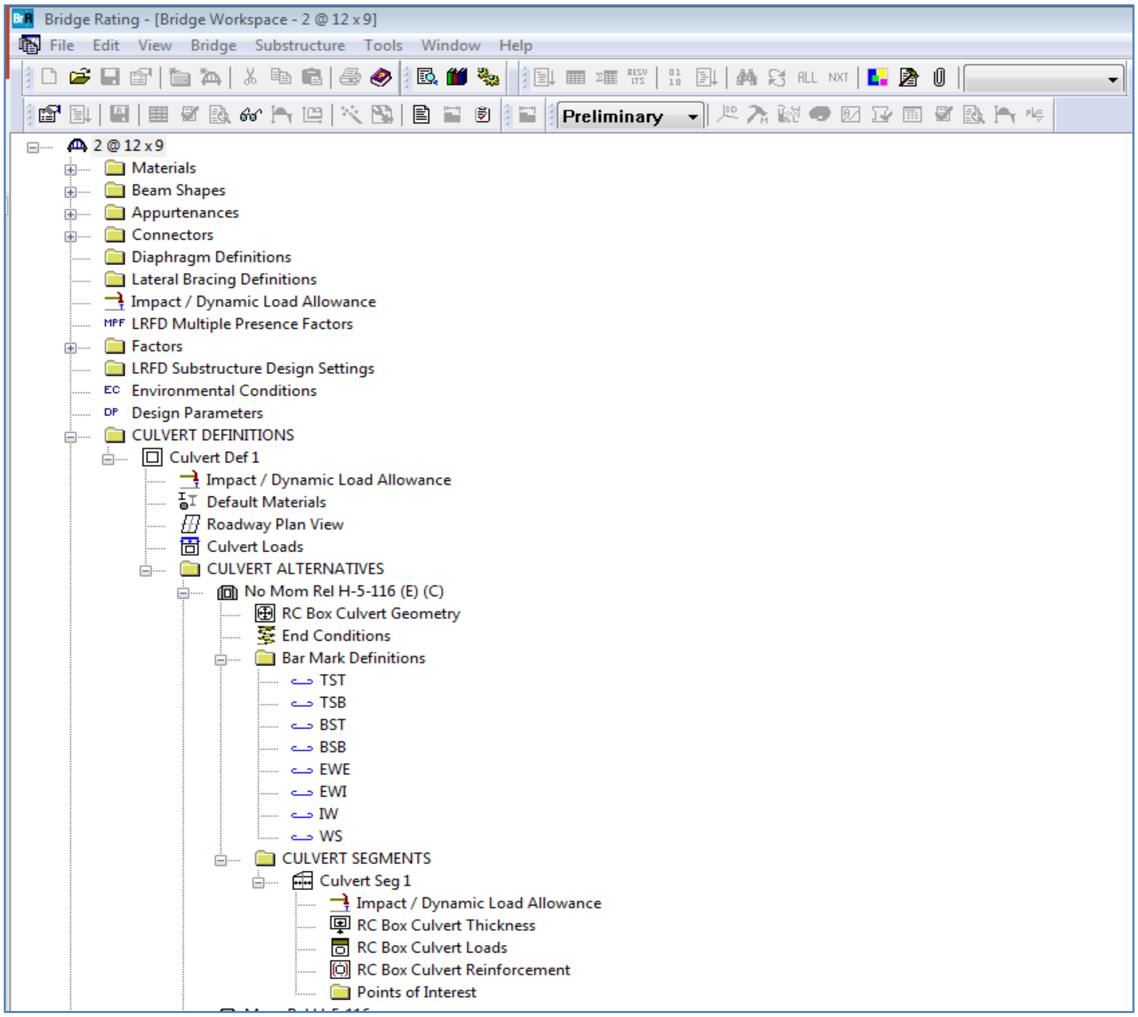


Figure 3.1: AASHTOWare Culvert Menu

3.2 AASHTOWare Culvert Modeling

As mentioned previously, in order to ensure accurate results, the model must be constructed in a manner that most closely represents the in-situ conditions of the structure needing to be analyzed. To make sure this was carried out, the original drawings used to design and build the culverts were received from TDOT. Additionally, the most recent TDOT bridge inspection report for each culvert, containing information including culvert type, geometry, fill depth, and overall condition, was transmitted to the research team, which was critical in developing an accurate model.

3.2.1 Input Data

The following information was required to accurately assemble a computer model of a given culvert. The information was based on the original design drawing as well as the TDOT bridge inspection report for the culvert. The data required included:

- Material properties
- Culvert geometry – which included clear span, height, and number of cells
- Culvert type – box or slab culvert
- Connection type at slab to wall interfaces – fixed or pinned
- Steel reinforcement definitions – size, shape, and length of the various reinforcement present
- Culvert thicknesses – for the walls and slabs
- Depth of fill present
- Dead load due to earth pressures
- Construction installation type – trench or embankment condition
- Soil-structure interaction factor
- Steel reinforcement detailing – amount, location, spacing, and clear cover for each bar
- Selection of various truck configurations to be analyzed

3.2.2 Culvert Modeling

The first step in building the culvert model was to define the structural properties of the different materials to be used in the analysis. Typically, this included the properties of the cured concrete, the steel reinforcement, mainly deformed bars, and the soil backfill. Once these materials were defined, the specification used to analyze the structure was defined. For this research the Load and Resistance Factor Rating (LRFR) method was used. Next, the culvert geometry, based on the given information in the inspection report, was defined. This included whether a culvert was a box or slab culvert. The main difference between the two is the presence of the bottom slab. Slab culverts do not have a bottom slab while a box culvert does. Slab culverts are typically built on relatively small strip footings. For simplicity, the wall height for a given slab culvert did not include the height of the strip footing. An example of each type of culvert is shown below in Figures 3.2 and 3.3 respectively.

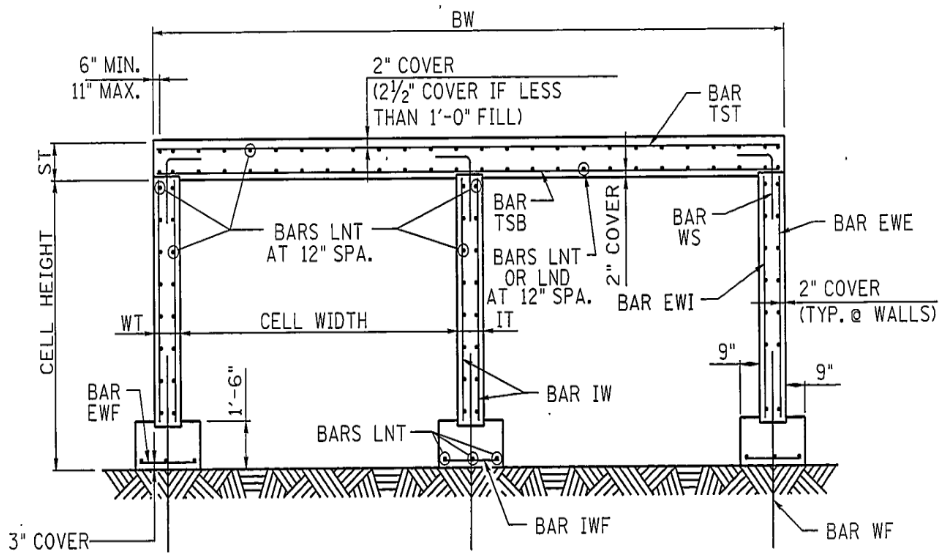


Figure 3.2: Typical Slab Culvert Geometry

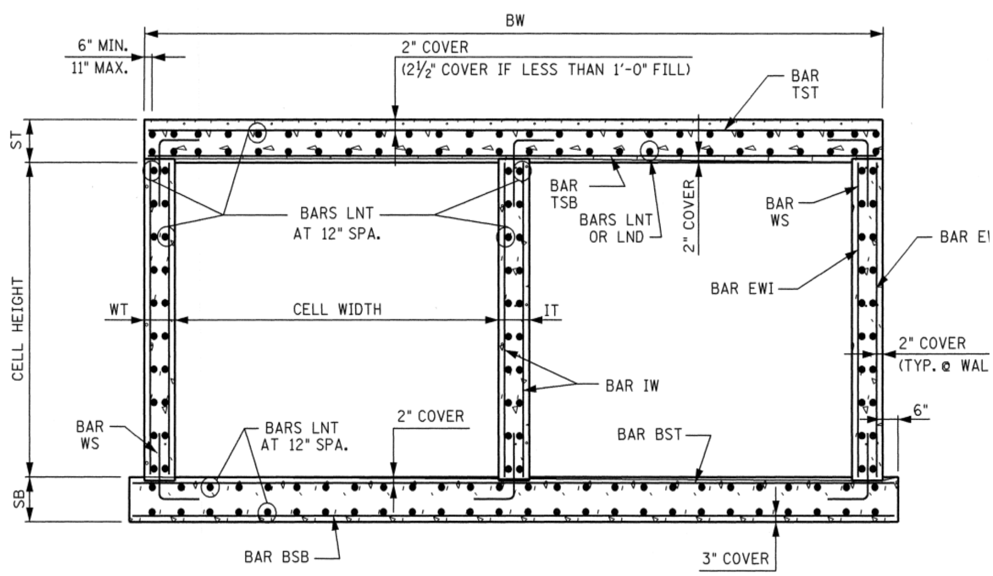


Figure 3.3: Typical Box Culvert Geometry

After culvert geometry, each type of transverse rebar was defined based on shape, strength, size, and length. The culvert wall and slab thicknesses were input next followed by the fill depth and load due to soil and wearing surface. Finally, the location and spacing of each transverse rebar was input. Figure 3.4, below, shows example inputs for the various steps mentioned in the modeling process. Once all components, materials, and analysis options were defined, the culvert was ready to be analyzed. An example of a completed culvert model is shown in Figure 3.5 below.

The next aspect of rating the culvert includes defining the loading scenarios applied to the constructed culvert. Typically, AASHTO specifies HL-93 loading, as defined earlier, to be applied to culverts for rating purposes. However, due to the FAST Act's new loading requirements for emergency vehicles, additional loading scenarios needed to be considered for these culverts since they meet the requirements of being reasonably close to or installed along U.S. interstates. The loading configuration for emergency vehicles EV2 and EV3 were input into AASHTOWare per Figure 3.6 below. As mentioned in section 2.3.1, EV2 and EV3 were evaluated as legal loads with a live load factor of 2.0 for all buried structures. Figure 3.7 shows the load factors used for all loads and evaluation levels.

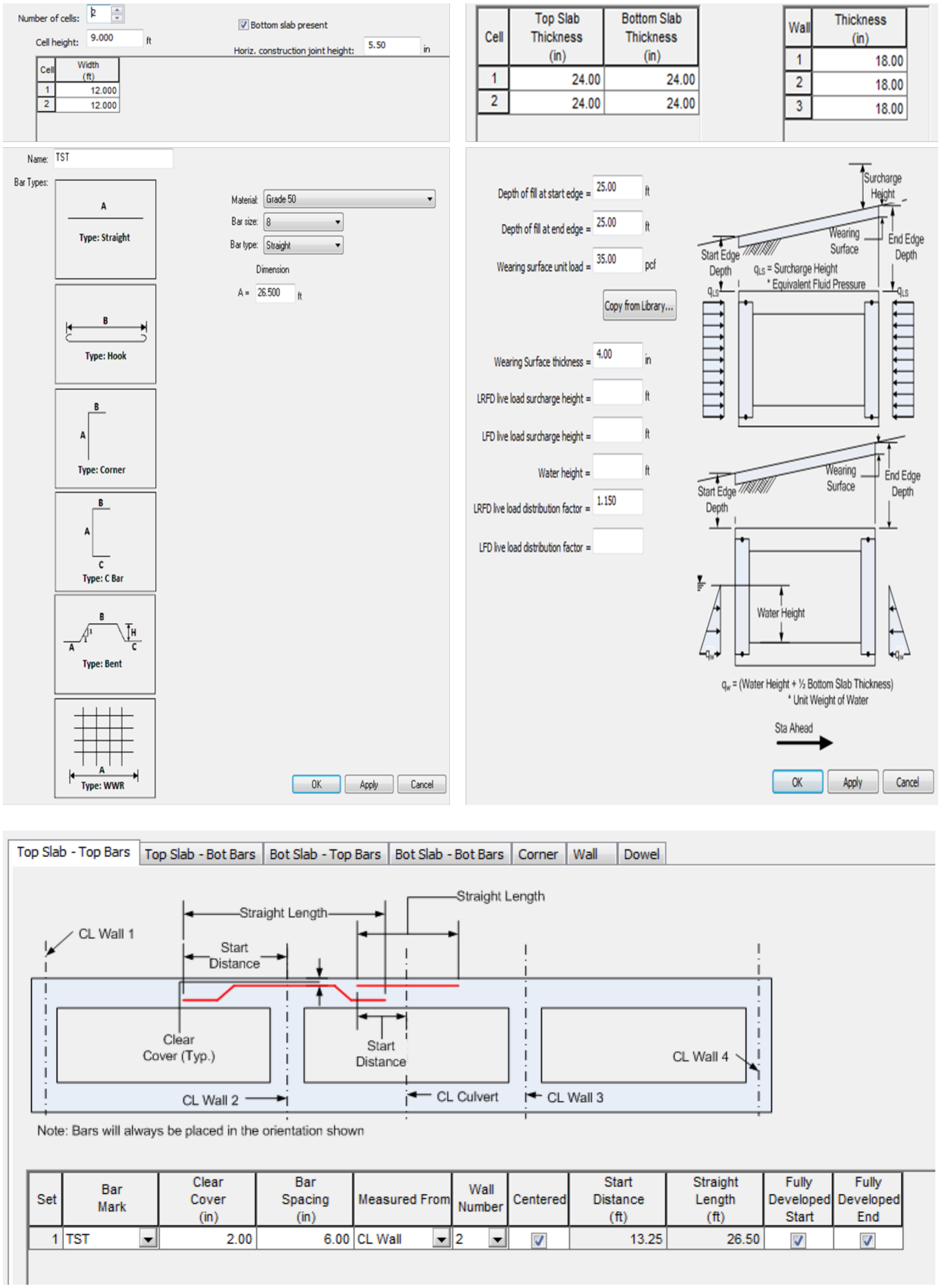


Figure 3.4: AASHTOWare Example Inputs

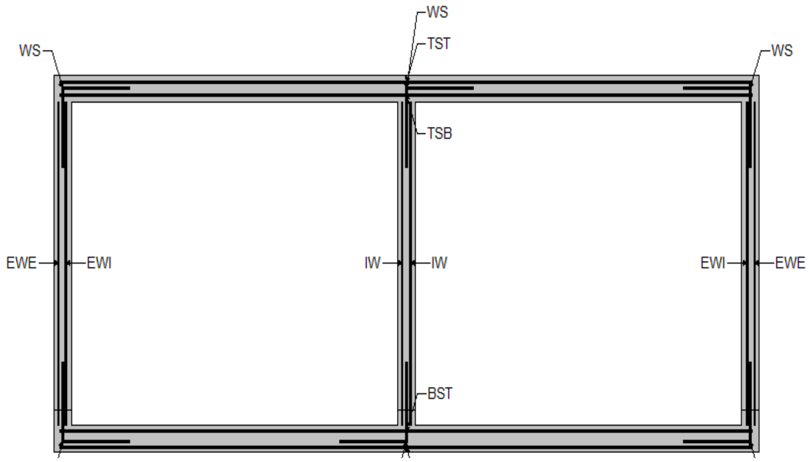
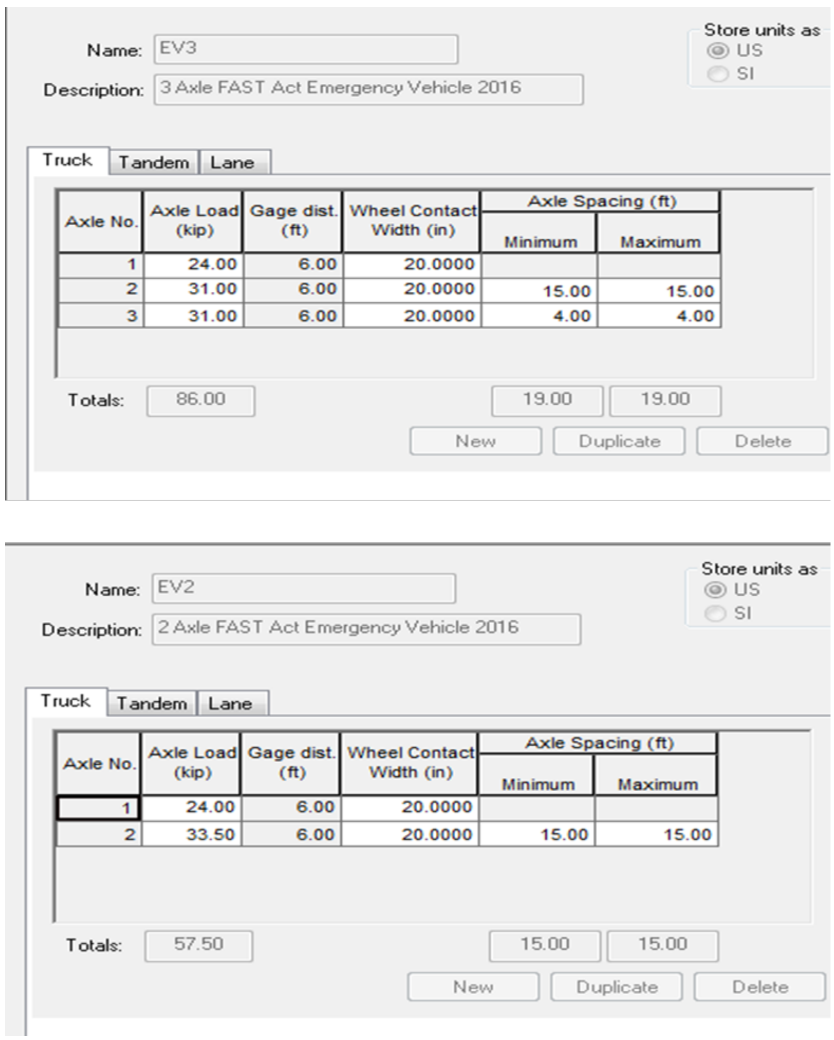


Figure 3.5: Completed Culvert Model with Rebar Callouts



Name: EV3

Description: 3 Axle FAST Act Emergency Vehicle 2016

Store units as: US / SI

Truck | Tandem | Lane

Axle No.	Axle Load (kip)	Gage dist. (ft)	Wheel Contact Width (in)	Axle Spacing (ft)	
				Minimum	Maximum
1	24.00	6.00	20.0000		
2	31.00	6.00	20.0000	15.00	15.00
3	31.00	6.00	20.0000	4.00	4.00

Totals: 86.00 — 19.00 — 19.00

New | Duplicate | Delete

Name: EV2

Description: 2 Axle FAST Act Emergency Vehicle 2016

Store units as: US / SI

Truck | Tandem | Lane

Axle No.	Axle Load (kip)	Gage dist. (ft)	Wheel Contact Width (in)	Axle Spacing (ft)	
				Minimum	Maximum
1	24.00	6.00	20.0000		
2	33.50	6.00	20.0000	15.00	15.00

Totals: 57.50 — 15.00 — 15.00

New | Duplicate | Delete

Figure 3.6: EV2 and EV3 AASHTOWare Loading

Bridge Type: Reinforced-Concrete Box Culvert

Limit State	DC Max	DC Min	DW Max	DW Min	Design Load Invent LL	Design Load Operatin LL	Design Load Legal LL	Design Load Permit LL	LS Max	LS Min	EH Max	EH Min	EV Max	EV Min	ES Max	ES Min
STRENGTH I	1.250	0.900	1.500	0.650	1.750	1.350	2.000		*	0.000	1.350	0.900	1.300	0.900	1.500	0.750
STRENGTH II	1.250	0.900	1.500	0.650				Table	**	0.000	1.350	0.900	1.300	0.900	1.500	0.750

Figure 3.7: AAHSTO LRFR Load Factors

3.2.3 Output Data

A typical output data file from AASHTOWare for a given culvert is shown in Figure 3.8.

Report Type: Rating Results Summary
Lane/Impact Loading Type: (•) As Requested ( ) Detailed
Display Format: Single rating level per row

Live Load	Live Load Type	Rating Method	Rating Level	Load Rating (Ton)	Rating Factor	Component	Location (ft)	Location (%)	Limit State
HL-93 (US)	Tandem	LRFR	Operating	254.90	10.196	Top Slab 1	4.80	40.000	Flexure
SU5	Axle Load	LRFR	Legal	317.13	10.230	Top Slab 1	4.80	40.000	Flexure
SU4	Axle Load	LRFR	Legal	292.54	10.835	Top Slab 1	4.80	40.000	Flexure
Type 3	Axle Load	LRFR	Legal	298.69	11.948	Top Slab 1	4.80	40.000	Flexure
Type 3S2	Axle Load	LRFR	Legal	433.95	12.054	Top Slab 1	4.80	40.000	Flexure
HL-93 (US)	Axle Load	LRFR	Operating	437.07	12.141	Top Slab 1	4.80	40.000	Flexure
HS 20-44	Axle Load	LRFR	Operating	437.07	12.141	Top Slab 1	4.80	40.000	Flexure
Type 3-3	Axle Load	LRFR	Legal	513.87	12.847	Top Slab 1	4.80	40.000	Flexure
H 15-44	Axle Load	LRFR	Inventory	255.19	17.013	Top Slab 1	4.80	40.000	Flexure
H 15-44	Axle Load	LRFR	Operating	330.80	22.054	Top Slab 1	4.80	40.000	Flexure
EV3	Axle Load	LRFR	Legal	298.69	6.946	Top Slab 1	4.80	40.000	Flexure
HL-93 (US)	Tandem	LRFR	Inventory	196.64	7.866	Top Slab 1	4.80	40.000	Flexure
HL-93 (US)	Axle Load	LRFR	Inventory	337.16	9.366	Top Slab 1	4.80	40.000	Flexure
HS 20-44	Axle Load	LRFR	Inventory	337.16	9.366	Top Slab 1	4.80	40.000	Flexure
SU7	Axle Load	LRFR	Legal	366.32	9.453	Top Slab 1	4.80	40.000	Flexure
EV2	Axle Load	LRFR	Legal	274.10	9.534	Top Slab 1	4.80	40.000	Flexure
SU6	Axle Load	LRFR	Legal	341.73	9.834	Top Slab 1	4.80	40.000	Flexure

Figure 3.8: Culvert Rating Results for Various Live Loads

The first column in the output file shows which live load condition was analyzed. The next column defines what type of live load was considered, with axle load referring to a truck configuration and tandem load referring to the tandem configuration. The rating method used for analysis is shown next. Followed by the level at which a specific load type was analyzed. A gross vehicle load rating shown in tons is reported in the next column. This corresponds to the rating factor shown in the column next to it. The controlling component of the culvert and the location of the cross section with the smallest rating is reported in the next columns. Figure 3.9, below, shows what is meant by the component and location. In AASHTOWare, the slab location is defined from left to right with the leftmost section of the slab being 0.0 ft and increasing to the right, while the wall location is defined from the top down. The top of the wall is 0.0 ft and increases as the depth decreases. For example, the controlling component per Figure 3.8 above is “Top Slab 1” and the location is 4.8 ft. This means that the smallest rating factor was found to exist in the top slab of the first cell from the left, 4.8 feet from the right of the exterior wall to slab interface.

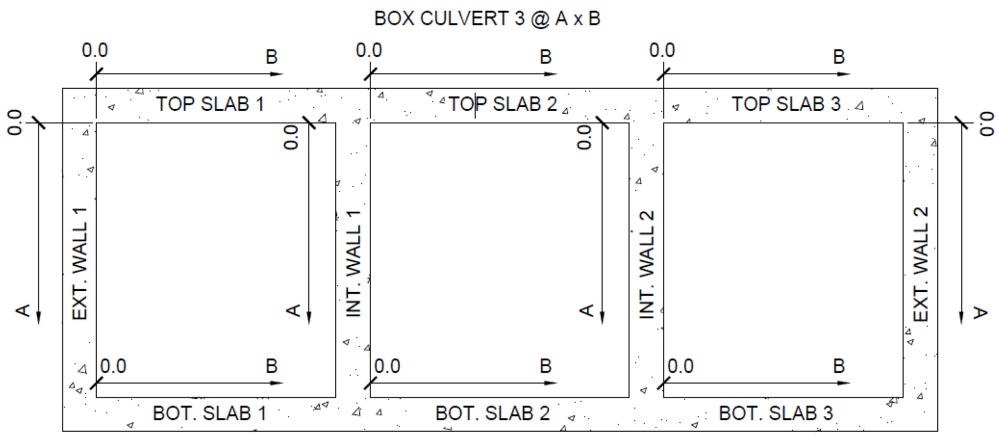


Figure 3.9: Rating Factor Locations for a Typical 3-Cell Box Culvert

The final column in the output file reports what limit state controls for the culvert analyzed, either flexure or shear.

3.3 Culverts Built After 2000

Per discussions with TDOT regarding the different historical designs used to construct these culverts, it was noted that there exists significant difference in the design of culverts built before 2000 from those built after 2000. This is mainly due to the implementation of the new LRFD code when designing new structures compared to the Load and Factor Design (LFD) method and the Allowable Stress Design (ASD) method. All culverts built after 2000 were designed to have pinned connections between the walls and slabs. Because of this, the models constructed for all culverts built after 2000 reflect this design intent. The culverts were built based on TDOT standard drawing series 15 and 17. An example of a typical cross section for culverts built with these drawing series is shown below in Figure 3.10.

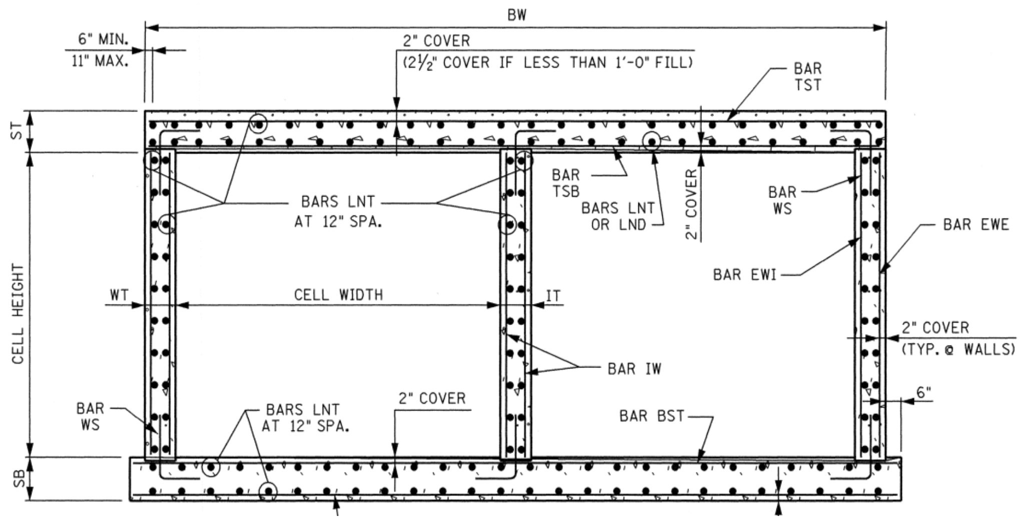


Figure 3.10: TDOT STD 15 and STD 17 Typical Cross Section

The standard 17 drawing culverts were designed to meet the requirements of the LRFD bridge spec. Per discussions with TDOT, it was noted that, to reduce the thickness of the top and bottom slabs, these culverts were designed to have simple shear connections at the interface of the walls and slabs. Previously, culverts were designed as frames with the full moment capacity of the top slab of the culvert being allowed to transfer into the wall of the culvert. This required a relatively large wall and slab thickness to achieve proper moment transfer. By designing the new culverts with shear connections and allowing the top slab to act as a simply-supported continuous slab, a more efficient design was developed. To achieve this, only one corner bar was specified to be placed at the center of the interface between all slabs and walls as opposed to the extreme corner of each interface. Due to the location and relatively short development length of this corner bar, three feet into the slab and two feet into the wall, the culvert was designed to have simple shear connections. This design modification was very significant when determining how to most accurately model and rate each culvert. If the culvert was constructed after 2000 based on either the standard 15 or standard 17 drawing set, the structure was modeled as a simple, continuous slab with no moment transfer between the slab and the culvert walls. This prevents the structure from behaving as a frame with negative moment getting transferred into the culvert walls.

3.4 Culverts Built Before 2000

Culverts built before 2000 were not designed based on the LRFD method. Rather they were designed based on either the LFD method or the ASD method depending on when they were built. In contrast to the culverts built after 2000, these culverts were predominantly designed as structural frames with adequately developed corner reinforcement placed at the extreme corner extents of each slab to wall interface. When originally assembling the computer models for the culverts built prior to 2000, the structures were modeled as a frame with the full moment capacity of the top slab being transferred into the culvert walls which were in turn transferred from the walls to the bottom slab for box culverts where a bottom slab was present. If the culvert was a slab culvert, then the models did not allow any moment capacity to be transferred from the walls into the soil bed at the bottom of the culvert. Figure 3.11 below shows a typical cross section for most culverts that were built prior to 2000.

It was noticed that not all culverts built prior to 2000 had corner reinforcement specified in the original design drawings. An example of a culvert design drawing without corner reinforcement is shown in Figure 3.12 below. For culverts without corner reinforcement, the model did not allow moment to be transferred from the slab to the wall.

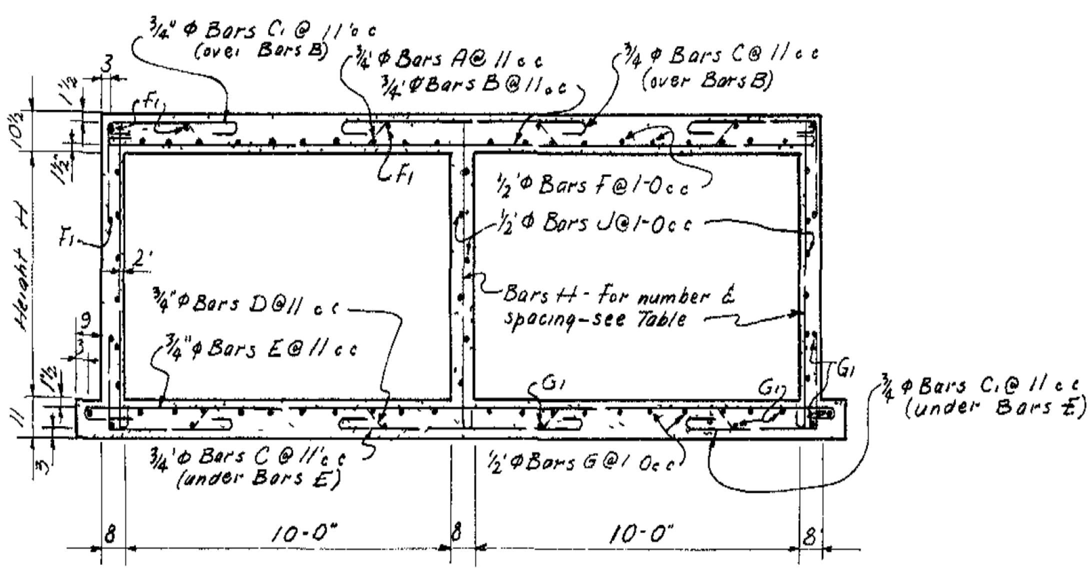


Figure 3.11: Culvert Built Before 2000 Typical Cross Section

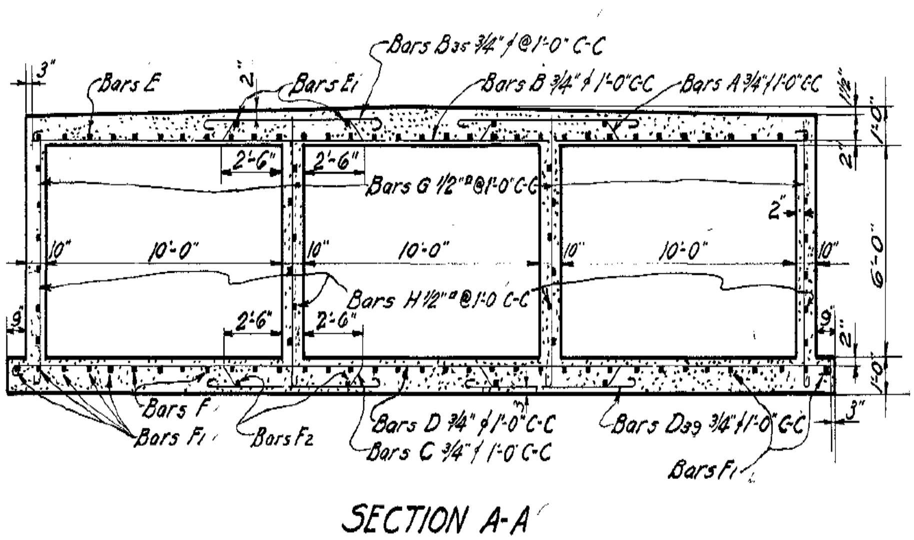


Figure 3.12: Culvert without Corner Reinforcement

Upon completion of the original analysis, it was determined that regardless of the existence of corner reinforcement, it is probable that the existing culverts may in fact be acting as a continuous slab structure with no moment transfer at the slab-wall interface. This is due to the likelihood of cracks in the concrete forming in the corner or insufficient stiffness in the design of the steel reinforcement. Additionally, it was noticed that a large number of culvert ratings were surprisingly limited by their exterior wall. This was not anticipated based on previous culvert rating results being predominately controlled by the culvert slab. The exterior wall would be the controlling culvert component because of the presence of negative moment in the wall. The only way negative moment could develop in the wall of the culvert is if the culvert was acting as a rigid frame. All of this led to the alternative analysis which was run after the original analysis.

For the alternative analysis, all culvert models, regardless of the presence of corner reinforcement, were constructed as continuous slabs with no moment transfer between the walls and slabs at the top and bottom of the culvert. Since there is no definitive way to know how the culvert was originally intended to be designed, the alternative analysis was necessary to see if different ratings were possible and potentially more accurate to the in-situ conditions.

CHAPTER 4 RATING RESULTS OF CULVERTS AFFECTED BY EMERGENCY VEHICLE LOADS

As previously discussed, the focus of this study was to rate as many culverts affected by the new emergency vehicle loading as possible based on the available information. Each culvert was modeled as accurately as possible to reflect the in-situ conditions of the structure and extra care was taken to ensure the model for each culvert most closely reflected the original design intent of the given culvert as well as the site-specific conditions based on available information. In total, 827 culverts were modeled and rated based on their original design drawings and bridge inspection reports. 85 of the 827 culverts were constructed after 2000, and their models reflect the structural design considerations discussed previously. Table 4.1 below includes the following information for a sample of culverts that were analyzed in this project: structure identification number, year the culvert was built, the number of culvert cells present, the clear span of the culvert, the culvert's clear height, the original design drawing used to construct the culvert, whether the culvert is a box culvert or a slab culvert, and the depth of fill present.

Table 4.1: Characteristics of a Set of the Culverts Affected by Emergency Vehicle Loads

Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
2003	2	10	7	Standard 15	B	1.0
1960	2	10	6	G-10-108	B	0.0
1992	2	12	7	H-5-118	S	0.0
1987	2	10	8	E-2-32	S	0.0
1935	2	10	4	A-14-123	B	0.0
1973	3	10	6	K-38-17	B	3.0
1964	3	9	9	G-10-15	S	0.0
2014	3	18	8	Standard 17	B	0.0
1960	2	12	8	E-8-35	B	4.0
1973	3	12	10	K-38-21	B	2.0

Refer to Appendix A for the complete list of characteristics for culverts affected by the new loading requirements. After all culverts were analyzed, rating results for each culvert were recorded.

Table 4.2 below, shows a brief sample of culvert rating results.

Table 4.2: Rating Results for a Set of the Culverts Affected by Emergency Vehicle Loads

Year Built	EV3 Legal Rating	EV2 Legal Rating	HL-93 Inventory Tandem Rating	HL-93 Inventory Axle Load Rating	HL-93 Operating Tandem Rating	HL-93 Operating Axle Load Rating
2003	0.589	0.929	0.696	0.921	0.902	1.194
1960	0.459	0.661	0.542	0.659	0.703	0.854
1992	0.501	0.795	0.607	0.777	0.787	1.008
1987	0.932	1.366	1.162	1.325	1.506	1.717
1935	0.898	1.093	1.06	1.089	1.375	1.412
1973	0.613	0.909	0.772	0.89	1.001	1.153
1964	0.953	1.512	1.505	1.321	1.951	1.713
2014	0.688	1.014	0.986	0.848	1.278	1.1
1960	0.779	1.091	0.946	0.942	1.227	1.222
1973	0.925	1.448	1.086	1.285	1.408	1.666

The first column in the table shows the year a culvert was built. The next six columns are the rating results for the various loading configurations that were gathered for each culvert which include EV2 and EV3 loading evaluated as legal loads, HL-93 truck and HL-93 tandem loading evaluated at both the inventory and operating rating levels. If a culvert's rating for a given configuration is less than or equal to 1.0, then the value is shown in red. If the rating is greater than 1.0, than the value is shown in green. A brief summary of rating results of the 85 culverts built after 2000 and the 742 culverts built before 2000 are discussed below.

4.1 Rating Results

There were two types of analyses performed on these culverts. There was an original analysis that considered the wall to slab joints fixed for every culvert built before 2000 unless the culvert does not have any corner reinforcement present. Table 4.3 below shows a brief summary of the results from this analysis.

Table 4.3: Original Analysis Rating Results Summary

	Number of Culverts	*Percent of Total*
All ratings > 1.0	347	42.0%
All ratings < 1.0	232	28.1%
EV3 rating < 1.0	450	54.4%
EV2 rating < 1.0	346	41.8%
HL-93 Tandem rating < 1.0	317	38.3%
HL-93 Truck rating < 1.0	262	31.7%
EV3 rating controls	811	98.1%

From Table 4.3 it can be seen that for the vast majority of culverts, the EV3 rating controls over any other loading configuration. This is expected considering the EV3 truck does not meet the restrictions of the federal bridge formula, the axle weights are greater than the other configurations, and the highest load factor is used. Only 42% of the 827 culverts had ratings for every configuration greater than 1.0. Again, this is not necessarily surprising considering 669 of the 827 culverts analyzed were constructed before 1994. That was the first year that bridges were required to be designed using LRFD specifications and HL-93 loading. As mentioned earlier, the EV3 loading is larger than the HL-93 loading.

For the alternate analysis, all wall to slab joints were considered pinned. For every culvert built after 2000, the wall to slab joints were considered to be pinned for both the original and the alternate analysis. Table 4.4 below shows a brief summary of the results from this analysis.

Table 4.4: Alternate Analysis Rating Results Summary

	Number of Culverts	*Percent of Total*	*Percent Change from Original*
All ratings > 1.0	481	58.2%	38.6%
All ratings < 1.0	199	24.1%	-14.2%
EV3 rating < 1.0	345	41.7%	-23.3%
EV2 rating < 1.0	256	31.0%	-26.0%
HL-93 Tandem rating < 1.0	216	26.1%	-31.9%
HL-93 Truck rating < 1.0	204	24.7%	-22.1%
EV3 rating controls	816	98.7%	0.6%

Once again, the EV3 loading configuration controls for nearly every culvert analyzed in this project. Table 4.4 above also includes a column for the percent change from the original analysis. This column was determined based on the equation shown below.

$$Percent\ Change = \frac{(Alternative\ Analysis\ Result - Original\ Analysis\ Result)}{Original\ Analysis\ Result}$$

In general, the culvert ratings improved for the alternative analysis. 58% of the culverts analyzed had ratings greater than for all loading configurations which is an increase of 38.6% compared to the original analysis. Additionally, the number of culverts with ratings less than one for each loading configuration decreased compared to the original by at least 22.1%. The main difference between the two analyses were how the culverts were considered to behave structurally. Since all slab to wall joints were released for the alternative analysis, no moment was transferred from the slab to the wall. This prevents any negative moment from being developed in the walls. Due to the fact that culverts designed before 2000 typically do not include negative reinforcement in any wall, higher ratings for the alternative analysis is to be expected.

4.2 Original Analysis Rating Results

The results discussed in this section pertain to the original analysis. To eliminate potential errors in analysis due to outliers, only culverts whose ratings were found to be less than 10 were included in this discussion. Figures 4.1, 4.2, and 4.3 below show the rating results for the EV3 loading configuration compared to the HL-93 truck evaluated at the operating level for culverts built in three different date ranges: 1915 to 1950, 1951 to 1999, and 2000 to 2016.

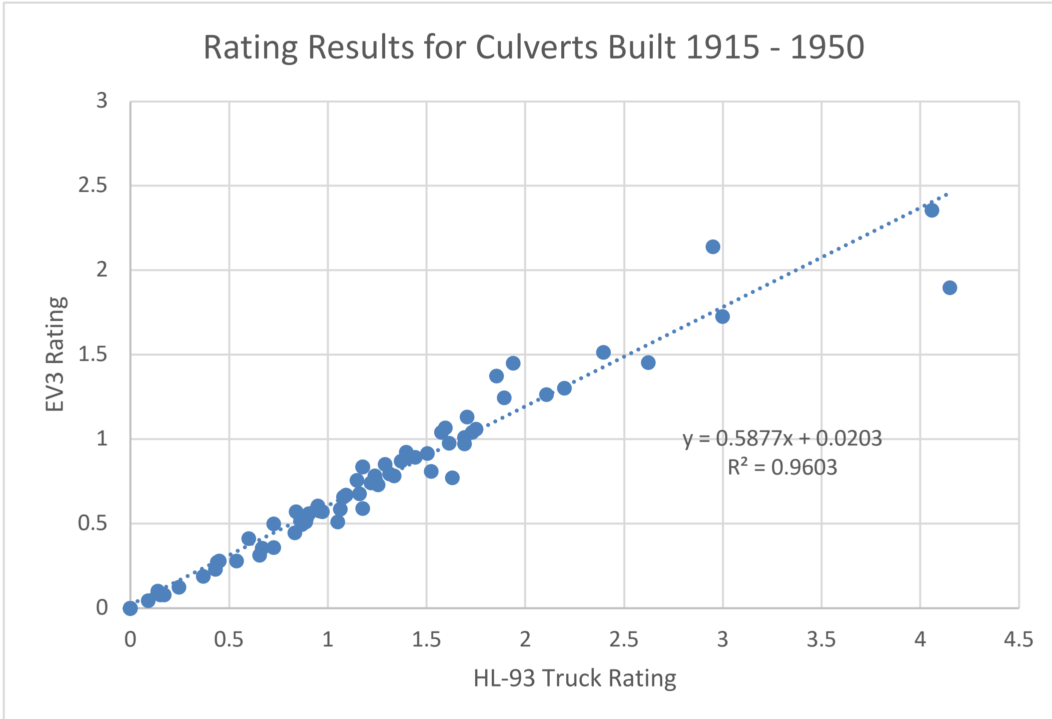


Figure 4.1: Original Analysis Rating Results EV3 vs. HL-93 Truck 1915 – 1950

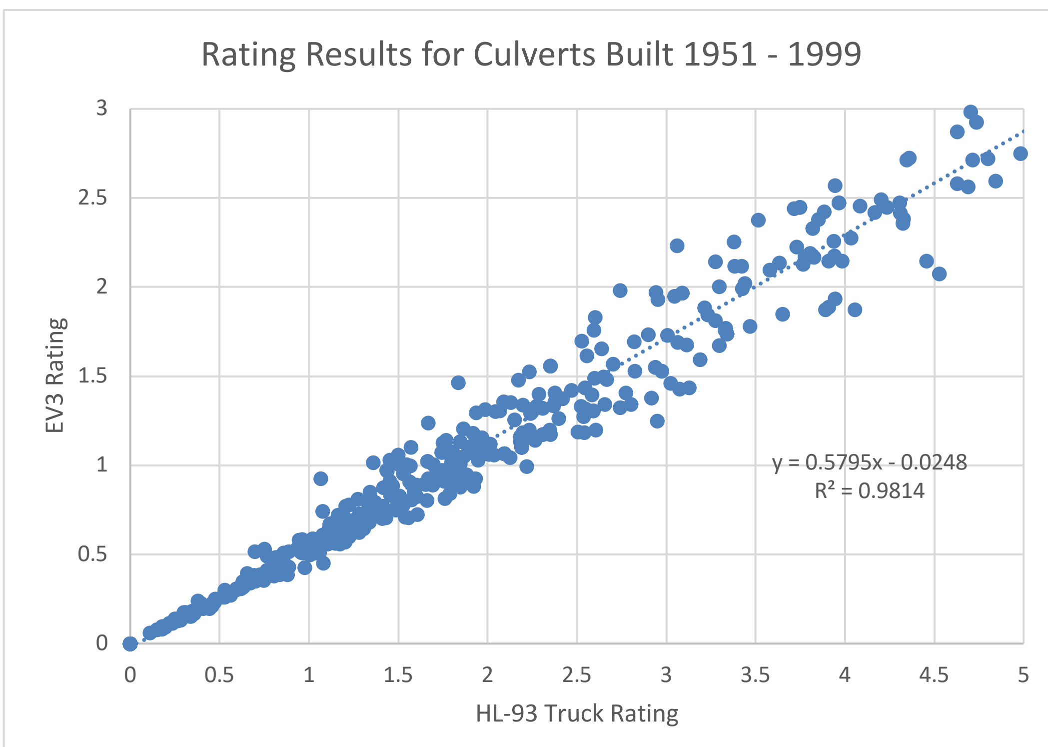


Figure 4.2: Original Analysis Rating Results EV3 vs. HL-93 Truck 1951 – 1999

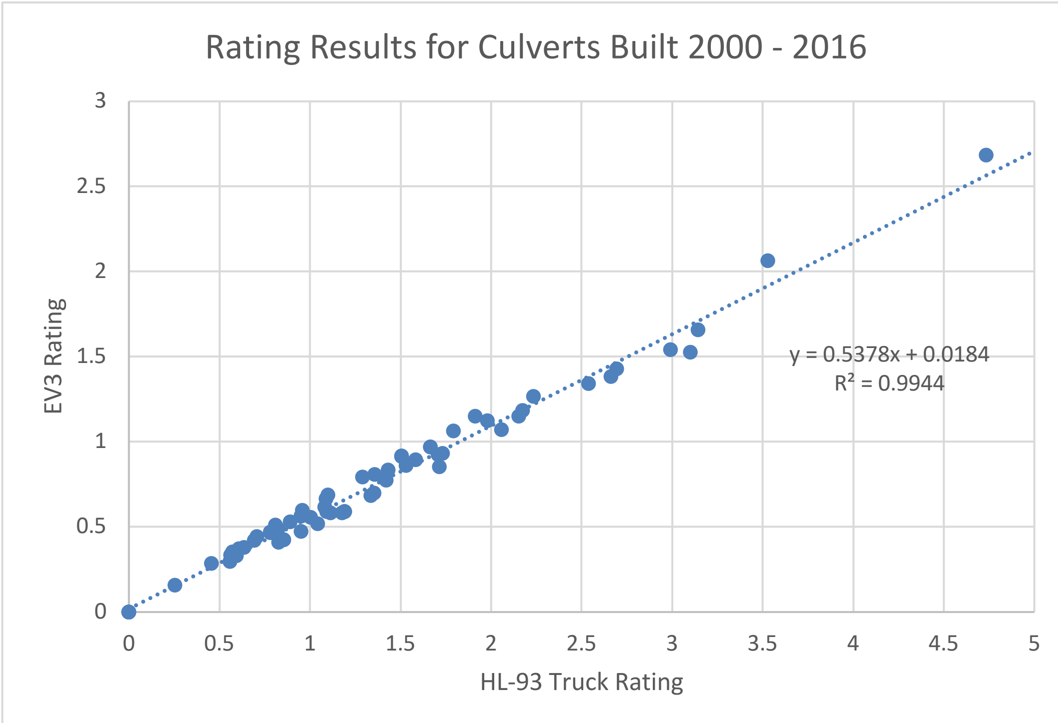


Figure 4.3: Original Analysis Rating Results EV3 vs. HL-93 Truck 2000 – 2016

The minimum R-squared value when the two ratings are compared is 0.9603 for the three date ranges. The comparison implies that the linear regression equations calculated for these comparisons could be reasonably used as a relatively accurate method for determining a structure's EV3 rating if the HL-93 Truck operating rating has previously been determined. The linear regression equations are shown in the figures above for the various date ranges.

Figures 4.4, 4.5, and 4.6 below show the rating results for the EV2 loading configuration compared to the HL-93 truck evaluated at the operating level for culverts built in three different date ranges: 1915 to 1950, 1951 to 1999, and 2000 to 2016.

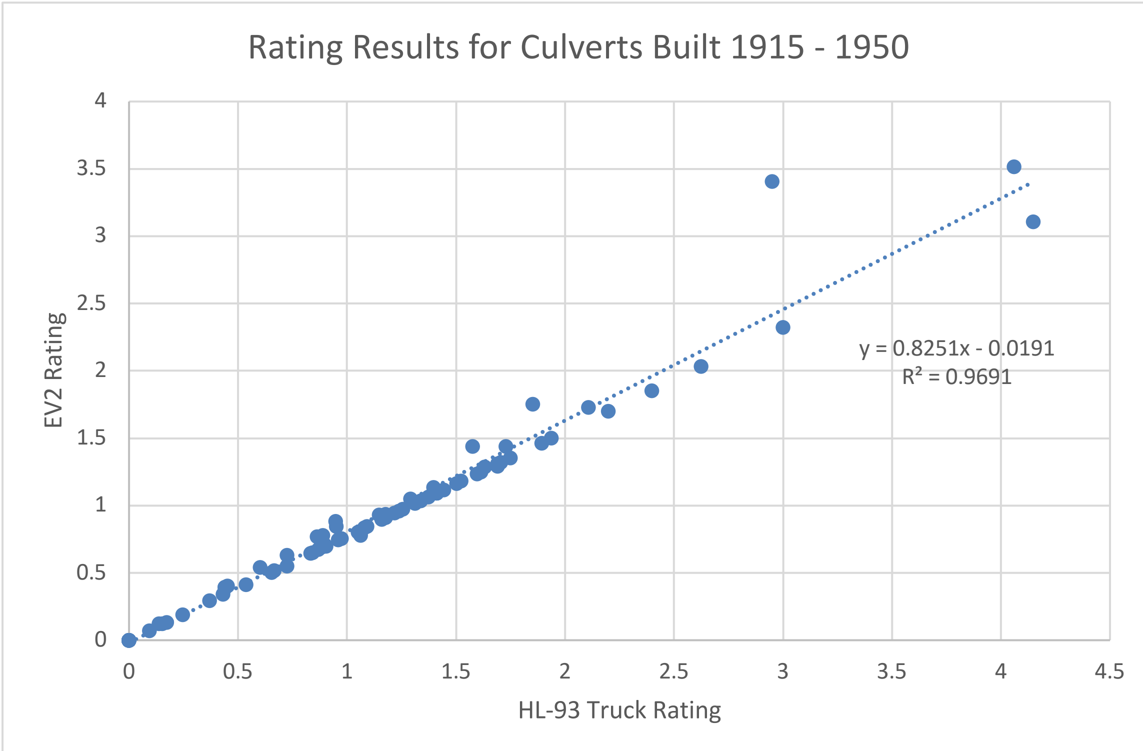


Figure 4.4: Original Analysis Rating Results EV2 vs. HL-93 Truck 1915 – 1950

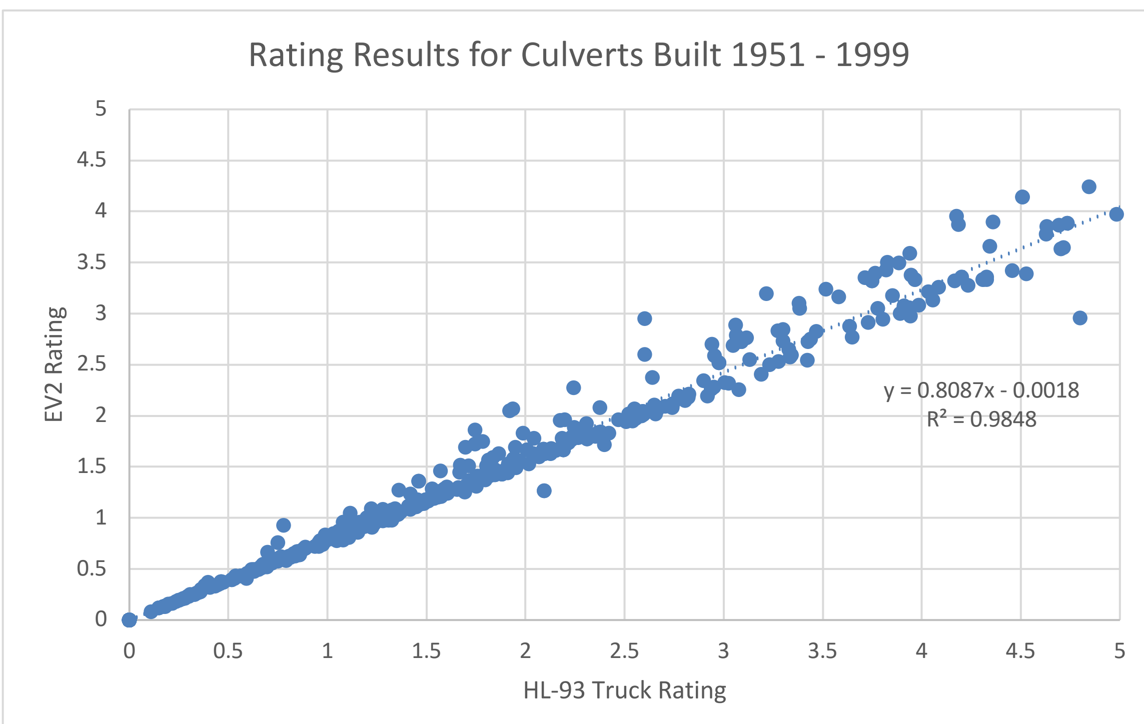


Figure 4.5: Original Analysis Rating Results EV2 vs. HL-93 Truck 1951 – 1999

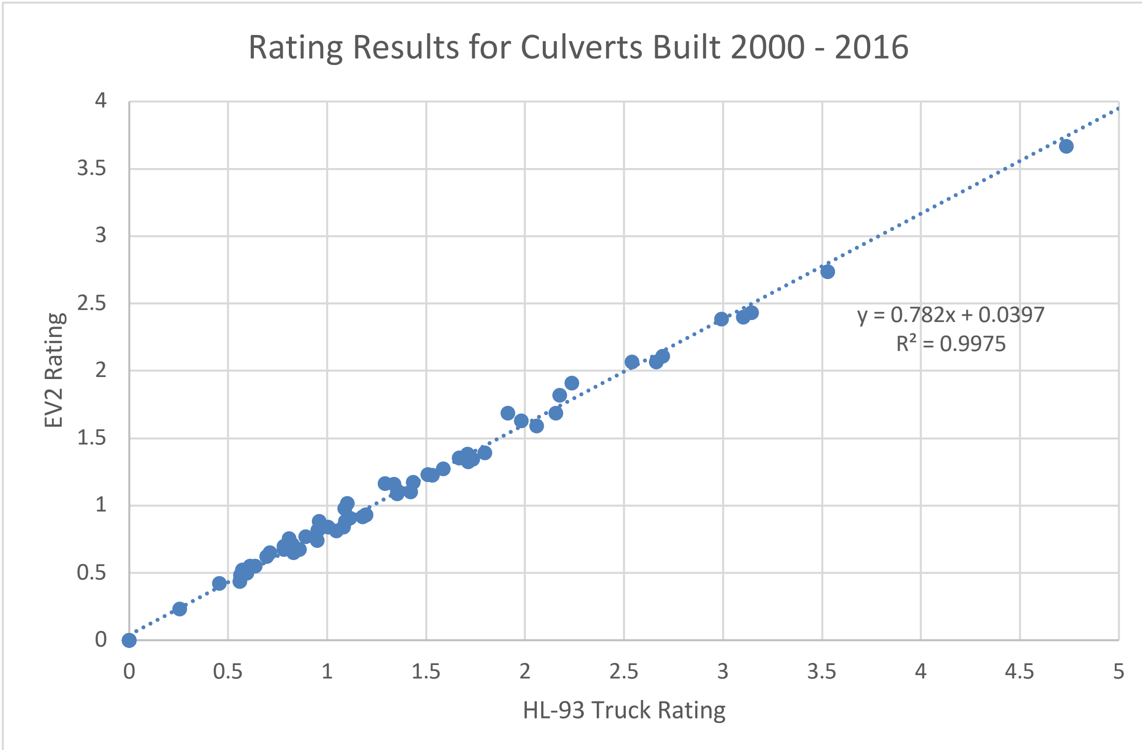


Figure 4.6: Original Analysis Rating Results EV2 vs. HL-93 Truck 2000 – 2016

The minimum R-squared value when the two ratings are compared is 0.9691 for the three date ranges. As shown, these linear regression equations could be used as a relatively accurate method for determining a structure's EV2 rating if the HL-93 Truck operating rating has previously been determined.

Figures 4.7, 4.8, and 4.9 below show the rating results for the EV3 loading configuration compared to the HL-93 tandem vehicle evaluated at the operating level for culverts built in three different date ranges: 1915 to 1950, 1951 to 1999, and 2000 to 2016.

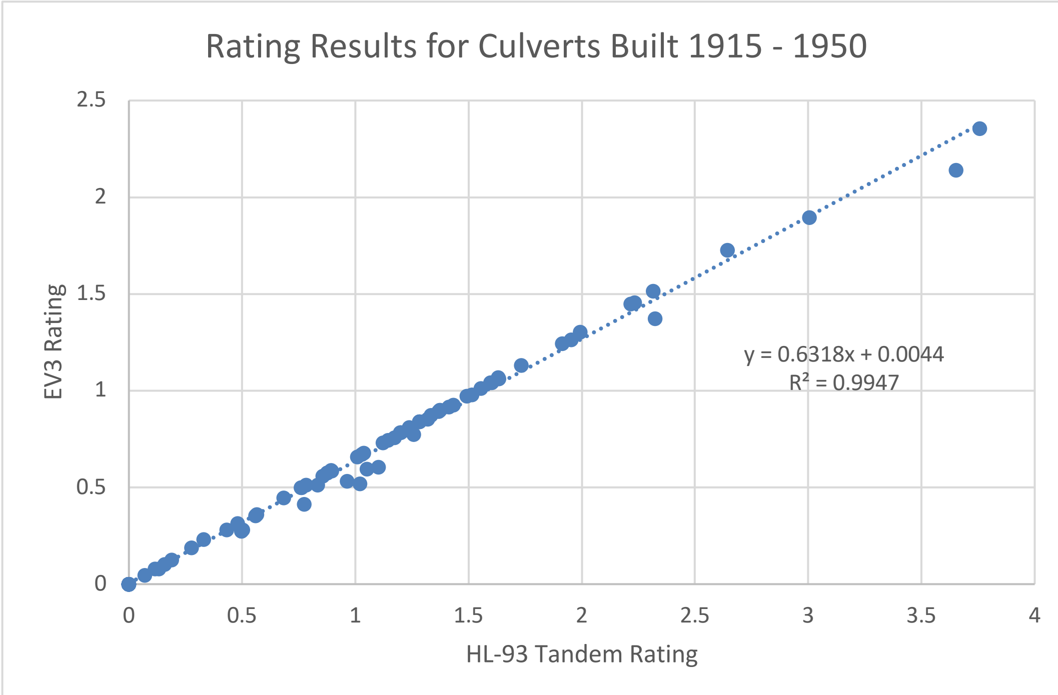


Figure 4.7: Original Analysis Rating Results EV3 vs. HL-93 Tandem 1915 – 1950

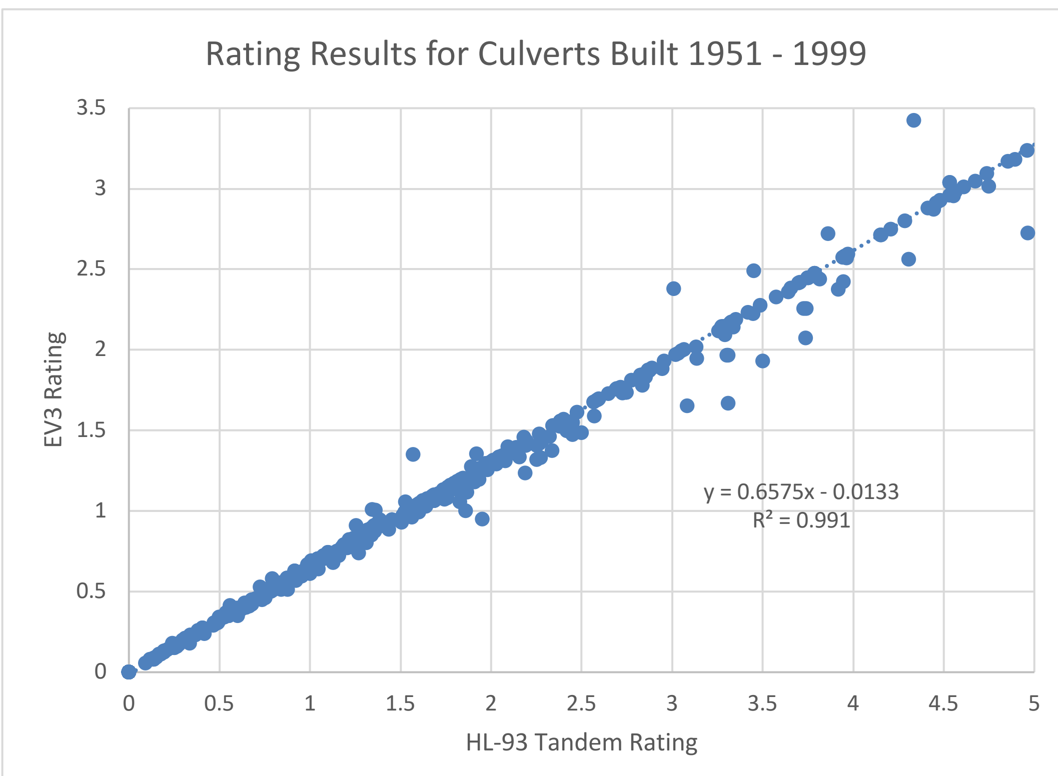


Figure 4.8: Original Analysis Rating Results EV3 vs. HL-93 Tandem 1951 – 1999

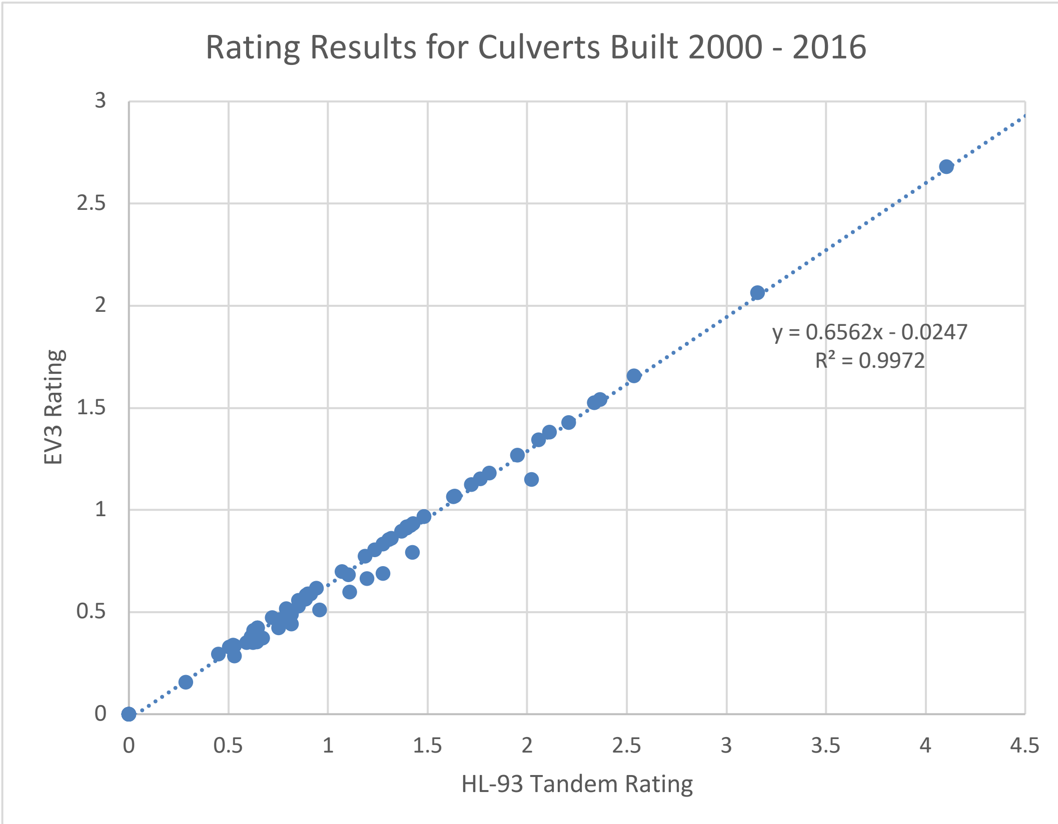


Figure 4.9: Original Analysis Rating Results EV3 vs. HL-93 Tandem 2000 – 2016

The minimum R-squared value when the two ratings are compared is 0.991 for the three date ranges. These linear regression equations showed excellent correlation between load ratings from EV3 truck and HL-93 tandem. Therefore, the equations could be used as a relatively accurate method for determining a structure's EV3 rating if the HL-93 Tandem operating rating has previously been determined.

Figures 4.10, 4.11, and 4.12 below show the rating results for the EV2 loading configuration compared to the HL-93 tandem vehicle evaluated at the operating level for culverts built in three different date ranges: 1915 to 1950, 1951 to 1999, and 2000 to 2016.

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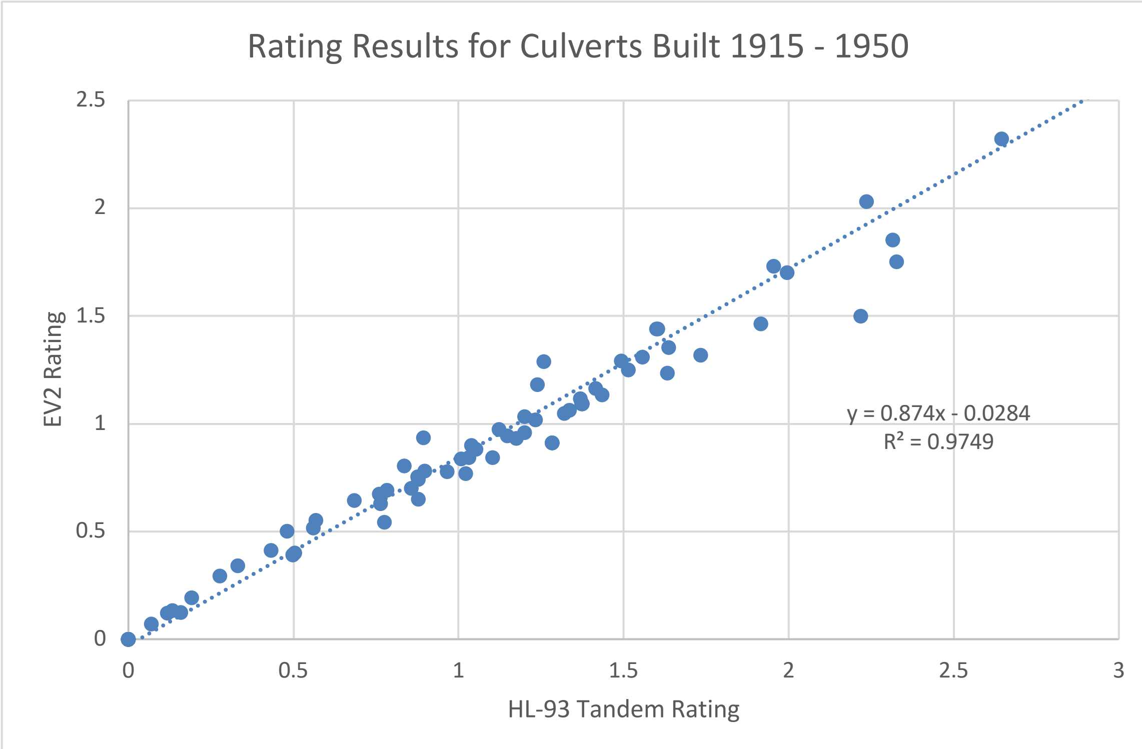

Figure 4.10: Original Analysis Rating Results EV2 vs. HL-93 Tandem 1915 – 1950

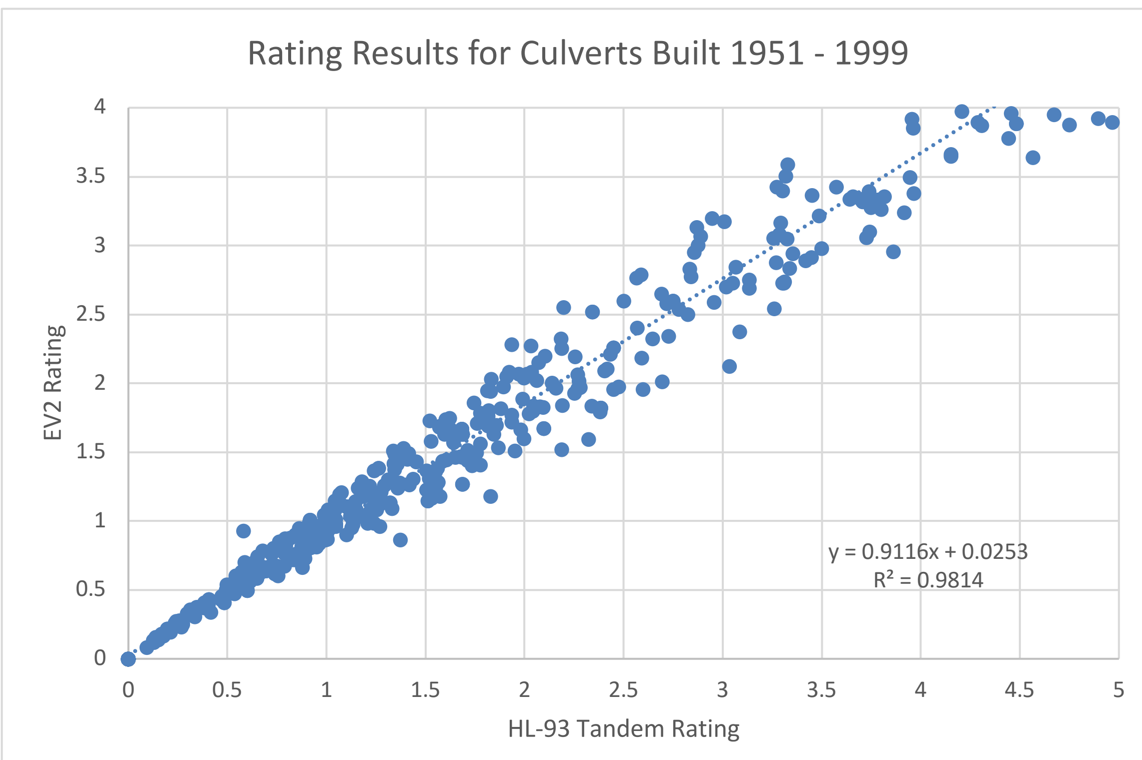

Figure 4.11: Original Analysis Rating Results EV2 vs. HL-93 Tandem 1951 – 1999

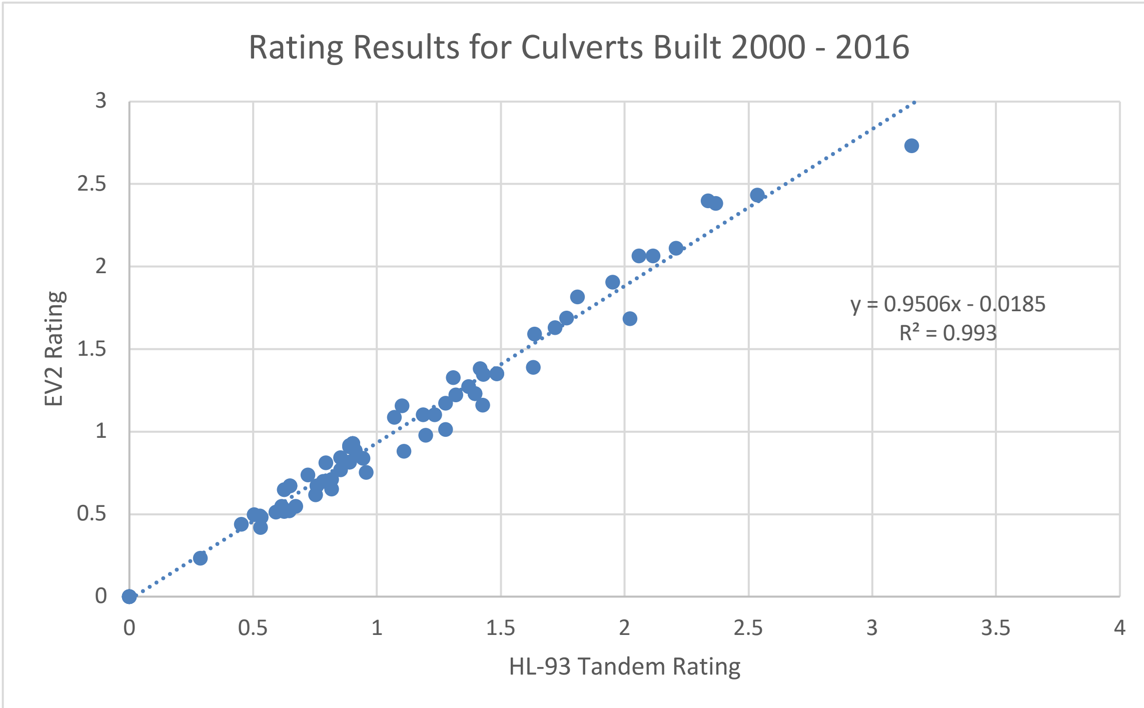

Figure 4.12: Original Analysis Rating Results EV2 vs. HL-93 Tandem 2000 – 2016

The minimum R-squared value when the two ratings are compared is 0.9749 for the three date ranges. The correlation between the rating factors of EV2 and HL-93 Tandem were obvious but not as good as the ones for EV3 and HL-93 Tandem. These linear regression equations calculated for these comparisons could be reasonably used as a relatively accurate method for determining a structure's EV2 rating if the HL-93 Tandem operating rating has previously been determined.

4.3 Alternate Analysis Rating Results

The results of the alternate analysis are reported in this section. As was the case with the original analysis, only culverts whose ratings were found to be less than 10 were included to eliminate outliers. Figures 4.13, 4.14, and 4.15 below show the rating results for the EV3 loading configuration compared to the HL-93 truck evaluated at the operating level for culverts built in three different date ranges: 1915 to 1950, 1951 to 1999, and 2000 to 2016.

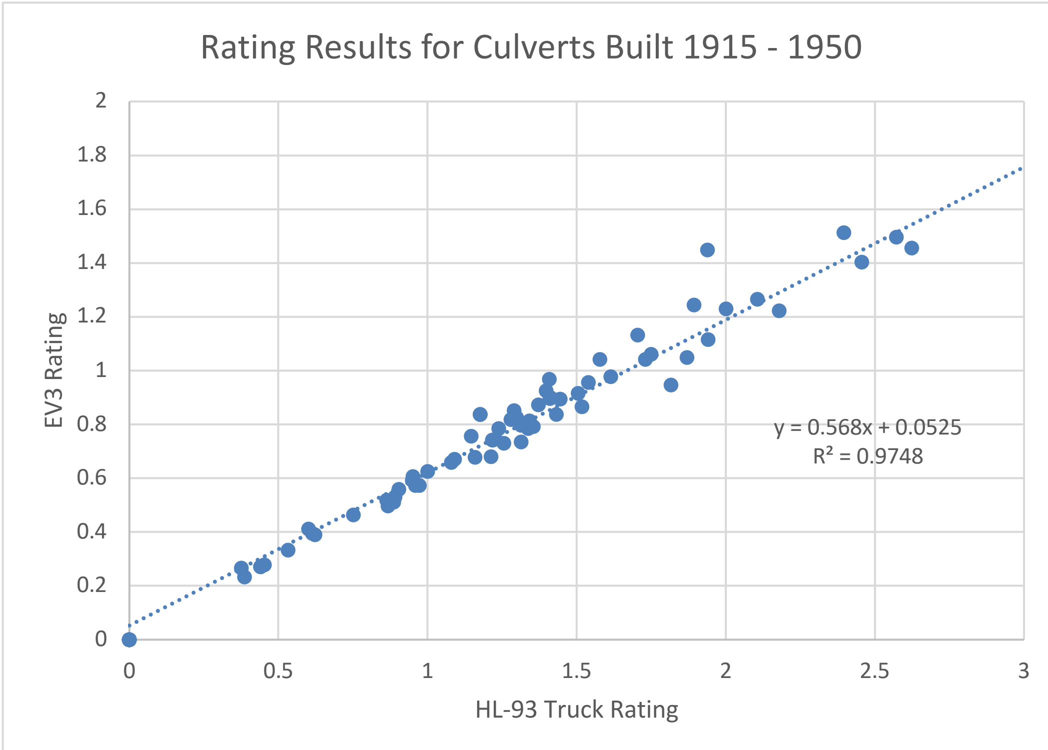

Figure 4.13: Alternate Analysis Rating Results EV3 vs. HL-93 Truck 1915 – 1950

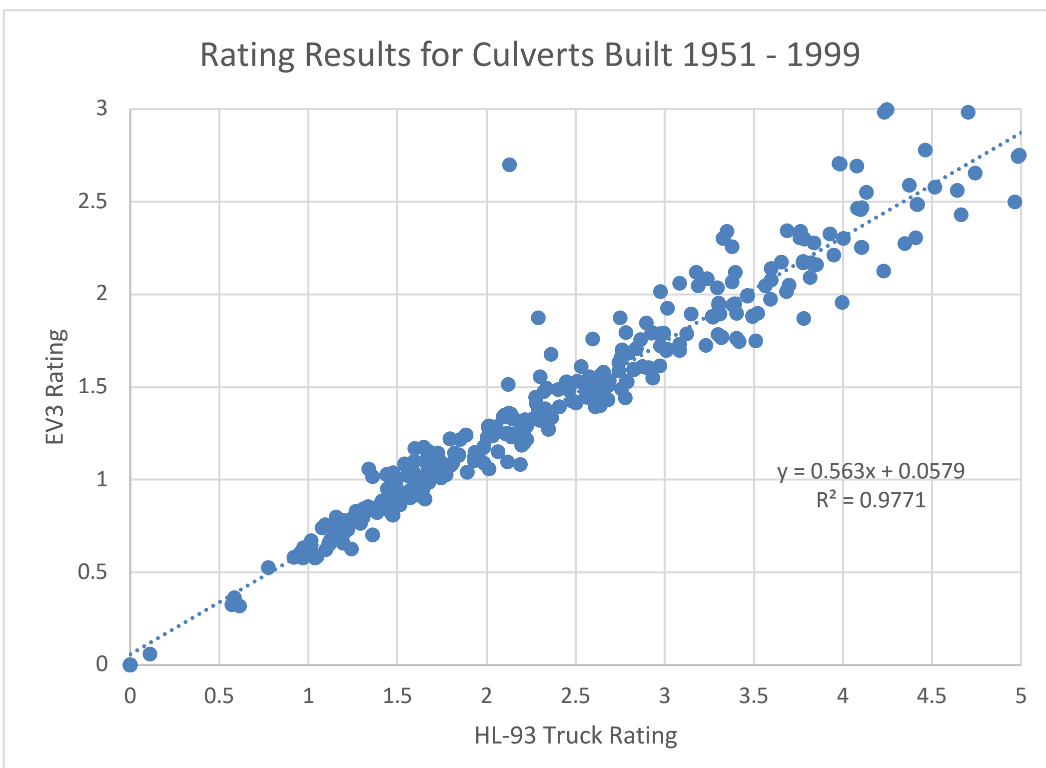

Figure 4.14: Alternate Analysis Rating Results EV3 vs. HL-93 Truck 1951 – 1999

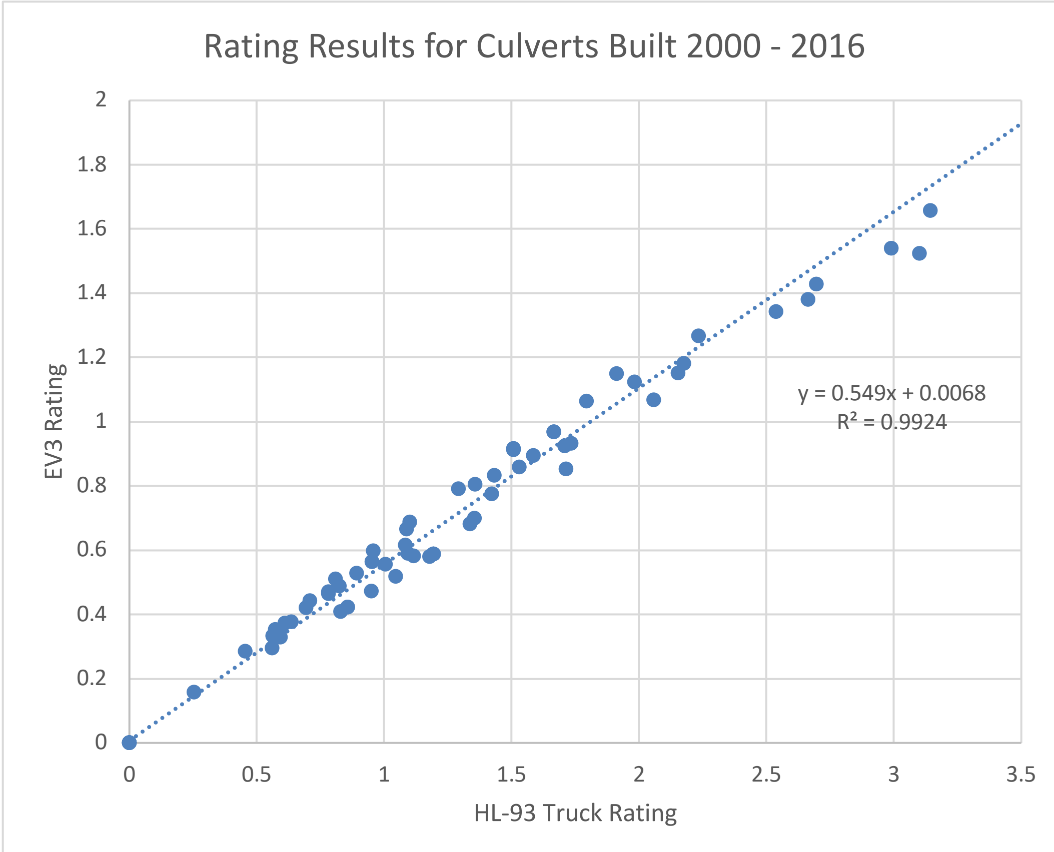

Figure 4.15: Alternate Analysis Rating Results EV3 vs. HL-93 Truck 2000 – 2016

The minimum R-squared value when the two ratings are compared is 0.9748 for the three date ranges. Similar conclusions can be drawn for the rating results of the alternate analysis. The comparison implies that the linear regression equations calculated for these comparisons could be reasonably used as a relatively accurate method for determining a structure's EV3 rating if the HL-93 Truck operating rating has previously been determined.

Figures 4.16, 4.17, and 4.18 below show the rating results for the EV2 loading configuration compared to the HL-93 truck evaluated at the operating level for culverts built in three different date ranges: 1915 to 1950, 1951 to 1999, and 2000 to 2016.

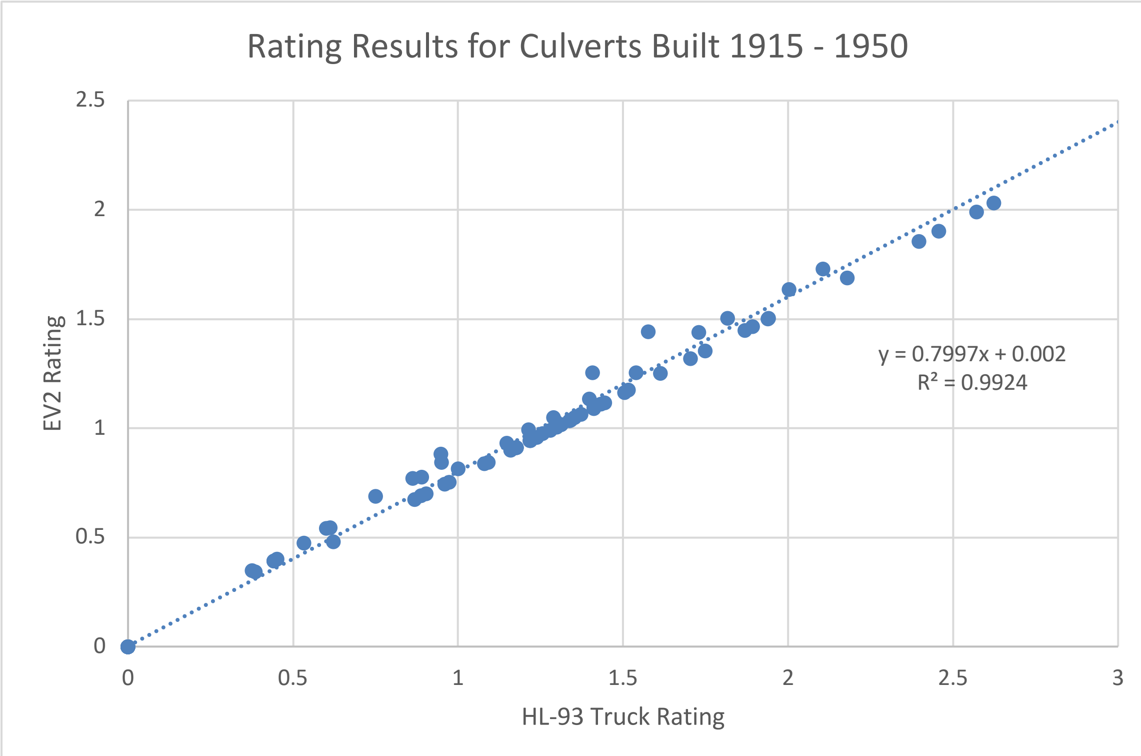

Figure 4.16: Alternate Analysis Rating Results EV2 vs. HL-93 Truck 1915 – 1950

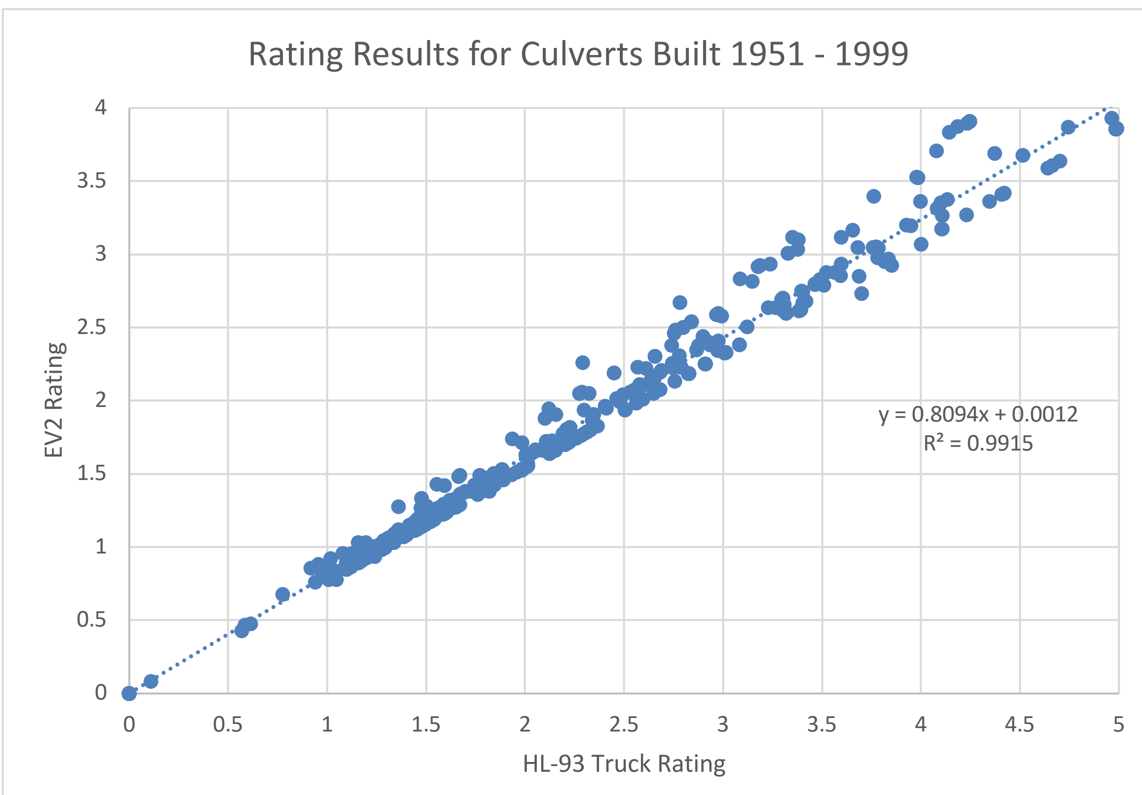

Figure 4.17: Alternate Analysis Rating Results EV2 vs. HL-93 Truck 1951 – 1999

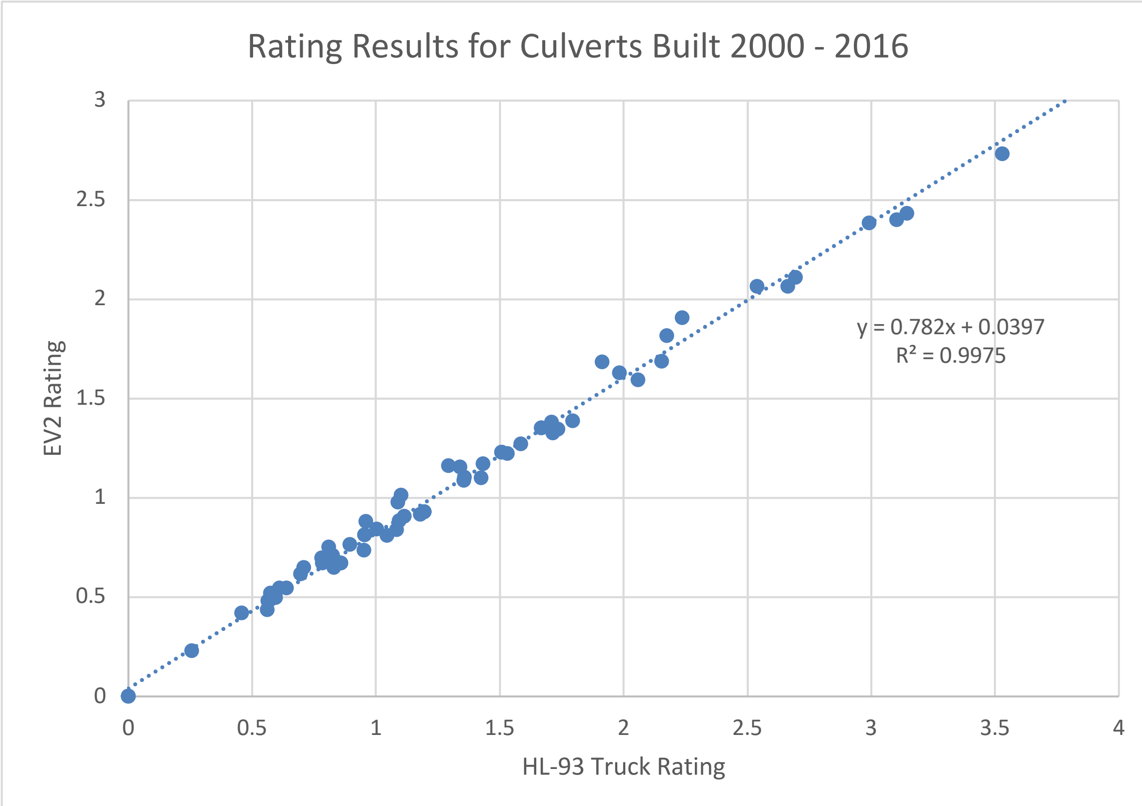

Figure 4.18: Alternate Analysis Rating Results EV2 vs. HL-93 Truck 2000 – 2016

The minimum R-squared value when the two ratings are compared is 0.9915 for the three date ranges. As shown, these linear regression equations could be used as a relatively accurate method for determining a structure's EV2 rating if the HL-93 Truck operating rating has previously been determined.

Figures 4.19, 4.20, and 4.21 below show the rating results for the EV3 loading configuration compared to the HL-93 tandem vehicle evaluated at the operating level for culverts built in three different date ranges: 1915 to 1950, 1951 to 1999, and 2000 to 2016.

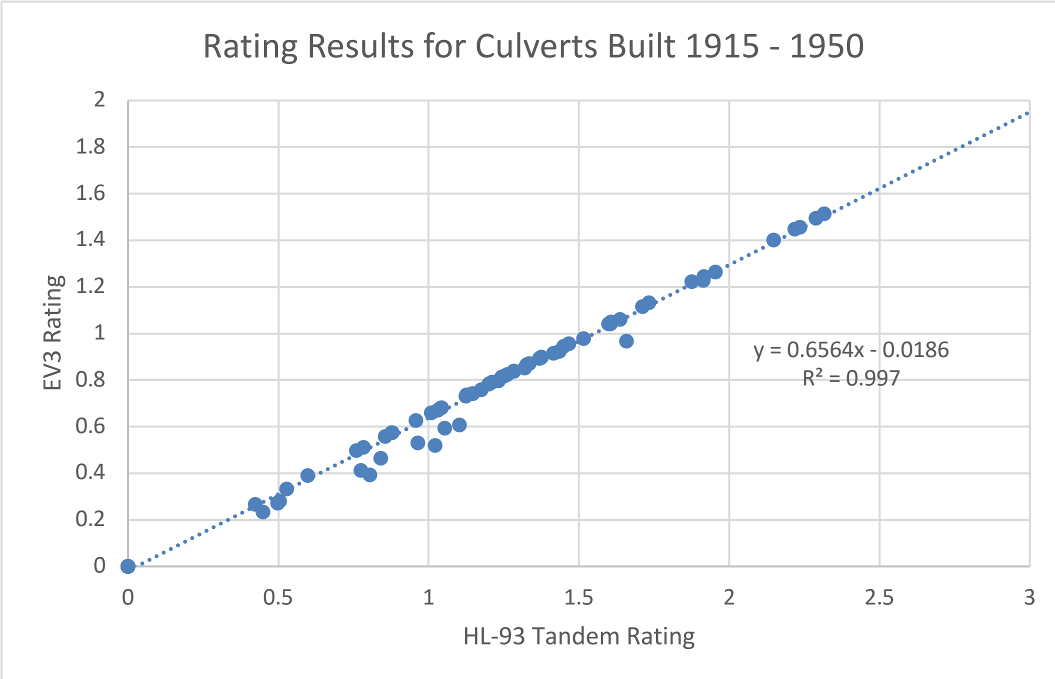

Figure 4.19: Alternate Analysis Rating Results EV3 vs. HL-93 Tandem 1915 – 1950

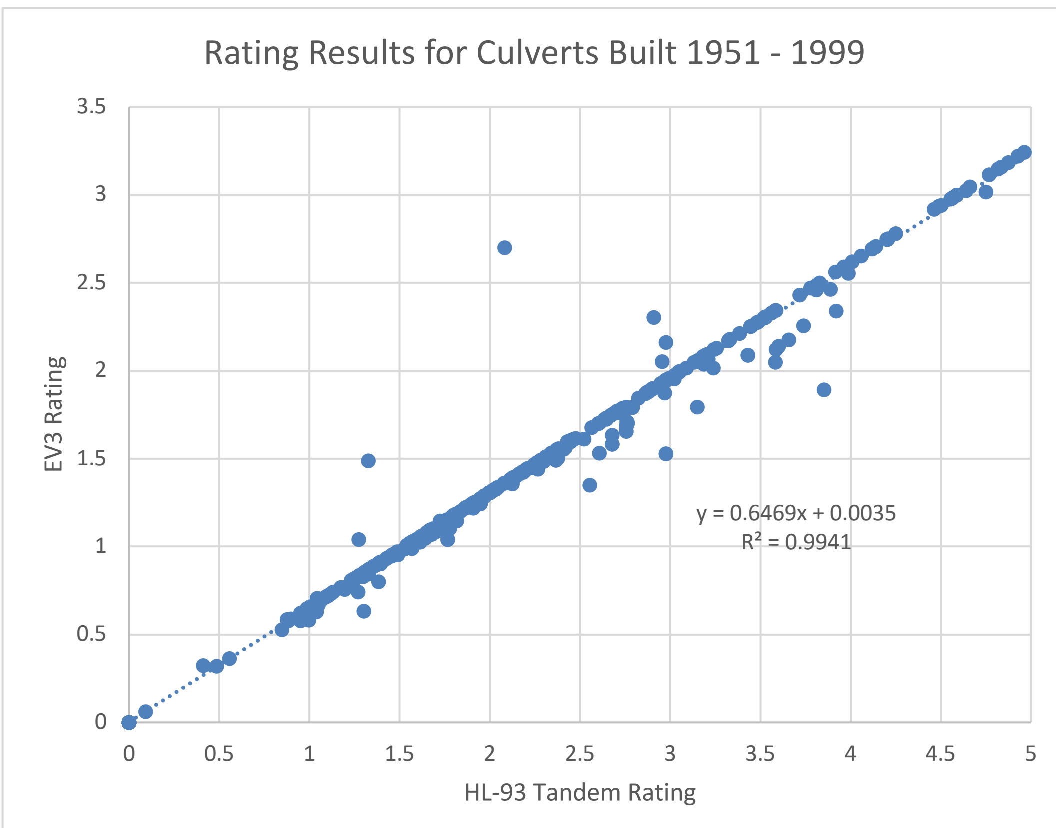

Figure 4.20: Alternate Analysis Rating Results EV3 vs. HL-93 Tandem 1951 – 1999

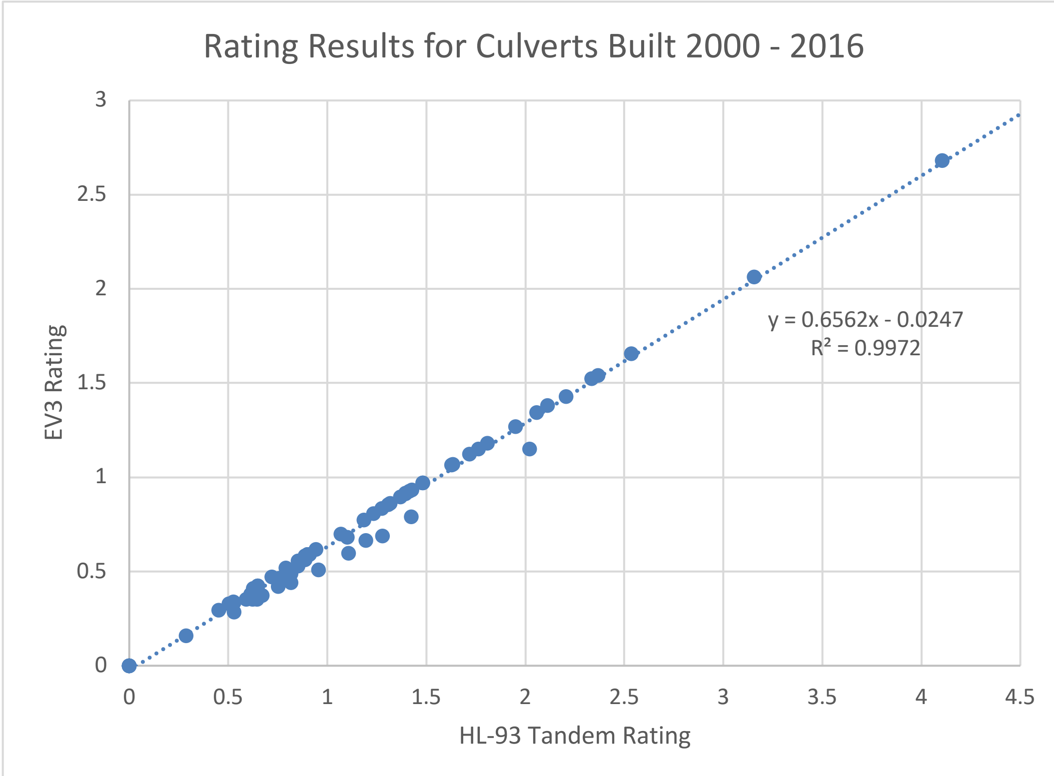

Figure 4.21: Alternate Analysis Rating Results EV3 vs. HL-93 Tandem 2000 – 2016

The minimum R-squared value when the two ratings are compared is 0.9941 for the three date ranges. Similar to the original analysis results, these linear regression equations showed excellent correlation between load ratings from EV3 truck and HL-93 tandem. Therefore, the equations could be used as a relatively accurate method for determining a structure's EV3 rating if the HL-93 Tandem operating rating has previously been determined.

Figures 4.22, 4.23, and 4.24 below show the rating results for the EV2 loading configuration compared to the HL-93 tandem vehicle evaluated at the operating level for culverts built in three different date ranges: 1915 to 1950, 1951 to 1999, and 2000 to 2016.

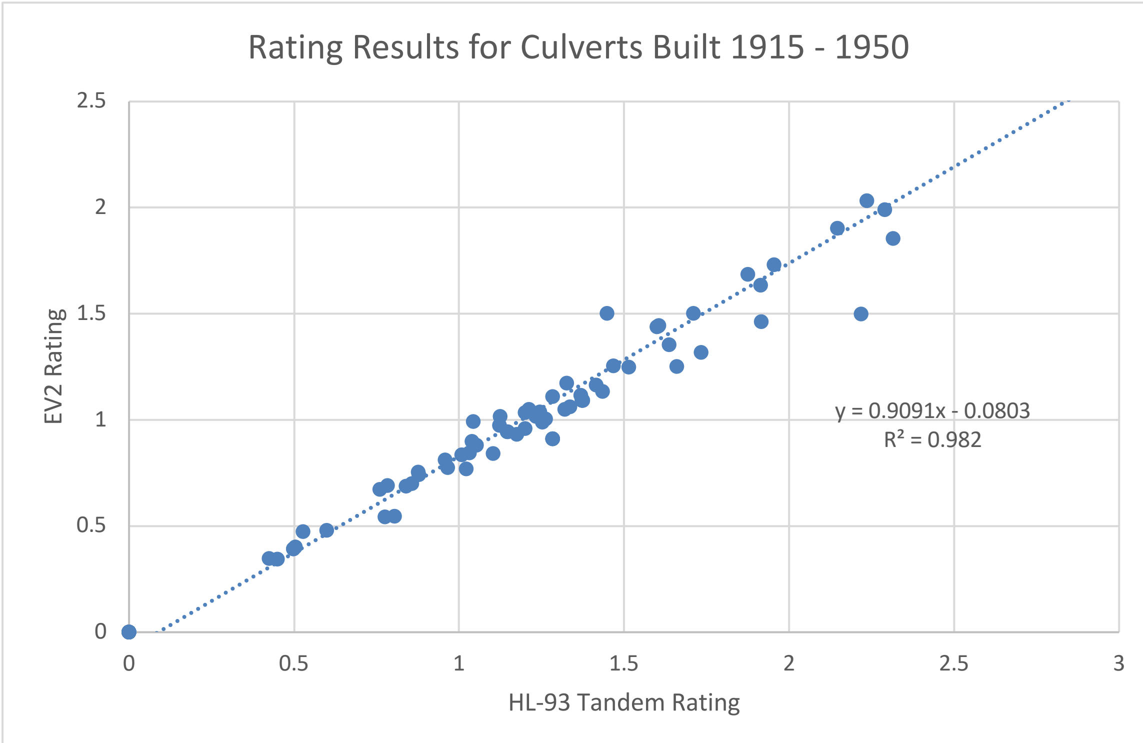

Figure 4.22: Alternate Analysis Rating Results EV2 vs. HL-93 Tandem 1915 – 1950

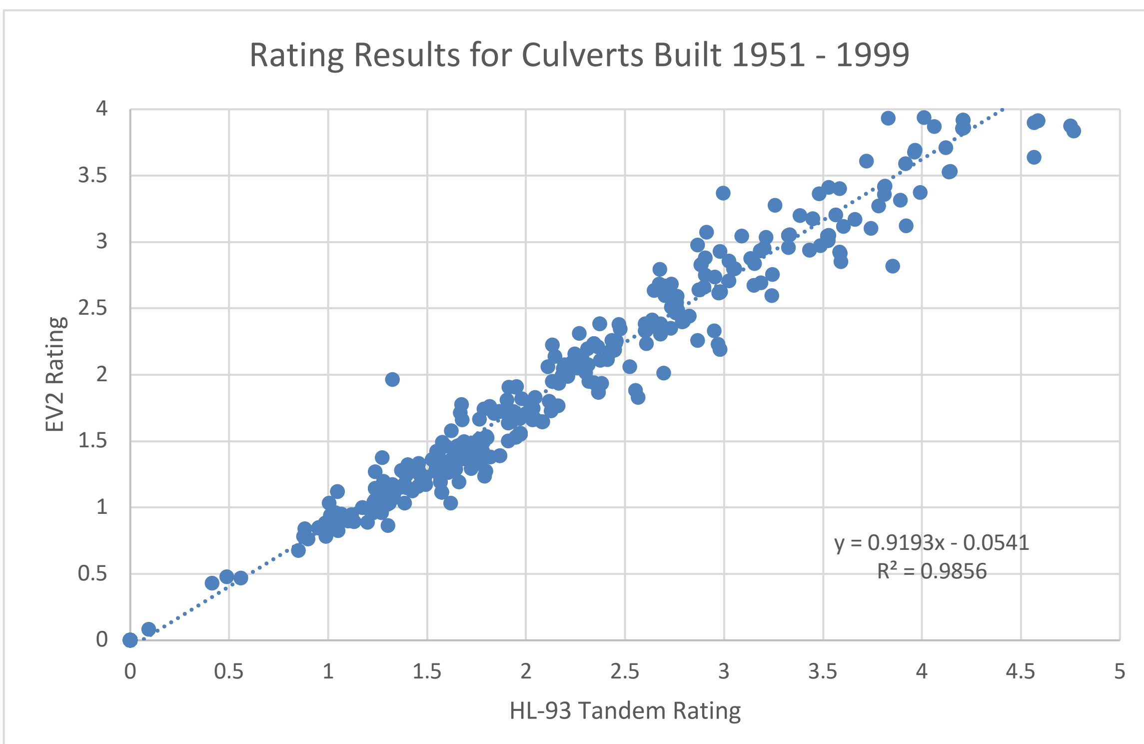

Figure 4.23: Alternate Analysis Rating Results EV2 vs. HL-93 Tandem 1951 – 1999

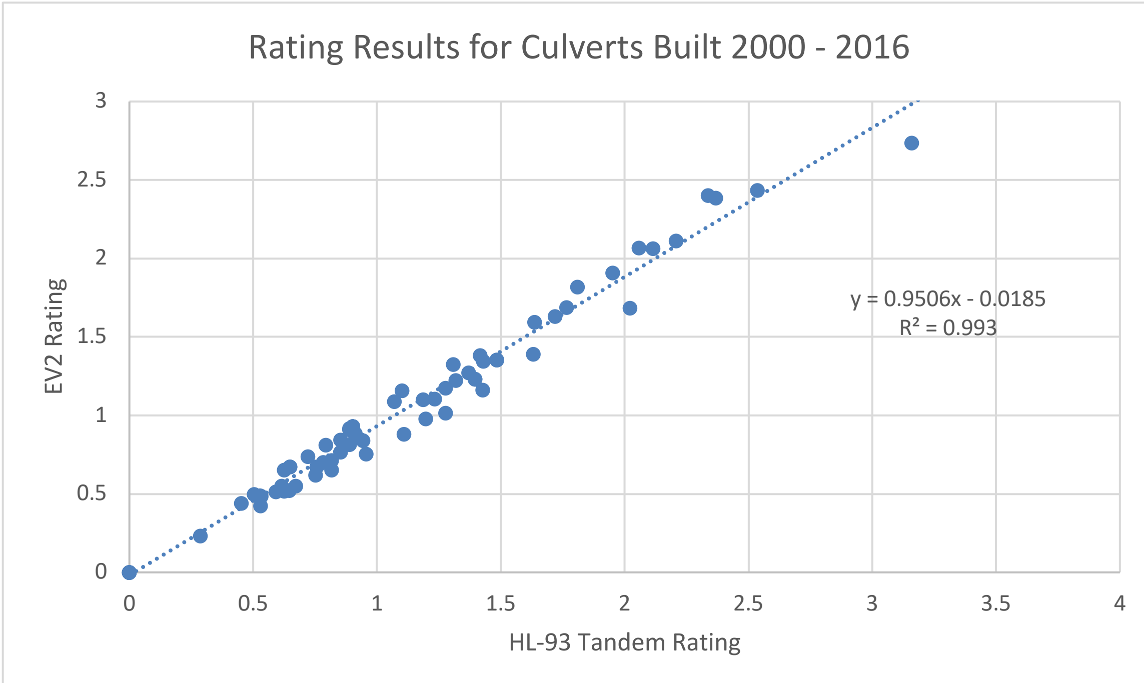

Figure 4.24: Alternate Analysis Rating Results EV2 vs. HL-93 Tandem 2000 – 2016

The minimum R-squared value when the two ratings are compared is 0.982 for the three date ranges. These linear regression equations calculated for these comparisons could be reasonably used as a relatively accurate method for determining a structure's EV2 rating if the HL-93 Tandem operating rating has previously been determined.

4.4 Recommended Posting Loads

Load posting is recommended when culverts ratings obtained from structural modeling for legal loads are less than one. The general procedure for posting is described in section 2.1.3 for the LRFR method. The general equation for load posting is based on equation 6A.8.3-1 and is shown below

$$Safe\ Posting\ Load = \frac{W}{0.7}[(RF) - 0.3] \quad (6A.8.3\text{-}1)$$

Where W is the weight of the rating vehicle in tons, and RF is the load rating factor determined by the engineer. This equation only determines the recommended gross vehicle weight to be posted for a given bridge

For the new FAST Act, the FHWA included a new procedure for posting for the new emergency vehicle loading configurations EV2 and EV3. This procedure is discussed in section 2.3.2, and includes recommended posting limits for a single axle weight, a tandem axle weight, and the vehicle's gross weight. The process for determining the three recommended posting limits for emergency vehicle loading is shown in Figure 2.11 in previous section.

Upon completion of load rating all culverts affected by new emergency vehicle loading, the previous LRFR load posting procedure and the new emergency vehicle load posting procedure were followed to determine what posting loads, if any, would be recommended. Table 4.5 reports rating results for some of the culverts included in the original analysis.

Table 4.5: A Set of Rating Results for Culverts Affected by Emergency Vehicle Loads

	Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	EV3 Legal Rating	EV2 Legal Rating	HL-93 Operating Tandem Rating	HL-93 Operating Axle Load Rating
1	2003	2	10	7	0.589	0.929	0.902	1.194
2	1960	2	10	6	0.459	0.661	0.703	0.854
3	1973	3	12	10	0.925	1.448	1.408	1.666
4	1992	2	12	7	0.501	0.795	0.787	1.008
5	1987	2	10	8	0.932	1.366	1.506	1.717
6	1935	2	10	4	0.898	1.093	1.375	1.412
7	1973	3	10	6	0.613	0.909	1.001	1.153
8	1964	3	9	9	0.953	1.512	1.951	1.713
9	2014	3	18	8	0.688	1.014	1.278	1.1
10	1960	2	12	8	0.779	1.091	1.227	1.222

The table includes the year the culvert was built and the culvert's geometry. The table also shows the rating factors determined from the analysis for EV3 and EV2 legal loads and HL-93 truck and tandem operating loads. Based on the rating results shown in Table 4.5, Table 4.6 below shows the posting loads that would be required for these culverts based on the existing LRFR posting procedure and the new emergency vehicle loading procedure.

Table 4.6: A Set of Recommended Posting Loads for Culverts Affected by EV2/EV3 Loading

	Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	EV2/EV3 Single Axle Posting Load (tons)	EV2/EV3 Tandem Posting Load (tons)	EV2/EV3 Gross Posting Load (tons)	HL-93 Gross Posting Load (tons)
1	2003	2	10	7	16	18	25	22
2	1960	2	10	6	11	14	19	14
3	1973	3	12	10	17	29	40	N/A
4	1992	2	12	7	13	16	22	17
5	1987	2	10	8	17	29	40	N/A
6	1935	2	10	4	17	28	39	N/A
7	1973	3	10	6	15	19	26	N/A
8	1964	3	9	9	17	30	41	N/A
9	2014	3	18	8	17	21	30	N/A
10	1960	2	12	8	17	24	33	N/A

This table includes a single axle posting load as well as restrictions on tandem axle and gross vehicle weight based on EV2 and EV3 load posting procedure. In addition, the last column in the table displays the tonnage to be posted for the gross vehicle weight limit based on a culvert's HL-93 rating determined using the LRFR load posting procedure. The posting loads required for all culverts affected by EV2 and EV3 loads based on the original analysis are shown in Appendix B.

The existing LRFR load posting procedure does not include restrictions on single axle weight or tandem axle weight, but it does restrict the gross vehicle weight based on the results of the rating investigation. This vehicle posting load was compared to the new posting load based on EV2 and EV3 loading. On average, it was found that the recommended posting load for the existing process was 42% higher based on the original analysis. This means the recommended limitations determined by the new emergency vehicle posting procedure are more restrictive. Lighter trucks than the existing procedure are recommended to be prevented from traversing structures.

In Table 4.6, "N/A" indicates a posting load is not required for a given culvert due to a sufficient rating factor. There are quite a few culverts whose HL-93 rating does not require posting, but their EV2 or EV3 rating do require posting. In total, there are 129 culverts with recommended posting due to EV2 and EV3 loads that do not have recommended posting for HL-93 loads. Of the 827 culverts analyzed in the original analysis 301 culverts are recommended to be load posted for at least one of the three restrictions.

For the alternate analysis, 186 culverts have recommended posting loads for one of the restrictions. This includes 124 culverts with recommended posting due to EV2 and EV3 loads that do not have recommended posting for HL-93 loads. Among culverts with gross vehicle restrictions recommended for load posting procedures, posting loads are decreased by an average of 10%. Again, this means that, on average, the recommended limitations determined by the new emergency vehicle posting procedure are more restrictive. Lighter trucks than the existing LRFR procedure are recommended to be prevented from traversing structures. The posting loads recommended based on the rating results of the alternate analysis are included in Appendix C.

CHAPTER 5 ANALYTICAL STUDY OF CULVERTS AFFECTED BY EMERGENCY VEHICLE LOADING

Additional analytical study was performed to determine the impact that the new loading configurations, EV2 and EV3, have on the rating of concrete culverts across Tennessee. It involved a parametric study to determine if there exists any correlation between rating results and different culvert characteristics as well as an additional analysis that was performed on culverts affected by emergency vehicle loading that have 0' fill. The results of the parametric study for both the original and alternative analysis are summarized in section 5.1 and the analysis of culverts that have 0' fill present are discussed in Section 5.2. Section 5.3 includes the rating results between EV2/EV3 loads and HL-93 inventory loading for various fill depths.

5.1 Parametric Study

A parametric study of the concrete culvert rating results was performed. The main goal of the study was to determine the impact that new loading configurations have on culverts compared to existing HL-93 loading evaluated at the operating level. Since many factors go into a given culvert's rating, it was decided that it would not be beneficial to compare the results of one culvert to another. The contributing factors are too numerous to standardize. Rather, it was determined that the results of different loading configurations should be compared on a per culvert basis to see on average what kind of difference exists between the various loading configurations.

Additionally, to avoid inconsistencies in trends due to outliers and to ensure the data reflects the changes due to live load and not primarily controlled by dead load, only culverts whose ratings ranged from 0.6 to 6.0 were selected to be analyzed. Culverts with ratings outside of this range are typically controlled by dead load resulting from deeper fill depths. The deeper the fill depth present, the smaller percentage of live load that gets developed into the top slab of the culvert. If the amount of live load present is minimal, it would be difficult to determine what kind of effect variable wheel loading configurations would potentially have on a given structure.

5.1.1 Study on Original Analysis Ratings

For this study, average ratio of rating results of EV load and HL-93 load for 449 culverts that had controlling ratings between 0.6 and 6.0 were examined. The parameters or variables investigated in this study include: year of culvert built, fill depth of culvert, culvert span length and culvert clear height. The average ratios were determined by dividing the emergency vehicle ratings by the HL-93 truck and tandem operating ratings for each culvert, and then averaging the ratios for a given range of those identified parameters. A regression analysis of the average ratios was performed to see if any relationship or general trend could be found between the average ratios and the parameters studied. This procedure was repeated for the various parameters examined in this study.

a. Year of Culvert Built

Table 5.1 tabulates data of average rating ratio by year of built based on the Original Analysis ratings. Figure 5.1 shows the EV2 to HL-93 tandem average ratio gets closer to 1.0 as the culvert age gets younger. This shows that the difference in EV2 rating and HL-93 tandem rating decreases through the years. The EV3 to HL-93 tandem ratio and the EV2 to HL-93 truck ratio stays roughly the same for any culvert construction date. The EV3 to HL-93 truck ratio decreases as culvert age decreases which shows that the difference between the ratings increases for newer culverts.

Table 5.1: Original Analysis Average Rating Ratio by Year of Built

Year of Built	Number of Culverts	EV2/HL-93 Truck Average Ratio	EV3/HL-93 Truck Average Ratio	EV2/HL-93 Tandem Average Ratio	EV3/HL-93 Tandem Average Ratio
1925 - 1949	34	0.804	0.632	0.820	0.643
1950 - 1959	24	0.796	0.6	0.866	0.645
1960 - 1964	59	0.813	0.588	0.886	0.639
1965 - 1969	69	0.809	0.575	0.927	0.654
1970 - 1979	76	0.826	0.575	0.927	0.640
1980 - 1989	72	0.803	0.544	0.969	0.653
1990 - 1999	80	0.792	0.553	0.945	0.656
2000 -	35	0.81	0.557	0.933	0.641

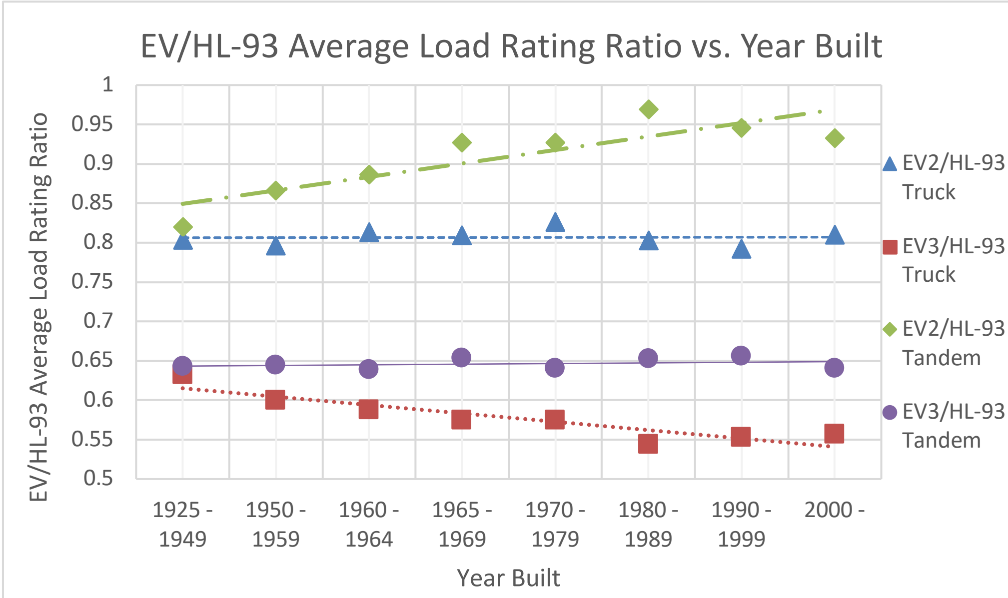

Figure 5.1: Original Analysis Average Rating Ratio vs. Year Built

As shown in Figure 5.1 above, all four average ratios of EV loads vs. HL-93 loads are less than one for any years that the culverts were built. This means that on average, EV2 and EV3 rating results are less than HL-93 truck and tandem ratings at the operating rating level regardless of the year the culvert was built.

b. Fill Depth of Culvert

Table 5.2 below shows the tabulated data for average rating ratios compared to the depth of fill present for the original analysis. Figure 5.2, below, shows the comparison graphically.

Table 5.2: Original Analysis Average Rating Ratio by Fill Depth

Fill Depth	Number of Culverts	EV2/HL-93 Truck Average Ratio	EV3/HL-93 Truck Average Ratio	EV2/HL-93 Tandem Average Ratio	EV3/HL-93 Tandem Average Ratio
0'	124	0.797	0.575	0.911	0.651
0.5' - 1.0'	53	0.802	0.582	0.897	0.644
1.5' - 2.0'	45	0.787	0.545	0.947	0.651
2.5' - 3.5'	46	0.797	0.547	0.930	0.635
4.0' - 4.5'	45	0.804	0.560	0.928	0.642
5.0' - 5.5'	31	0.832	0.592	0.915	0.645
6.0' - 6.5'	32	0.817	0.591	0.898	0.645
7.0' - 9.0'	30	0.849	0.600	0.917	0.645
9.5' -	42	0.826	0.571	0.957	0.661

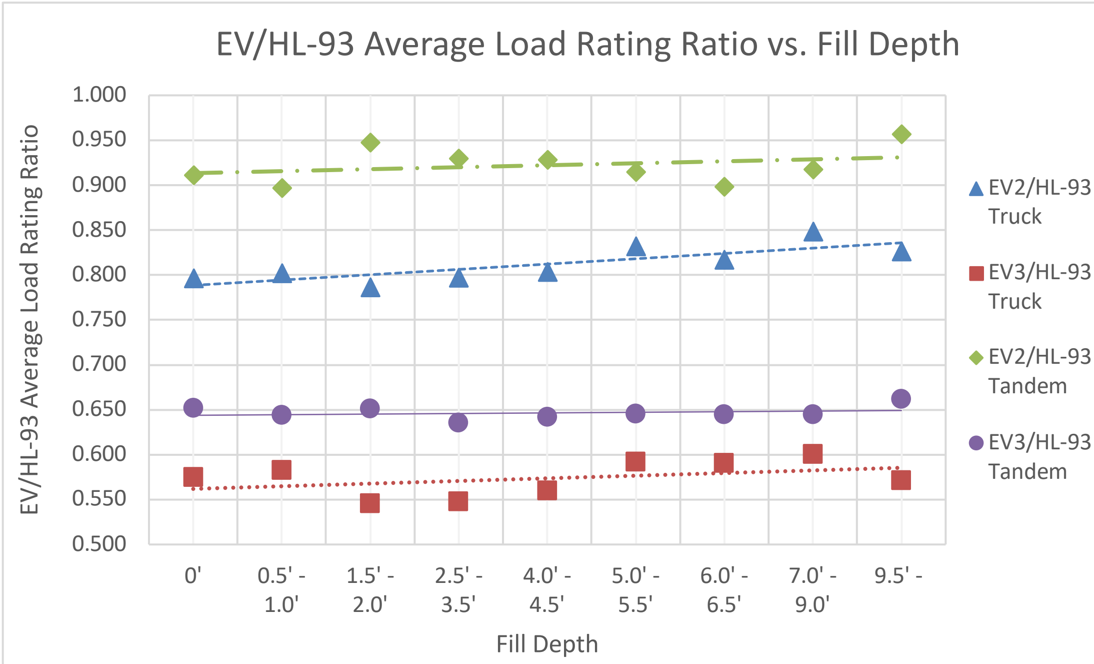

Figure 5.2: Original Analysis Average Rating Ratio vs. Fill Depth

It can be seen from Figure 5.2 that the four average ratios between emergency vehicle loading and HL-93 loads are less than one for any range of fill depth, which indicates that the average EV2 and EV3 rating is less than the HL-93 rating regardless of the fill depth present. Figure 5.2 also shows that, in general, the difference between the EV2 ratings and HL-93 truck ratings as well as EV3 ratings and HL-93 truck ratings decreases as fill depth increases. However, for the other two ratios EV2 vs HL-93 tandem and EV3 vs. HL-93 tandem, there is no significant change.

c. Culvert Span Length

Table 5.3 shows the average rating ratios of EV loads and HL-93 loads by culvert span length.

Table 5.3: Original Analysis Average Rating Ratio by Span Length

Span Length	Number of Culverts	EV2/HL-93 Truck Average Ratio	EV3/HL-93 Truck Average Ratio	EV2/HL-93 Tandem Average Ratio	EV3/HL-93 Tandem Average Ratio
6' - 9'	42	0.803	0.601	0.878	0.648
10'	204	0.803	0.590	0.878	0.643
11' - 12'	91	0.799	0.553	0.945	0.650
13'- 15'	83	0.828	0.545	0.993	0.651
16' -	29	0.818	0.540	0.996	0.659

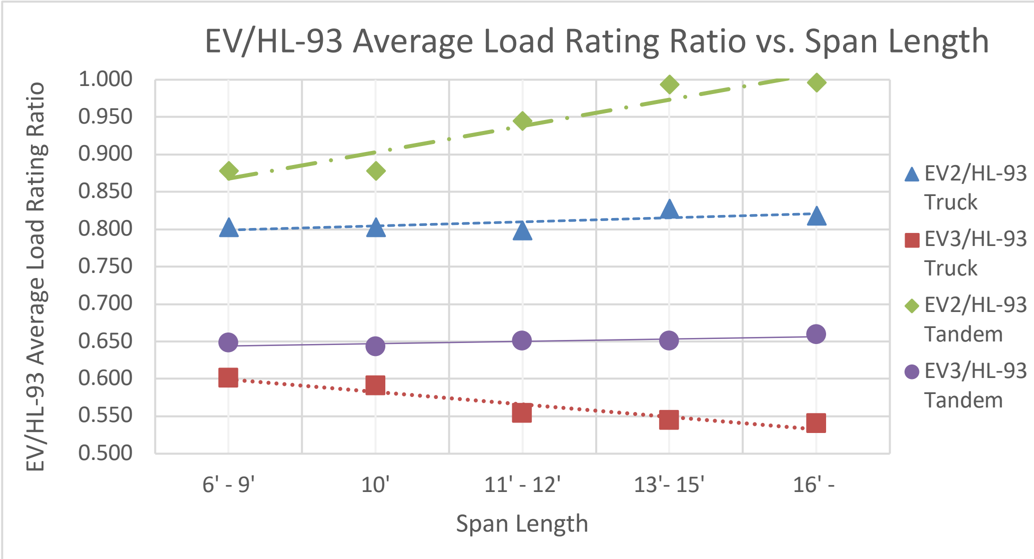

Figure 5.3: Original Analysis Average Rating Ratio by Span Length

Figure 5.3 shows that the four ratios between emergency vehicle rating and HL-93 rating are less than one for all span lengths. This means that the EV2 and EV3 rating is on average less than HL-93 rating for any culvert span length.

Figure 5.3, also shows that the EV2 rating decreases faster than the HL-93 tandem rating as culvert span increases since the trendline gets closer to 1.0 for larger span lengths. The trendlines for EV2 vs. HL-93 truck ratings and EV3 vs. HL-93 tandem ratings do not show any significant change. This means that the difference between the ratings does not change as span length increases. In contrast, EV3 vs. HL-93 truck rating ratios decrease as span length increases which shows that, in general, as the span length increases the EV3 rating decreases faster compared to the HL-93 truck load.

d. Culvert Clear Height

In Table 5.4 below, results are shown for average rating ratios based on the clear height of the culvert. Figure 5.4 compares the average ratio to the clear height.

Table 5.4: Original Analysis Average Rating Ratio by Culvert Clear Height

Clear Height	Number of Culverts	EV2/HL-93 Truck Average Ratio	EV3/HL-93 Truck Average Ratio	EV2/HL-93 Tandem Average Ratio	EV3/HL-93 Tandem Average Ratio
3' -4'	23	0.811	0.586	0.888	0.641
5'	31	0.802	0.592	0.871	0.640
6'	83	0.805	0.576	0.913	0.648
7'	45	0.802	0.569	0.928	0.657
8'	95	0.809	0.569	0.923	0.646
9'	28	0.810	0.567	0.919	0.639
10'	80	0.808	0.579	0.918	0.650
11' - 12'	42	0.804	0.546	0.966	0.647
13' - 18'	22	0.826	0.568	0.953	0.649

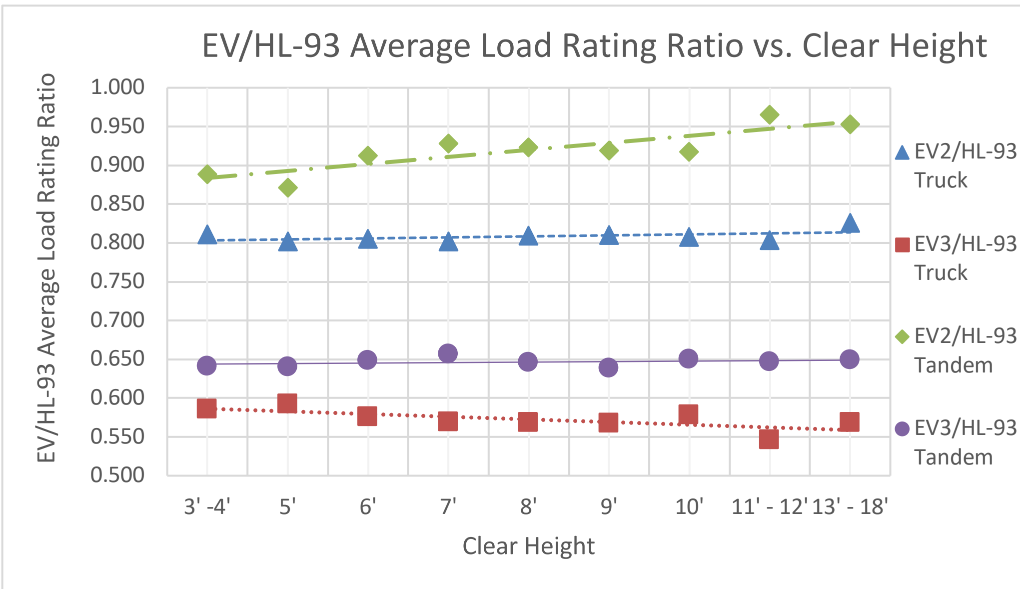

Figure 5.4: Original Analysis Average Rating Ratio vs. Clear Height

The average ratio between emergency vehicle ratings and HL-93 ratings is less than one for all clear heights. This means that the EV2 and EV3 ratings are, on average, less than the HL-93 ratings for culverts of any clear height.

In general, Figure 5.4 above shows that the EV2 vs. HL-93 tandem ratio gets closer to 1.0 as clear height increases, meaning the difference between the two ratings is decreasing. As clear height increases, the ratio between EV2 ratings vs. the HL-93 truck ratings does not significantly change, this is also true for the ratio between EV3 and HL-93 tandem ratings and EV3 versus HL-93 truck ratings.

5.1.2 Alternate Analysis Study

Rating results of 562 culverts that have controlling ratings between 0.6 and 6.0 were used in the parametric study for the alternate analysis. Same four parameters, year of culvert built, fill depth of culvert, culvert span length and culvert clear height, were investigated for the rating results from alternate analysis.

a. Year of Culvert Built

Table 5.5 tabulates the average ratios of emergency vehicle ratings compared to HL-93 truck and tandem operating ratings for a given range of year of built. Figure 5.5 shows the average rating ratios between EV loads and HL-93 loads vs. the year culverts were built.

Table 5.5: Alternate Analysis Average Rating Ratio by Construction Date

Construction Date	Number of Culverts	EV2/HL-93 Truck Average Ratio	EV3/HL-93 Truck Average Ratio	EV2/HL-93 Tandem Average Ratio	EV3/HL-93 Tandem Average Ratio
1915 - 1939	26	0.791	0.633	0.808	0.645
1940 - 1949	15	0.802	0.614	0.852	0.651
1950 - 1959	35	0.800	0.605	0.865	0.649
1960 - 1969	152	0.824	0.613	0.875	0.648
1970 - 1979	99	0.813	0.595	0.892	0.649
1980 - 1989	103	0.795	0.590	0.881	0.651
1990 - 1999	97	0.795	0.584	0.891	0.651
2000 -	35	0.810	0.557	0.933	0.641

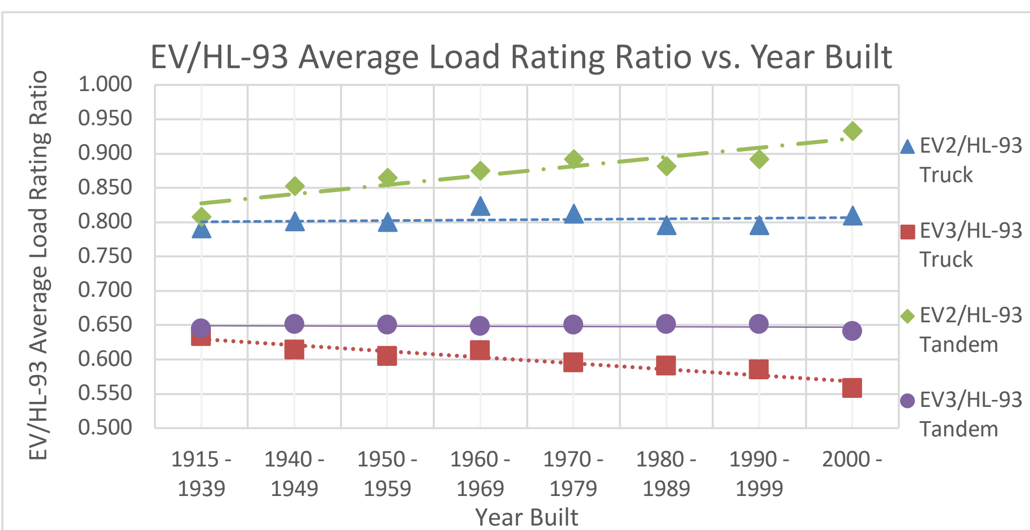

Figure 5.5: Alternate Analysis Average Rating Ratio vs. Year Built

A few trends can be observed from Figure 5.5. All four average rating ratios are less than one for any years that the culverts were built, which meant, on average, EV2 and EV3 rating results are less than HL-93 truck and HL-93 tandem ratings evaluated at the operating rating level regardless of the year the culvert was built. Figure 5.5 also shows the EV2 to HL-93 tandem average ratio gets closer to 1.0 as the culvert age gets younger. This shows that the difference in EV2 rating and HL-93 tandem rating decreases through the years. The EV3 to HL-93 tandem ratio and the EV2 to HL-93 truck ratio stays roughly the same for any culvert construction date. The EV3 to HL-93 tandem ratio in general decreases as culvert age decreases which shows that the difference between the ratings increases for newer culverts.

b. Fill Depth of Culvert

Table 5.6 below shows the tabulated data for average rating ratios compared to the depth of fill present for the original analysis. Figure 5.6 shows the comparison graphically.

Table 5.6: Alternate Analysis Average Rating Ratio by Fill Depth

Fill Depth	Number of Culverts	EV2/HL-93 Truck Average Ratio	EV3/HL-93 Truck Average Ratio	EV2/HL-93 Tandem Average Ratio	EV3/HL-93 Tandem Average Ratio
0'	192	0.789	0.610	0.851	0.654
0.5' - 1.0'	76	0.795	0.598	0.868	0.649
1.5' - 2.5'	71	0.792	0.577	0.898	0.651
3.0' - 3.5'	59	0.805	0.574	0.910	0.646
4.0' - 4.5'	49	0.836	0.590	0.912	0.642
5.0' - 7.0'	66	0.851	0.614	0.887	0.637
8.0' - 10'	30	0.870	0.610	0.918	0.640
11' -	14	0.770	0.540	0.971	0.683

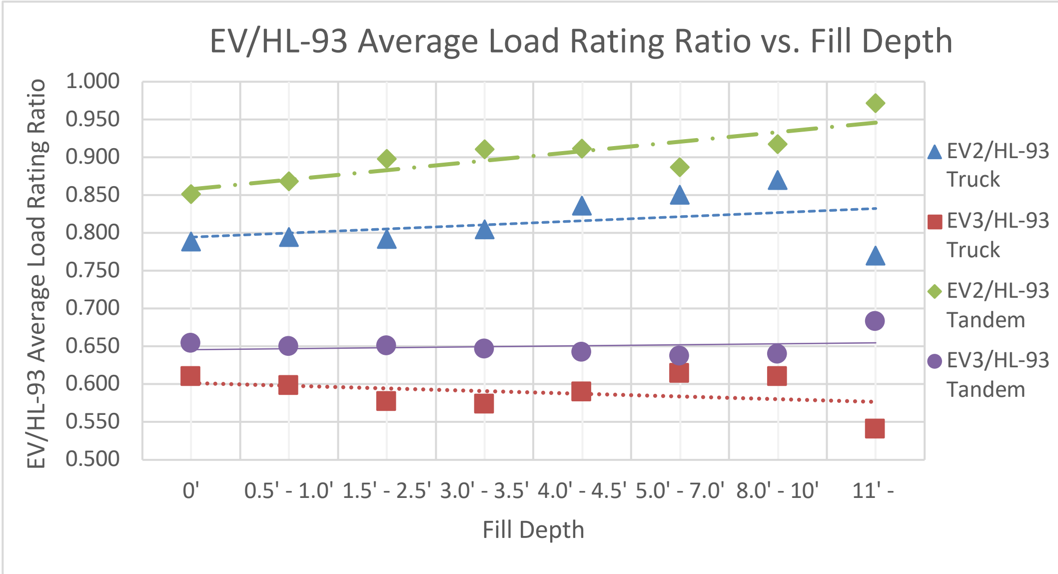

Figure 5.6: Alternate Analysis Average Rating Ratio vs. Fill Depth

It can be seen from Figure 5.6 above that the four average ratios between emergency vehicle loading and HL-93 loading are less than one for any range of fill depth. This means that the average EV2 and EV3 rating is less than the HL-93 rating regardless of the fill depth present. Figure 5.6 also shows that, in general, the difference between the EV2 ratings and HL-93 truck ratings as well as EV3 ratings and HL-93 truck ratings decreases as fill depth increases since the trends for the ratios get closer to 1.0. However, for the other two ratios EV2 vs HL-93 tandem and EV3 vs. HL-93 tandem there is no significant change in average ratio.

c. Culvert Span Length

Table 5.7 list results of the average rating ratios compared to culvert span length. Figure 5.7 shows the comparison in a graphic view.

Table 5.7: Alternate Analysis Average Rating Ratio by Span Length

Span Length	Number of Culverts	EV2/HL-93 Truck Average Ratio	EV3/HL-93 Truck Average Ratio	EV2/HL-93 Tandem Average Ratio	EV3/HL-93 Tandem Average Ratio
6' - 9'	53	0.806	0.644	0.826	0.650
10'	224	0.805	0.620	0.849	0.653
11' - 12'	141	0.811	0.589	0.887	0.644
13' - 15'	111	0.809	0.559	0.938	0.647
16' -	32	0.799	0.534	0.974	0.649

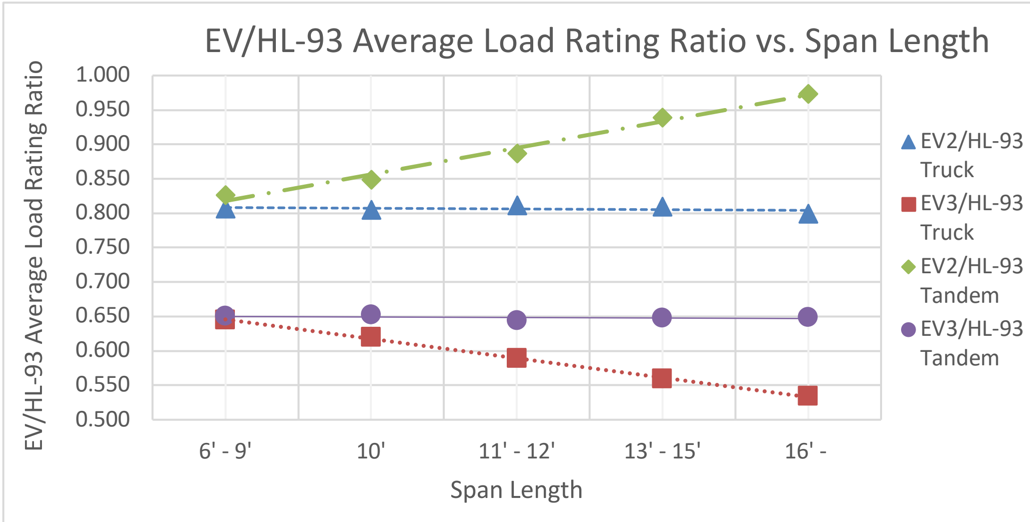

Figure 5.7: Alternate Analysis Average Rating Ratio by Span Length

Figure 5.7 shows that the four ratios between emergency vehicle rating and HL-93 rating are less than one for all span lengths. This means that the EV2 and EV3 ratings are on average less than HL-93 rating for any culvert span length. Figure 5.7 also shows that in general the difference between EV2 ratings and HL-93 tandem ratings decreases as culvert span increases. The trendlines for EV2 vs. HL-93 truck ratings and EV3 vs. HL-93 tandem ratings do not show any significant change, signifying that the difference between these rating ratios are not affected by span length. EV3 vs. HL-93 truck rating ratios decrease as span length increases which shows that, in general, the difference between the two ratings increases for longer spans.

d. Culvert Clear Height

Table 5.8 tabulates results of average rating ratios based on culvert clear height. Figure 5.8 compares the average ratio to the clear height.

Table 5.8: Alternate Analysis Average Rating Ratio by Clear Height

Clear Height	Number of Culverts	EV2/HL-93 Truck Average Ratio	EV3/HL-93 Truck Average Ratio	EV2/HL-93 Tandem Average Ratio	EV3/HL-93 Tandem Average Ratio
3' - 4'	57	0.784	0.607	0.845	0.651
5'	77	0.803	0.605	0.871	0.652
6'	118	0.808	0.607	0.872	0.650
7'	58	0.817	0.613	0.884	0.659
8'	99	0.815	0.596	0.882	0.643
9' - 10'	99	0.810	0.587	0.892	0.644
11' - 12'	39	0.805	0.565	0.925	0.649
13' - 18'	15	0.805	0.555	0.946	0.647

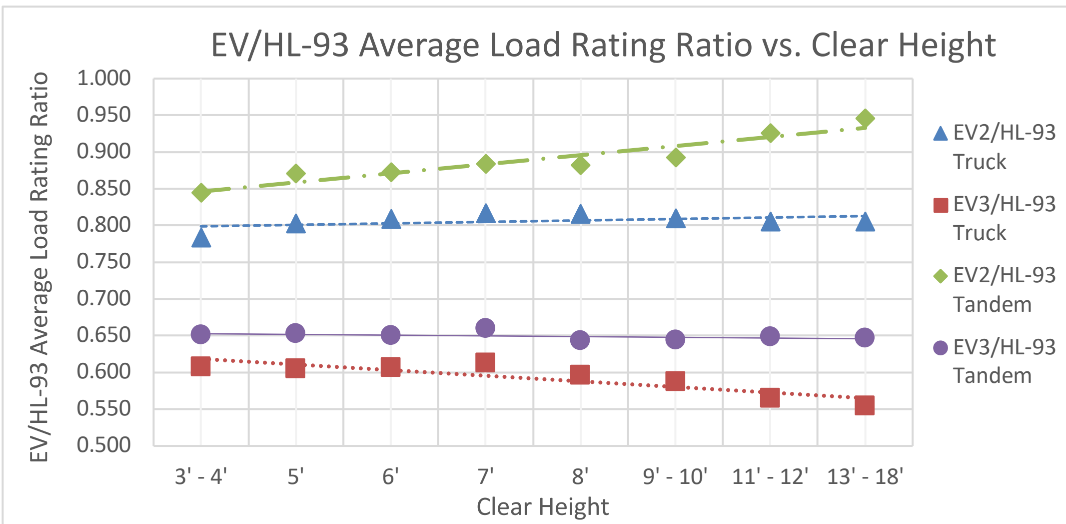

Figure 5.8: Alternate Analysis Average Rating Ratio vs. Clear Height

The ratio between emergency vehicle ratings and HL-93 ratings is less than one for all culvert clear heights. This means that the emergency vehicle ratings are, on average, less than the HL-93 ratings for culverts of any clear height.

In general, Figure 5.8 shows that the EV2 vs. HL-93 tandem ratio gets closer to 1.0 as clear height increases, indicating the difference between the two ratings is decreasing. As clear height increases, the ratio between EV2 ratings vs. the HL-93 truck ratings does not significantly change, this is also true for the ratio between EV3 and HL-93 tandem ratings. However, the ratio between EV3 and HL-93 truck ratings clearly decrease as clear height increases, signifying that the difference between the two ratings is increasing.

5.2 Culverts with 0' Fill

As mentioned earlier, there is a wide range of fill depths for culverts affected by the new loading requirements. However, a significant number of culverts, 203 of the 742 culverts built before 2000, have zero feet fill depth as indicated in bridge inspection reports. Section 2.3.1 of this report outlined the new specifications for emergency vehicle loading rating from FHWA that include using 1.3 for the live load rating factor for analysis of bridges subjected to EV2 and EV3 loading. However, FHWA further specified that, "a single live load factor of 1.3 does not apply to buried structures. For buried structures, utilize the appropriate live load factor of 2.0 per MBE Article 6A.5.12.10.3," (Office of Bridges and Structures 2018). Although culverts are typically buried, instances where no fill is present could potentially be considered non-buried structures. In those instances, the culverts would need to be analyzed with a live load factor of 1.3, not 2.0, for EV2 and EV3 loads. Since there was a large number of culverts with no fill present, an additional culvert rating analysis was performed to see the impact a different emergency vehicle live load factor has on rating results. Table 5.9 shows an sample rating results for this analysis. The complete list of rating results can be found in Appendix D.

Table 5.9: Adjusted EV2 and EV3 Ratings for Non-Buried Culverts

Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	Fill (ft)	EV3 Legal Rating	EV2 Legal Rating	EV3 Rating Non-Buried	EV2 Rating Non-Buried	EV3 Rating Percent Change	EV2 Rating Percent Change
1992	2	10	6	0.0	0.52	0.761	0.718	1.05	38.1%	38.0%
1950	2	10	10	0.0	1.066	1.235	1.471	1.703	38.0%	37.9%
1983	2	10	8	0.0	1.067	1.629	1.472	2.247	38.0%	37.9%
1965	2	10	14	0.0	1.465	1.595	2.02	2.2	37.9%	37.9%
1960	2	10	6	0.0	0.459	0.661	0.633	0.911	37.9%	37.8%
1982	2	10	5	0.0	0.447	0.664	0.617	0.917	38.0%	38.1%

If the engineer chooses to analyze culverts with no fill with a live load factor of 1.3 instead of 2.0, the ratings will be increased. The table above includes the culvert geometry, fill depth, and year built as well as the EV2 and EV3 rating based on the original analysis with a load factor of 2.0. The columns titled EV3 Rating Non-Buried and EV2 Rating Non-Buried report the culvert rating results based on a live load factor of 1.3 for EV3 and EV2 respectively. The final two columns show the percent change for EV3 and EV2 culverts from the original analysis to the new analysis. The columns are determined based on the equation shown below.

$$EV\ Rating\ Percent\ Change = \frac{(EV\ NonBuried\ Rating - EV\ Rating)}{EV\ Rating}$$

On average, the EV3 ratings increased by 38.3%, and the EV2 ratings increased by 37.6% when culverts with zero feet fill were analyzed as non-buried structures. This increase will also have a significant effect on load posting. Due to the increase in rating results that occurs, engineers may take advantage of this exception to reduce the frequency of culverts needing to be posted under the new emergency vehicle load posting procedure.

5.3 Culvert Rating Results vs. Bridge Rating Results

Figure 2.8 in section 2.3.1 showed FHWA's findings when HL-93 inventory ratings were compared to EV2 and EV3 ratings for the same bridge based on the bridge's span length. For the EV2 and EV3 ratings a live load factor of 1.3 was used. The comparison showed that the HL-93 inventory rating was less than the EV2 and EV3 rating for bridges of every span length examined. The bridge span length varied from approximately 15' to 200'. The highest HL-93 rating required to achieve an EV2 rating of 1.0 was roughly 0.61, while the highest HL-93 rating required to achieve an EV3 rating of 1.0 was approximately 0.90. Both of these maximum values occurred at relatively short span lengths.

Based on the culvert analysis performed in this study the following figure was developed. Figure 5.11, below, shows the HL-93 inventory rating that would be required to achieve an EV2 or EV3 rating of 1.0 for various culvert span lengths.

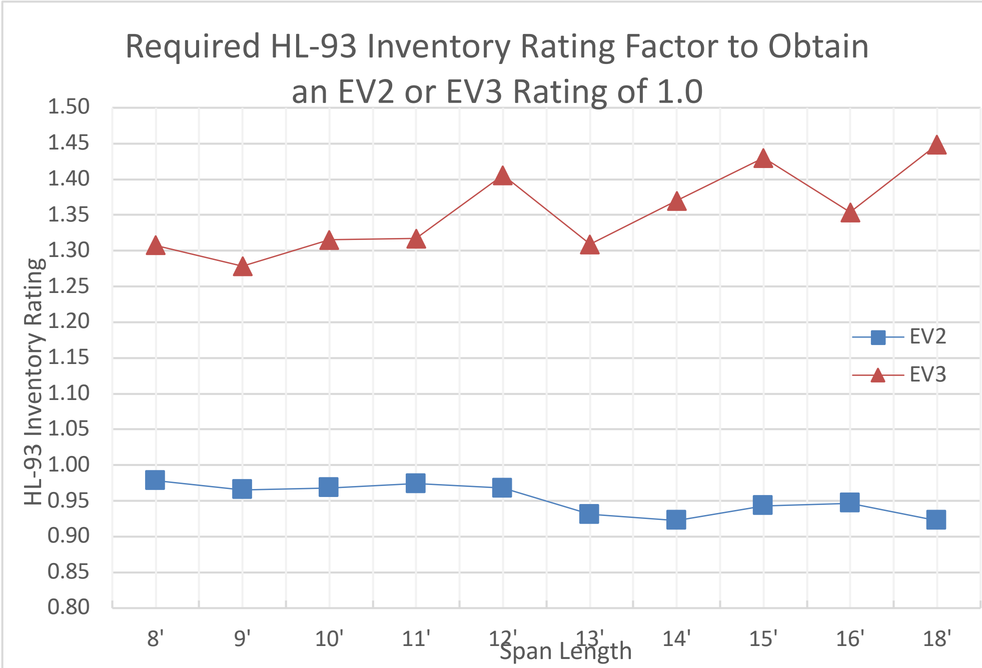

Figure 5.9: HL-93 Inventory Rating Required to Achieve an EV2 or EV3 Rating of 1.0 for Various Span Lengths

This chart is set up exactly the same manner as Figure 2.8 which was developed by FHWA. The results shown were obtained by comparing the HL-93 Inventory rating to EV2 and EV3 ratings for all culverts of a certain span length. A regression analysis was done to derive equations for determining HL-93 inventory ratings based on EV2 or EV3 ratings. If the R squared value for the regression analysis was statistically significant, then the derived equation was used to determine what the HL-93 inventory rating would be if either the EV2 or EV3 rating was 1.0 for the various culvert spans shown in Figure 5.11. Appendix E includes all the results of the regression analyses for the comparison in rating results between HL-93 inventory and EV2 or EV3 loading. Appendix F includes a similar Figure comparing HL-93 operating ratings to EV2 or EV3 ratings as well as the regression analyses for each comparison based on culvert span length.

When Figures 5.11 and 2.8 are compared, it is clearly seen that the HL-93 inventory ratings required to produce EV2 or EV3 ratings of 1.0 are significantly different for the two analyses. The results from this research show required HL-93 inventory values ranging from 0.92 to 0.98 when trying to obtain a rating of 1.0 for EV2 loading. This is much higher than the maximum required HL-93 rating found by FHWA of 0.61 for bridges of similar span length. This means that the difference between the

EV2 rating and HL-93 inventory rating is much smaller for culverts than bridges. For EV3 versus HL-93 inventory ratings the same increase occurs. The results of this analysis show required HL-93 ratings ranging from 1.27 to 1.45 to achieve an EV3 rating of 1.0. All bridge spans analyzed by FHWA reported HL-93 inventory ratings that controlled over EV3 ratings. However, the rating results of this investigation show that for any culvert span length, the EV3 ratings control over HL-93 inventory ratings. Since both structures are analyzed using the same overall methodologies, it would be expected that the relationship between HL-93 inventory ratings and EV2 or EV3 ratings would be consistent. However, since a live load factor of 1.3 is used for EV2 and EV3 loading for bridges compared to a live load factor of 2.0 for culverts, this difference in comparison is anticipated. The results also show that culverts do not perform as well, relatively, under EV2 or EV3 loads compared to bridges.

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made based on the findings of this research.

6.1 Conclusions

The objectives, procedures, results and findings of multiple analyses of all culverts affected by new emergency vehicle loading in Tennessee was summarized. The project was initiated to determine structural ratings of concrete culverts. These ratings were provided to TDOT and determined based on the most recent editions of the AASHTO LRFD bridge spec and the MBE. A literature review of previous culvert research, emergency vehicles, and soil dead load was completed to understand what goes in to load rating and what new changes are being made to the load rating process. Computer models of existing culverts were developed based on the most accurate site-specific information available. The results of the computer model analyses were summarized and a parametric study was performed to determine various trends that can be found in the rating results. Of the 827 culverts analyzed, the following conclusions were found:

- Emergency vehicle loading configurations EV3 and EV2 produce culvert rating results that are less than HL-93 operating truck and tandem ratings
- Load posting for concrete culverts in Tennessee will be greatly impacted by new EV loading and will be the controlling posting for all culverts where posting is applicable, and numerous culverts may have to be load posted for EV loads even though they won't need posting for HL-93 loads
- By analyzing culverts with no fill as if they are not buried structures, EV3 and EV2 ratings greatly improve which also improves the recommended posting loads
- Culvert ratings are, on average, increased when the slab to wall joints are considered pinned and not fixed regardless of the amount of rebar present for all loading configurations due to the decrease in negative moment present in the exterior wall

- The embankment installation technique results in a dead load larger than other construction techniques and in excess of the overburden present. This has a negative impact on culvert rating due to increased load

These findings are likely the result of a few factors. First, the loading configurations of the EV3 and EV2 truck do not pass federal bridge formula B which was developed to minimize potentially damaging stresses in bridges by limiting the amount of load that may be concentrated over a certain distance. Second, the EV2 configuration has the heaviest single axle point load, 33,500 pounds over the rear axle, of any legal truck load currently in use. And, similarly, the EV3 configuration has the heaviest tandem axle load, 64,000 pounds over the rear axle, that has ever been considered for the legal load rating level. And finally, the culverts were nearly always controlled by either the EV3 or EV2 loading configuration because the MBE requires a load factor of 2.0, the largest load factor of any configuration, be used for all buried structures instead of the 1.3 exception defined in the FHWA memo. EV loading reduces the structural rating on concrete culverts in Tennessee compared to the existing HL-93 loading configuration.

6.2 Recommendations

The following recommendations in regard to culvert ratings in Tennessee are made based on the conclusions of this research project.

1. If EV2 and EV3 ratings are not available for a given culvert but HL-93 tandem or truck operating ratings are currently available, the equations derived in section 4.2 may be used as an estimate for EV2 and EV3 ratings.
2. Whether a culvert is analyzed with pinned joints or fixed joints is dependent on available information as well as engineering judgement. Significant difference exists in the rating results for culverts when the different analysis types are used which leads to significantly different required posting loads. Care should be taken when determining which type of connection is present for a given culvert based on inspection reports, original design drawings, and current state of the actual culvert condition.

3. Culverts where no fill is present will have increased EV rating results if they are not analyzed as buried structures, and engineers take advantage of the live load factor exception included in the FHWA memo.
4. There is a potential for cost-savings in design of future culverts if installation techniques other than the embankment technique are used. These include the induced trench method which showed significant reduction in dead load due to positive soil arching compared to overburden pressure.
5. If the details of the construction technique used for installation are known as well as the site-specific soil parameters, a finite element analysis may be run to determine the actual soil pressure due to dead load. This method may increase culvert ratings due to a potential reduced load compared to the conservative dead load calculation approach specified in the LRFD bridge spec which is based on an embankment installation technique.

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APPENDICES

APPENDIX A

CHARACTERISTICS OF TN CULVERTS AFFECTED BY NEW EV LOADS

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
1971	3	15	10	M-1-150	B	5.0
1971	3	15	10	M-1-150	B	5.0
1970	2	10	10	K-15-109	B	10.0
2010	3	18	9	Standard 15	B	1.0
1975	4	15	18	M-71-134	B	10.0
1967	2	10	9	H-5-123	S	18.0
1993	2	10	10	G-10-53	S	6.0
1993	2	10	5	G-10-137	S	2.0
1960	3	8	9	H-5-117	B	17.0
2003	2	10	7	Standard 15	B	1.0
2003	2	10	7	Standard 15	B	1.0
1990	3	15	10	K-38-24	B	10.0
1990	2	10	10	K-15-31	B	8.0
1990	3	12	10	M-1-91	S	20.0
1982	2	10	6	E-12-30	S	1.5
1993	3	18	9	M-1-102	B	2.0
1992	2	10	6	G-10-53	S	0.0
2003	2	10	7	Standard 15	B	1.0
1950	2	10	10	C-2-69)	B	0.0
1983	2	10	8	K-15-109	B	0.0
1965	2	10	14	K-15-109	B	0.0
1970	2	7	5	G-10-34)	B	1.0
1960	2	8	7	H-5-116	B	15.0
1960	2	10	6	G-10-108)	B	0.0
1982	2	10	5	K-15-110)	B	0.0
1990	2	10	5	K-15-29A	B	10.0
1979	3	12	12	K-38-20	B	1.0
1954	2	12	6	K-15-124	B	5.0
1973	3	12	10	K-38-21	B	2.0
1960	2	12	12	K-15-124	B	4.0
1965	3	12	8	K-38-21	B	6.0
2014	1	18	16	Standard 17	S	0.0
1930	2	15	6	A-6-20	S	0.0
1945	3	12	6	C-2-99	B	3.0
1991	3	18	9	M-1-59	S	0.0
1970	2	10	10	K-15-109	B	5.0
1972	2	12	8	H-5-116	B	20.0
1973	2	10	8	H-5-116	B	11.0

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
2000	2	10	9	K-15-29A	B	18.0
2000	2	15	10	Standard 15	B	1.0
1992	2	15	10	M-26-150	B	0.0
1979	2	10	7	K-15-109	B	5.0
1965	12	8	5	C-10-68	S	0.0
2003	3	15	15	Standard 15	B	1.0
1970	2	10	8	K-15-109	B	3.0
1970	2	10	5	K-15-109	B	0.0
1969	2	10	9	G-10-53	B	4.0
1977	3	13	8	K-72-119	B	14.0
1986	2	8	8	K-65-13	B	1.0
1969	2	10	9	K-15-112	B	12.0
1968	3	14	10	K-72-119	B	5.0
2003	3	15	12	Standard 15	B	2.0
1980	3	13	4	K-72-119	B	1.0
1999	3	15	10	M-1-62	B	1.0
1999	1	18	6	M-1-114	B	1.0
1999	2	6	6	M-1-140	B	1.0
1980	3	14	8	K-38-24	B	0.0
1980	3	8	4	K-38-135	B	0.0
1999	2	10	6	K-15-29A	B	1.0
2000	2	10	8	Standard 15	B	2.0
1999	2	10	4	K-15-109	B	1.0
1987	3	12	8	K-38-21	B	0.0
1992	3	10	6	K-38-141	B	4.0
1992	3	10	5	H-5-47	S	0.0
1992	2	12	7	H-5-118	S	0.0
1994	2	15	10	M-1-72	S	0.0
1995	2	8	5	K-38-128	B	4.0
1985	2	12	7	M-19-68	B	0.0
1965	2	10	6	K-15-111	B	2.0
1960	2	10	8	H-5-118	S	10.0
2000	3	15	10	Standard 15	B	0.0
1989	3	15	6	M-1-86	S	2.0
1987	2	10	5	H-5-118B	S	3.0
1994	2	10	4	K-15-109	S	1.0
1960	5	12	5	A-8-149	S	3.0
2002	4	15	6	Standard 15	B	0.0

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
1938	3	10	5	B-10-61	B	0.0
1983	2	15	6	K-15-144	B	0.0
1988	3	15	10	M-1-62	S	2.0
1970	2	10	6	K-15-109	B	3.0
1984	2	15	11	M-26-150	B	0.0
1972	2	10	6	H-5-126	B	12.0
1972	2	15	10	K-15-143	B	30.0
1965	3	8	4	K-65-25	B	20.0
1965	2	8	6	H-5-116	B	20.0
1960	2	8	8	G-10-30	B	0.0
1985	4	10	6	K-38-139	S	1.0
2014	2	14	11	Standard 17	B	0.0
1965	3	10	6	K-38-141	B	1.5
1965	3	10	6	K-38-141	B	2.0
1996	3	12	8	H-5-117C	B	2.0
2002	3	12	12	Standard 15	B	60.0
1940	2	10	5	A-6-20	S	4.5
1984	3	12	11	F-010-088	B	0.0
2000	2	12	8	Standard 15	B	0.0
1965	2	12	11	K-15-125	B	4.0
1965	2	10	5	K-15-111	B	13.0
1983	2	12	6	K-15-126	B	0.0
1935	2	10	5	A-14-123	B	3.0
1935	2	8	6	B-2-103	B	0.0
1935	2	10	4	A-14-123	B	0.0
1962	2	10	8	K-15-111	B	6.0
1993	2	10	8	E-12-143	S	0.0
1985	2	12	6	K-15-124.	B	0.0
1936	2	10	8	A-0-187	B	1.0
2009	3	12	14	Standard 15	S	0.0
1986	2	10	4	K-15-110	B	0.0
2005	3	14	5	Standard 15	B	0.0
1970	3	10	10	K-49-61	S	50.0
1965	3	10	8	K-38-15	B	15.0
1974	2	8	7	H-5-118A	B	10.0
1997	2	12	8	M-19-69	B	0.0
1975	2	10	8	K-15-112	B	0.0
1960	4	14	8	E-12-112	B	0.0
1967	2	14	5	K-15-143	B	0.0

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
1960	2	17	8	H-5-57	S	0.0
1994	2	12	10	M-19-69	B	0.0
1970	3	10	8	K-38-141	B	8.0
1970	2	10	10	H-5-123	S	5.0
1970	2	10	10	K-15-111	S	5.0
1965	2	10	10	H-005-088	B	30.0
1966	2	10	5	K-15-111	B	8.0
1966	2	10	5	K-15-111	B	3.0
1965	2	10	8	K-15-109	B	3.0
1988	3	15	11	M-1-97	B	0.0
1967	2	10	10	K-15-111	B	10.0
1966	2	10	9	K-52-93	B	50.0
1960	2	12	8	F-2-37	B	5.0
1999	3	10	6	K-38-141	B	0.0
1950	2	10	6	C-10-132	S	1.0
1940	2	9	6	A-14-82	B	1.5
1988	2	12	6	E-12-94	S	0.0
1985	2	12	10	K-15-124	B	0.0
1950	2	8	6	B-2-103	B	1.5
1950	2	13	6	G-5-28	S	1.0
1986	3	18	15	M-1-47	S	0.0
1972	2	11	5	G-10-38	S	0.0
1997	2	10	4	K-15-111	B	0.0
1986	2	10	4	E-12-17	S	0.0
1960	2	10	3	E-4-11	S	0.5
1965	2	12	5	K-15-124	B	3.0
1940	3	14	5	D-0-111	S	0.0
1984	3	12	5	M-1-91	S	0.0
1980	2	10	6	E-12-30	S	0.0
1974	2	8	4	K-38-128	B	0.0
1980	2	12	10	K-15-124	B	4.0
1915	3	11	5	F-2-99	S	1.0
1960	2	12	3	H-5-67A	S	0.0
1965	2	12	3	E-12-94	S	0.0
1985	2	10	9	C-4-92	S	1.5
1985	2	15	7	M-1-72	S	1.5
1982	3	10	10	H-5-102	S	8.0
1984	2	12	8	F-10-121	S	0.0

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
1980	3	10	4	H-5-47	S	1.0
2010	5	18	16	Standard 15	B	0.0
2003	2	10	7	Standard 15	B	1.0
1978	3	10	6	F-10-147	S	6.0
1975	3	10	6	A-8-33	S	0.8
1975	3	10	6	F-2-51	S	0.7
1955	2	12	12	K-15-16	S	1.0
1950	3	18	6	M-1-89	S	1.0
1950	2	14	8	H-5-57	S	0.0
1960	2	11	6	K-15-124	S	0.0
1965	2	10	7	K-15-109	S	0.0
1960	2	10	5	G-10-105	S	0.0
1975	2	10	5	K-15-112	B	1.0
1935	2	10	5	A-6-20	S	2.0
1986	2	12	10	K-15-31	S	0.0
1984	3	12	8	E-8-65	S	0.0
1965	3	14	5	F-2-99	S	0.0
1960	2	11	4	H-5-67A	S	0.0
1950	2	13	3	C-10-132	S	1.0
1958	3	9	5	G-10-115	S	1.5
2014	1	22	5	Standard 17	S	0.0
2003	2	10	7	Standard 15	B	1.0
1985	2	10	3	E-4-11	S	2.0
1965	2	15	7	H-5-69	B	0.0
1959	2	8	5	C-10-68	S	3.0
1960	2	11	6	E-8-133	S	3.0
1965	2	15	7	K-15-145	B	0.5
1975	2	12	4	K-15-124	B	0.8
1960	2	10	7	K-15-109	B	8.0
2000	2	12	6	Standard 15	S	2.5
1986	3	15	10	M-1-62	S	0.0
1986	2	10	5	K-15-109	B	3.0
2012	2	12	3	Standard 17	B	0.0
2004	4	15	10	Standard 15	S	2.0
1987	3	12	6	F-10-122	S	0.0
1965	3	10	6	G-10-138	S	9.0
1965	2	10	6	K-15-109	B	1.0
1940	2	13	6	G-5-22	S	0.0
1940	2	12	3	K-15-125	S	1.0

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
1965	3	10	8	H-5-119	S	20.0
1958	2	12	7	G-10-59	S	2.0
1958	2	12	9	H-5-118	S	18.0
1958	2	10	9	G-5-93	B	3.0
1958	2	10	7	H-5-118	S	22.0
1976	2	10	10	K-15-112	B	0.0
1972	3	15	8	M-1-62	B	21.0
1972	3	12	7	H-5-117A	B	24.0
1972	3	10	6	K-38-17	B	3.0
1972	4	12	10	K-85-148	B	20.0
1977	3	12	7	H-5-117A	B	20.0
1976	1	15	13	M-1-144	B	4.0
1976	1	15	13	M-1-144	B	4.0
1958	3	12	6	F-10-93	S	10.0
1958	3	12	6	F-10-122	S	15.0
1972	3	15	8	M-1-62	S	8.0
1959	2	10	10	H-5-118B	S	40.0
1959	2	10	8	G-10-50	B	12.0
1959	2	11	8	H-5-118	S	20.0
1960	2	12	10	F-2-57	B	20.0
1969	3	14	8	G-5-53	B	8.0
1961	4	11	7	K-54-146	S	15.0
1964	2	12	6	K-15-124	B	12.0
1966	2	8	6	K-38-128	B	5.0
1977	2	12	5	H-5-118	S	7.0
1966	2	10	8	G-10-50	B	16.0
1995	4	15	6	M-1-148	S	5.0
1969	3	10	10	H-5-102	S	0.0
1950	2	16	7	E-4-83	S	1.0
1931	2	15	7	E-12-110	S	5.0
1942	2	10	6	B-10-30	B	6.0
1955	2	10	4	E-4-5	B	4.0
1928	3	10	9	A-0-88	S	0.0
1928	2	10	6	A-4-35	S	0.0
1928	2	10	6	D-4-91	B	2.0
1928	2	11	7	E-4-144	B	0.0
1928	2	10	7	A-0-100	B	1.0
1932	3	10	6	A-8-59	S	15.0

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
1992	2	15	15	M-1-72	B	0.0
1990	3	15	7	M-1-62	B	0.0
1990	3	15	12	M-1-62	S	12.0
2007	2	14	14	Standard 15	S	12.0
1990	2	8	6	K-15-28	B	0.0
1994	3	15	8	M-1-97	S	0.0
1994	1	15	4	M-1-144	S	0.0
1949	2	10	5	A-8-12	S	0.0
2004	3	18	18	M-376-199	S	40.0
2004	2	10	10	H-5-118B	S	20.0
2004	3	18	18	M-376-199	S	20.0
2004	4	15	15	M-376-200	S	30.0
1983	2	15	11	K-15-146	B	1.0
1979	2	12	15	M-26-150	B	3.0
1960	2	10	9	H-5-101	B	2.0
1980	4	15	10	M-59-27	B	0.0
1979	2	15	15	M-25-150	B	3.0
1963	3	10	8	K-38-14	B	3.0
1963	2	10	5	K-15-109	B	3.0
1963	2	12	4	M-19-69	B	4.0
1999	2	12	12	M-19-69	B	1.0
2005	2	10	6	Standard 15	B	25.0
2005	2	10	6	Standard 15	B	3.5
1964	2	10	10	K-15-109	B	4.0
1964	3	10	7	K-38-141	B	4.0
1964	4	10	6	G-10-61	B	6.0
1965	4	10	6	G-10-61	B	6.0
1965	2	10	7	K-15-109	B	6.0
1965	3	8	5	K-65-25	B	50.0
1965	2	10	6	K-49-62	B	6.0
1966	2	10	9	K-15-109	B	2.0
1946	2	10	8	B-10-29	B	6.0
1970	2	8	8	K-65-13	B	8.0
1970	2	10	10	H-5-118	B	30.0
1970	2	10	10	K-15-109	B	30.0
1970	3	8	6	K-65-25	B	40.0
1970	3	8	6	K-65-25	B	40.0
1970	2	13	12	K-15-16	B	5.0
1970	2	13	12	K-15-16	B	5.0

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
1968	2	10	8	K-15-109	B	5.0
1968	2	10	7	K-15-110	B	8.0
1970	3	10	7	H-5-119	B	15.0
1970	2	10	8	H-5-116	B	20.0
1970	4	12	10	K-85-148	B	30.0
1970	2	10	9	H-5-118	B	30.0
1973	2	8	7	K-15-29	B	20.0
1973	2	8	6	K-15-29	B	30.0
1973	2	8	8	K-56-63	B	20.0
1929	2	10	6	D-0-71	B	3.0
1980	3	15	14	K-38-23	B	0.0
1998	2	12	12	K-015-125	B	0.0
1997	3	15	9	M-1-150	B	0.0
1986	2	12	6	G-5-28	S	0.0
1983	3	12	9	K-38-20	B	0.0
1987	2	10	8	E-2-32	S	0.0
1970	2	12	8	F-10-121	S	1.0
1966	2	10	6	K-15-109	S	2.0
1970	2	12	10	K-15-124	B	50.0
1971	2	10	6	K-49-62	B	49.0
1972	2	10	10	K-15-109	B	50.0
1972	2	12	12	H-5-116	B	30.0
1964	2	10	8	K-15-109	B	35.0
1968	3	12	6	H-5-58	B	0.0
1925	1	11	6	D-0-199	B	0.0
1962	2	10	10	K-15-109	B	7.0
1965	1	8	6	H-5-150	B	0.0
1960	2	10	6	G-10-124	B	5.0
1975	2	10	5	K-15-110	B	1.0
1963	2	10	6	K-15-109	B	7.0
1983	2	10	5	K-15-109	B	0.0
1983	2	10	5	K-15-109	B	1.0
1998	2	10	8	K-15-112	B	1.5
1960	2	8	7	H-5-116	B	1.0
1960	2	8	7	H-5-116	B	4.0
1959	2	10	6	B-2-70	B	3.0
1960	2	10	5	H-5-116	B	25.0
1960	2	10	6	G-10-124	B	7.0

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
1960	3	10	5	H-5-117	B	18.0
1960	3	10	5	H-5-117	B	17.0
2003	3	16	9	Standard 15	B	0.0
1960	2	10	6	G-10-124	B	0.0
1960	2	10	6	H-5-126	B	3.0
1965	3	10	6	B-6-122	S	10.0
1950	2	12	4	E-2-131	B	1.0
1940	2	10	9	B-10-60	B	2.0
1933	2	7	6	A-14-95	B	0.0
1998	2	7	7	K-38-128	B	7.0
1992	2	10	10	K-15-109	B	0.0
2010	2	18	12	Standard 15	B	1.5
1962	3	10	6	H-5-117	B	3.0
1962	3	10	7	G-5-52	B	3.0
1961	2	12	10	F-2-57	B	4.0
1960	2	10	10	G-10-53	B	0.0
2016	1	10	6	Standard 17	B	3.0
1925	2	10	8	D-0-200	B	0.0
1925	2	10	4	D-0-71	B	1.0
1965	2	12	9	K-15-124	B	4.0
1965	3	12	6	K-38-18	B	6.0
1965	4	15	5	K-15-102	B	4.0
1965	2	12	8	K-15-124	B	6.0
1965	3	15	6	K-38-23	B	3.0
1965	3	15	6	K-15-101	B	18.0
1995	2	15	5	K-15-143	B	0.0
1966	2	10	6	G-10-108	B	4.0
1966	2	12	6	K-15-124	B	2.0
1964	4	12	12	M-7-51	B	4.0
1964	2	10	5	K-15-111	B	4.0
1964	2	12	8	K-15-125	B	4.0
1966	4	12	10	C-10-88	B	0.0
1964	3	8	7	K-15-25	B	3.0
1964	3	8	7	K-15-25	B	3.0
1965	4	12	6	K-15-103	B	4.0
1965	4	12	6	K-15-103	B	4.0
1949	2	10	8	C-10-113	B	13.0
1949	2	10	6	C-10-143	B	10.0
1993	2	10	8	K-15-29A	B	20.0

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
1965	2	10	7	K-15-112	B	4.0
1997	2	12	10	M-19-69	B	0.0
1973	3	10	10	K-38-15	B	10.0
1973	3	12	10	K-38-21	B	6.0
1967	2	10	8	K-15-111	B	7.0
1967	2	10	7	K-15-109	B	60.0
1967	2	12	5	M-19-69	B	20.0
1960	2	8	8	H-5-116	B	12.0
1987	2	8	8	H-5-116	B	8.0
1930	2	10	5	D-0-225	B	0.0
1930	2	10	6	B-2-31	B	5.0
1995	3	10	6	K-38-141	B	0.0
1935	2	12	6	A-6-20	S	0.0
1997	3	12	8	H-5-117C	B	2.0
2001	2	15	7	Standard 15	B	0.0
1993	3	10	8	K-38-15	B	2.0
1935	2	10	4	A-14-123	B	0.0
1997	3	18	6	M-1-138	S	0.0
1935	1	12	5	K-15-8	S	0.0
1980	2	8	7	K-38-128	B	0.0
1970	3	10	10	F-10-38.	B	1.0
1960	2	10	14	H-5-116	B	0.0
1965	3	12	10	K-38-18	B	0.0
1966	2	10	6	G-10-124	B	5.0
1936	3	10	4	B-2-85	S	0.0
1981	3	8	6	H-5-117	B	15.0
1930	2	15	6	A-6-20	S	0.0
1999	3	12	9	H-5-117C	B	0.0
1970	2	12	7	K-15-124	B	4.0
1940	2	10	8	A-14-82	B	0.0
1987	2	12	7	K-15-125	B	0.0
1984	3	10	5	K-38-14	B	0.0
1970	3	10	7	K-38-15	B	0.0
1981	3	12	12	K-38-18	B	6.0
1963	2	16	8	K-15-143	B	15.0
1965	3	12	12	H-5-117	B	40.0
1967	2	12	10	M-10-150	B	45.0
1967	3	10	10	H-5-117	B	15.0

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
2006	2	16	6	Standard 15	B	1.0
1981	2	12	7	H-5-116	B	15.0
1981	2	10	6	K-15-111	B	4.0
1969	2	10	10	K-15-109	B	50.0
1969	2	10	6	H-5-116	B	25.0
1962	3	10	8	H-5-117	B	4.0
1965	3	10	10	K-49-61	B	8.0
1965	3	10	8	K-38-141	B	5.0
1990	3	12	12	H-5-117A	B	20.0
1970	4	10	10	K-15-145	B	25.0
1981	3	12	12	M-1-91	B	3.0
1981	2	8	8	K-38-128	B	10.0
2010	2	18	13	Standard 15	B	0.0
1965	2	10	4	K-15-109	B	0.0
1950	3	12	6	E-12-77.	B	0.0
2006	3	16	8	Standard 15	S	0.0
1997	3	18	16	M-1-102	B	4.0
1971	4	10	10	G-5-82	B	0.0
1971	4	10	10	G-5-50	B	0.0
1981	4	10	10	G-5-82	B	8.0
1985	2	8	8	K-65-13	B	3.0
1960	2	12	6	G-5-18	B	0.0
1950	2	12	15	M-19-68.	B	0.0
1972	2	12	12	M-19-69	B	10.0
1978	3	12	12	H-5-117A	B	15.0
2000	3	12	7	Standard 15	B	3.0
1965	2	12	8	K-15-124	B	7.0
1957	2	10	8	E-12-19	B	6.0
1965	2	12	7	K-15-124	B	4.0
1997	2	10	9	K-15-110	S	0.0
1960	2	10	7	H-5-116	B	20.0
1959	2	10	10	H-5-116	B	20.0
1972	2	10	7	K-15-112	B	8.0
1972	2	12	8	H-5-116	B	10.0
1972	2	10	8	K-15-111	B	2.0
1972	2	10	8	K-15-111	B	8.0
1972	2	8	8	K-38-128	B	8.0
1972	2	8	8	H-5-116	B	12.0
1972	2	10	8	H-5-116	B	25.0

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
1974	3	10	8	H-5-117	B	20.0
1967	3	12	5	K-38-21	B	5.0
1984	2	8	6	K-38-128	B	2.0
1984	2	8	6	K-38-128	B	4.0
1983	2	8	6	K-38-128	B	6.0
1975	3	8	6	H-5-117	B	18.0
2009	2	10	6	Standard 15	B	0.0
1984	2	15	12	K-15-144	B	0.0
1981	3	15	12	K-38-23	B	2.0
1984	3	15	11	K-38-24	B	0.0
1968	3	12	6	H-5-117A	B	20.0
2003	2	10	4	Standard 15	B	20.0
1967	2	12	8	K-15-125	B	3.0
1987	2	10	8	K-15-109	B	0.0
1971	3	8	6	K-38-135	B	10.0
1972	3	12	6	K-38-20	B	8.0
1972	2	12	8	K-15-127	B	6.0
1972	2	12	8	K-15-125	B	4.0
1973	3	10	6	K-38-17	B	3.0
1973	2	10	6	K-15-110	B	3.0
1973	3	8	5	K-65-25	B	2.0
2013	2	12	10	Standard 17	B	1.0
1991	2	12	5	M-10-150	B	2.5
1986	3	15	15	K-72-119	B	13.0
1994	2	15	10	M-1-72	B	1.5
1991	2	10	9	K-15-29A	B	15.0
1990	2	12	7	M-19-69	B	4.0
1995	2	12	10	M-10-150	B	20.0
1939	2	10	6	B-6-16	B	2.0
1963	2	10	8	K-15-109	B	10.0
1963	2	10	6	K-15-109	B	6.0
1963	2	10	8	K-15-109	B	0.0
1965	4	10	4	K-38-14	B	2.0
1965	2	10	10	K-15-109	B	10.0
1965	3	10	6	K-38-141	B	10.0
1965	3	12	12	K-38-20	B	6.0
1965	2	10	8	K-15-109	B	8.0
1929	2	10	4	D-7-41	B	0.0

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
1975	4	15	8	K-15-36	S	0.0
1987	2	12	6	G-5-38	S	0.0
1975	2	12	10	H-5-38	S	0.5
1988	3	12	6	H-5-58	S	0.0
1964	2	12	12	K-15-124	B	4.0
1964	2	12	12	K-15-124	B	6.0
1964	2	11	11	H-5-118	S	2.0
1964	2	11	11	H-5-118	S	2.0
1964	3	9	9	H-5-119	S	0.0
1964	3	9	9	G-10-15	S	0.0
1999	2	10	5	K-15-29A	B	1.0
1993	3	18	6	M-1-47	S	0.0
1990	3	18	8	M-1-47	S	1.5
1984	2	15	7	M-26-150	B	0.0
1984	2	12	4	M-1-41	S	0.0
1965	3	15	10	F-2-55	S	0.0
1965	2	15	11	H-5-59	S	4.0
1965	2	10	7	K-15-109	B	10.0
1963	2	12	7	G-10-38	S	4.0
1960	3	15	7	K-38-24	B	4.0
1954	3	12	7	E-12-96	S	0.0
1989	2	10	6	E-12-30	S	3.0
1989	3	18	6	M-1-59	S	1.0
1989	3	18	5	M-1-102	S	1.0
1990	3	12	12	H-5-117	B	10.0
1989	3	18	11	M-1-102	S	6.0
1975	2	16	12	K-15-143	B	0.0
1995	2	10	4	K-15-29A	B	1.0
2008	2	16	11	Standard 15	B	0.0
1990	1	18	15	H-5-46B	B	3.0
1984	2	10	10	K-15-109	B	1.0
2012	2	10	10	Standard 17	B	6.5
2012	2	10	9	Standard 17	B	7.0
2012	3	14	5	Standard 17	B	3.0
2012	2	10	9	Standard 17	B	5.0
2000	3	15	12	Standard 15	B	0.0
1974	2	15	12	K-15-143	B	4.0
1979	2	10	10	K-15-109	B	5.0
1983	3	15	12	K-38-23	B	2.0

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
1925	2	10	5	D-4-8	B	5.0
1988	2	12	9	H-5-116	B	5.0
1988	2	12	9	H-5-116	B	25.0
1982	2	10	5	K-15-110	B	20.0
1987	2	10	10	K-15-111	B	30.0
1970	2	12	8	G-10-33	B	0.0
1991	3	12	8	K-38-18	B	0.0
1961	2	15	10	H-5-59	S	28.0
1963	2	10	5	E-12-131	S	20.0
1960	2	15	10	M-82-144	S	11.0
1977	2	10	7	K-15-110	B	9.0
1971	3	10	10	K-15-109	B	6.0
1996	2	10	4	K-15-111	B	0.0
1965	4	10	9	F-10-109	B	2.0
1970	3	12	7	F-10-136	B	0.0
1965	4	10	7	F-10-137	B	0.0
1994	2	10	8	K-15-109	B	0.0
1955	2	10	8	A-6-26	B	0.0
1955	2	10	6	D-0-212	B	5.0
1970	2	12	8	K-15-124	B	1.0
1969	2	10	8	H-5-116	B	18.0
1970	3	15	8	K-38-24	B	5.0
1970	4	10	7	G-5-45	B	12.0
1958	3	10	7	H-5-128	B	2.0
1960	3	10	7	G-5-52	B	7.0
1950	2	10	8	B-2-134	B	0.0
1950	3	10	4	K-38-15	B	2.0
1950	3	10	7	K-38-17	B	10.0
1947	2	10	6	K-15-111	B	8.0
1975	2	15	3	K-15-143	S	0.0
1973	2	10	7	K-15-109	B	20.0
1973	2	10	7	K-15-109	B	20.0
1973	2	10	6	K-15-112	B	5.0
1973	2	10	6	K-15-112	B	5.0
1973	3	15	7	K-72-119	B	35.0
1969	2	15	12	K-15-143	B	25.0
1967	2	10	5	K-15-109	B	20.0
1967	3	12	7	K-38-20	B	8.0

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
1967	3	15	10	K-38-12	B	6.0
1968	4	10	7	G-5-45	S	2.0
1970	3	12	7	H-5-119	S	1.5
1974	3	10	7	H-5-82	S	5.0
1982	3	15	8	K-38-23	S	1.0
1992	2	10	3	K-15-112	B	0.0
1990	3	15	9	K-38-24	S	1.0
1992	2	10	3	K-15-109	B	0.0
2000	3	15	11	Standard 15	S	0.0
2000	3	15	10	Standard 15	S	0.0
2007	12	16	12	Standard 15	S	0.0
1975	3	15	6	M-1-62	S	0.0
2014	3	18	8	Standard 17	B	0.0
1968	3	12	5	K-38-20	S	2.0
1969	4	12	3	K-54-14	S	5.0
1969	2	10	4	K-15-109	B	4.0
1971	3	15	10	F-2-93	B	2.0
1971	3	15	10	F-2-93	B	3.0
1971	4	15	10	F-10-144	B	2.0
1971	4	15	10	F-10-144	B	2.0
1971	4	15	10	F-10-144	B	3.0
1971	4	15	10	F-10-144	B	3.0
1971	2	12	5	K-15-124	B	3.0
1971	2	12	5	K-15-124	B	3.0
1971	2	10	5	K-15-110	B	3.0
1969	3	12	5	K-38-18	S	4.0
1969	3	15	7	K-38-23	S	2.0
1969	3	15	7	K-38-24	S	1.5
1972	2	15	7	H-5-65	S	0.5
1936	2	10	4	A-14-110	S	3.0
1936	2	9	5	A-6-20	S	1.0
1967	4	10	5	F-10-107	S	3.0
2007	2	10	4	Standard 15	B	0.0
1982	3	15	8	K-56-103	B	3.0
1982	2	12	5	K-15-124	B	6.0
1998	3	16	16	M-1-102	B	8.0
1998	3	10	8	H-5-117	B	6.0
1998	3	12	8	H-5-117C	B	5.0
1997	3	18	5	M-1-102	B	3.5

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
1998	2	10	8	K-15-29A	B	4.0
1975	2	10	8	H-5-116	B	20.0
1975	2	10	8	H-5-116	B	18.0
1975	3	15	12	K-38-23	B	10.0
1970	3	8	3	K-65-25	B	2.0
1987	3	10	5	K-38-15	B	0.0
1964	3	19	11	F-2-20	B	0.0
1965	2	10	6	K-15-109	B	2.0
1969	2	10	6	K-15-109	B	1.0
1960	2	9	5	H-5-116	B	1.0
1992	2	12	12	M-19-69	B	1.0
1992	2	20	11	M-1-138	B	0.0
1960	3	19	11	G-10-65	B	0.0
1945	2	9	8	B-10-29	B	3.0
1960	1	16	6	M-1-140	B	3.0
1950	2	12	6	E-8-35	B	1.5
1940	2	12	6	D-4-209	B	0.0
1950	2	13	6	D-4-209	B	0.0
1950	2	9	7	E-4-23	B	2.0
1970	2	8	8	K-65-13	B	1.0
1980	3	8	4	K-38-135	B	2.0
1980	2	12	9	K-15-124	B	0.0
1994	2	12	10	K-15-124	B	2.0
1993	2	10	14	K-15-29A	B	0.0
1999	2	10	10	K-15-29A	B	1.0
1975	1	16	9	M-1-140	B	1.0
1970	2	12	8	M-19-69	B	2.0
1950	2	12	11	E-4-145	B	2.0
1999	2	12	4	M-19-69	B	0.0
2009	2	15	10	Standard 15	B	1.0
1993	2	10	8	K-15-29A	B	2.0
2002	3	15	10	M-1-89	B	1.5
2008	2	12	10	Standard 15	B	0.0
2008	2	12	6	Standard 15	B	3.0
2008	2	12	10	Standard 15	B	5.0
2009	2	12	12	Standard 15	B	3.0
1995	2	10	6	K-15-109	B	3.0
1999	3	15	10	M-1-150	B	1.0

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
1964	3	14	12	K-38-23	B	16.0
1976	3	12	6	H-5-117A	B	20.0
1962	3	14	10	H-012-038	B	20.0
1962	3	14	10	H-012-038	B	25.0
1960	2	10	6	H-5-126	B	10.0
1969	2	10	6	K-15-109	B	4.0
1960	2	12	8	H-5-116	B	4.0
1960	2	10	10	H-5-116	B	10.0
1963	2	12	8	H-5-116	B	15.0
1963	2	10	8	K-15-109	B	4.0
1960	2	12	8	H-5-116	B	6.0
1960	2	12	8	E-8-35	B	4.0
1968	2	10	8	H-5-116	B	12.0
1961	2	12	8	K-15-124	B	4.0
1965	2	10	8	K-15-110	B	4.0
1968	2	8	5	K-38-128	B	8.0
1960	3	10	4	F-2-110	B	0.0
1960	3	10	9	H-5-117	B	1.0
1963	2	10	10	K-15-112	B	6.0
2008	2	16	15	Standard 15	B	10.0
1939	3	12	12	B-2-118	B	0.0
1997	2	15	12	K-015-143	B	1.5
1934	2	10	10	A-4-120	B	2.0
1930	2	10	10	A-4-120	B	0.0
1983	2	12	15	M-26-150	B	15.0
1960	2	10	8	H-5-116	B	12.0
1933	2	13	11	A-14-82	B	15.0
1978	2	8	7	H-5-116	B	5.0
1966	3	14	11	K-72-119	B	1.0
1928	3	10	10	D-7-85	B	2.0
1930	2	10	7	D-0-212	B	1.5
2008	2	10	4	Standard 15	B	0.0
2014	2	8	4	Standard 17	B	3.0
1982	2	12	10	K-15-124	B	2.0
1980	2	10	5	K-15-111	B	2.0
1996	2	10	10	K-15-29A	B	25.0
1996	3	18	18	M-1-47	B	3.0
1996	3	15	15	M-1-97	B	6.0
1996	2	12	5	M-10-150	B	4.0

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
1996	3	15	15	M-21-105	B	10.0
1996	2	10	4	K-015-110	B	1.0
1999	3	15	15	M-1-150	B	25.0
2007	2	10	8	Standard 15	B	6.0
2001	2	10	4	Standard 15	B	2.0
2001	2	10	10	Standard 15	B	6.0
2001	2	12	12	Standard 15	B	16.0
1994	3	15	15	M-1-150	B	10.0
1963	3	10	10	H-15-117	B	15.0
1987	2	10	10	H-5-118B	S	22.0
1995	2	12	7	M-10-150	B	1.0
1992	2	10	4	H-5-118B	S	0.0
1971	3	10	8	H-5-117	B	20.0
1969	2	10	8	H-5-116	B	15.0
1981	3	12	10	H-5-117	B	35.0
1973	3	10	8	K-38-141	B	6.0
1990	2	15	8	M-1-72.	B	0.0
1954	2	10	6	K-15-109	B	0.0
1953	2	10	8	K-15-109	B	0.0
1959	3	15	8	D-4-202	S	50.0
1960	1	8	6	C-4-141	B	30.0
1954	3	10	5	B-6-17	S	1.0
1959	3	10	5	G-10-47	B	15.0
1981	3	12	6	K-38-20	B	3.0
1981	3	12	10	K-38-18	B	4.0
1975	3	10	10	K-38-141	B	1.0
1999	3	8	8	K-65-25	B	6.0
1960	2	15	8	F-10-2	S	1.0
1990	3	15	8	M-1-62	S	0.0
1960	2	9	4	H-5-66	S	0.0
1984	2	12	4	M-1-41	S	0.0
1965	2	10	5	E-12-17	S	5.0
1965	6	12	5	E-4-8	S	0.0
1965	1	15	3	M-1-144	S	0.0
1993	3	15	5	M-1-62	S	0.0
1978	3	15	4	M-1-97	S	0.0
1965	4	15	12	F-10-144	S	0.0
1965	2	10	10	K-15-109	S	0.0

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
1972	3	10	5	K-38-141	B	8.0
1972	3	10	5	K-38-141	B	5.0
1947	3	10	5	C-2-64	S	4.0
1947	2	10	6	C-10-143	B	1.0
1947	2	10	7	B-10-29	B	1.0
1989	2	15	10	M-1-72	B	20.0
1983	4	10	8	G-10-56	S	0.0
1983	2	12	7	H-5-118	S	6.0
1976	2	10	6	K-15-111	B	0.0
1976	2	10	5	K-15-110	B	0.0
1984	2	10	10	K-15-109	B	0.0
1982	4	15	9	M-33-59	S	0.0
1984	2	18	7	M-1-138	B	0.0
1983	1	15	7	M-1-144	B	0.0
1995	3	15	7	M-1-62	B	0.0
1983	2	12	6	K-15-124	S	0.0
1986	3	15	11	M-1-62	B	1.0
1998	2	15	7	K-15-144	B	1.0
2000	1	32	6	M-388-276	B	0.0
1980	2	10	8	K-15-112	B	3.0
1985	2	10	8	K-38-141	B	3.0
1981	2	10	5	K-15-110	B	3.0
1981	2	10	6	K-15-109	B	2.0
1977	3	15	10	M-1-150	B	5.0
1999	2	12	10	M-10-150	B	100.0
1976	2	10	8	B-2-134	B	1.0
1960	3	12	6	E-12-77	B	4.0
1948	2	10	8	E-4-23	B	4.0
1999	1	10	4	C-10-14	B	2.0
1928	2	10	6	A-14-82	B	0.0
1928	2	8	6	B-2-103	B	0.0
1940	2	11	5	B-2-114	B	1.0
1999	2	12	9	K-15-124	B	0.0
1979	3	15	9	K-72-119	B	1.5
1992	2	12	9	M-10-150	B	0.0
1995	2	8	5	K-38-128	B	3.0
1995	3	12	10	G-10-54	S	0.0
2002	3	15	10	Standard 15	B	4.0
1965	2	10	6	K-15-112	B	3.0

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
1984	2	15	10	M-26-150	B	0.0
1969	3	10	10	H-5-119	S	11.0
1969	3	10	10	H-5-119	S	11.0
1979	3	12	8	K-38-21	?	Yes
1955	3	10	10	K-38-141	?	Yes
1970	2	8	4	K-38-128	?	Yes
2006	3	10	6	-		0.0
1996	3	12	9	K-38-18	B	0.0
1987	2	10	8	K-15-112	B	5.0
1969	3	15	10	K-56-103	B	?
1977	2	15	6	G-5-23	S	0.0
1970	2	10	4	H-5-118B	S	3.0
1965	2	15	9	H-5-54	S	6.0
1982	2	15	8	M-26-150	B	0.0
1977	3	15	4	M-1-97	S	1.0
1977	2	15	5	H-5-118	S	1.0
1983	2	10	3	E-12-17	S	2.0
1975	3	15	9	F-10-151	S	1.0
1950	2	12	5	E-4-8	S	2.0
1965	2	10	5	H-5-118	S	2.5
1954	1	15	4	M-1-144	S	0.0
1990	2	12	5	K-15-124	B	0.0
1990	2	12	7	G-10-59	S	2.0
1991	2	12	4	K-15-31	S	0.0
2000	3	18	7	M-1-102	B	2.0
1963	2	10	9	H-5-118	S	10.0
1963	2	12	11	H-5-118	S	20.0
1962	2	10	7	G-10-134	S	8.0
1965	3	12	11	H-5-119	S	4.0
1989	2	10	6	H-5-118B	S	25.0
1979	3	15	9	K-38-23	B	0.0
1932	2	10	6	G-10-50	?	Yes
1945	2	8	8	D-7-56	B	1.0
1995	2	19	10	M-1-138	S	4.0
2001	3	15	10	Standard 15	S	10.0
2001	4	15	18	M-376-200	S	20.0
1966	2	10	7	H-5-118	S	10.0
1998	3	15	8	M-1-97	S	0.0

Year Built	Number of Cells (ft)	Clear Span (ft)	Clear Height (ft)	Design Drawing Used	Box or Slab?	Fill Depth (ft)
2001	3	16	16	M-376-201	S	80.0
1999	2	12	12	M-10-150	B	15.0
2011	3	18	15	Standard 17	S	40.0
2011	3	12	11	Standard 17	S	20.0
1984	2	15	5	M-26-150	S	0.0
1951	2	10	5	E-4-5	B	0.0
1940	2	10	3	A-8-12	S	1.0
1970	1	16	6	M-1-142	S	0.0
1988	2	15	8	F-10-60	S	0.0
1970	2	10	5	K-15-109	S	3.0
1985	3	18	8	M-1-47	S	0.0
2001	3	15	6	Standard 15	B	3.0
1988	5	15	10	M-74-151	S	0.0
2003	3	18	8	Standard 15	S	0.0
2003	3	12	8	Standard 15	S	1.0
2003	2	10	8	Standard 15	B	1.0
2003	3	18	11	Standard 15	S	8.0
2003	3	12	6	Standard 15	S	1.0
1945	2	15	5	A-6-20	S	2.0
1940	3	15	7	M-1-62	S	0.0
1981	4	15	5	K-15-102	B	1.0
1965	3	12	6	E-12-51	S	4.0
1965	2	10	8	K-15-109	S	10.0
1965	3	10	10	H-5-117	S	10.0
1965	2	10	10	K-15-110	S	3.0
1964	3	10	8	G-10-84	S	10.0
2002	3	15	6	Standard 15	B	6.0
1955	3	10	7	E-12-84	B	0.0
1958	3	18	11	E-4-54	S	1.0
1958	3	18	11	F-2-20	B	1.0
1965	2	11	8	H-5-118	S	15.0
1999	3	12	10	M-1-91	S	6.0
2001	3	15	8	Standard 15	B	8.0
2001	2	12	6	Standard 15	S	5.0
1947	2	9	4	C-10-132	S	0.0
1994	1	15	10	M-1-144	B	2.0
1994	2	12	7	H-5-119	S	10.0
1994	3	15	4	M-1-97	B	5.0

APPENDIX B

ORIGINAL ANALYSIS RECOMMENDED POSTING LOADS FOR CULVERTS AFFECTED BY EV LOADS IN TENNESSEE

Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	EV Single Axle Posting Load (tons)	EV Tandem Posting Load (tons)	EV Gross Posting Load (tons)	HL-93 Gross Posting Load (tons)
2010	3	18	9	15	19	25	34
1993	2	10	5	14	20	25	24
2003	2	10	7	16	18	25	22
2003	2	10	7	16	18	25	22
1982	2	10	6	12	16	21	19
1993	3	18	9	12	13	18	13
1992	2	10	6	13	16	22	20
2003	2	10	7	16	18	25	22
1960	2	10	6	11	14	19	14
1982	2	10	5	11	14	19	14
1973	3	12	10	17	29	40	N/A
1990	2	12	10	17	28	38	N/A
2000	2	15	10	14	17	23	21
2003	3	15	15	16	21	28	N/A
1970	2	10	5	11	14	19	14
1980	3	14	8	10	13	17	9
1980	3	8	4	13	18	23	22
2000	2	10	8	14	16	22	18
1999	2	10	4	9	11	15	8
1987	3	12	8	17	25	35	N/A
1992	3	10	5	9	12	16	11
1992	2	12	7	13	16	22	17
1995	2	8	5	12	18	21	21
1985	2	12	7	10	12	17	10
1965	2	10	6	17	26	36	N/A
2000	3	15	10	17	25	34	N/A
1994	2	10	4	16	22	28	N/A
2002	4	15	6	13	16	22	26
1938	3	10	5	17	29	40	N/A
1985	4	10	6	17	22	30	N/A
2014	2	14	11	8	11	14	8
1965	3	10	6	17	21	29	N/A
1965	3	10	6	16	20	27	24
1996	3	12	8	17	25	34	N/A
1984	3	12	11	17	31	43	N/A
2000	2	12	8	12	15	20	25
1935	2	8	6	15	26	26	N/A
1935	2	10	4	17	28	39	N/A

Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	EV Single Axle Posting Load (tons)	EV Tandem Posting Load (tons)	EV Gross Posting Load (tons)	HL-93 Gross Posting Load (tons)
2009	3	12	14	17	25	35	N/A
1986	2	10	4	9	12	16	10
2005	3	14	5	9	11	15	14
1997	2	12	8	15	17	24	20
1960	2	17	8	17	28	38	N/A
1994	2	12	10	17	27	38	N/A
1966	2	10	5	17	24	33	N/A
1966	2	10	5	13	16	21	20
1999	3	10	6	17	20	27	N/A
1950	2	10	6	17	30	42	N/A
1988	2	12	6	8	10	14	7
1985	2	12	10	17	28	38	N/A
1950	2	8	6	15	26	26	N/A
1950	2	13	6	9	11	15	10
1972	2	11	5	14	18	23	21
1997	2	10	4	9	11	15	8
1960	2	10	3	15	22	26	N/A
1940	3	14	5	13	16	22	30
1980	2	10	6	11	14	19	16
1974	2	8	4	7	9	12	7
1915	3	11	5	9	11	15	9
1960	2	12	3	10	12	16	10
1965	2	12	3	8	10	14	7
1985	2	15	7	17	31	43	N/A
1984	2	12	8	15	18	24	22
1975	2	8	5	9	12	15	10
2003	2	10	7	16	18	25	22
1975	3	10	6	16	24	28	N/A
1975	3	10	6	13	16	22	20
1955	2	12	12	14	29	25	N/A
1950	2	14	8	16	18	25	21
1960	2	11	6	13	16	22	18
1975	2	10	5	11	14	18	14
1935	2	10	5	16	23	28	N/A
1984	3	12	8	10	12	16	10
1965	3	14	5	13	16	22	15
1960	2	11	4	11	13	18	13
1958	3	9	5	17	28	39	N/A

Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	EV Single Axle Posting Load (tons)	EV Tandem Posting Load (tons)	EV Gross Posting Load (tons)	HL-93 Gross Posting Load (tons)
2003	2	10	7	16	18	25	22
1985	2	10	3	14	20	25	25
1960	2	11	6	16	21	28	N/A
1965	2	15	7	17	24	33	N/A
2000	2	12	6	17	29	40	N/A
1986	2	10	5	14	18	23	22
2012	2	12	3	14	17	24	20
2004	4	15	10	17	29	40	N/A
1987	3	12	6	9	11	15	9
1965	2	10	6	15	20	26	25
1940	2	13	6	17	24	33	N/A
1958	2	12	7	16	20	28	N/A
1972	3	10	6	15	19	26	N/A
1958	3	12	6	17	27	38	N/A
1977	2	12	5	13	18	22	21
1928	3	10	9	16	23	27	N/A
1928	2	10	6	16	24	28	N/A
1928	2	10	6	15	21	26	N/A
1928	2	11	7	14	20	24	N/A
1928	2	10	7	16	23	27	N/A
1990	3	15	7	17	20	27	22
1990	2	8	6	14	19	24	23
1949	2	10	5	14	21	24	N/A
1983	2	15	11	17	22	30	N/A
1980	4	15	10	15	17	23	18
1963	2	10	5	14	18	23	22
2005	2	10	6	14	19	24	23
1964	4	10	6	17	30	41	N/A
1965	4	10	6	17	30	41	N/A
1929	2	10	6	14	19	24	33
1986	2	12	6	9	11	15	9
1983	3	12	9	17	22	31	N/A
1987	2	10	8	17	29	40	N/A
1970	2	12	8	16	19	27	25
1966	2	10	6	17	23	32	N/A
1968	3	12	6	8	10	13	7
1925	1	11	6	12	18	21	21
1960	2	10	6	17	26	36	N/A

Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	EV Single Axle Posting Load (tons)	EV Tandem Posting Load (tons)	EV Gross Posting Load (tons)	HL-93 Gross Posting Load (tons)
1983	2	10	5	11	14	19	14
1983	2	10	5	11	14	18	14
1959	2	10	6	14	19	23	23
2003	3	16	9	9	11	15	14
1960	2	10	6	10	13	18	13
1960	2	10	6	17	25	35	N/A
1950	2	12	4	11	15	19	16
2010	2	18	12	12	15	20	18
1962	3	10	6	11	14	19	16
1962	3	10	7	17	28	38	N/A
1925	2	10	8	13	16	22	29
1966	2	10	6	17	24	33	N/A
1964	2	10	5	14	19	24	24
1964	2	12	8	17	29	41	N/A
1966	4	12	10	17	28	39	N/A
1997	2	12	10	17	27	38	N/A
1995	3	10	6	17	19	27	N/A
1935	2	12	6	9	13	16	15
1997	3	12	8	17	25	34	N/A
2001	2	15	7	8	10	14	8
1935	2	10	4	17	28	39	N/A
1935	1	12	5	13	16	22	19
1980	2	8	7	17	25	34	N/A
1965	3	12	10	17	28	39	N/A
1936	3	10	4	17	26	37	N/A
1970	2	12	7	11	13	18	14
1940	2	10	8	17	27	37	N/A
1987	2	12	7	10	12	17	10
1984	3	10	5	11	14	19	15
1970	3	10	7	17	26	37	N/A
2006	2	16	6	13	16	22	20
2010	2	18	13	9	11	15	15
1965	2	10	4	9	11	15	8
2006	3	16	8	17	28	38	N/A
1997	3	18	16	17	28	39	N/A
1971	4	10	10	17	30	42	N/A
1971	4	10	10	17	30	42	N/A
1981	4	10	10	17	25	35	N/A

Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	EV Single Axle Posting Load (tons)	EV Tandem Posting Load (tons)	EV Gross Posting Load (tons)	HL-93 Gross Posting Load (tons)
1957	2	10	8	11	16	19	20
1965	2	12	7	11	13	18	14
1955	2	10	5	13	18	22	21
1984	2	8	6	13	18	23	22
2009	2	10	6	11	13	18	12
1984	2	15	12	17	25	35	N/A
1981	3	15	12	17	26	36	N/A
1984	3	15	11	17	22	30	N/A
1967	2	12	8	17	25	35	N/A
1972	2	12	8	17	29	41	N/A
1973	3	10	6	15	19	26	N/A
1973	3	8	5	8	12	14	11
1990	2	12	7	11	13	18	14
1929	2	10	4	15	18	25	33
1975	4	15	8	9	11	15	7
1987	2	12	6	9	11	15	9
1988	3	12	6	9	11	15	9
1964	2	11	11	16	20	27	25
1964	2	11	11	16	20	27	25
1964	3	9	9	17	30	41	N/A
1984	2	12	4	17	23	32	N/A
1965	3	15	10	17	22	30	N/A
1965	2	15	11	17	29	40	N/A
1954	3	12	7	10	12	17	12
1989	2	10	6	16	21	27	N/A
1989	3	18	5	17	30	42	N/A
1975	2	16	12	17	22	30	N/A
2008	2	16	11	9	12	16	11
1990	1	18	15	17	27	38	N/A
2000	3	15	12	9	12	16	16
1983	3	15	12	17	26	36	N/A
1970	2	12	8	14	16	22	18
1991	3	12	8	14	17	23	18
1996	2	10	4	9	11	15	8
1970	3	12	7	10	12	17	9
1965	4	10	7	14	18	24	22
1955	2	10	8	16	22	28	N/A
1955	2	10	6	16	23	28	N/A

Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	EV Single Axle Posting Load (tons)	EV Tandem Posting Load (tons)	EV Gross Posting Load (tons)	HL-93 Gross Posting Load (tons)
1958	3	10	7	17	26	36	N/A
1950	2	10	8	17	25	35	N/A
1968	4	10	7	17	23	31	N/A
1970	3	12	7	13	16	22	17
1982	3	15	8	16	12	16	10
1990	3	15	9	15	18	25	18
2000	3	15	11	17	30	42	N/A
2000	3	15	10	17	30	42	N/A
2007	12	16	12	17	27	37	N/A
2014	3	18	8	17	21	30	N/A
1969	4	12	3	10	15	17	16
1969	2	10	4	8	11	14	8
1971	3	15	10	16	18	25	21
1971	4	15	10	14	16	22	16
1971	4	15	10	14	16	22	16
1971	4	15	10	17	19	26	22
1971	4	15	10	17	19	26	22
1971	2	10	5	13	16	21	20
1972	2	15	7	11	12	16	10
1936	2	9	5	17	28	38	N/A
1967	4	10	5	12	16	21	20
2007	2	10	4	11	13	18	12
1987	3	10	5	17	21	29	N/A
1964	3	19	11	12	12	17	10
1965	2	10	6	16	19	26	23
1969	2	10	6	15	20	26	25
1960	2	9	5	8	10	13	6
1960	3	19	11	12	12	17	11
1950	2	12	6	8	10	14	6
1940	2	12	6	13	18	22	21
1950	2	13	6	12	16	20	17
1950	2	9	7	13	18	22	21
1980	3	8	4	12	17	21	19
1980	2	12	9	17	22	30	N/A
1994	2	12	10	17	27	38	N/A
1970	2	12	8	13	16	22	17
2009	2	15	10	14	17	23	21
2008	2	12	10	8	10	14	7

Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	EV Single Axle Posting Load (tons)	EV Tandem Posting Load (tons)	EV Gross Posting Load (tons)	HL-93 Gross Posting Load (tons)
2008	2	12	10	17	22	30	N/A
1960	2	12	8	17	24	33	N/A
1961	2	12	8	17	23	32	N/A
1997	2	15	12	17	27	38	N/A
1934	2	10	10	11	15	18	22
1930	2	10	10	11	18	19	28
2008	2	10	4	11	13	18	12
1982	2	12	10	17	27	38	N/A
1980	2	10	5	10	12	17	12
1996	2	10	4	9	11	15	9
2001	2	10	4	12	15	20	15
1992	2	10	4	17	30	41	N/A
1954	2	10	6	15	19	25	23
1954	3	10	5	17	26	37	N/A
1960	2	15	8	11	12	17	10
1960	2	9	4	8	11	14	11
1984	2	12	4	17	23	32	N/A
1993	3	15	5	10	12	16	9
1965	4	15	12	15	17	24	18
1972	3	10	5	9	12	15	10
1972	3	10	5	11	16	19	17
1947	2	10	6	12	17	20	20
1947	2	10	7	17	28	39	N/A
1983	4	10	8	16	20	28	N/A
1976	2	10	6	15	19	25	23
1976	2	10	5	11	14	19	14
1995	3	15	7	17	20	27	22
1983	2	12	6	10	12	17	10
2000	1	32	6	15	18	25	22
1981	2	10	5	13	16	21	20
1981	2	10	6	16	19	26	23
1976	2	10	8	17	28	38	N/A
1948	2	10	8	17	30	42	N/A
1999	1	10	4	14	19	24	23
1928	2	10	6	17	28	39	N/A
1928	2	8	6	15	26	26	N/A
1940	2	11	5	17	24	34	N/A
1999	2	12	9	17	22	30	N/A

Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	EV Single Axle Posting Load (tons)	EV Tandem Posting Load (tons)	EV Gross Posting Load (tons)	HL-93 Gross Posting Load (tons)
1995	2	8	5	10	15	18	16
1979	3	12	8	17	21	29	25
1970	2	8	4	7	9	12	7
2006	3	10	6	11	14	19	16
1996	3	12	9	17	22	30	N/A
1969	3	15	10	13	15	21	15
1965	2	15	9	15	19	26	24
1983	2	10	3	15	20	25	N/A
1975	3	15	9	15	17	24	19
1965	2	10	5	17	30	41	N/A
1990	2	12	7	16	20	28	N/A
1991	2	12	4	17	26	35	N/A
2000	3	18	7	11	14	19	21
1979	3	15	9	12	13	19	12
1932	2	10	6	11	14	19	14
2000	3	12	8	17	26	36	N/A
1951	2	10	5	17	25	28	N/A
1940	2	10	3	17	25	34	N/A
1988	2	15	8	17	22	31	N/A
1970	2	10	5	17	24	33	N/A
2001	3	15	6	17	21	29	N/A
1988	5	15	10	17	29	41	N/A
2003	3	12	8	17	28	39	N/A
2003	2	10	8	15	18	25	21
2003	3	12	6	17	28	39	N/A
1955	3	10	7	15	18	25	23
1958	3	18	11	13	14	19	14
2001	2	12	6	17	24	33	N/A

APPENDIX C

ALTERNATE ANALYSIS RECOMMENDED POSTING LOADS FOR CULVERTS AFFECTED BY EV LOADS IN TENNESSEE

Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	EV Single Axle Posting Load (tons)	EV Tandem Posting Load (tons)	EV Gross Posting Load (tons)	HL-93 Gross Posting Load (tons)
1958	3	18	11	8	10	14	7
1965	2	11	8	7	10	12	4
2008	2	12	10	8	10	14	7
1950	2	16	7	8	10	14	8
2001	2	15	7	8	10	14	8
2014	2	14	11	8	11	14	8
2005	3	14	5	9	11	15	14
2010	2	18	13	9	11	15	15
2003	3	16	9	9	11	15	14
1965	6	12	5	8	11	14	9
2000	3	15	12	9	12	16	16
2008	2	16	11	9	12	16	11
1930	2	10	10	8	12	14	11
1931	2	15	7	9	12	16	16
2009	2	10	6	11	13	18	12
1935	2	12	6	9	13	16	15
2000	3	12	7	10	13	18	20
2007	2	10	4	11	13	18	12
2008	2	10	4	11	13	18	12
2000	3	18	7	11	14	19	21
1930	2	10	7	12	14	20	23
2006	3	10	6	11	14	19	16
2000	2	12	8	12	15	20	25
2001	2	10	4	12	15	20	15
2010	2	18	12	12	15	20	18
1950	2	12	4	11	15	19	16
2002	4	15	6	13	16	22	26
1950	2	13	6	12	16	20	17
1925	2	10	8	13	16	22	29
2000	2	10	8	14	16	22	18
1958	3	12	6	11	16	19	24
2006	2	16	6	13	16	22	20
1940	3	14	5	13	16	22	30
2012	2	12	3	14	17	24	20
1947	2	10	6	12	17	20	20
2000	2	15	10	14	17	23	21
2009	2	15	10	14	17	23	21

Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	EV Single Axle Posting Load (tons)	EV Tandem Posting Load (tons)	EV Gross Posting Load (tons)	HL-93 Gross Posting Load (tons)
1925	1	11	6	12	18	21	21
1960	5	12	5	14	18	24	21
1960	3	12	6	14	18	24	23
2003	2	10	8	15	18	25	21
1960	3	19	11	14	18	25	32
2008	2	12	6	15	18	25	21
1955	2	10	5	13	18	22	21
1984	3	12	8	13	18	22	21
2003	2	10	7	16	18	25	22
2003	2	10	7	16	18	25	22
2003	2	10	7	16	18	25	22
2003	2	10	7	16	18	25	22
2003	2	10	7	16	18	25	22
2000	1	32	6	15	18	25	22
1929	2	10	4	15	18	25	33
2010	3	18	9	15	19	25	34
1960	4	14	8	15	19	25	34
1929	2	10	6	14	19	24	33
2005	2	10	6	14	19	24	23
1999	1	10	4	14	19	24	23
1950	3	12	6	14	19	23	24
1971	3	15	10	15	19	27	N/A
1972	2	10	6	16	19	27	N/A
1965	2	15	9	14	20	25	35
1993	2	10	8	13	20	22	25
1985	2	10	3	14	20	25	25
1983	2	10	3	15	20	25	N/A
1972	2	8	8	17	20	28	N/A
1928	2	11	7	14	20	24	N/A
2003	3	15	15	16	21	28	N/A
1949	2	10	5	14	21	24	N/A
1955	3	10	7	14	21	24	N/A
1960	2	11	6	16	21	28	N/A
1928	2	10	6	15	21	26	N/A
1945	3	12	6	17	21	29	N/A
2001	3	15	6	17	21	29	N/A
2014	3	18	8	17	21	30	N/A
1965	3	14	5	16	22	27	N/A

Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	EV Single Axle Posting Load (tons)	EV Tandem Posting Load (tons)	EV Gross Posting Load (tons)	HL-93 Gross Posting Load (tons)
1984	2	12	4	15	22	26	N/A
2008	2	12	10	17	22	30	N/A
1971	4	15	10	17	22	30	N/A
1971	4	15	10	17	22	30	N/A
1994	2	12	10	16	22	27	N/A
1997	2	12	10	16	22	27	N/A
1954	3	12	7	16	22	27	N/A
1960	2	10	3	15	22	26	N/A
1935	2	10	5	16	23	28	N/A
1982	2	10	6	16	23	27	N/A
1950	2	12	6	17	23	32	N/A
1980	2	10	6	15	23	26	N/A
1955	2	10	6	16	23	28	N/A
1928	2	10	7	16	23	27	N/A
1936	2	10	8	16	23	27	N/A
1965	12	8	5	15	23	26	N/A
1928	3	10	9	16	23	27	N/A
1988	2	12	6	17	24	33	N/A
1965	2	12	3	17	24	33	N/A
1975	3	10	6	16	24	28	N/A
2001	2	12	6	17	24	33	N/A
1965	4	10	7	16	24	28	N/A
1928	2	10	6	16	24	28	N/A
1940	2	11	5	17	24	34	N/A
1970	3	10	10	17	24	34	N/A
1940	2	10	9	17	25	34	N/A
2000	3	15	10	17	25	34	N/A
1940	2	10	3	17	25	34	N/A
1968	4	10	7	17	25	34	N/A
1969	2	10	9	17	25	34	N/A
1984	3	12	11	17	25	35	N/A
1970	3	12	7	17	25	35	N/A
2009	3	12	14	17	25	35	N/A
1958	2	12	7	17	25	35	N/A
1968	2	8	5	17	25	35	N/A
1990	2	12	7	17	25	35	N/A
1955	2	10	8	17	25	28	N/A
1951	2	10	5	17	25	28	N/A

Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	EV Single Axle Posting Load (tons)	EV Tandem Posting Load (tons)	EV Gross Posting Load (tons)	HL-93 Gross Posting Load (tons)
1960	2	10	10	17	25	28	N/A
1932	2	10	6	17	25	28	N/A
1970	2	12	8	17	25	35	N/A
1960	2	12	6	17	26	35	N/A
1950	2	10	10	17	26	35	N/A
1989	2	10	6	17	26	36	N/A
1983	4	10	8	17	26	36	N/A
1965	3	12	6	17	26	36	N/A
2000	3	12	8	17	26	36	N/A
1968	3	12	6	17	26	36	N/A
1928	2	8	6	15	26	26	N/A
1935	2	8	6	15	26	26	N/A
1939	2	10	6	17	26	36	N/A
1950	2	8	6	15	26	26	N/A
1975	3	10	6	17	26	36	N/A
1993	2	10	5	17	26	36	N/A
1936	3	10	4	17	26	37	N/A
1954	3	10	5	17	26	37	N/A
1960	2	10	5	17	26	37	N/A
1960	2	10	6	17	26	37	N/A
1960	2	10	6	17	26	37	N/A
2014	1	22	5	17	26	37	N/A
2007	12	16	12	17	27	37	N/A
1970	2	12	8	17	27	37	N/A
1950	2	13	6	17	27	37	N/A
1960	2	10	6	17	27	37	N/A
1940	2	10	8	17	27	37	N/A
1984	2	12	8	17	27	37	N/A
1986	2	12	6	17	27	37	N/A
1987	2	12	6	17	27	37	N/A
1995	3	12	10	17	27	38	N/A
1987	3	12	6	17	27	38	N/A
1988	3	12	6	17	27	38	N/A
1936	2	9	5	17	28	38	N/A
1960	2	17	8	17	28	38	N/A
2006	3	16	8	17	28	38	N/A
1950	2	10	8	17	28	39	N/A
1928	2	10	6	17	28	39	N/A

Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	EV Single Axle Posting Load (tons)	EV Tandem Posting Load (tons)	EV Gross Posting Load (tons)	HL-93 Gross Posting Load (tons)
1935	2	10	4	17	28	39	N/A
1962	3	10	7	17	28	39	N/A
1976	2	10	8	17	28	39	N/A
1965	4	15	12	17	28	39	N/A
1960	2	12	3	17	28	39	N/A
1965	3	15	10	17	28	39	N/A
2003	3	12	8	17	28	39	N/A
1975	3	15	9	17	28	39	N/A
1947	2	10	7	17	28	39	N/A
2003	3	12	6	17	28	39	N/A
1938	3	10	5	17	29	40	N/A
2004	4	15	10	17	29	40	N/A
1992	2	10	6	17	29	40	N/A
2000	2	12	6	17	29	40	N/A
1958	2	10	9	17	29	40	N/A
1967	3	12	7	17	29	41	N/A
1950	2	12	15	17	29	41	N/A
1987	2	10	8	17	29	41	N/A
1960	3	10	4	17	29	41	N/A
1969	3	15	10	17	30	41	N/A
1985	2	10	9	17	30	41	N/A
1915	3	11	5	17	30	41	N/A
1930	2	10	6	17	30	42	N/A
2000	3	15	11	17	30	42	N/A
2000	3	15	10	17	30	42	N/A
1972	2	11	5	17	30	42	N/A
1950	2	10	6	17	30	42	N/A
1967	4	10	5	17	31	42	N/A
1973	3	8	5	17	31	42	N/A
1970	3	8	3	17	31	43	N/A
1965	3	10	6	17	31	43	N/A

APPENDIX D

EV RATINGS FOR CULVERTS WITH 0’ FILL MODELED AS NON-BURIED STRUCTURES

Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	Fill (ft)	EV3 Legal Rating	EV2 Legal Rating	EV3 Rating Non-Buried	EV2 Rating Non-Buried	EV3 Rating Percent Change	EV2 Rating Percent Change
1992	2	10	6	0.0	0.52	0.761	0.718	1.05	38.1%	38.0%
1950	2	10	10	0.0	1.066	1.235	1.471	1.703	38.0%	37.9%
1983	2	10	8	0.0	1.067	1.629	1.472	2.247	38.0%	37.9%
1965	2	10	14	0.0	1.465	1.595	2.02	2.2	37.9%	37.9%
1960	2	10	6	0.0	0.459	0.661	0.633	0.911	37.9%	37.8%
1982	2	10	5	0.0	0.447	0.664	0.617	0.917	38.0%	38.1%
1930	2	15	6	0.0	0.272	0.392	0.375	0.54	37.9%	37.8%
1991	3	18	9	0.0	2.095	3.166	2.89	4.367	37.9%	37.9%
1992	2	15	10	0.0	2.747	3.858	3.789	5.322	37.9%	37.9%
1970	2	10	5	0.0	0.447	0.664	0.617	0.917	38.0%	38.1%
1980	3	14	8	0.0	0.413	0.605	0.57	0.835	38.0%	38.0%
1980	3	8	4	0.0	0.569	0.775	0.784	1.069	37.8%	37.9%
1987	3	12	8	0.0	0.816	1.167	1.126	1.609	38.0%	37.9%
1992	3	10	5	0.0	0.382	0.56	0.527	0.773	38.0%	38.0%
1992	2	12	7	0.0	1.096	1.467	1.511	2.023	37.9%	37.9%
1994	2	15	10	0.0	2.912	3.962	4.016	5.464	37.9%	37.9%
1985	2	12	7	0.0	0.39	0.616	0.538	0.849	37.9%	37.8%
1938	3	10	5	0.0	0.924	1.135	1.274	1.566	37.9%	38.0%
1983	2	15	6	0.0	0.239	0.341	0.33	0.47	38.1%	37.8%
1984	2	15	11	0.0	2.246	2.97	3.098	4.097	37.9%	37.9%
1960	2	8	8	0.0	1.981	2.122	2.733	2.927	38.0%	37.9%
1984	3	12	11	0.0	0.996	1.253	1.373	1.728	37.9%	37.9%
1983	2	12	6	0.0	0.274	0.433	0.378	0.598	38.0%	38.1%
1935	2	8	6	0.0	0.838	0.911	1.156	1.257	37.9%	38.0%
1935	2	10	4	0.0	0.898	1.093	1.239	1.507	38.0%	37.9%
1985	2	12	6	0.0	0.274	0.433	0.378	0.598	38.0%	38.1%
1986	2	10	4	0.0	0.373	0.558	0.514	0.77	37.8%	38.0%
1975	2	10	8	0.0	1.067	1.629	1.472	2.247	38.0%	37.9%
1960	4	14	8	0.0	0.181	0.305	0.249	0.42	37.6%	37.7%
1967	2	14	5	0.0	0.131	0.218	0.181	0.3	38.2%	37.6%
1955	3	15	6	0.0	0.132	0.217	0.183	0.299	38.6%	37.8%
1960	2	17	8	0.0	0.111	0.187	0.153	0.257	37.8%	37.4%
1994	2	12	10	0.0	0.885	1.136	1.221	1.566	38.0%	37.9%
1988	3	15	11	0.0	2.421	3.32	3.34	4.579	38.0%	37.9%
1999	3	10	6	0.0	0.633	0.998	0.867	1.36	37.0%	36.3%
1988	2	12	6	0.0	0.315	0.496	0.435	0.684	38.1%	37.9%
1985	2	12	10	0.0	0.885	1.379	1.221	1.902	38.0%	37.9%

Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	Fill (ft)	EV3 Legal Rating	EV2 Legal Rating	EV3 Rating Non-Buried	EV2 Rating Non-Buried	EV3 Rating Percent Change	EV2 Rating Percent Change
1972	2	11	5	0.0	0.354	0.546	0.489	0.753	38.1%	37.9%
1997	2	10	4	0.0	0.345	0.517	0.517	0.713	49.9%	37.9%
1986	2	10	4	0.0	0.056	0.081	0.078	0.112	39.3%	38.3%
1940	3	14	5	0.0	0.531	0.776	0.733	1.07	38.0%	37.9%
1984	3	12	5	0.0	1.671	2.737	2.305	3.775	37.9%	37.9%
1980	2	10	6	0.0	0.462	0.675	0.637	0.931	37.9%	37.9%
1974	2	8	4	0.0	0.302	0.407	0.417	0.526	38.1%	29.2%
1960	2	12	3	0.0	0.38	0.58	0.524	0.8	37.9%	37.9%
1965	2	12	3	0.0	0.323	0.492	0.445	0.679	37.8%	38.0%
1984	2	12	8	0.0	0.623	0.973	0.859	1.342	37.9%	37.9%
1975	2	8	5	0.0	0.383	0.512	0.529	0.707	38.1%	38.1%
1950	2	14	8	0.0	0.434	0.705	0.599	0.973	38.0%	38.0%
1960	2	11	6	0.0	0.512	0.78	0.706	1.076	37.9%	37.9%
1965	2	10	7	0.0	1.199	1.769	1.564	2.439	30.4%	37.9%
1960	2	10	5	0.0	0.095	0.141	0.132	0.195	38.9%	38.3%
1986	2	12	10	0.0	0.998	1.554	1.377	2.143	38.0%	37.9%
1984	3	12	8	0.0	0.377	0.582	0.52	0.802	37.9%	37.8%
1965	3	14	5	0.0	0.531	0.763	0.732	1.052	37.9%	37.9%
1960	2	11	4	0.0	0.411	0.631	0.567	0.871	38.0%	38.0%
1965	2	15	7	0.0	0.226	0.372	0.312	0.514	38.1%	38.2%
1986	3	15	10	0.0	2.43	3.305	3.352	4.559	37.9%	37.9%
1987	3	12	6	0.0	0.351	0.547	0.484	0.755	37.9%	38.0%
1940	2	13	6	0.0	0.772	1.289	1.065	1.778	38.0%	37.9%
1976	2	10	10	0.0	1.558	1.82	2.149	2.51	37.9%	37.9%
1969	3	10	10	0.0	1.526	1.794	2.104	2.474	37.9%	37.9%
1928	2	10	6	0.0	0.784	0.958	1.081	1.322	37.9%	38.0%
1928	2	11	7	0.0	0.659	0.836	0.909	1.153	37.9%	37.9%
1992	2	15	15	0.0	2.092	2.952	2.885	4.072	37.9%	37.9%
1990	3	15	7	0.0	0.631	0.99	0.871	1.365	38.0%	37.9%
1990	2	8	6	0.0	0.608	0.834	0.846	1.128	39.1%	35.3%
1994	3	15	8	0.0	2.714	3.661	3.743	5.05	37.9%	37.9%
1994	1	15	4	0.0	0.152	0.263	0.209	0.363	37.5%	38.0%
1949	2	10	5	0.0	0.059	0.086	0.081	0.118	37.3%	37.2%
1980	4	15	10	0.0	1.786	2.508	2.464	3.459	38.0%	37.9%
1980	3	15	14	0.0	1.066	1.749	1.47	2.412	37.9%	37.9%
1998	2	12	12	0.0	1.275	1.973	1.758	2.722	37.9%	38.0%
1997	3	15	9	0.0	3.384	4.668	4.667	6.438	37.9%	37.9%
1986	2	12	6	0.0	0.352	0.553	0.486	0.763	38.1%	38.0%

Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	Fill (ft)	EV3 Legal Rating	EV2 Legal Rating	EV3 Rating Non-Buried	EV2 Rating Non-Buried	EV3 Rating Percent Change	EV2 Rating Percent Change
1987	2	10	8	0.0	0.932	1.366	1.31	1.596	40.6%	16.8%
1968	3	12	6	0.0	0.309	0.5	0.426	0.69	37.9%	38.0%
1965	1	8	6	0.0	1.085	1.192	1.497	1.644	38.0%	37.9%
1983	2	10	5	0.0	0.447	0.664	0.617	0.917	38.0%	38.1%
1960	2	10	6	0.0	0.432	0.621	0.595	0.856	37.7%	37.8%
1933	2	7	6	0.0	0.584	0.449	0.805	0.62	37.8%	38.1%
1992	2	10	10	0.0	1.284	1.555	1.772	2.144	38.0%	37.9%
1960	2	10	10	0.0	1.001	1.168	1.38	1.611	37.9%	37.9%
1995	2	15	5	0.0	1.604	2.253	2.212	3.108	37.9%	37.9%
1966	4	12	10	0.0	0.91	1.158	1.256	1.597	38.0%	37.9%
1997	2	12	10	0.0	0.885	1.136	1.221	1.566	38.0%	37.9%
1930	2	10	5	0.0	0.15	0.217	0.207	0.299	38.0%	37.8%
1995	3	10	6	0.0	1.025	1.263	1.413	1.743	37.9%	38.0%
1935	2	10	4	0.0	0.898	1.093	1.239	1.507	38.0%	37.9%
1997	3	18	6	0.0	3.86	5.679	5.324	7.833	37.9%	37.9%
1935	1	12	5	0.0	0.356	0.555	0.492	0.765	38.2%	37.8%
1980	2	8	7	0.0	0.793	1.06	1.094	1.462	38.0%	37.9%
1960	2	10	14	0.0	2.257	3.059	3.114	4.22	38.0%	38.0%
1965	3	12	10	0.0	0.911	1.412	1.257	1.948	38.0%	38.0%
1936	3	10	4	0.0	0.104	0.151	0.143	0.208	37.5%	37.7%
1930	2	15	6	0.0	0.272	0.392	0.375	0.54	37.9%	37.8%
1999	3	12	9	0.0	2.119	2.753	2.923	3.798	37.9%	38.0%
1940	2	10	8	0.0	0.234	0.325	0.322	0.448	37.6%	37.8%
1987	2	12	7	0.0	1.305	1.703	1.8	2.348	37.9%	37.9%
1984	3	10	5	0.0	0.453	0.671	0.625	0.926	38.0%	38.0%
1970	3	10	7	0.0	0.85	1.286	1.172	1.774	37.9%	37.9%
1965	2	10	4	0.0	0.345	0.517	0.517	0.713	49.9%	37.9%
1950	3	12	6	0.0	0.229	0.342	0.315	0.471	37.6%	37.7%
1971	4	10	10	0.0	0.97	1.15	1.337	1.586	37.8%	37.9%
1971	4	10	10	0.0	0.97	1.15	1.337	1.586	37.8%	37.9%
1960	2	12	6	0.0	0.262	0.41	0.362	0.566	38.2%	38.0%
1950	2	12	15	0.0	1.297	1.897	1.789	2.617	37.9%	38.0%
1997	2	10	9	0.0	1.435	1.97	1.979	2.718	37.9%	38.0%
1984	2	15	12	0.0	0.813	1.366	1.121	1.884	37.9%	37.9%
1984	3	15	11	0.0	0.705	1.149	0.973	1.585	38.0%	37.9%
1987	2	10	8	0.0	1.067	1.629	1.472	2.247	38.0%	37.9%
1963	2	10	8	0.0	1.067	1.629	1.472	2.247	38.0%	37.9%
1929	2	10	4	0.0	0.077	0.112	0.106	0.154	37.7%	37.5%

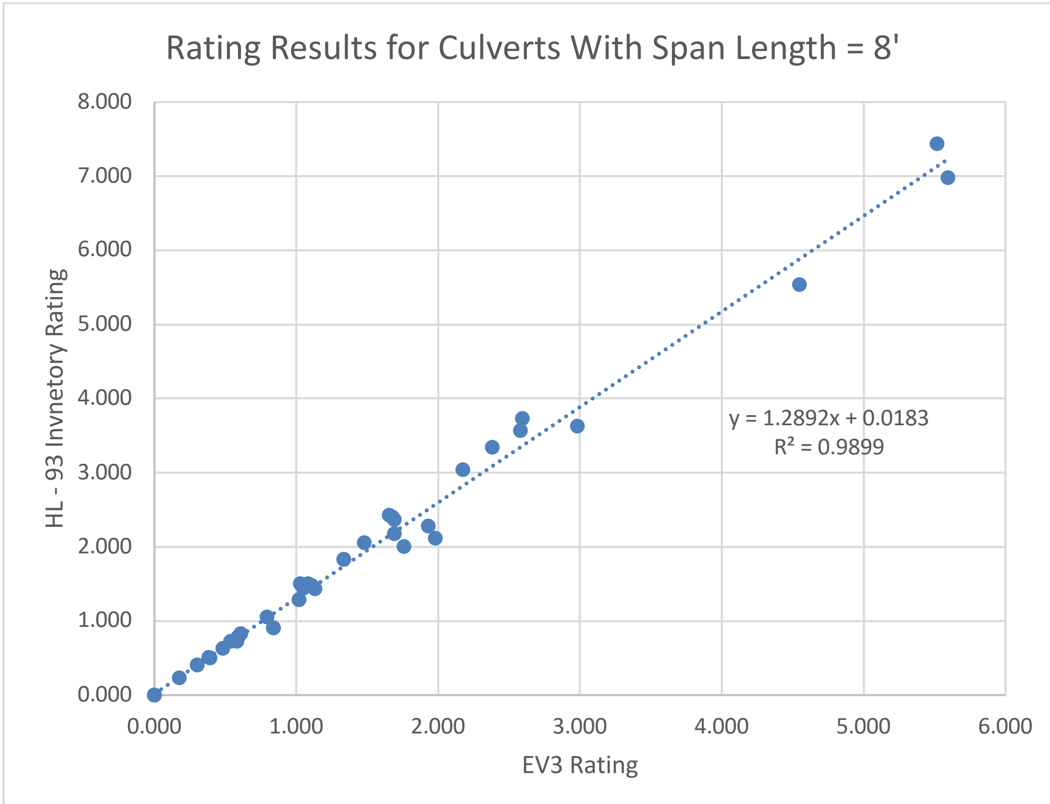
Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	Fill (ft)	EV3 Legal Rating	EV2 Legal Rating	EV3 Rating Non-Buried	EV2 Rating Non-Buried	EV3 Rating Percent Change	EV2 Rating Percent Change
1987	2	12	6	0.0	0.352	0.553	0.486	0.763	38.1%	38.0%
1988	3	12	6	0.0	0.351	0.547	0.484	0.755	37.9%	38.0%
1964	3	9	9	0.0	1.321	1.928	1.822	2.66	37.9%	38.0%
1964	3	9	9	0.0	0.953	1.512	1.315	2.086	38.0%	38.0%
1993	3	18	6	0.0	0.181	0.272	0.25	0.375	38.1%	37.9%
1984	2	15	7	0.0	1.249	2.283	1.722	3.148	37.9%	37.9%
1984	2	12	4	0.0	0.744	1.108	1.026	1.528	37.9%	37.9%
1965	3	15	10	0.0	0.694	1.081	0.957	1.491	37.9%	37.9%
1954	3	12	7	0.0	0.395	0.625	0.544	0.862	37.7%	37.9%
1975	2	16	12	0.0	0.709	1.192	0.978	1.644	37.9%	37.9%
1970	2	12	8	0.0	0.517	0.817	0.713	1.127	37.9%	37.9%
1991	3	12	8	0.0	0.538	0.824	0.743	1.137	38.1%	38.0%
1996	2	10	4	0.0	0.345	0.517	0.517	0.713	49.9%	37.9%
1970	3	12	7	0.0	0.388	0.577	0.536	0.796	38.1%	38.0%
1965	4	10	7	0.0	0.57	0.838	0.787	1.156	38.1%	37.9%
1994	2	10	8	0.0	1.067	1.629	1.472	2.247	38.0%	37.9%
1955	2	10	8	0.0	0.694	0.968	0.957	1.336	37.9%	38.0%
1950	2	10	8	0.0	0.81	1.181	1.117	1.629	37.9%	37.9%
1975	2	15	3	0.0	0.113	0.182	0.156	0.251	38.1%	37.9%
1992	2	10	3	0.0	0.263	0.396	0.362	0.547	37.6%	38.1%
1992	2	10	3	0.0	0.263	0.396	0.362	0.547	37.6%	38.1%
1975	3	15	6	0.0	1.832	2.951	2.527	4.07	37.9%	37.9%
1987	3	10	5	0.0	0.667	1.006	0.92	1.388	37.9%	38.0%
1964	3	19	11	0.0	0.388	0.7	0.535	0.7	37.9%	0.0%
1992	2	20	11	0.0	3.691	5.367	5.091	7.403	37.9%	37.9%
1960	3	19	11	0.0	0.399	0.688	0.55	0.95	37.8%	38.1%
1950	2	13	6	0.0	0.511	0.691	0.705	0.954	38.0%	38.1%
1980	2	12	9	0.0	1.305	1.702	1.8	2.348	37.9%	38.0%
1993	2	10	14	0.0	3.184	3.921	4.392	5.408	37.9%	37.9%
1999	2	12	4	0.0	0.248	0.372	0.341	0.513	37.5%	37.9%
1960	3	10	4	0.0	0.172	0.253	0.238	0.349	38.4%	37.9%
1939	3	12	12	0.0	0.842	1.06	1.162	1.463	38.0%	38.0%
1930	2	10	10	0.0	0.233	0.343	0.322	0.473	38.2%	37.9%
1992	2	10	4	0.0	1.375	1.834	1.896	2.53	37.9%	37.9%
1990	2	15	8	0.0	2.722	2.958	3.754	4.08	37.9%	37.9%
1954	2	10	6	0.0	0.61	0.882	0.842	1.217	38.0%	38.0%
1953	2	10	8	0.0	1.067	1.629	1.472	2.247	38.0%	37.9%
1990	3	15	8	0.0	2.493	3.363	3.438	4.639	37.9%	37.9%

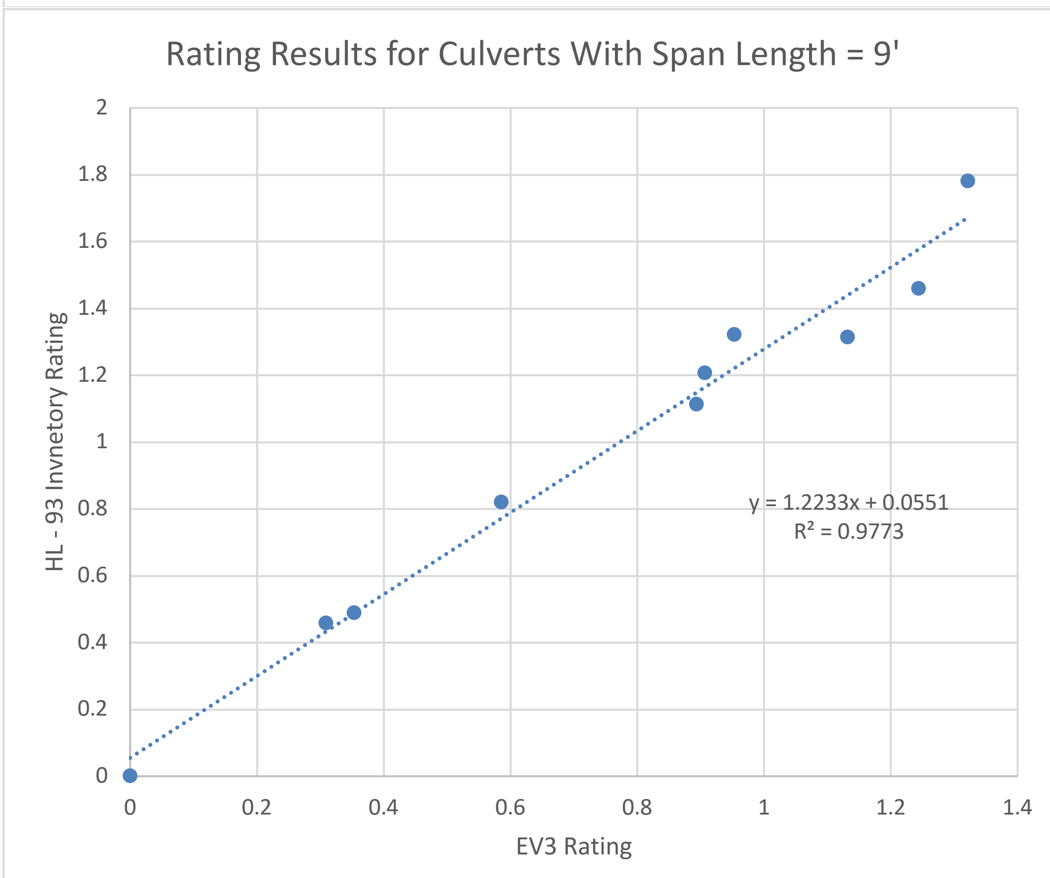
Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	Fill (ft)	EV3 Legal Rating	EV2 Legal Rating	EV3 Rating Non-Buried	EV2 Rating Non-Buried	EV3 Rating Percent Change	EV2 Rating Percent Change
1984	2	12	4	0.0	0.744	1.108	1.026	1.528	37.9%	37.9%
1965	6	12	5	0.0	0.154	0.232	0.213	0.32	38.3%	37.9%
1965	1	15	3	0.0	0.191	0.331	0.263	0.457	37.7%	38.1%
1993	3	15	5	0.0	0.372	0.573	0.514	0.79	38.2%	37.9%
1978	3	15	4	0.0	0.212	0.343	0.292	0.473	37.7%	37.9%
1965	4	15	12	0.0	0.559	0.876	0.771	1.208	37.9%	37.9%
1965	2	10	10	0.0	1.697	1.956	2.34	2.698	37.9%	37.9%
1983	4	10	8	0.0	0.641	0.962	0.884	1.327	37.9%	37.9%
1976	2	10	6	0.0	0.61	0.882	0.842	1.217	38.0%	38.0%
1976	2	10	5	0.0	0.447	0.664	0.617	0.917	38.0%	38.1%
1984	2	10	10	0.0	1.558	1.82	2.149	2.51	37.9%	37.9%
1982	4	15	9	0.0	1.488	2.6	2.053	3.586	38.0%	37.9%
1984	2	18	7	0.0	4.191	3.862	5.78	5.326	37.9%	37.9%
1983	1	15	7	0.0	3.172	4.423	4.375	6.1	37.9%	37.9%
1995	3	15	7	0.0	0.631	0.99	0.871	1.365	38.0%	37.9%
1983	2	12	6	0.0	0.385	0.592	0.531	0.817	37.9%	38.0%
1928	2	10	6	0.0	0.21	0.301	0.289	0.416	37.6%	38.2%
1928	2	8	6	0.0	0.838	0.911	1.156	1.257	37.9%	38.0%
1999	2	12	9	0.0	1.305	1.702	1.8	2.348	37.9%	38.0%
1992	2	12	9	0.0	5.116	6.625	7.057	9.137	37.9%	37.9%
1995	3	12	10	0.0	1.126	1.404	1.554	1.936	38.0%	37.9%
1988	2	12	4	0.0	0.159	0.254	0.219	0.35	37.7%	37.8%
1984	2	15	10	0.0	2.747	3.858	3.789	5.322	37.9%	37.9%
1996	3	12	9	0.0	0.704	1.084	0.97	1.495	37.8%	37.9%
1977	2	15	6	0.0	0.233	0.369	0.322	0.509	38.2%	37.9%
1982	2	15	8	0.0	1.46	2.323	2.014	3.204	37.9%	37.9%
1954	1	15	4	0.0	0.191	0.331	0.263	0.457	37.7%	38.1%
1990	2	12	5	0.0	0.211	0.335	0.291	0.462	37.9%	37.9%
1991	2	12	4	0.0	0.824	1.256	1.136	1.732	37.9%	37.9%
1979	3	15	9	0.0	0.432	0.704	0.596	0.972	38.0%	38.1%
1998	3	15	8	0.0	2.174	3.661	3.743	5.05	72.2%	37.9%
1984	2	15	5	0.0	1.012	1.376	1.396	1.897	37.9%	37.9%
1951	2	10	5	0.0	0.104	0.15	0.144	0.207	38.5%	38.0%
1970	1	16	6	0.0	3.243	4.705	4.473	6.49	37.9%	37.9%
1988	2	15	8	0.0	0.725	1.242	1.0	1.713	37.9%	37.9%
1985	3	18	8	0.0	1.885	3.2	2.6	4.413	37.9%	37.9%
1988	5	15	10	0.0	0.949	1.489	1.309	2.053	37.9%	37.9%
1940	3	15	7	0.0	2.14	3.404	2.952	4.694	37.9%	37.9%

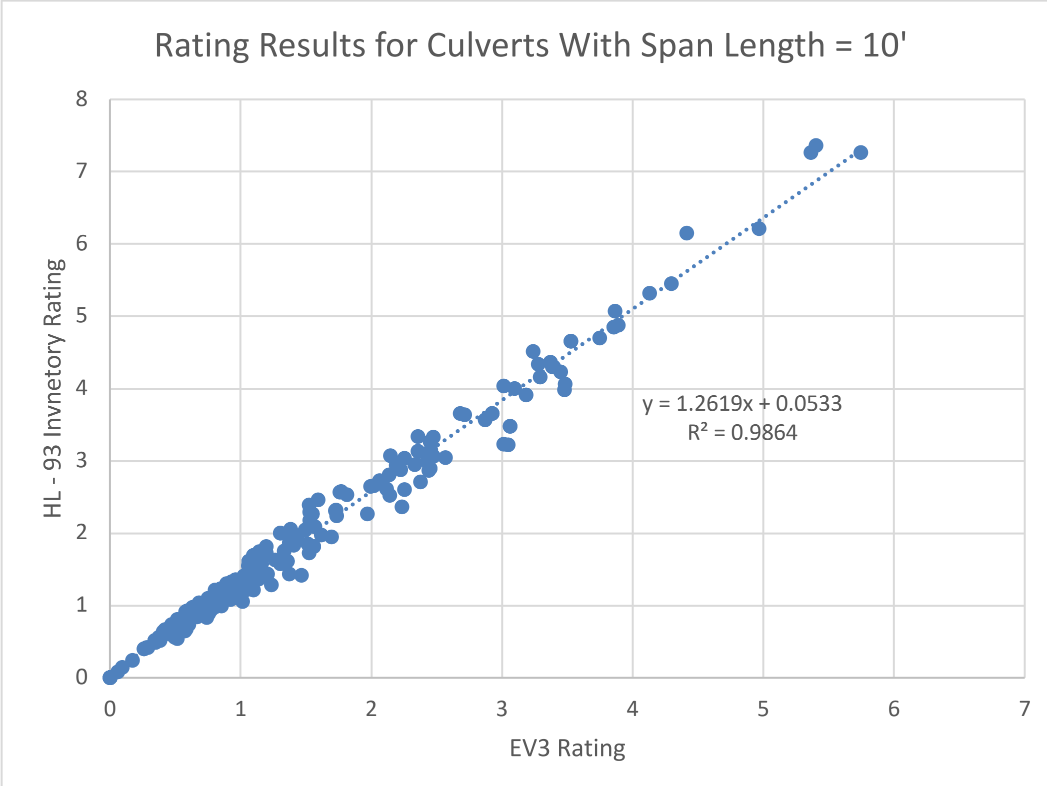
Year Built	Number of Cells	Clear Span (ft)	Clear Height (ft)	Fill (ft)	EV3 Legal Rating	EV2 Legal Rating	EV3 Rating Non-Buried	EV2 Rating Non-Buried	EV3 Rating Percent Change	EV2 Rating Percent Change
1947	2	9	4	0.0	0.096	0.121	0.133	0.167	38.5%	38.0%

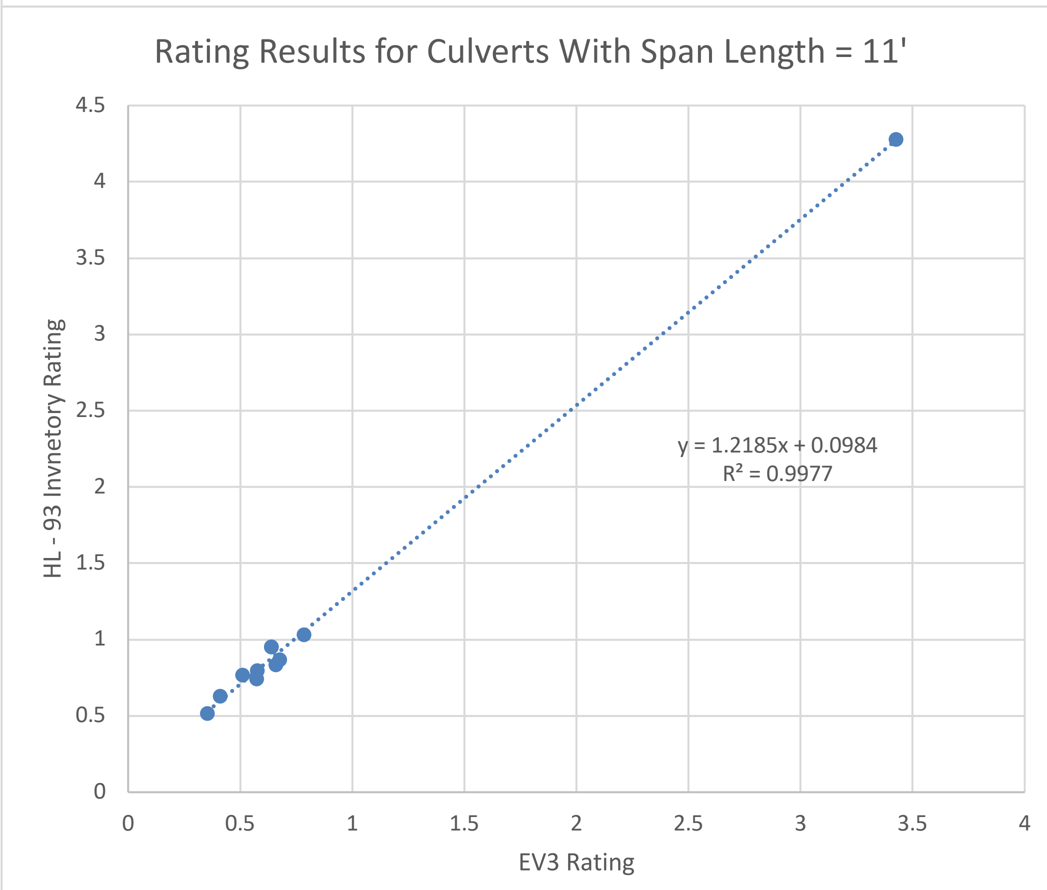
APPENDIX E

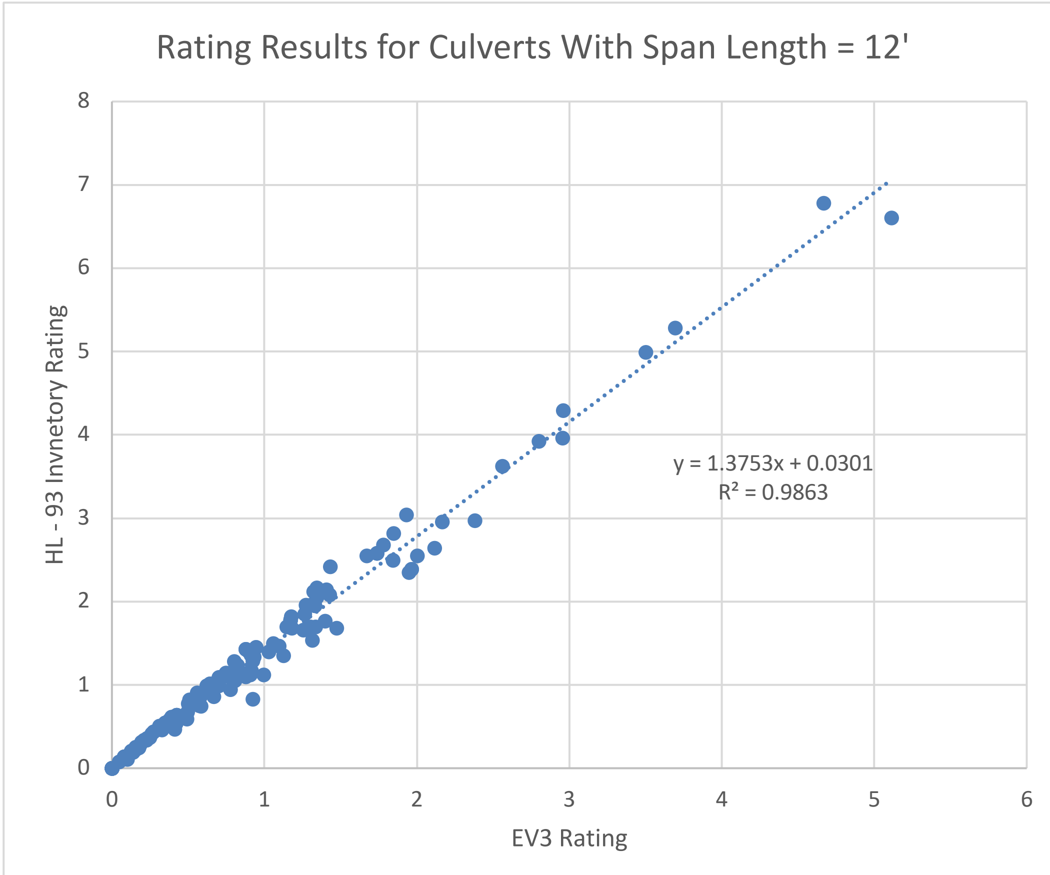
HL-93 INVENTORY RATINGS VERSUS EV2 AND EV3 RATINGS FOR VARIOUS CULVERT SPAN LENGTHS


Rating Results for Culverts With Span Length = 8'
8.000
7.000
6.000
5.000
4.000
3.000
2.000
1.000
0.000
0.000
1.000
2.000
3.000
4.000
5.000
6.000
HL - 93 Invnetory Rating
EV3 Rating
y = 1.2892x + 0.0183
R² = 0.9899

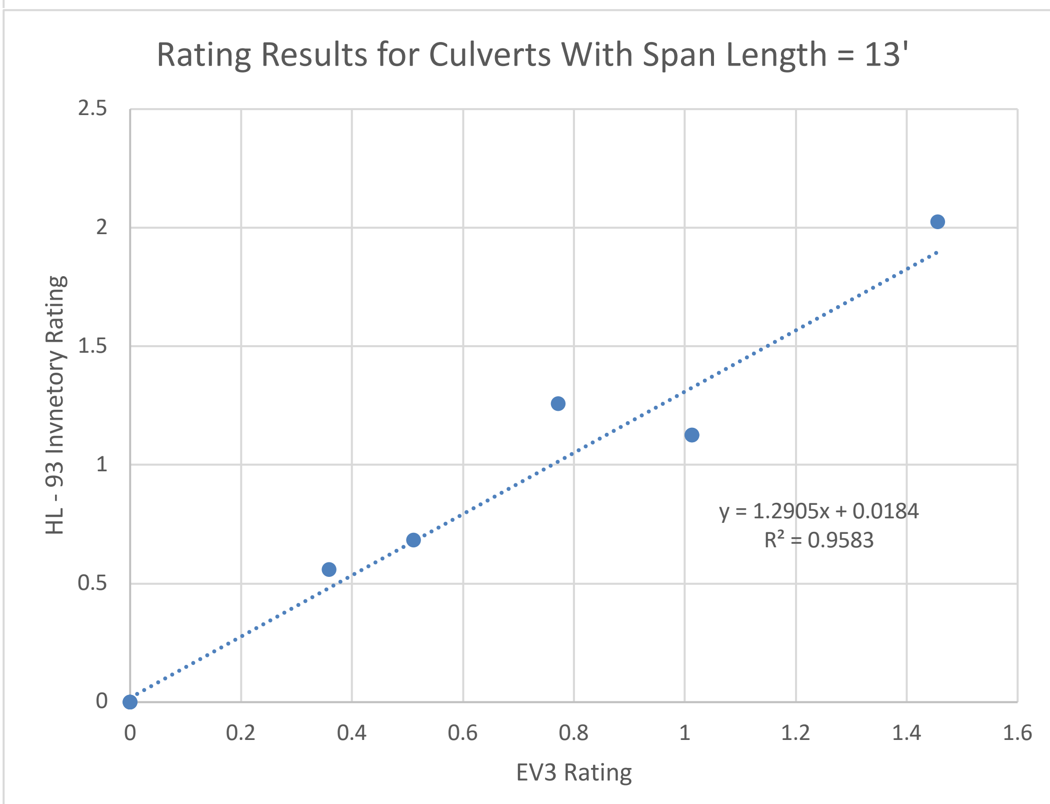

Rating Results for Culverts With Span Length = 9'
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
HL - 93 Invnetory Rating
EV3 Rating
y = 1.2233x + 0.0551
R² = 0.9773


Rating Results for Culverts With Span Length = 10'
HL - 93 Invnetory Rating
EV3 Rating
y = 1.2619x + 0.0533
R² = 0.9864
0
1
2
3
4
5
6
7
8

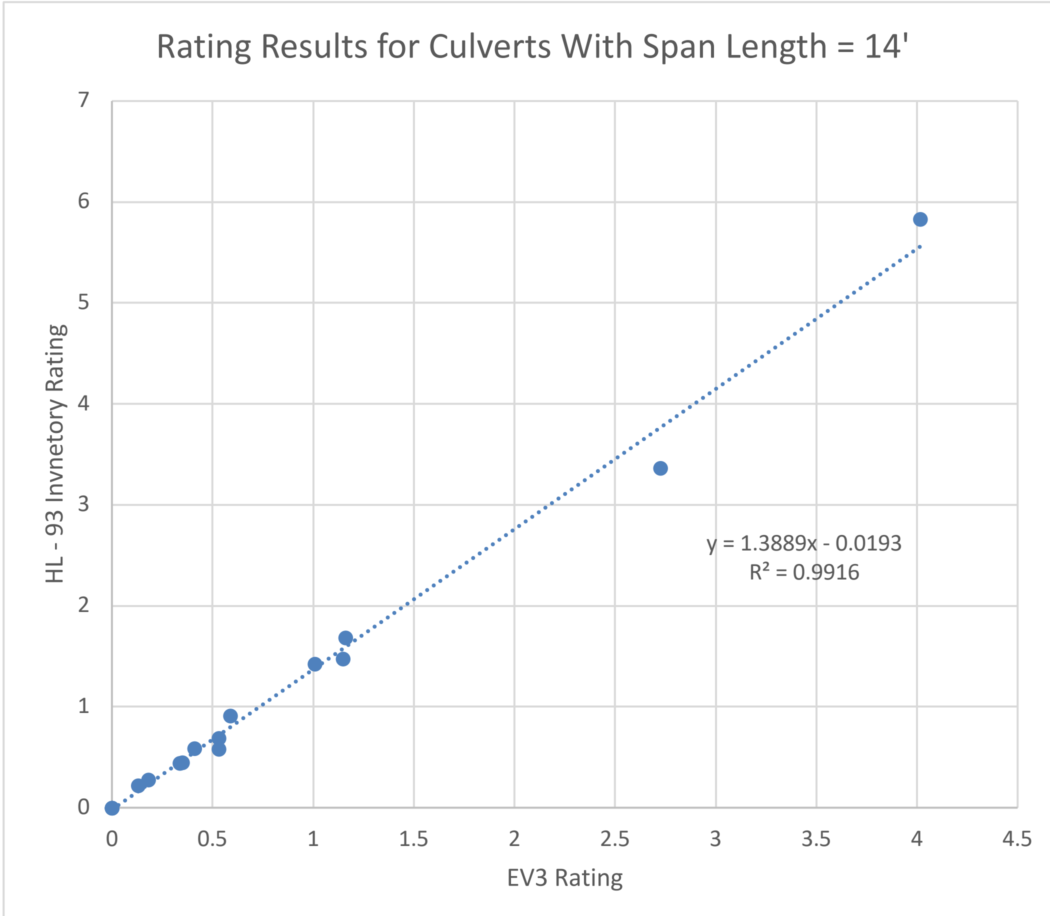

Rating Results for Culverts With Span Length = 11'
HL - 93 Invnetory Rating
EV3 Rating
y = 1.2185x + 0.0984
R² = 0.9977
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

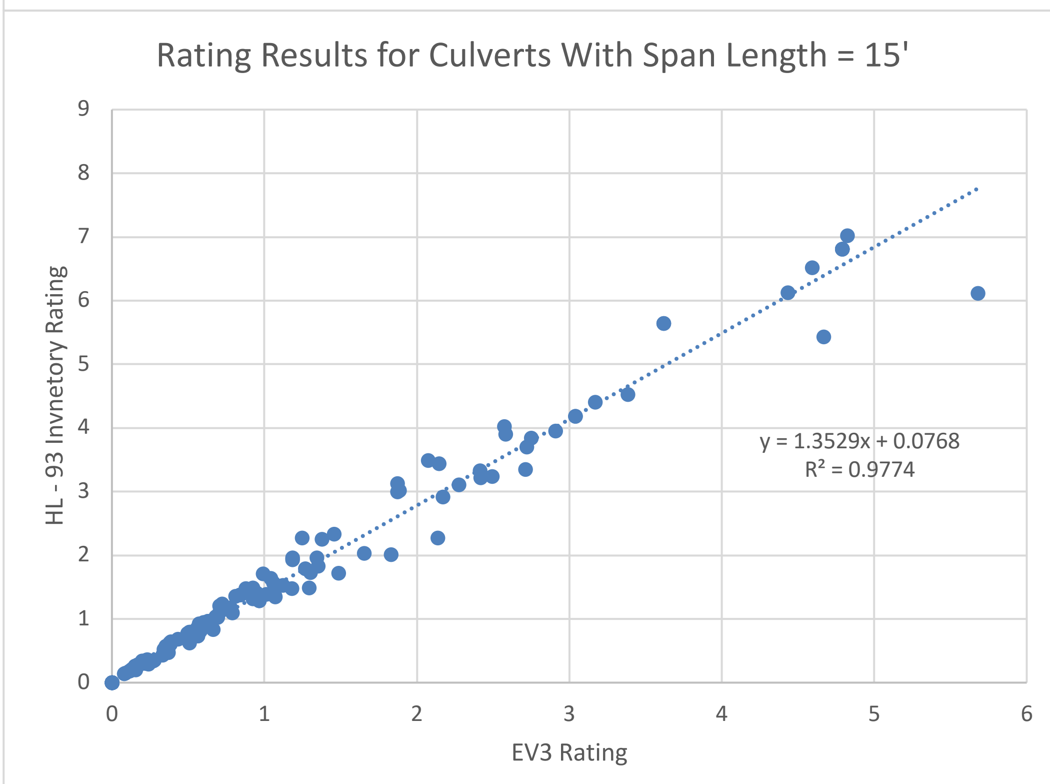


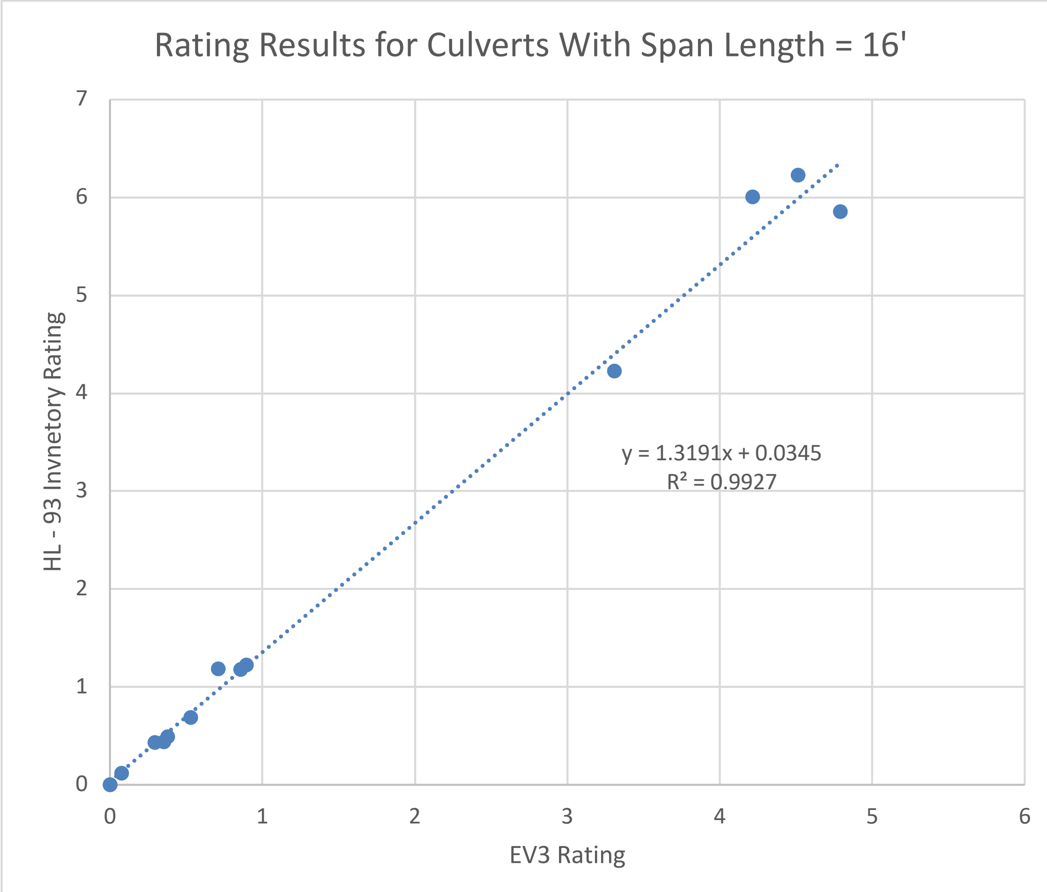
Rating Results for Culverts With Span Length = 12'
HL - 93 Invnetory Rating
EV3 Rating
y = 1.3753x + 0.0301
R² = 0.9863

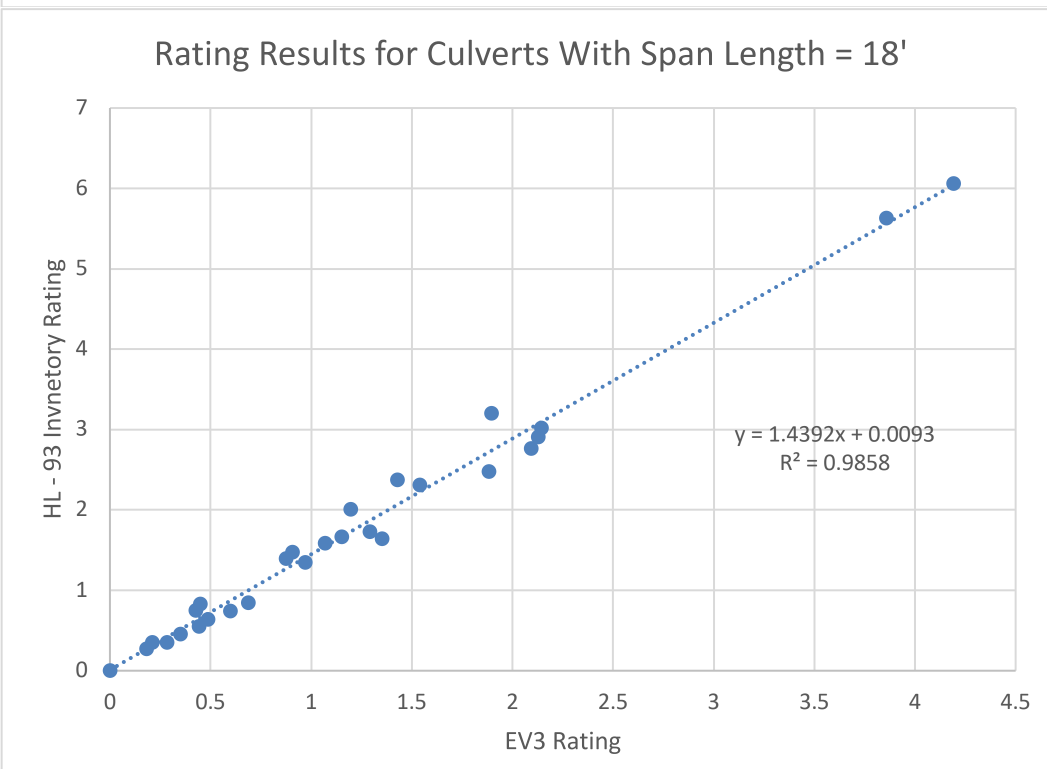


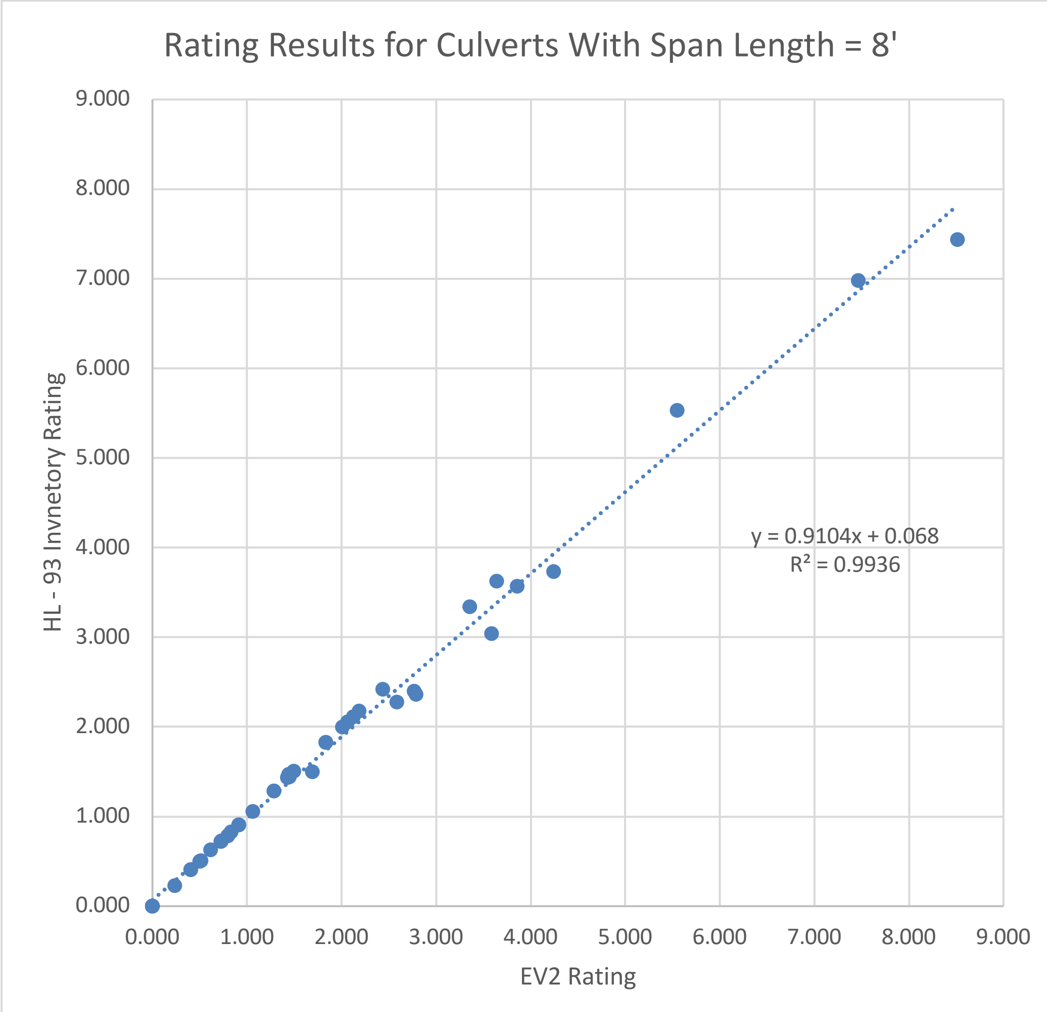
Rating Results for Culverts With Span Length = 13'
HL - 93 Invnetory Rating
EV3 Rating
y = 1.2905x + 0.0184
R² = 0.9583

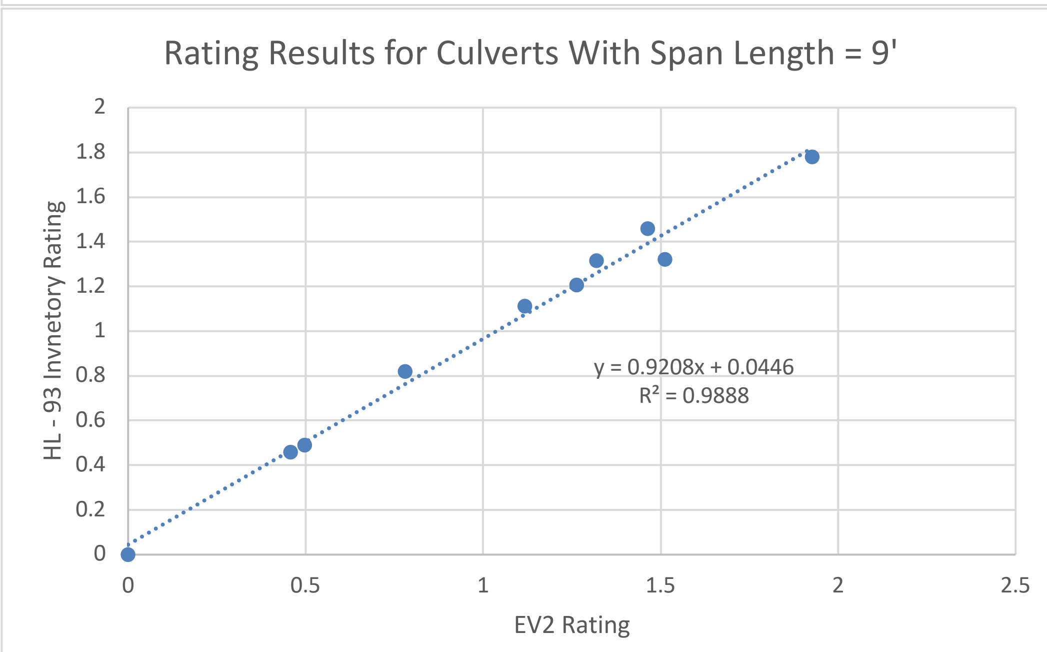

Rating Results for Culverts With Span Length = 14'
HL - 93 Invnetory Rating
EV3 Rating
y = 1.3889x - 0.0193
R² = 0.9916
0
1
2
3
4
5
6
7
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

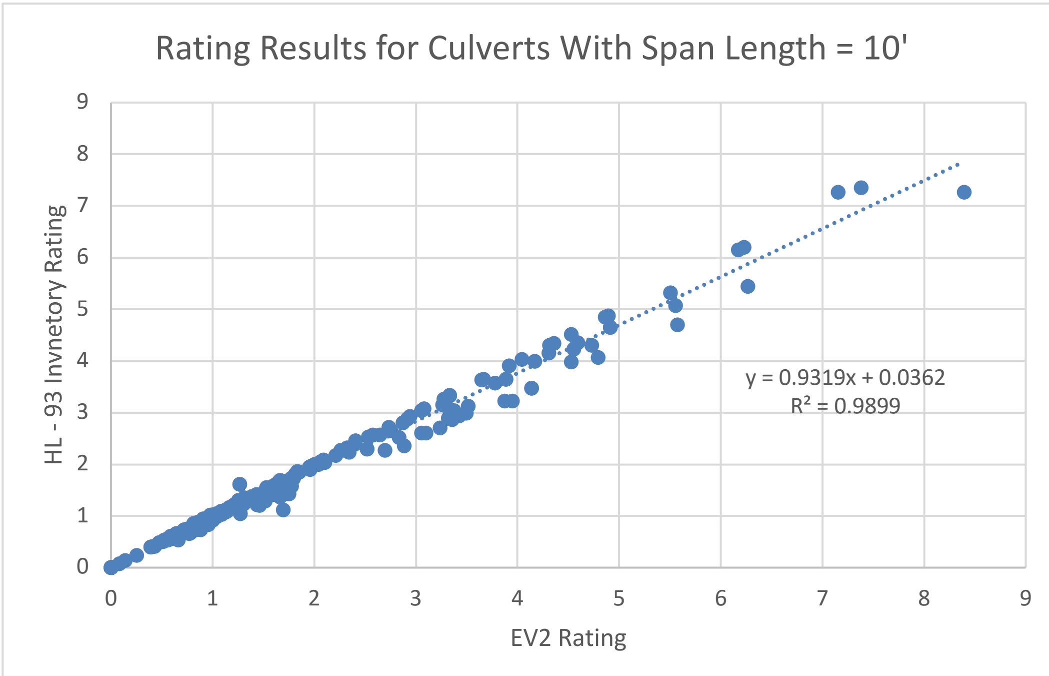

Rating Results for Culverts With Span Length = 15'
HL - 93 Invnetory Rating
EV3 Rating
y = 1.3529x + 0.0768
R² = 0.9774
0
1
2
3
4
5
6
7
8
9
0
1
2
3
4
5
6

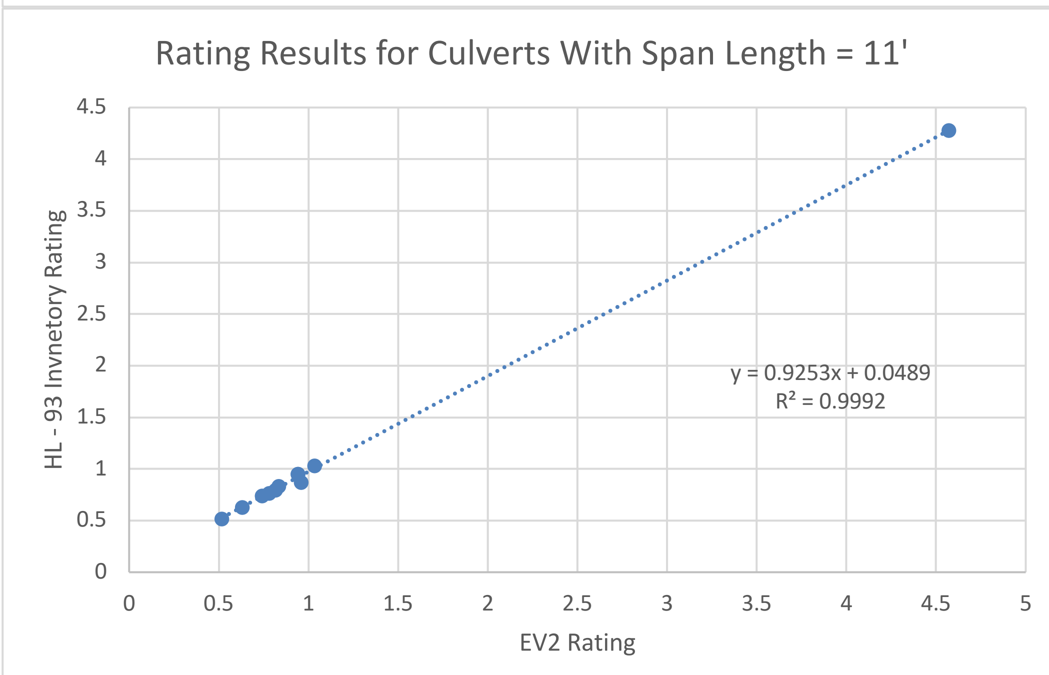

Rating Results for Culverts With Span Length = 16'
y = 1.3191x + 0.0345
R² = 0.9927
HL - 93 Invnetory Rating
EV3 Rating
0
1
2
3
4
5
6
7
0
1
2
3
4
5
6

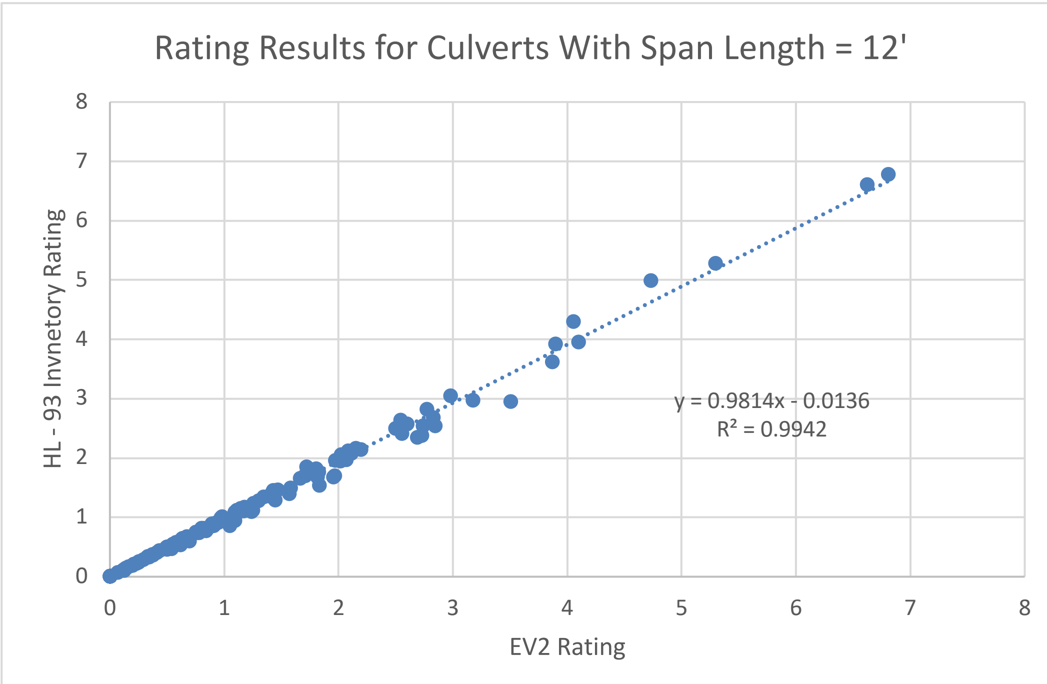

Rating Results for Culverts With Span Length = 18'
y = 1.4392x + 0.0093
R² = 0.9858
HL - 93 Invnetory Rating
EV3 Rating
0
1
2
3
4
5
6
7
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

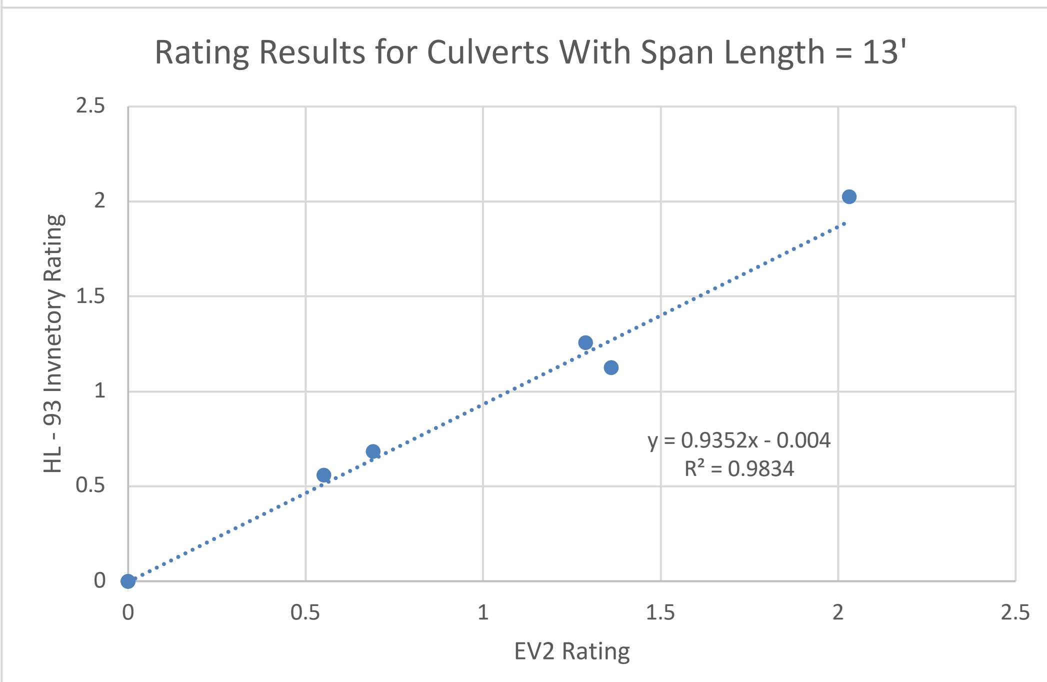

Rating Results for Culverts With Span Length = 8'
9.000
8.000
7.000
6.000
5.000
4.000
3.000
2.000
1.000
0.000
0.000
1.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
HL - 93 Invnetory Rating
EV2 Rating
y = 0.9104x + 0.068
R² = 0.9936

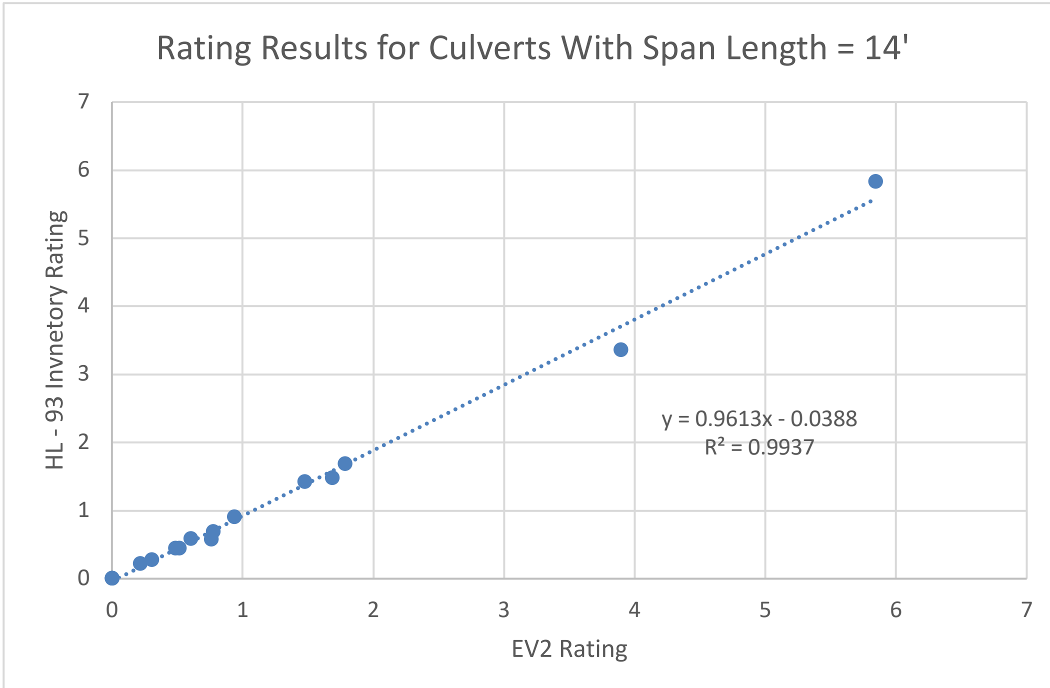

Rating Results for Culverts With Span Length = 9'
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
HL - 93 Invnetory Rating
EV2 Rating
y = 0.9208x + 0.0446
R² = 0.9888

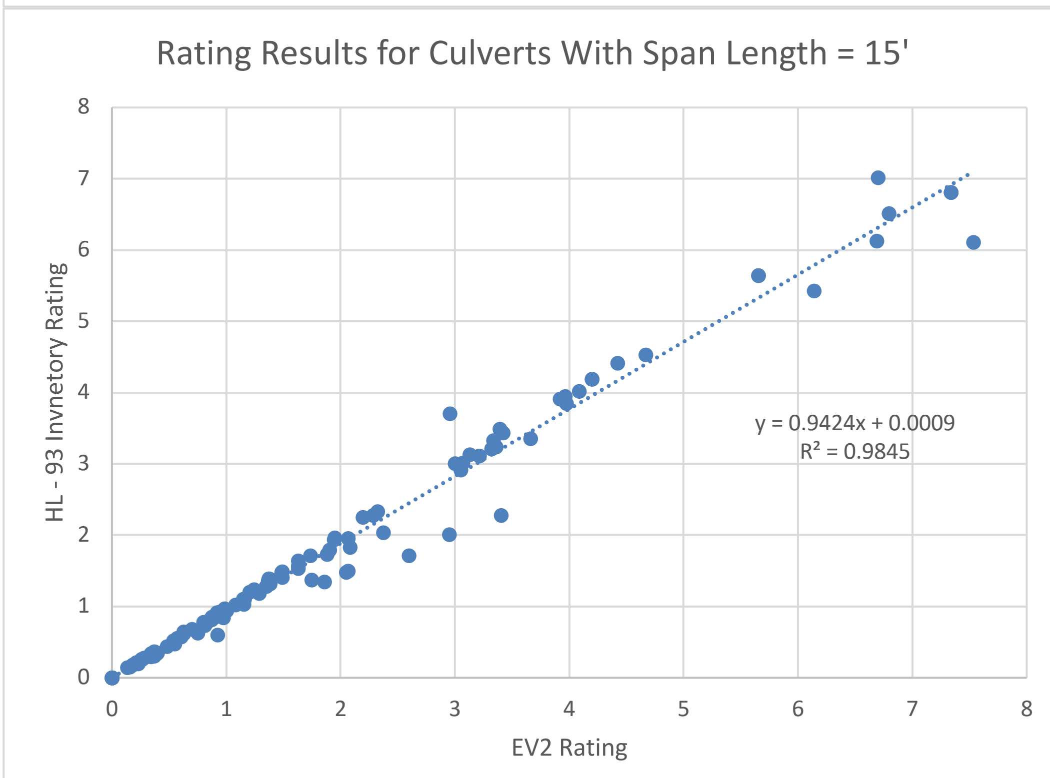

Rating Results for Culverts With Span Length = 10'
HL - 93 Invnetory Rating
EV2 Rating
y = 0.9319x + 0.0362
R² = 0.9899
0
1
2
3
4
5
6
7
8
9

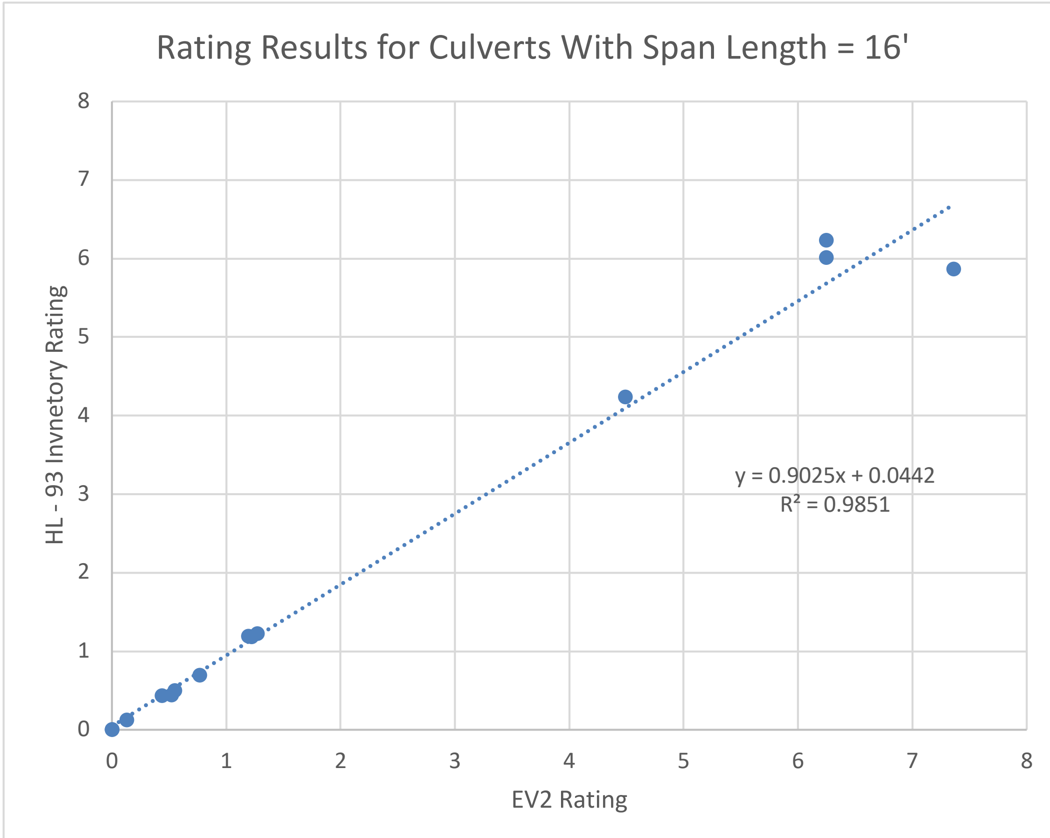

Rating Results for Culverts With Span Length = 11'
HL - 93 Invnetory Rating
EV2 Rating
y = 0.9253x + 0.0489
R² = 0.9992
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

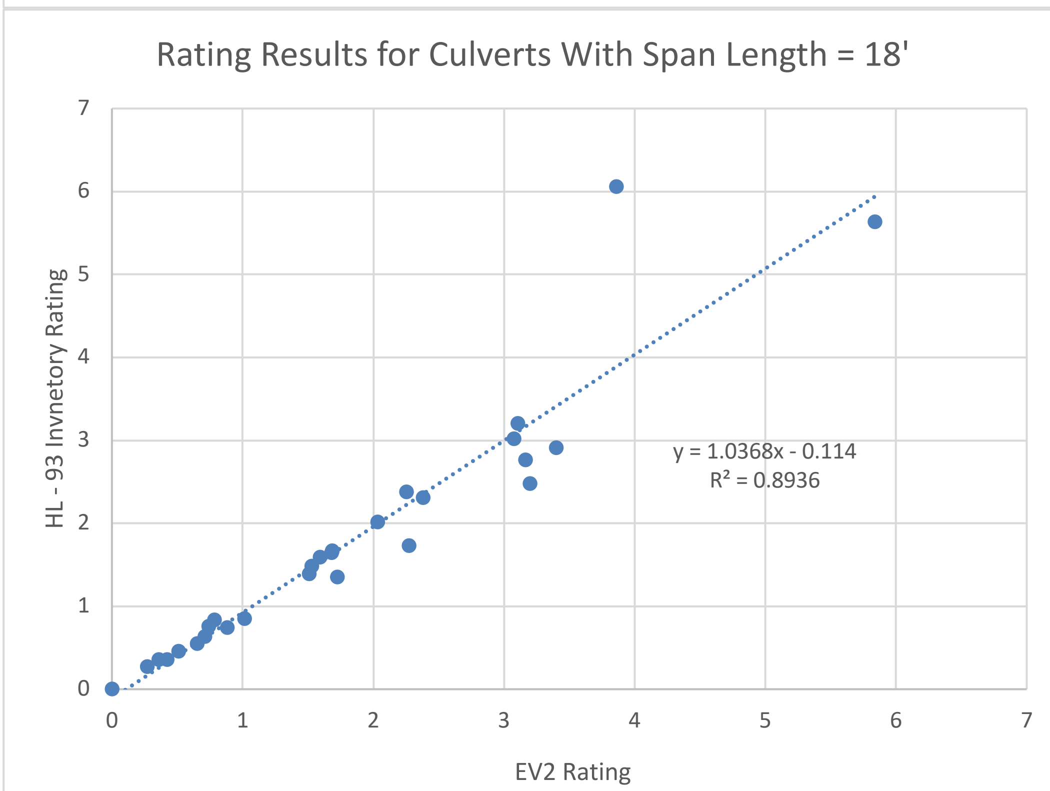

Rating Results for Culverts With Span Length = 12'
HL - 93 Invnetory Rating
EV2 Rating
y = 0.9814x - 0.0136
R² = 0.9942
0
1
2
3
4
5
6
7
8


Rating Results for Culverts With Span Length = 13'
HL - 93 Invnetory Rating
EV2 Rating
y = 0.9352x - 0.004
R² = 0.9834
0
0.5
1
1.5
2
2.5


Rating Results for Culverts With Span Length = 14'
HL - 93 Invnetory Rating
EV2 Rating
y = 0.9613x - 0.0388
R² = 0.9937
0
1
2
3
4
5
6
7

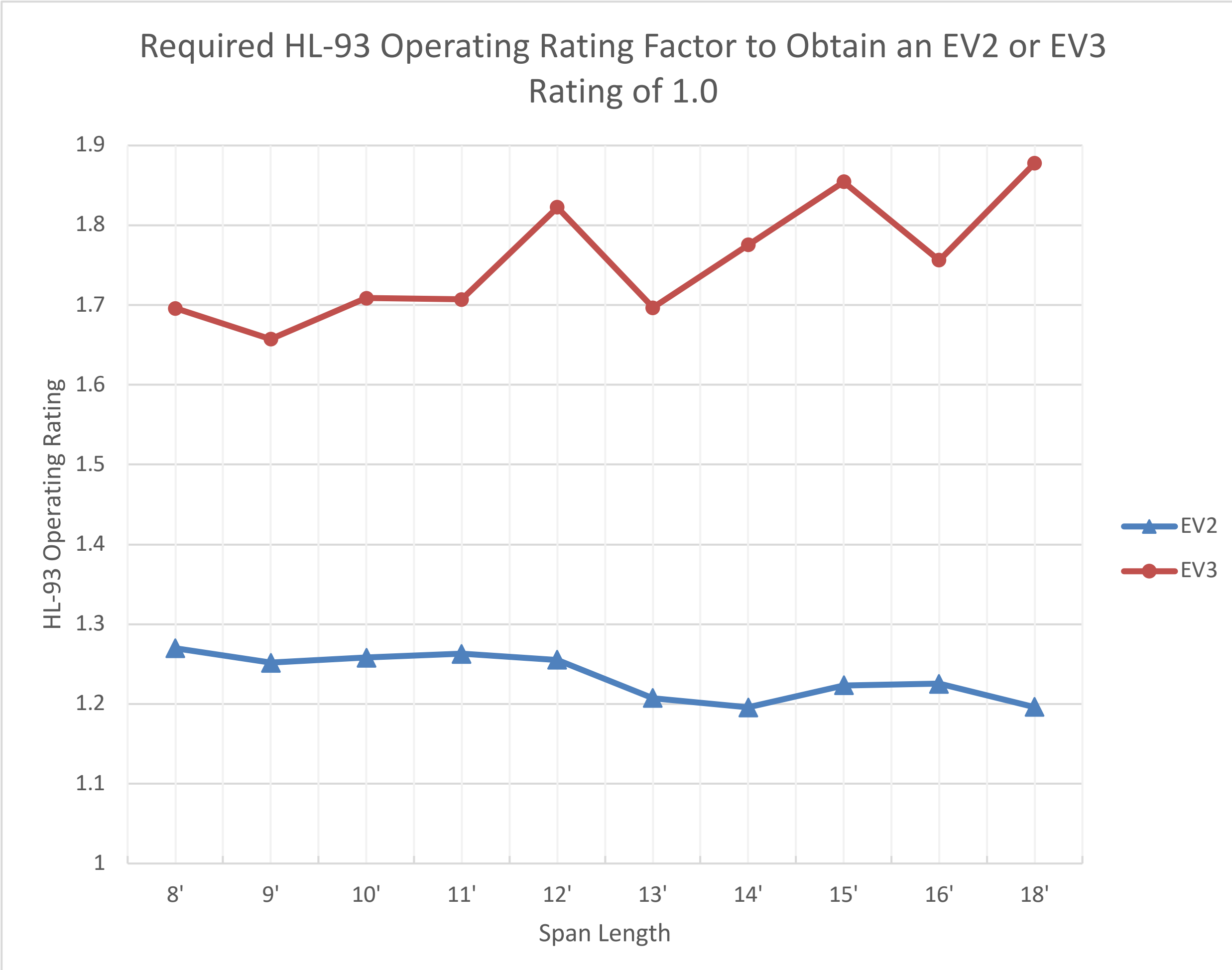

Rating Results for Culverts With Span Length = 15'
HL - 93 Invnetory Rating
EV2 Rating
y = 0.9424x + 0.0009
R² = 0.9845
0
1
2
3
4
5
6
7
8


Rating Results for Culverts With Span Length = 16'
HL - 93 Invnetory Rating
EV2 Rating
y = 0.9025x + 0.0442
R² = 0.9851
0
1
2
3
4
5
6
7
8

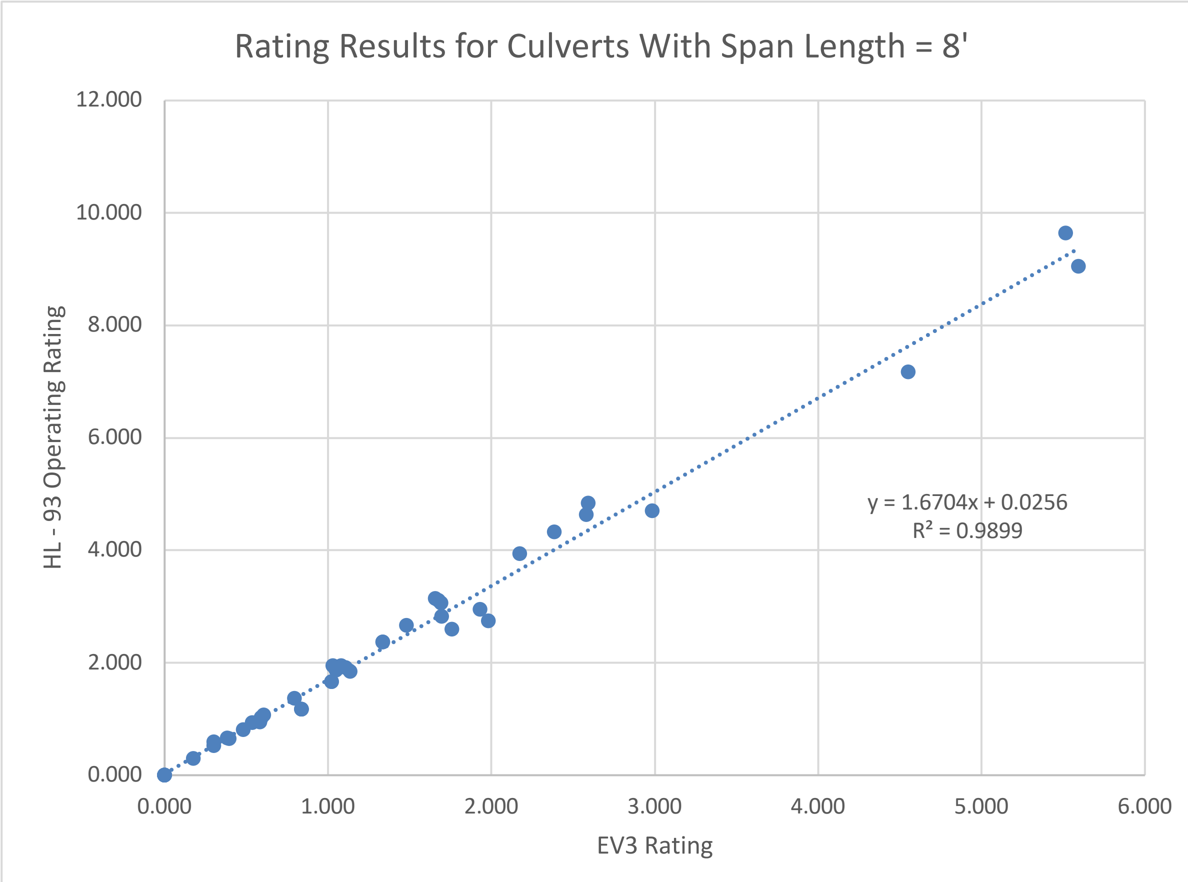

Rating Results for Culverts With Span Length = 18'
HL - 93 Invnetory Rating
EV2 Rating
y = 1.0368x - 0.114
R² = 0.8936
0
1
2
3
4
5
6
7

APPENDIX F

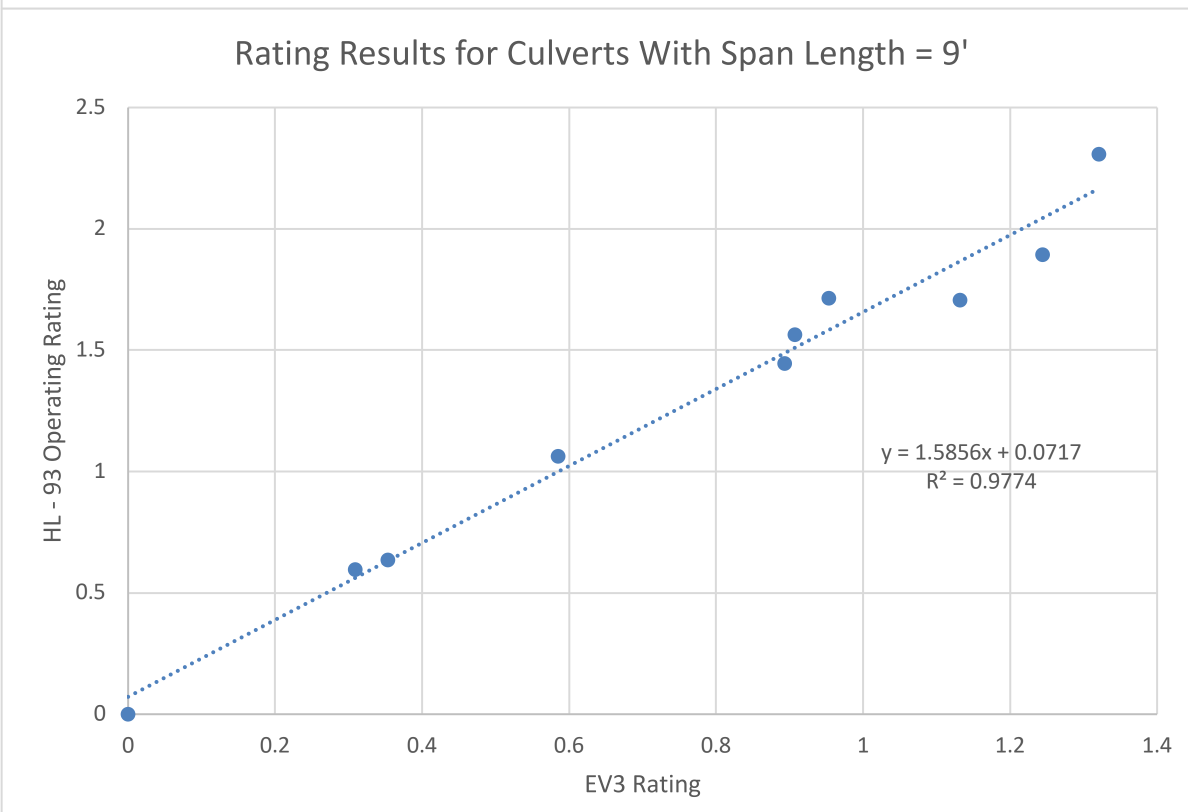
HL-93 OPERATING RATINGS VERSUS EV2 AND EV3 RATINGS FOR VARIOUS CULVERT SPAN LENGTH



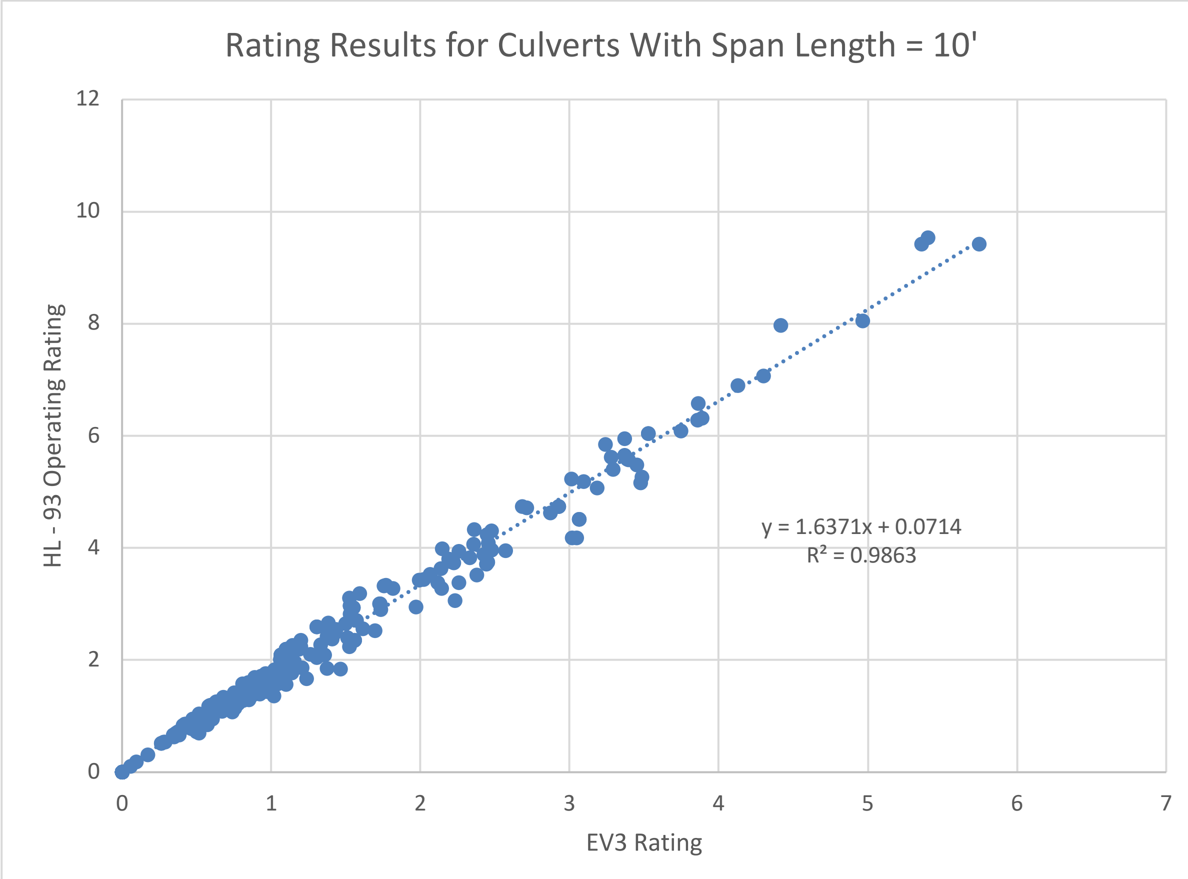
Required HL-93 Operating Rating Factor to Obtain an EV2 or EV3 Rating of 1.0
HL-93 Operating Rating
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
8'
9'
10'
11'
12'
13'
14'
15'
16'
18'
Span Length
EV2
EV3



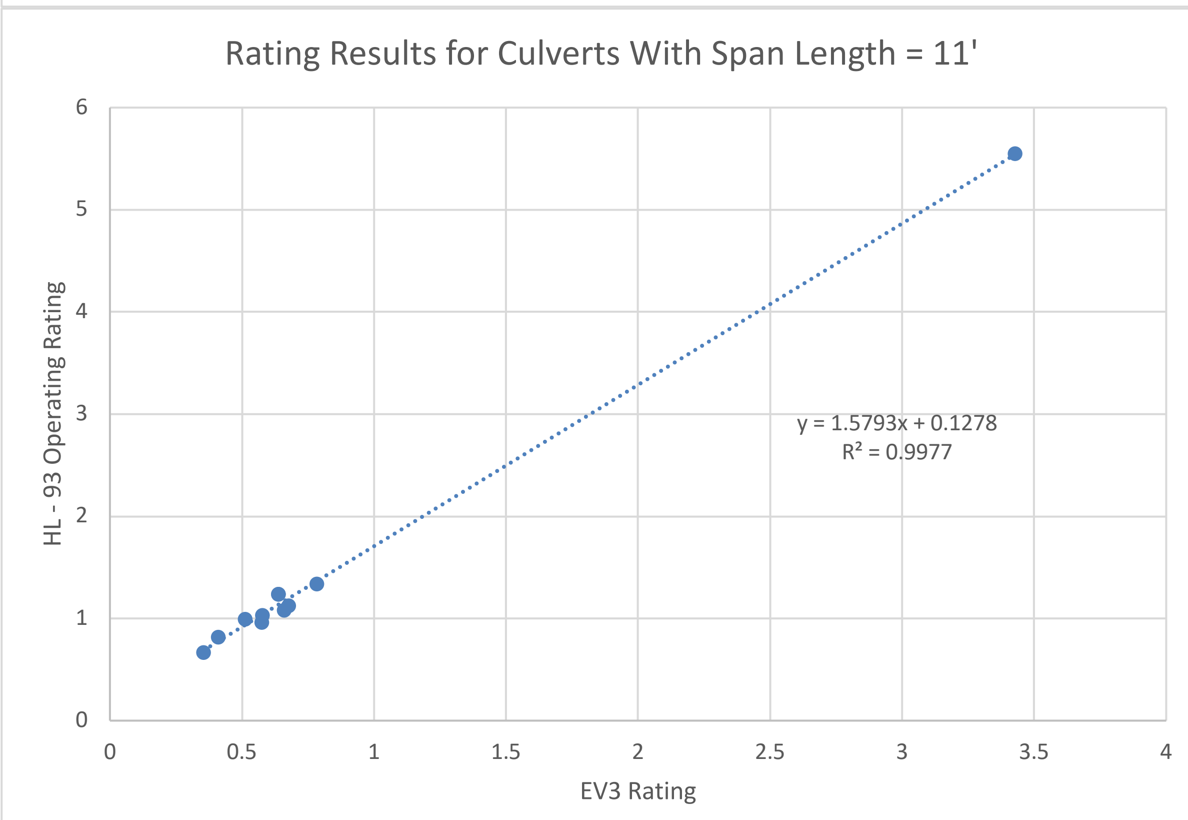
Rating Results for Culverts With Span Length = 8'
12.000
10.000
8.000
6.000
4.000
2.000
0.000
0.000
1.000
2.000
3.000
4.000
5.000
6.000
HL - 93 Operating Rating
EV3 Rating
y = 1.6704x + 0.0256
R² = 0.9899



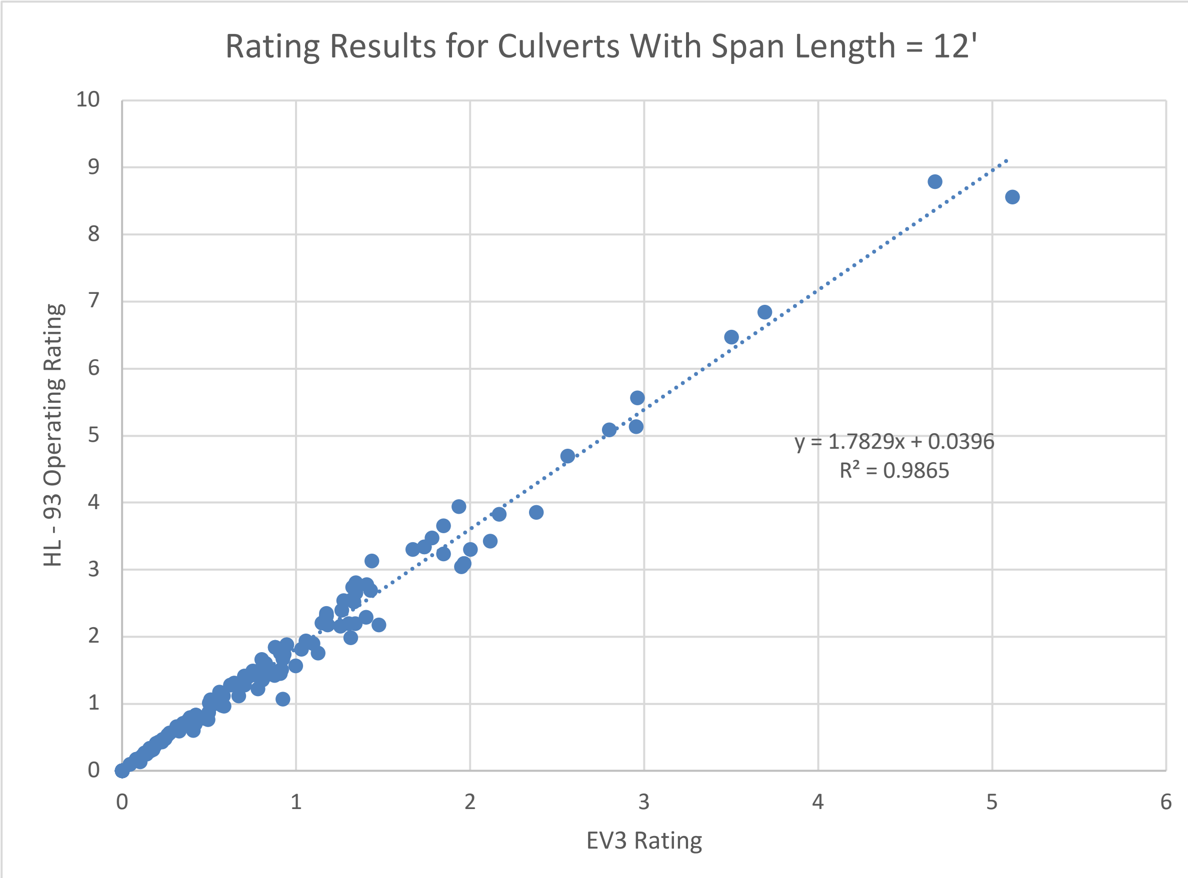
Rating Results for Culverts With Span Length = 9'
2.5
2
1.5
1
0.5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
HL - 93 Operating Rating
EV3 Rating
y = 1.5856x + 0.0717
R² = 0.9774

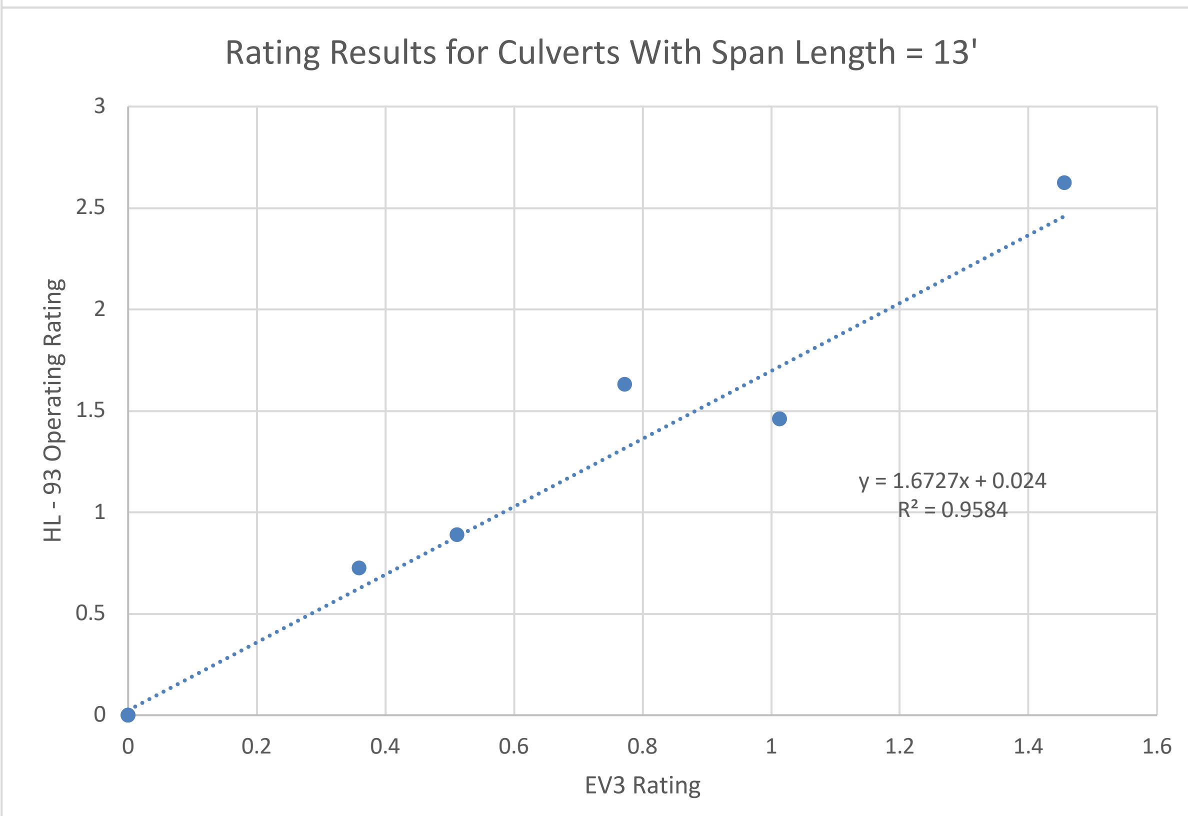


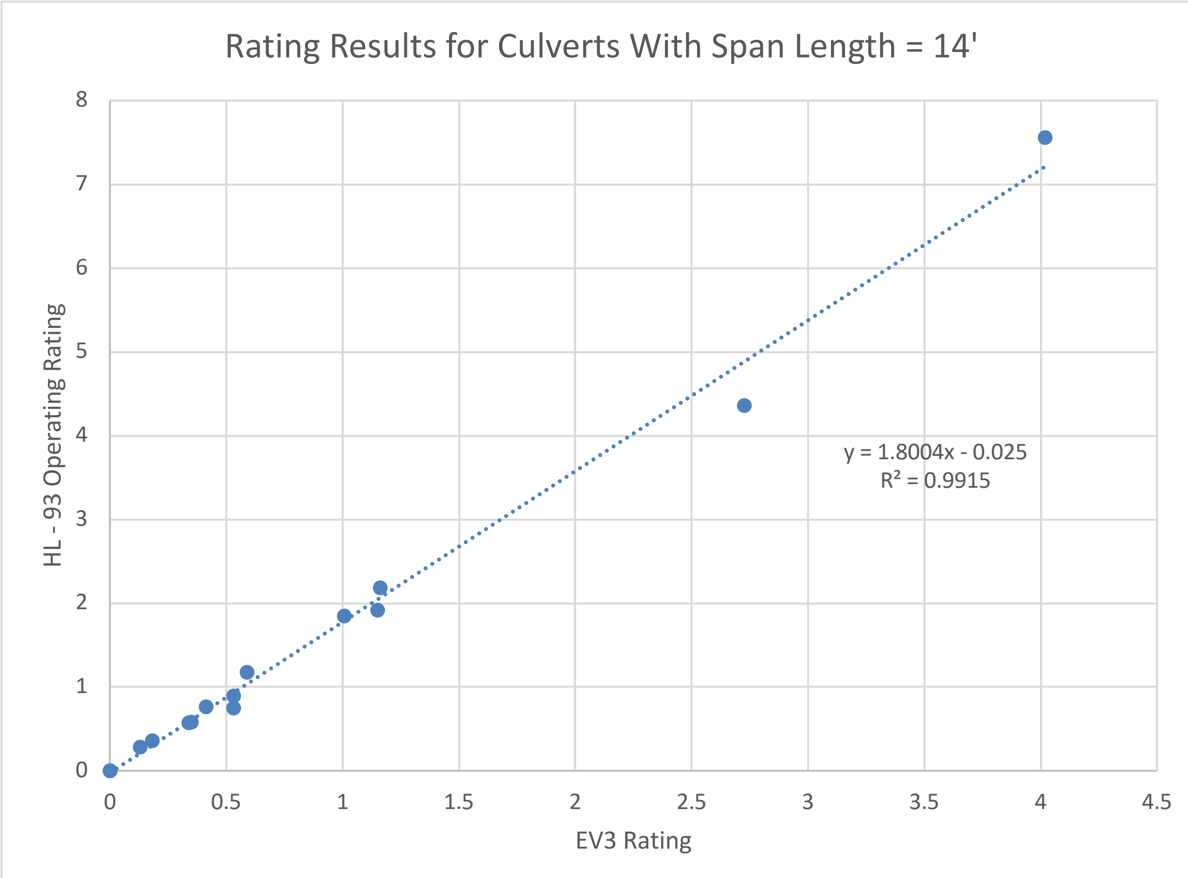
Rating Results for Culverts With Span Length = 10'
y = 1.6371x + 0.0714
R² = 0.9863
HL - 93 Operating Rating
EV3 Rating
0
2
4
6
8
10
12
0
1
2
3
4
5
6
7

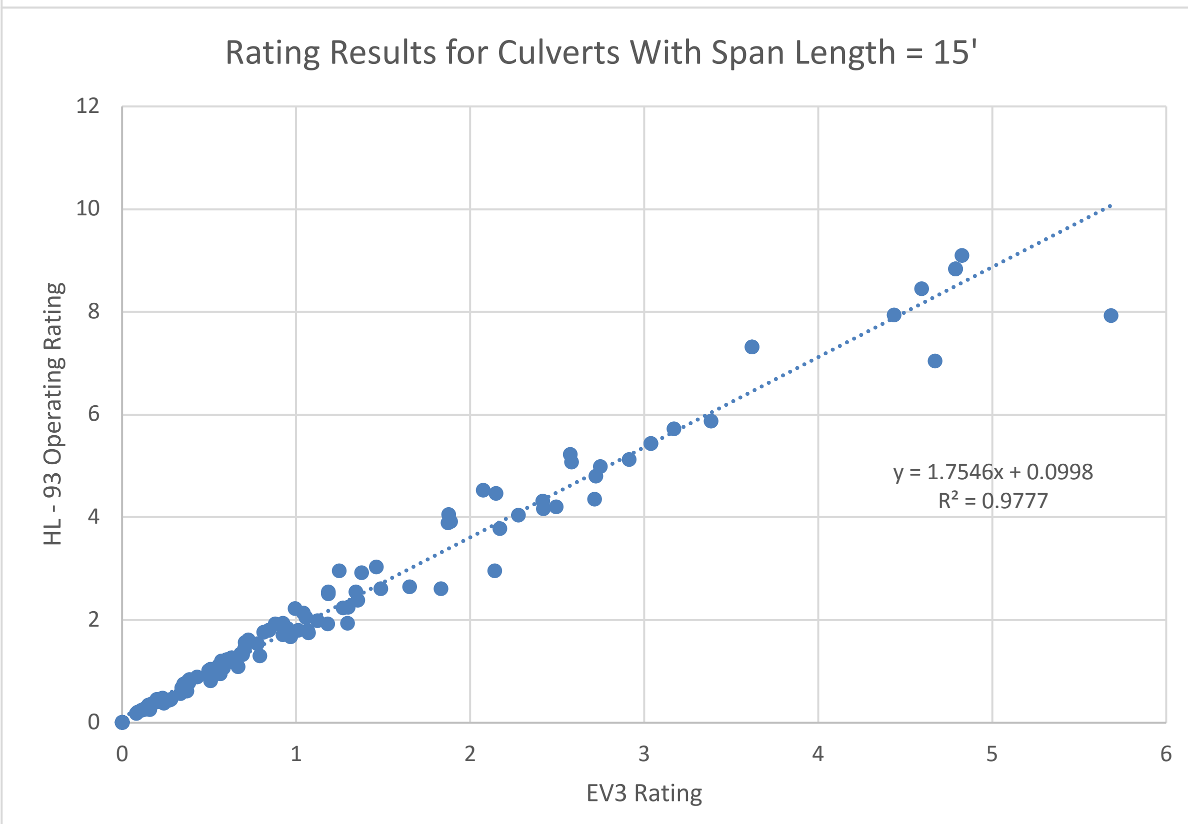


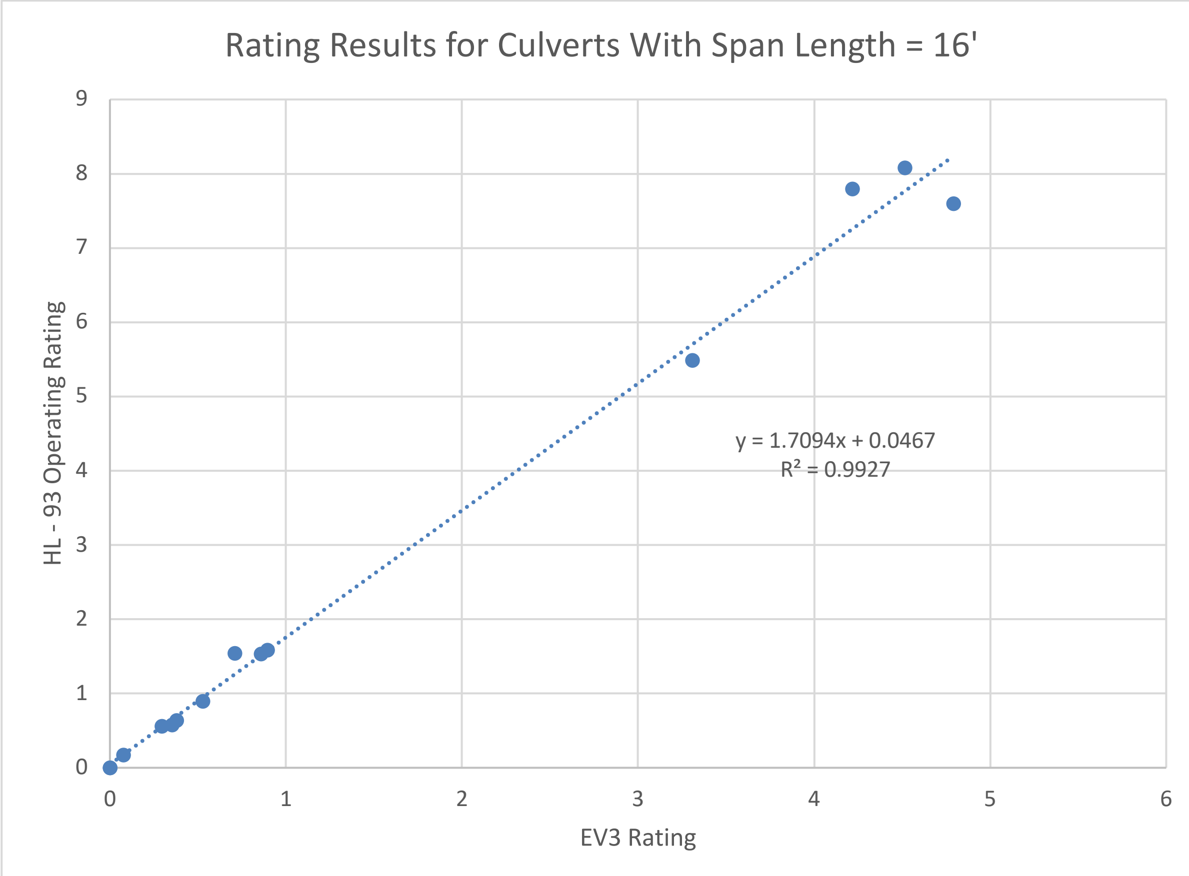
Rating Results for Culverts With Span Length = 11'
y = 1.5793x + 0.1278
R² = 0.9977
HL - 93 Operating Rating
EV3 Rating
0
1
2
3
4
5
6
0
0.5
1
1.5
2
2.5
3
3.5
4

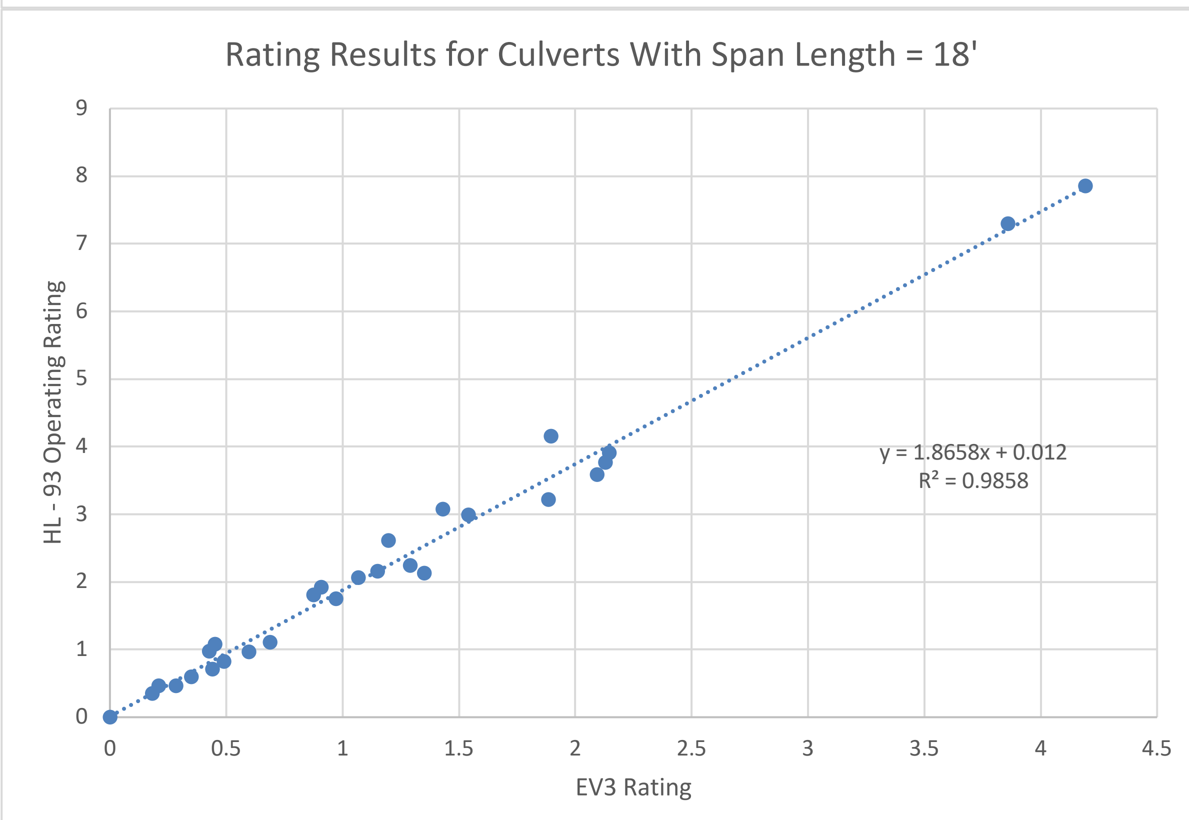

Rating Results for Culverts With Span Length = 12'
HL - 93 Operating Rating
EV3 Rating
y = 1.7829x + 0.0396
R² = 0.9865
0
1
2
3
4
5
6
7
8
9
10
0
1
2
3
4
5
6

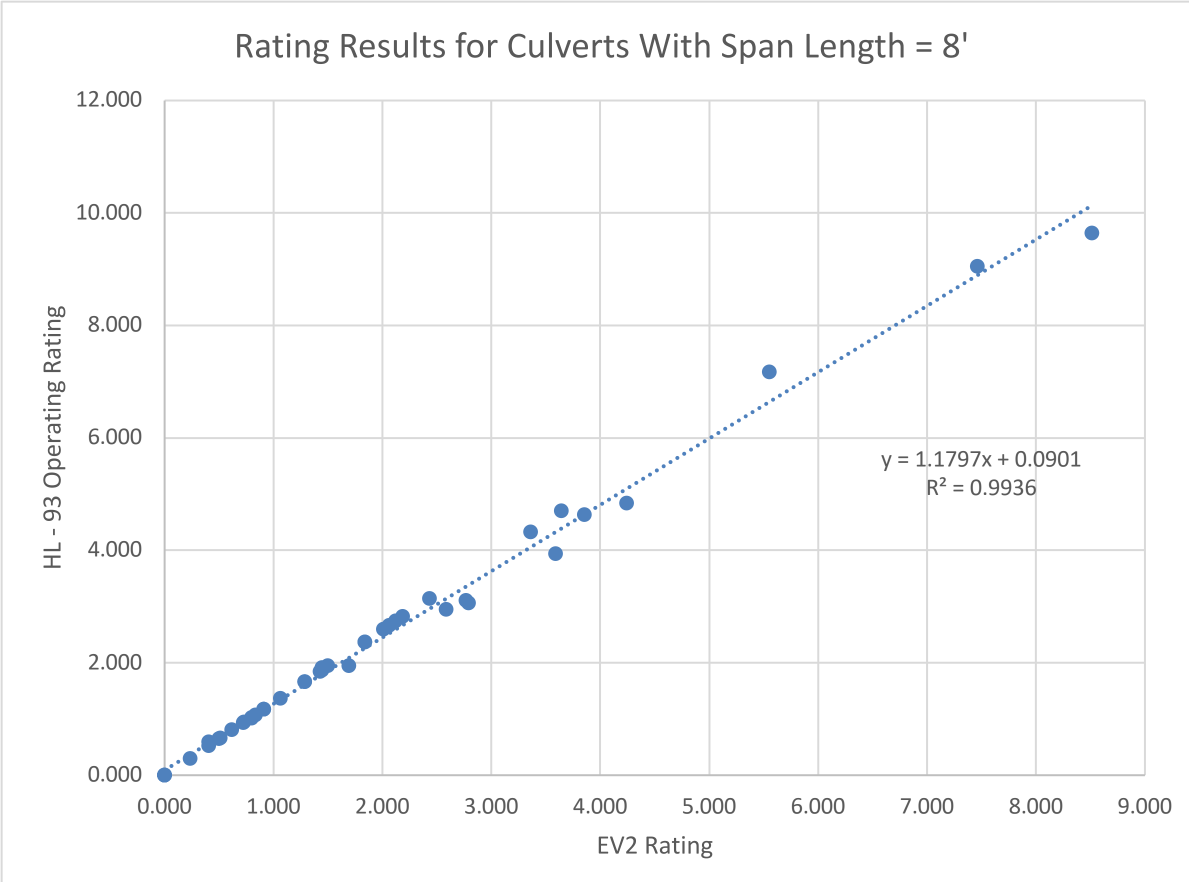

Rating Results for Culverts With Span Length = 13'
HL - 93 Operating Rating
EV3 Rating
y = 1.6727x + 0.024
R² = 0.9584
0
0.5
1
1.5
2
2.5
3
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6


Rating Results for Culverts With Span Length = 14'
HL - 93 Operating Rating
EV3 Rating
y = 1.8004x - 0.025
R² = 0.9915
0
1
2
3
4
5
6
7
8
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

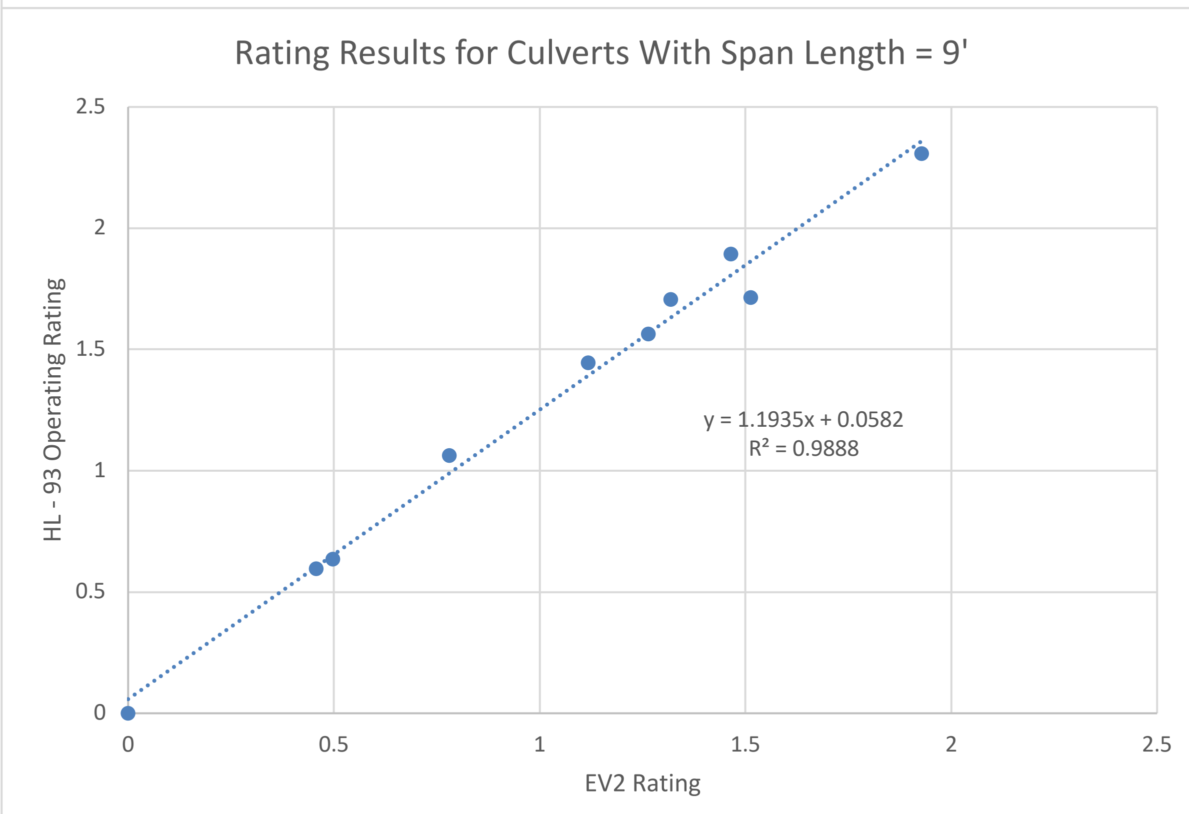

Rating Results for Culverts With Span Length = 15'
HL - 93 Operating Rating
EV3 Rating
y = 1.7546x + 0.0998
R² = 0.9777
0
2
4
6
8
10
12
0
1
2
3
4
5
6


Rating Results for Culverts With Span Length = 16'
y = 1.7094x + 0.0467
R² = 0.9927
HL - 93 Operating Rating
EV3 Rating
0
1
2
3
4
5
6
7
8
9
0
1
2
3
4
5
6

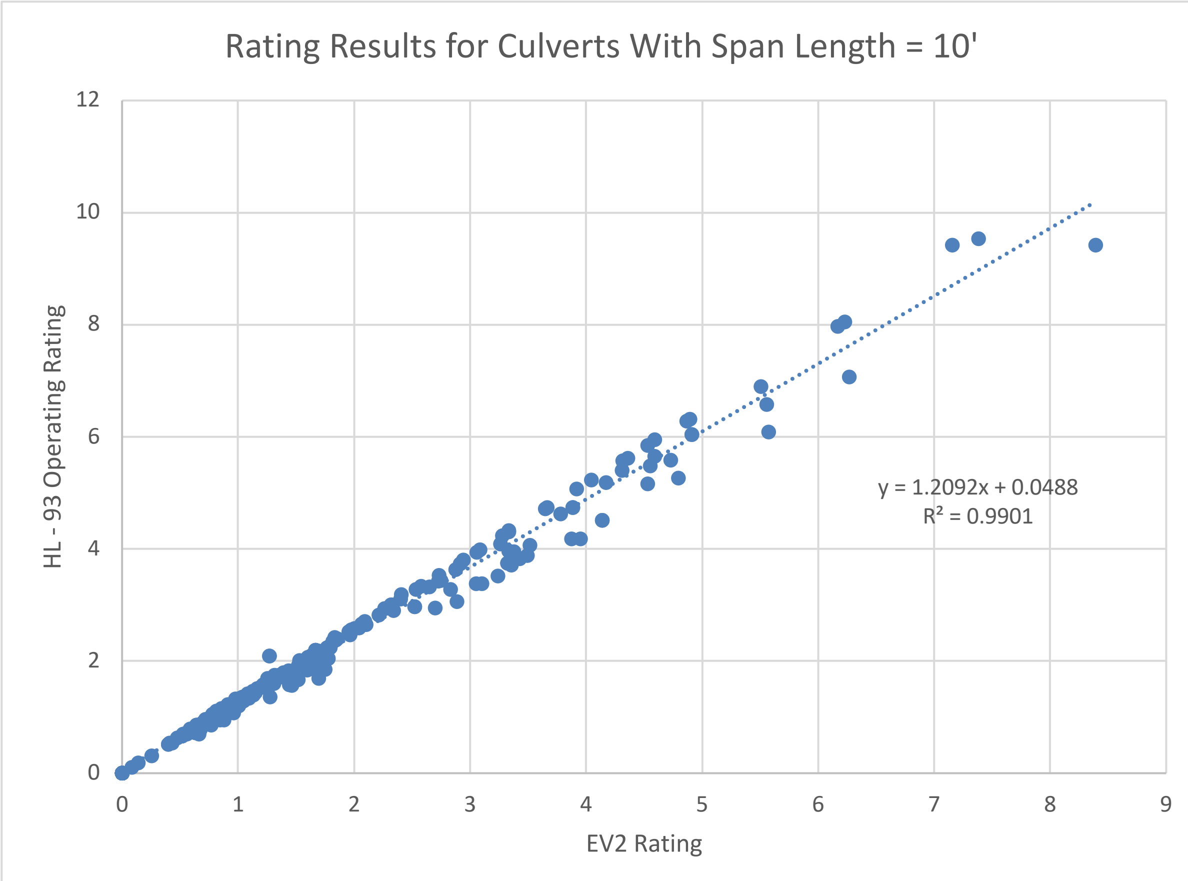

Rating Results for Culverts With Span Length = 18'
y = 1.8658x + 0.012
R² = 0.9858
HL - 93 Operating Rating
EV3 Rating
0
1
2
3
4
5
6
7
8
9
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

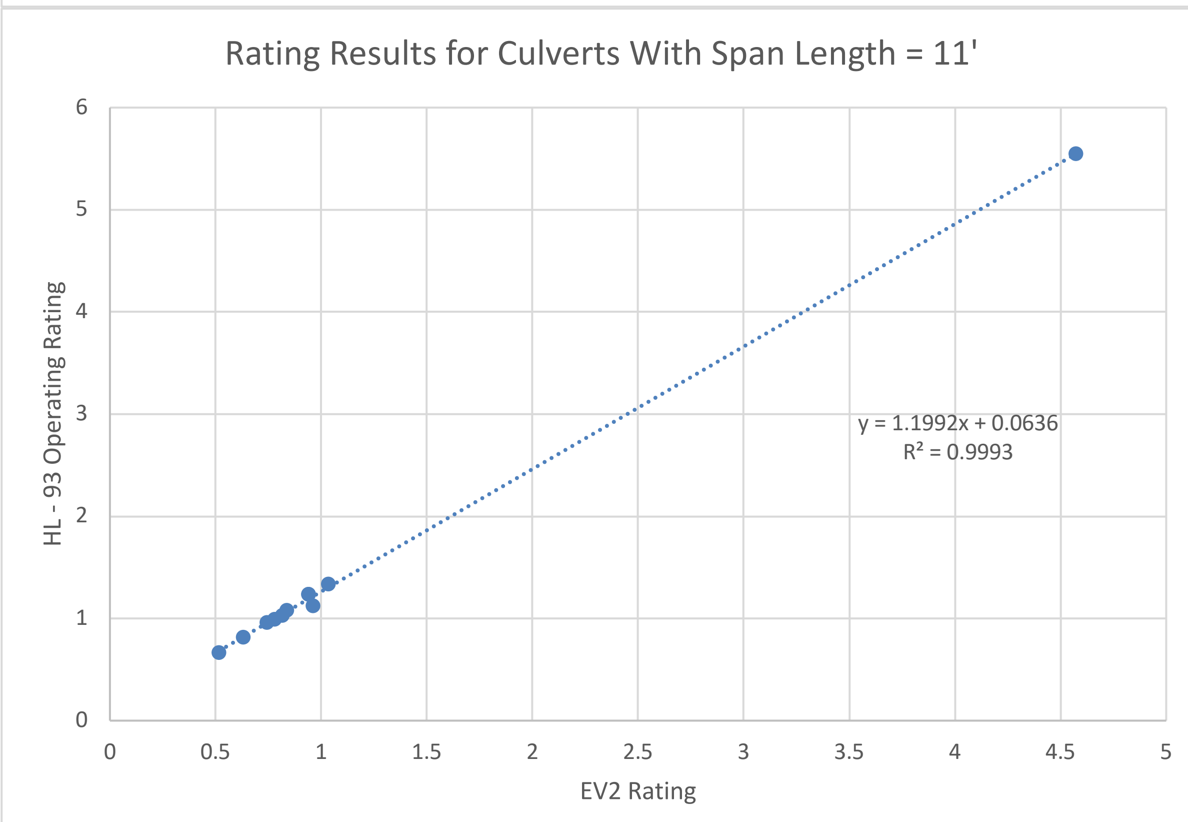


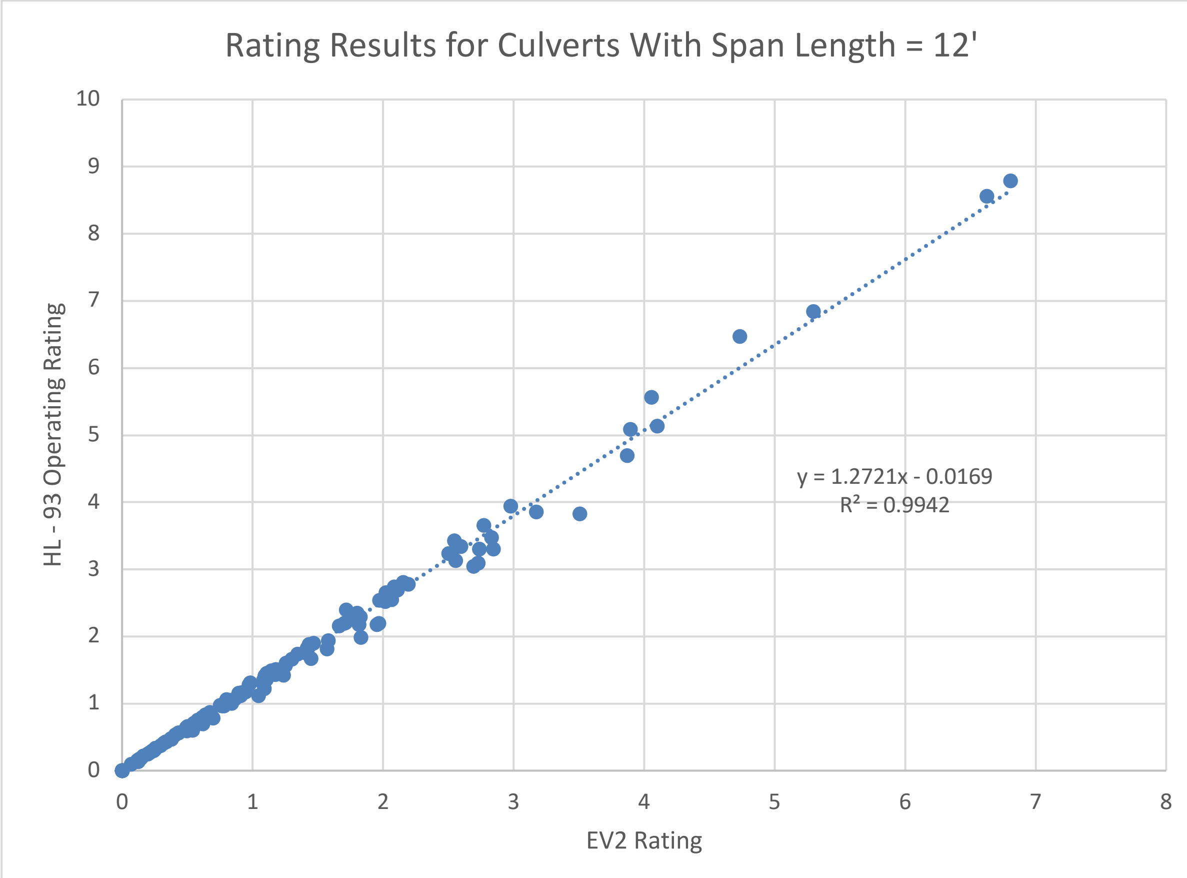
Rating Results for Culverts With Span Length = 8'
HL - 93 Operating Rating
EV2 Rating
y = 1.1797x + 0.0901
R² = 0.9936
0.000
2.000
4.000
6.000
8.000
10.000
12.000
1.000
3.000
5.000
7.000
9.000

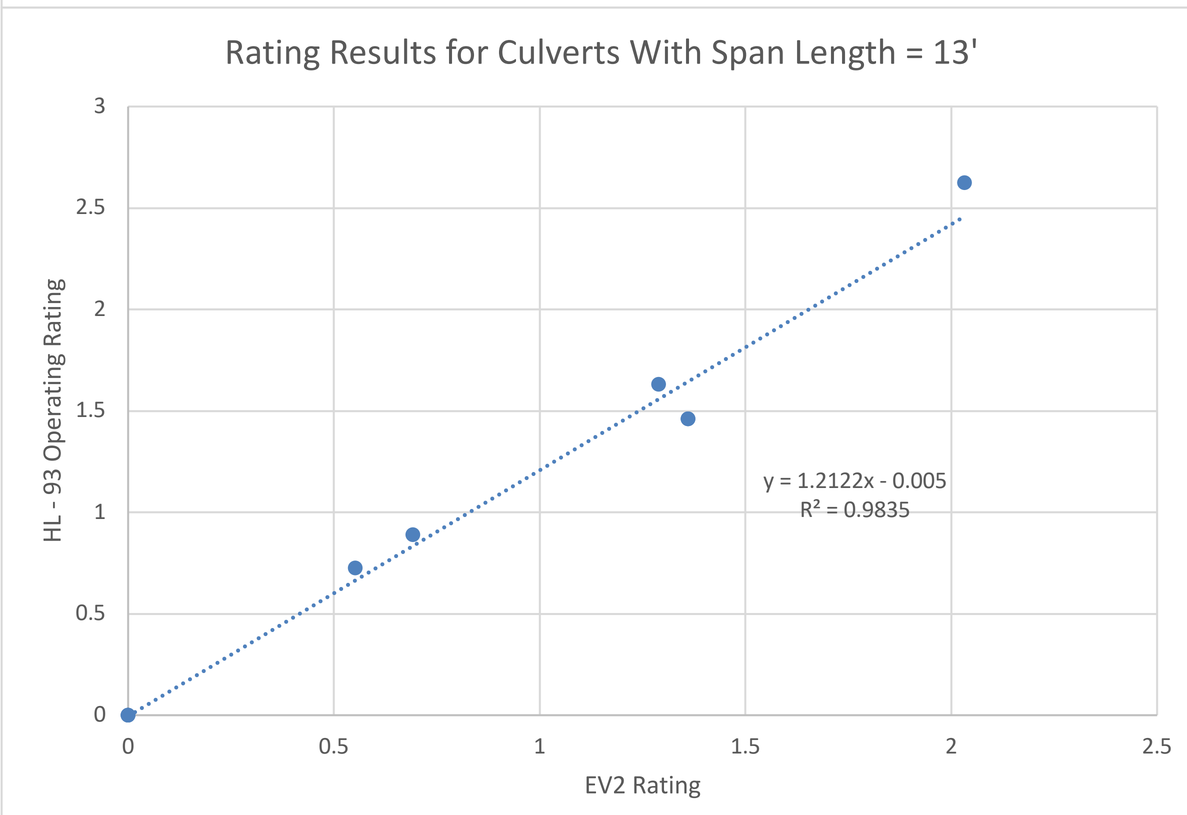


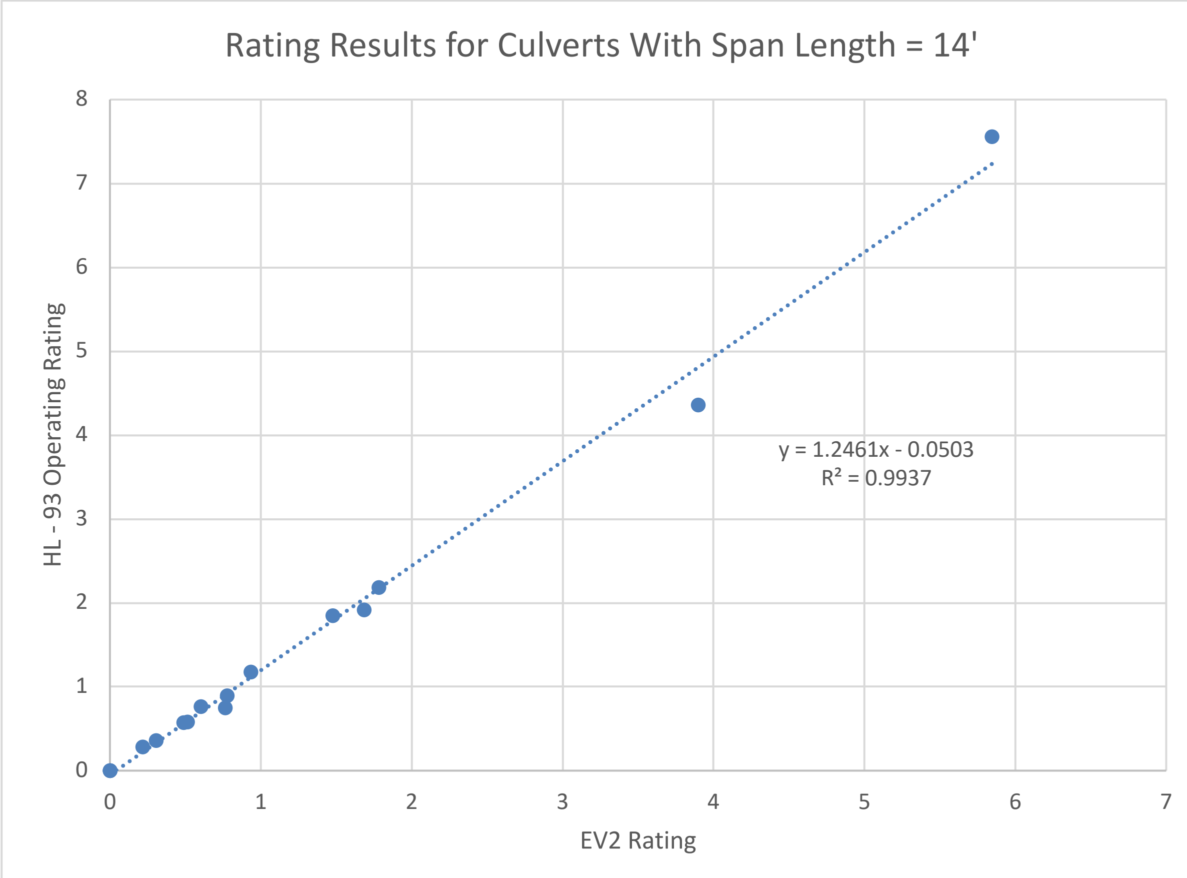
Rating Results for Culverts With Span Length = 9'
HL - 93 Operating Rating
EV2 Rating
y = 1.1935x + 0.0582
R² = 0.9888
0
0.5
1
1.5
2
2.5


Rating Results for Culverts With Span Length = 10'
HL - 93 Operating Rating
EV2 Rating
y = 1.2092x + 0.0488
R² = 0.9901
0
2
4
6
8
10
12
0
1
2
3
4
5
6
7
8
9

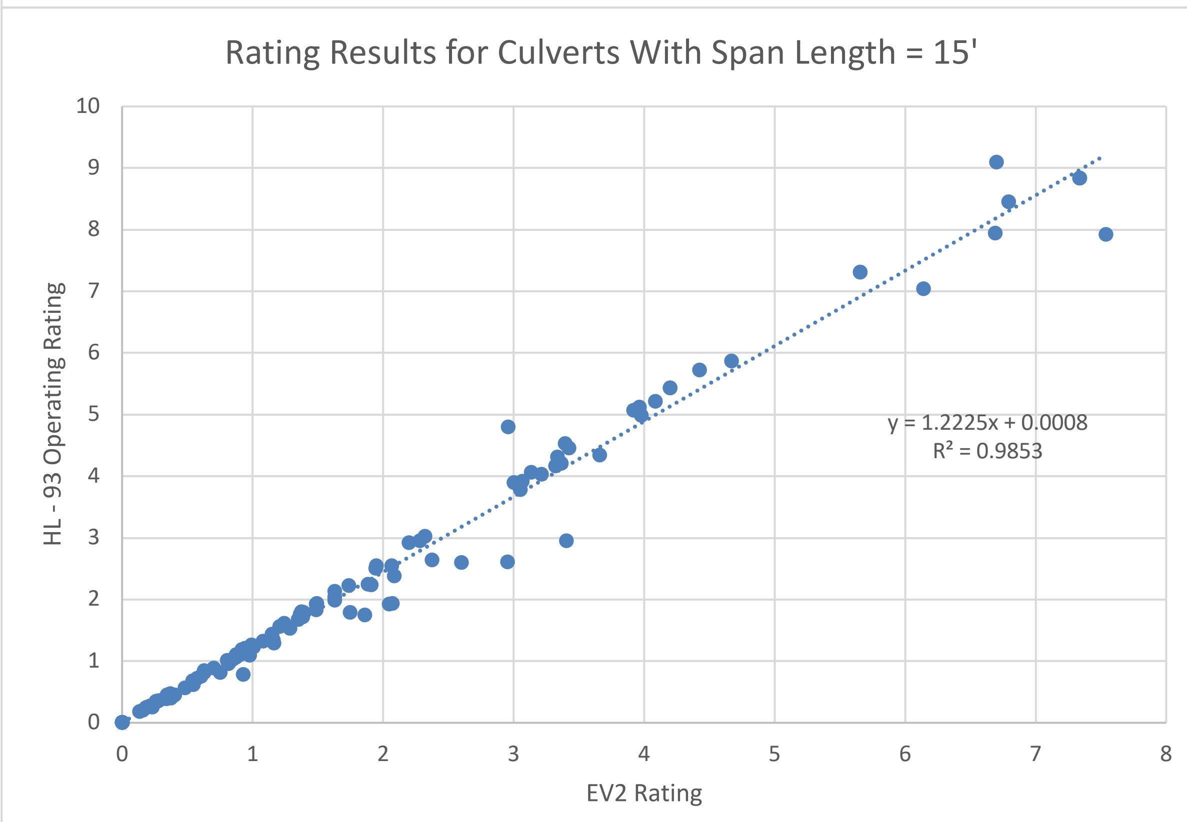

Rating Results for Culverts With Span Length = 11'
HL - 93 Operating Rating
EV2 Rating
y = 1.1992x + 0.0636
R² = 0.9993
0
1
2
3
4
5
6
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


Rating Results for Culverts With Span Length = 12'
HL - 93 Operating Rating
EV2 Rating
y = 1.2721x - 0.0169
R² = 0.9942
0
1
2
3
4
5
6
7
8
9
10
0
1
2
3
4
5
6
7
8

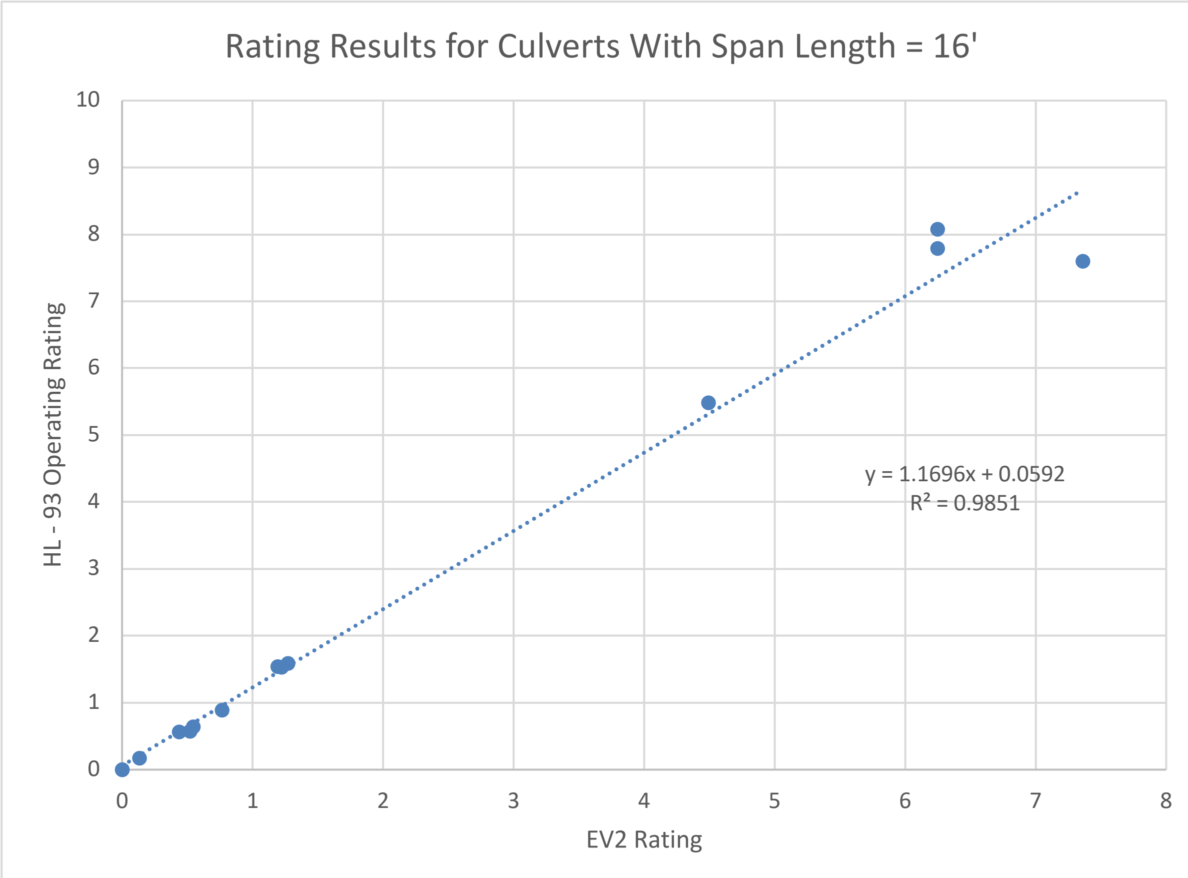

Rating Results for Culverts With Span Length = 13'
HL - 93 Operating Rating
EV2 Rating
y = 1.2122x - 0.005
R² = 0.9835
0
0.5
1
1.5
2
2.5
3
0
0.5
1
1.5
2
2.5

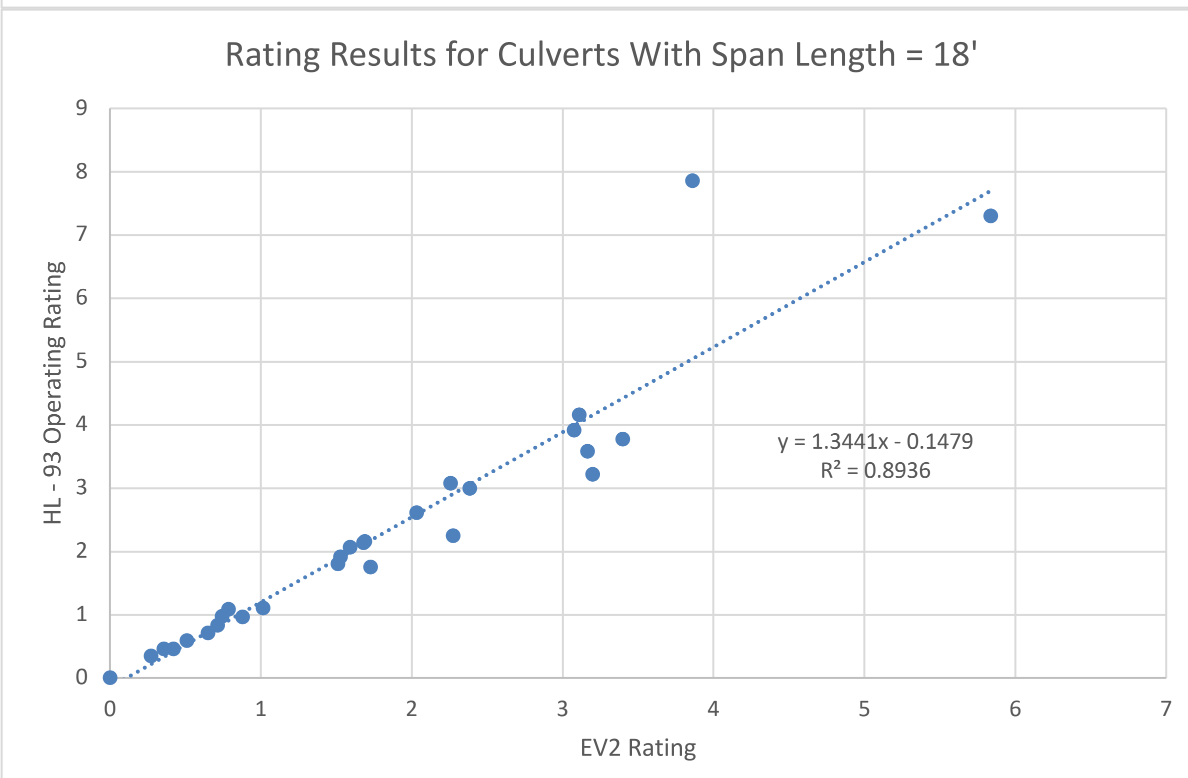


Rating Results for Culverts With Span Length = 14'
y = 1.2461x - 0.0503
R² = 0.9937
HL - 93 Operating Rating
EV2 Rating
0
1
2
3
4
5
6
7
8



Rating Results for Culverts With Span Length = 15'
y = 1.2225x + 0.0008
R² = 0.9853
HL - 93 Operating Rating
EV2 Rating
0
1
2
3
4
5
6
7
8
9
10


Rating Results for Culverts With Span Length = 16'
y = 1.1696x + 0.0592
R² = 0.9851
HL - 93 Operating Rating
EV2 Rating
0
1
2
3
4
5
6
7
8
9
10


Rating Results for Culverts With Span Length = 18'
y = 1.3441x - 0.1479
R² = 0.8936
HL - 93 Operating Rating
EV2 Rating
0
1
2
3
4
5
6
7
8
9