Report RC-1413

# Investigation of the Adequacy of Current Bridge Design Loads In the State of Michigan

Submitted jointly by:

**John W. van de Lindt (MTU) and Gongkang Fu (WSU)**

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16. Abstract

This report presents the process and results of a joint research effort between Michigan Technological University and Wayne State University to examine the adequacy of current vehicle loads used to design bridges in the State of Michigan. The target reliability index used in the AASHTO LRFD Bridge Design Specifications was used here as the criterion for evaluating the adequacy. Reliability indices were calculated for twenty different bridges selected randomly from the Michigan inventory of new bridges. The bridge suite included five bridges from each of four major types in Michigan: steel girder, prestressed I-beam, prestressed adjacent box girder, and prestressed spread box girder bridges. Existing weigh-in-motion data was processed to statistically characterize the truck load effect, i.e. moment, shear, and wheel load. For moment and shear in girders, two strengths were used in the reliability analyses for: 1.) strength as designed according to construction plans termed herein as *as-designed*; and 2.) strength required by the current design code as the sum of factored design dead load and live load (HS25) termed herein as *design-minimum*. For wheel load, punching shear capacities were used. The two different girder resistances resulted in different reliability levels for comparison. The reliability indices were calculated for each of those cases: 1.) entire state of Michigan; and 2.) Metro Region (Region 7). To cover the variation of truck traffic volume, two values of truck traffic were used in these analyses: $50^{th}$ and $90^{th}$ percentiles for several functional classes of roads.

The reliability indices were found to vary from bridge type to bridge type. The following conclusions are drawn based on the calculated reliability indices. 1.) The $50^{th}$ and $90^{th}$ percentiles of traffic volume do not noticeably influence the reliability indices. 2.) This also leads to an observation that the reliability indices for the entire state and for the Metro Region (Region 7) do not show significant differences. This is because both cases used the same WIM data collected from around the Metro Region. 3.) The current design load, HS25, for design of bridge beams may not be adequate, at least, for bridges in the Metro Region (Region 7). 4.) The deck design load of HS20 is adequate for reinforced concrete decks. It is recommended that a new design load level be developed for bridge beam design in the Metro Region.

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## Acknowledgements

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Andy Nowak of the University of Michigan helped the research team in understanding the format and some details of the WIM data collected by him and his associates. Graduate research assistants Waseem Dekelbab and Jihang Feng at Wayne State University assisted in computing and checking the resistances of the sample bridges. Their able assistance is appreciated.

Yingmin Zhou, a Ph.D. candidate at Michigan Technological University, organized and processed all of the live load data and also assisted in calculation of bridge resistances and reliability indices. Her assistance is gratefully acknowledged.

## Disclaimer

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# Chapter 1: Introduction

## 1.1 Background

The load carrying capacity of bridges is strongly influenced by the design load used in their design. The design load also has a significant effect on the durability of these bridges. Traditionally, the design load adopted in the design specifications is applied uniformly within the jurisdiction of a transportation agency, with some exception. For example, a state typically uses one design load level for most bridge designs in the state, with a possible exception for bridges that have a particular function or characteristic that may warrant a different design load, such as those on certain local roads. This practice has been justifiable in that it reduces required engineering design work and avoids bridge-specific design-load. On the other hand, this approach also neglects location-specific truck loads that may be substantially different from bridge to bridge.

This issue may become critical when the actual truck loads are noticeably higher than the design load. The motivation for this project was that bridges experiencing these higher loads are subjected to a higher risk of distress, damage, and even failure.

In 1972 the Michigan Department of Transportation (MDOT) changed the design load level for all bridges located on Interstate and Arterial highways from HS20 to HS25. Currently MDOT still uses the HS25 load for beam design and the HS20 load for deck design. Note that this design load is used in many other states.

On the other hand, the legal truck load in Michigan is higher than many other states, while the legal axle load is consistent with other states. There has been a concern as to whether the actual truck loads are adequately accounted for by the current bridge design load used in the state of Michigan. This is of particular concern for a state such as Michigan that has significant diversity of industries in different areas. This spatial diversity results in significantly different truck load spectra throughout the various roadways within the state. This concern is addressed in the present research project.

## 1.2 Objective, Approach, and Scope of Research

The objective of this research project is to determine whether or not the HS25 design load for beams and the HS20 design load for decks provide a desired margin of safety for Michigan bridges subjected to recently measured truck loads. Namely, it is to answer the question whether the current design loads provide typical highway bridges with the desired safety level.

Structural safety is measured in this study using the structural reliability index $\beta$. This approach has been used in several recent research projects related to bridge safety. The previous research most relevant to the present project is NCHRP Project 12-33: Development of LRFD Bridge Design Specifications (Nowak 1999). In that project, the LRFD bridge design code was calibrated with respect to structural safety, which was also measured using the reliability index $\beta$. This was the first time the concept of structural safety was used in the AASHTO specifications. While more details about the definition and calculation of $\beta$ are given in Section 1.4, it is noted here that a large $\beta$ indicates a higher safety level and a lower $\beta$ a lower safety level.

For evaluation of the design load, this research effort covers only the bridge superstructure. The design load is examined in the context of the load factor design (LFD) method contained in the AASHTO standard specifications (1996). This is the design standard currently used for bridge design in Michigan.

A survey of the state bridge inventory conducted in this study has found that the following four superstructure types represent 91% of the new bridges built in the past 10 years in Michigan. 1.) Steel beam bridges (40.0%). 2.) Prestessed concrete I beam bridges (30.6%). 3.) Adjacent prestressed concrete box beam bridges (14.6%). 4.) Spread prestressed box beam bridges (5.6%). Accordingly, only these four bridge superstructure types are covered in the present study, because they represent the population of new bridges in the state for foreseeable future. Each of these bridge types has a configuration of concrete-deck–supported-by-beams. For each of these four types, 5 bridges were randomly selected from those built in the past 10 years. This sample of 20 bridges was used in this study to represent the new bridge population in Michigan, particularly to provide information on dead loads, "as-designed" capacities, span lengths, etc., for the reliability analyses.

Structural reliability analysis was performed for the interior beams for each of these randomly selected bridges, as well as for the reinforced concrete decks. For the beams, both moment and shear effects are covered. For the deck, only punching shear was included because it is considered to be the major failure mode with respect to deck strength. Note that fatigue failure was not within the scope of this study for the beams nor for the reinforced concrete deck.

It is well known that the strength of a specific bridge's component can be higher than what is required by the design specifications. Depending on a number of factors, this additional amount of strength may be substantial over what is required by the design specifications. Some of the influencing factors are as follows. 1.) The designer may consciously exercise conservatism in design, leading to a higher strength than required. 2.) A particular load effect may represent a non-dominant failure mode. Thus, the strength for that load effect can become highly excessive. For example, shear may be a non-governing load effect for bridge beams having long spans. As a result, the shear capacity provided by the cross sections can be much higher than required if the section already meets the moment requirement. Accordingly, in this research project, the reliability index $\beta$ is computed for both cases of strength. The one using the strength required by the current design specifications is termed herein as "design-minimum", and the other strength as designed by the designer is termed herein as "as-designed". Comparison of these two $\beta$ values for the same component can show the influence of reserve strength on structural reliability, which is possibly provided in current design practice but not required by the design specifications. Reliability indices were calculated for the entire state of Michigan and Metro Region (Region 7) separately. The reasons for separation of Region 7 are explained in detail in Section 2.1 and have to do with the locations where the WIM data were gathered and the volumes of commercial traffic.

## 1.3 Structural Reliability Index $\beta$ as A Measurement of Bridge Safety

In this research project, the structural safety of a structural component is evaluated using its failure probability defined as follows.

$$\text{Failure Probability} = P_f = \text{Probability [ Resistance} - \text{Load Effect} < 0 \text{ ]}$$

$$= \text{Probability [ } R - S < 0 \text{ ]} \qquad (1\text{-}1)$$

where resistance R is the load carrying capacity of the structural component, and load effect, S, is the load demand on the component. For example, the load effect can be bending moment for a beam section and the resistance is the beam section's moment capacity. The resistance and load effect in Equation 1-1 are modeled as random variables because they both possess an amount of uncertainty. In general, the uncertainties associated with the resistance are due to material properties and the production and preparation process, construction quality, etc. The uncertainty associated with load effect is related to truck weight, truck type, traffic volume, etc. Note that the failure probability in Equation 1-1 refers to a load effect in a structural component. Namely, this definition can be applied to a variety of load effects, such as moment, shear, or even possibly displacement if this serviceability is an issue. It also can be applied to a variety of bridge structural components, such as beams, slabs, piers, etc.

The reliability index $\beta$ can be expressed in terms of the failure probability given in equation 1-1 as

$$\beta = \Phi^{-1}\left(1 - P_f\right) \tag{1-2}$$

where function $\Phi^{-1}$ is the inverse function of the standard normal random variable's cumulative distribution function. Calculation of this function has become a routine in a number of commercially available computer programs. For example in MicroSoft Excel, this function is symbolized as NORMSINV. Equation 1-2 indicates that $\beta$ is inversely monotonic with $P_f$. Namely, a small $P_f$ leads to a large $\beta$, or a large $P_f$ to a small $\beta$. Thus a large $\beta$ indicates a safer structural component and a small $\beta$ a less safe one. Table 1-1 shows this relationship between $\beta$ and $P_f$ for a range of different levels.

**Table 1-1: Probability of failure levels corresponding to various reliability indices**

| $\beta$ | $P_f$ |
|---|---|
| 1.0 | 0.159 |
| 1.5 | 0.067 |
| 2.0 | 0.023 |
| 2.5 | 0.0062 |
| 3.0 | 0.0013 |
| 3.5 | 0.000233 |
| 4.0 | 0.0000317 |
| 4.5 | 0.0000034 |
| 5.0 | 0.00000029 |
| 7.0 | 0.00000000000128 |
| 8.0 | 0.000000000000000666 |

When the resistance and load effect can be modeled as normal random variables independent of each other, the safety margin

$$Z = R - S \tag{1-3}$$

is then also a normal random variable. In this case the reliability index $\beta$ can be more easily expressed as

$$\beta = \frac{\mu_Z}{\sigma_Z} \tag{1-4}$$

where $\mu_Z$ and $\sigma_Z$ are the mean and the standard deviation of random variable Z. They can be computed as

$$\mu_Z = \mu_R - \mu_S \tag{1-5a}$$

$$\sigma_Z = \left(\sigma_R^2 + \sigma_S^2\right)^{1/2} \tag{1-5b}$$

where $\mu$ and $\sigma$ are symbols for the mean and standard deviation, and subscripts $R$ and $S$ indicate the random variables referenced. Thus, substituting equation 1-5 into equation 1-4 leads to

$$\beta = \frac{(\mu_R - \mu_S)}{\sqrt{\sigma_R^2 + \sigma_S^2}} \tag{1-6}$$

Note that a more general definition of the reliability index $\beta$ in the literature is given in a U-space of standardized normal variables (instead of the basic random variables as R and S in this problem) (Madsen et al 1986). The standardized normal random variables have a mean of 0 and standard deviation of 1. In this more general definition, β is defined as the shorted distance from the origin (0,0) to the failure surface Z=0, in the U-space. The following explains this general definition using the example defined in equation 1-3.

In this example, the basic random variables are $R$ and $S$. The U-space of standardized normal variables can then be constructed as follows. The normal random variable $X_R$ standardized from $R$ is defined as

$$X_R = \frac{(R - \mu_R)}{\sigma_R} \tag{1-7a}$$

and the normal variable $X_S$ standardized from $S$ is defined similarly as

$$X_S = \frac{(S - \mu_S)}{\sigma_S} \tag{1-7b}$$

where $\mu$ and $\sigma$ are symbols for the mean and standard deviation as defined earlier. The definition of $X_R$ and $X_S$ in equation 1-7 is such that they have mean value 0 and standard deviation of 1. In the U-space spanned by the standardized normal variables ($X_R$ and $X_S$ in this example), the origin is located at the mean values of the random variables, namely (0,0) in this example.

In the U-space, the failure surface $Z = 0$ must also be transformed from its original space (Equation 1-3 in this example). Through substitution of equations 1-7a and 1-7b into equation 1-3, $Z$ can be expressed as

$$Z = \sigma_R X_R + \mu_R - \sigma_S X_S - \mu_S \quad = 0 \tag{1-8}$$

The reliability index $\beta$ is then defined in this standardized U space as the shortest distance from the origin to the failure surface $Z = 0$. Figure1-1 presents the U space for this example defined using the two standardized random variables $X_R$ and $X_S$. The entire space is divided into two halves by the failure surface Z=0. The top right half space above the failure surface (Z=0) is defined by Z<0. This represents a region where the structural component fails. This region is marked as "failure region" as shown. In contrast, the bottom left half space below $Z = 0$, marked "safe region", represents a region where the structural component is safe. In this region, Z >0. For this simple example of a linear failure surface as defined in equation 1-8, it can be shown by derivation that in the U-space the reliability index $\beta$ is given by equation 1-6, where $\beta$ is the shortest distance from the origin (0,0) to the failure surface (Z=0). Thus, Equation 1-6 can be viewed as a special case for this more general definition of $\beta$ in the U-space. This $\beta$ value is also indicated in Figure 1-1. Note also that the point where $\beta$ is measured from the origin is referred to as the design point, as shown in Figure 1-1.

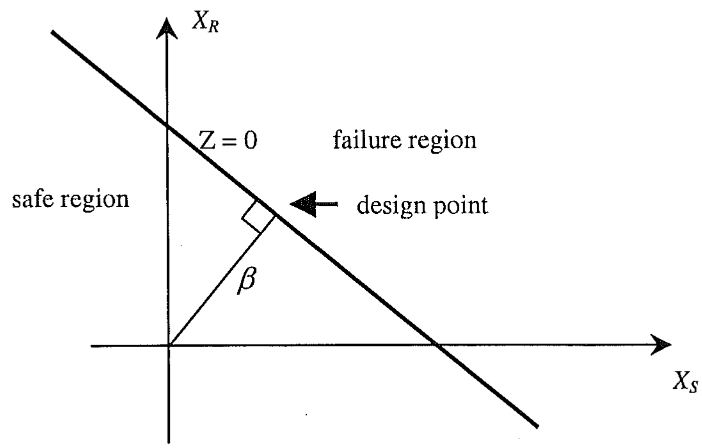


**Figure 1-1: General Definition of Reliability Index β in the Standardized U Space**

In general, the failure surface Z = 0 can be nonlinear, i.e., not linear as in this example. When this is the case, the failure surface may be linearized to provide an approximation for simplicity of computation. This simplification does not significantly sacrifice accuracy if the failure surface Z=0 is not highly nonlinear at the design point. When this linearization is performed using numerical methods, the resulting linearized failure surface is then used as the failure surface in the rest of the analysis. The approach described above can be used to determine the reliability index $\beta$. Note that the linearization is performed at the design point where the distance from the origin to the failure surface is minimized (Madsen et al 1986). This method of defining and calculating $\beta$ is referred to as the First Order Reliability Method (FORM) named appropriately for the first order (linear) approximation of the failure surface.

Furthermore, in general situations when the resistance $R$ and load effect $S$ are not normally distributed, they may be approximated using normal variables. These normal variables are determined such that they have the same probability density values and cumulative probability function values as the original random variables at the design point on the failure surface, where $\beta$ is then measured as the shortest distance to the origin (Madsen et al 1986). In general, the design point is not known prior to the computation. That is also the point where linearization of the failure surface is to be performed and the non-normal variables to be converted to normal variables and then standardized. Therefore an iterative approach is required to calculate the reliability index $\beta$ when the random variables involved are not normal variables and/or the failure surface is not linear.

In this research project, FORM is used to assess the safety level of bridge components to evaluate the adequacy of the design loads for highway bridges in Michigan. In reality, assuming random variables to be normally distributed may not always be valid for the resistances and load effects involved here. When this is the case, a hand calculation of reliability index $\beta$ using Equation 1-6 may not be accurate enough. Thus, when necessary, a computer program was used to compute the $\beta$ values, using the iterative approach discussed above.

### 1.4 AASHTO LRFD Bridge Design Specifications and Calibrated Safety Level

The AASHTO LRFD Bridge Design Specifications (1998) was calibrated using the same concept of bridge structural safety (Nowak 1999). More specifically, the research effort of calibrating this new set of specifications used the same method of structural reliability index $\beta$ as briefly presented above in Section 1.3. The target reliability index used in that study was 3.5. This is approximately equal to two failures in 10,000 (see Table 1-1). It is critical to understand that selection of a target reliability index is somewhat arbitrary. In that study, 3.5 was selected to provide the same average safety margin in the LRFD code that was estimated to exist in the previous AASHTO bridge design code. Thus, it is appropriate to state that that the particular target value 3.5 reflects an average of safety levels typically practiced in the country over several decades.

This research project uses the same structural reliability concept to assess structural safety of bridges designed using current Michigan design loads. In addition, many statistical parameters including the mean and standard deviation of the involved random variables are consistently used in this research project, so that the target $\beta$ value of 3.5 may still be used as the criterion for evaluating the adequacy of the current Michigan design load. Again, it should be stressed that a $\beta$ value of 3.5 here serves as a benchmark to define adequacy, which was also used in the LRFD code. In addition, the truck loads used in the reliability analyses in this study were modeled based on weigh-in-motion (WIM) truck weight data gathered in Michigan. The details of procurement and processing of the data are discussed in Chapter 2.

### 1.5 Locality of Truck Loads

As briefly discussed earlier, truck loads on a bridge depend significantly on the location of the bridge, the type of roadway it carries, the routine business or economic activity in its vicinity, etc. Thus, different locations may experience different truck loads (e.g., Kim et al. 1996). For example, Figures 1-2 and 1-3 show two truck weight histograms using WIM data obtained from two bridge sites in Michigan: I-94/Pierce Road and US-23/Saline River. It can be seen that the distribution of the truck gross vehicle weight (GVW) differs significantly between the two sites. This locality of truck loads has also been observed in other datasets collected over widely spread areas in the country (Moses and Verma 1987).

Nowak and his associates (1994) have collected truck load data from a number of bridges in the state of Michigan. The present research project uses those data sets to develop models of truck load and wheel load for the reliability analyses, as presented in Chapter 2. Due to observations of truck load variation, it was decided to investigate the metropolitan Detroit area separately from the rest of the state. The metro area and its vicinity have a large number of industry facilities. Economic activities related to these facilities result in unique truck traffic patterns in the surrounding areas. These patterns are different from the rest of the state and, to a certain extent, many areas in the nation.

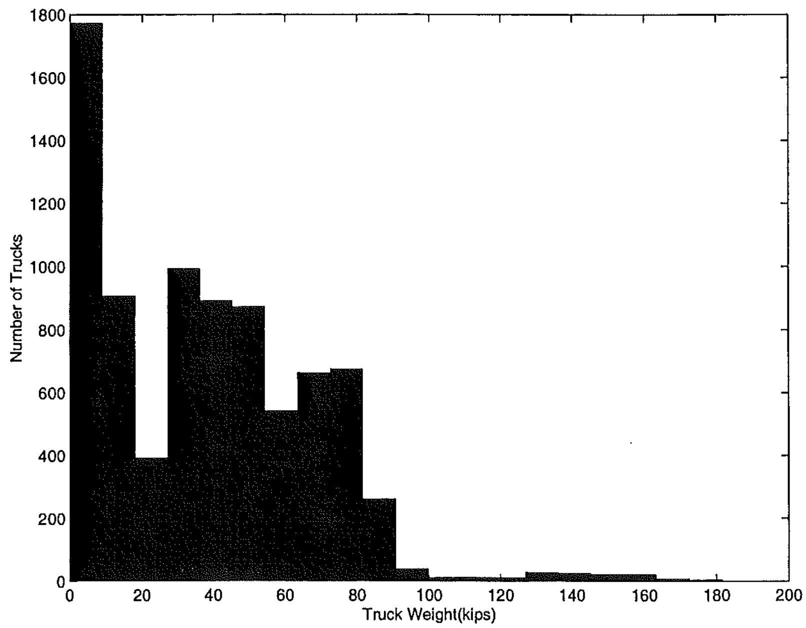


**Figure 1-2: Gross Truck Weight Histogram for Bridge on I-94 over Pierce Road**

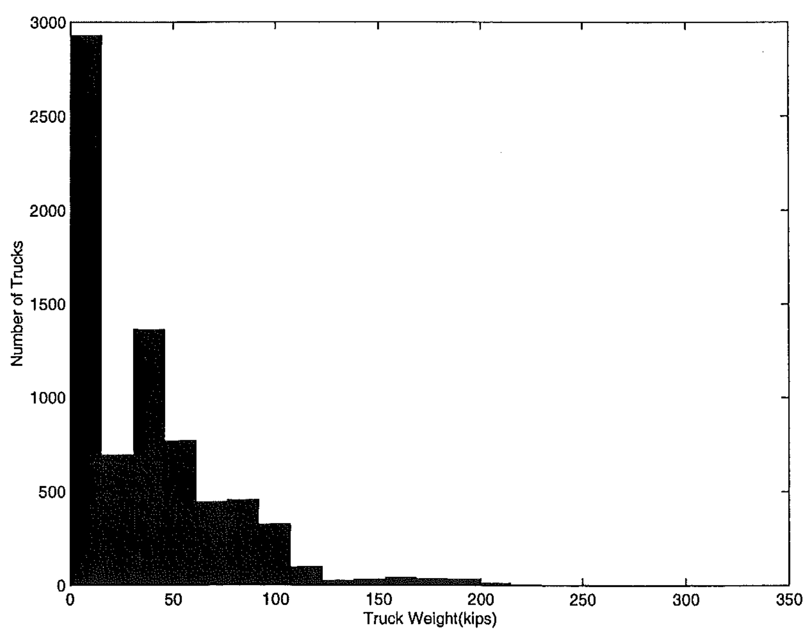


**Figure 1-3: Gross Truck Weight Histogram for Bridge on US-23 over Saline River**

### 1.6 Organization of Report

This report contains four chapters. Chapter 1 has provided an overview of the research project. This includes background and motivation for this investigation, research objective and scope, and the calculation procedure for the reliability index $\beta$. It also offers discussions on the requirement for $\beta$ as the criterion for determining the adequacy of current design loads. Chapter 2 presents modeling of the load effect and resistance as random variables in the reliability analysis. It covers the dead load effect, live load effect, and structural resistance of bridge components. This discussion covers beams as well as the reinforced concrete (RC) bridge deck. For the beams, both moment and shear effects are addressed. For the deck, punching shear is considered. Chapter 3 presents the details of the reliability analysis for assessing the safety of bridges, covering the following four types of common bridge construction in Michigan in recent years. 1.) Steel beam bridges (SC), 2.) Prestessed concrete I beam bridges (PI), 3.) Adjacent prestressed concrete box beam bridges (PCA), and 4.) Spread prestressed box beam bridges (PCS). Chapter 4 presents a discussion on the analysis results, the conclusions for the project, and recommendations based on the results.

## Chapter 2: Data Procurement, Organization, and Statistical Analysis

Chapter 1 has indicated the scope of this study covering 20 typical bridges randomly selected from the population of new bridges built in the past 10 years. Table 2-1 lists these 20 bridges, 5 from each of the 4 typical beam types: steel (SC), prestressed I (PI), prestressed concrete adjacent box (PCA), and spread prestressed concrete box (PCS). The table also provides some general information on the structural arrangement including the number of spans, whether the spans are continuous or simple, and span length.

For the reliability assessment of moment and shear for beams and punching shear for RC decks, equation 1-3 above can be expressed as

$$Z = R - D - L \tag{2-1}$$

where $D + L = S$. $D$ and $L$ are the dead and live load effects, respectively. Live load refers to truck load effect on bridge components such as moment and shear. Both are modeled as random variables in this study. In order to estimate the reliability indices for the twenty bridges it was necessary to calculate the statistical distributions for load effect as well as the structural resistance. This chapter discusses the modeling of these variables beginning with the raw data sets and explaining the processing procedure to make them representative of 75-year statistical distributions. The live load effects are truck induced moment and shear for beams, and wheel load punching shear for the reinforced concrete decks.

### 2.1 Live Loads

Existing weigh-in-motion (WIM) data files (Nowak et al. 1994) were made available for this project for five (5) different functional classifications (FC) of roadway. These Functional Classifications included 1.) FC01: Principal Arterial – Interstate Rural; 2.) FC02: Principal Arterial – Other – Rural; 3.) FC11: Principal Arterial – Interstate – Urban; 4.) FC12: Principal Arterial – Urban; and 5.) FC14: Other Principal Arterial – Urban. It should be noted that all the data available for use in this project was for principal arterial roadways of some type. As will become apparent in Chapter 3, the largest Average Daily Truck Traffic (ADTT) volumes typically occur in FC11 and FC12. Table 2-2 shows the number of trucks contained within each data set separated by FC and the location of the bridge at which the weights were obtained.

Although there was a total of over 46,000 trucks in the data set, resulting in over 250,000 axle weights, this number of trucks was slightly reduced to maintain consistency with the data preprocessing practices of NCHRP 368 (Nowak 1999). The following two criteria were imposed on the WIM data sets: 1.) Trucks having two axles must weigh more than 10 kips; and 2.) Trucks with three or more axles must weigh more than 15 kips. Trucks in the WIM datasets that did not meet these two criteria were eliminated from the datasets. In reliability analysis one is usually concerned with the upper tail of the load distribution and too much data in the left tail of the statistical distribution will result in inaccuracies in the parameter estimates. Another way to do this would be to keep all the data, i.e. truck weights, but only fit the upper tail of the distribution. The latter method is known as a tail fit, but was not applied here.

Five bridges of each type were selected from the Michigan Department of Transportation's bridge inventory: steel girder (SC), pre-stressed concrete I-beams (PI), pre-stressed concrete spread box girders

(PCS), and pre-stressed concrete adjacent box girders (PCA). All of these bridges are designed with a composite concrete deck. The bridges were selected randomly; however, a requirement that the bridges be constructed or re-constructed after 1990 was imposed on the selection as mentioned in Chapter 1. The purpose of this imposition was to ensure that the reliability estimates calculated were representative of bridges currently being designed in the state of Michigan. Some bridge details, including their locations and number of spans, are shown in Table 2-1.

**Table 2-1 Bridges used in Reliability Analysis**

| Bridge Type and I.D. | Number of Spans | Length of Spans (span no.) | Continuous or Simply Supported |
|---|---|---|---|
| **SC** | | | |
| 11072-B01 | 2 | 66' (1 & 2) | Continuous |
| 19042-S03 | 4 | 151' (1), 127'-2" (2 & 3) | Continuous |
| 41064-S20-3 | 1 | 130'-7" | Simply Supported |
| 41064-S18 | 1 | 146' | Simply Supported |
| 63174-S19 | 2 | 145'-3"(1), 160'-10"(2) | Continuous |
| **PI** | | | |
| 19033-S11 | 1 | 129' | Simply Supported |
| 11112-B02 | 7 | 118'-6"(1 & 7), 116'-3"(2,3, & 6), 116'-9"(4 & 5) | Simply Supported |
| 11052-B02 | 4 | 98'(1), 98'-5"(2,3 & 4) | Simply Supported |
| 19034-R01 | 3 | 41'(1 & 3), 32-6"(2) | Simply Supported |
| 11057-B04 | 7 | 123'-9"(1 & 7), 123'(3,4,5 & 6) | Simply Supported |
| **PCA** | | | |
| 46082-B02 | 1 | 41'-4" | Simply Supported |
| 82022-S05 | 2 | 71-6"(1 & 2) | Simply Supported |
| 82022-S06 | 2 | 71'-6"(1 & 2) | Simply Supported |
| 82022-S25 | 1 | 95'-7" | Simply Supported |
| 11015-S01 | 4 | 36'-5"(1), 76'-10"(2 & 3), 41'-11"(4) | Simply Supported |
| **PCS** | | | |
| 33084-S14 | 3 | 38'-5"(1), 70'-7"(2), 34'-11"(3) | Simply Supported |
| 55011-R01 | 1 | 72'-9" | Simply Supported |
| 63081-S06 | 3 | 28'(1), 73'-10"(2), 29'(3) | Simply Supported |
| 79031-B01 | 1 | 46'-7" | Simply Supported |
| 03072-B04 | 1 | 52' | Simply Supported |

**Table 2-2: Weigh-In-Motion (WIM) data used in the present study**

| Functional Classification | Location(s) | Bridge ID(s) | Total Number of Trucks in Database |
|---|---|---|---|
| **01** | I-94/Pierce Road | S03-81104 | 8,170 |
| **02** | US-23/Saline River | B05-58033 | 7,278 |
| **11** | EB I-94 Ramp to NB M-10<br>I-94/Jackson Road | S25-82023<br>S01-81062 | 21,539 |
| **12** | US-23/Huron River<br>US-23/Huron Railroad | R01-81074<br>R01-81103 | 5,942 |
| **14** | US-12 EB Ramp to EB I-94<br>Wyoming Road/I-94<br>M-153/M-39 | S32-82022<br>S36-82022<br>S01-82081 | 3,518 |
| | | | TOTAL = 46,447 |

Beam flexure and beam shear

In order to assess the reliability for beam flexure and beam shear it was necessary to numerically run each truck over influence lines for each bridge. Multiple influence lines were checked for each bridge and the maximum moment and shear were computed by combining the truck axle weights in the database and the influence lines. For example, if a two-span continuous steel composite (SC) bridge was being analyzed then it would be necessary to identify the critical positive bending moment on each span, the negative bending moment at the center support, the shear at each end support, and the shears to the left and right of the center support. Each of these load effects was processed and a reliability index associated with that load effect was computed as outlined in chapters 2 and 3 of this report. Appendix A presents the resulting un-projected data for each location on the bridges selected for analysis with an explanation of the notation used to identify the span and the location on the span. The data were kept separated by functional classification of the roadway. The main reason for keeping the data and subsequently the reliability analyses separated by FC is that the projection method outlined below is sensitive to the volume of truck traffic on a roadway, i.e. the Average Daily Truck Traffic (ADTT). However, it should be mentioned that the ADTT is not only a function of FC. Unfortunately, a tremendous amount of WIM data would be required to do location-specific analyses and draw conclusions for the entire state.

Deck punching shear

In order to assess the reliability for deck punching shear, the axle weights were taken directly from the data sets presented in Table 2-2. However, in order to calculate the 75-year load effect, the data were processed by using the following steps:

1. Each functional class was calculated independently, similar to the moment and shear calculations. However, it was not necessary to separate out each bridge, only bridge type (i.e. SC, PI, PCA, or PCS), since the slab for each bridge was assumed to be the same.
2. The steering axle weight of each truck was multiplied by 1.15, to account for stress concentration. This is because the steering wheels have a single tire, compared with other axles having dual tires. This approach is to make the steering wheels equivalent to other wheels in terms of induced shear stress on the deck.
3. The wheel weights, $w$, were determined by dividing the axle weights by 2.
4. The average number of wheels on one side of a truck axle, $N_{avg}$, was calculated as $N_{avg}$ = length($w$)/$N_{tr}$, where length($w$) is the total number of wheels in the data set, and $N_{tr}$ is the number of trucks in the data set.
5. The wheel loads were projected to 75 years using the same technique (see data projection technique below) that was used to project the shear and moments. They were projected using the $50^{th}$ and $90^{th}$ percentile of the ADTT from MDOT's planning division.

Table 2-3 presents the projected wheel loads after following the five (5) steps presented above for calculating the 75 year load effect.

**Table 2-3: Wheel load statistics by Functional Classification after projecting to 75 years**

| Percentile | MEAN (k) | | | | | STANDARD DEVIATION (k) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | FC 01 | FC 02 | FC 11 | FC 12 | FC 14 | FC 01 | FC 02 | FC 11 | FC 12 | FC 14 |
| $50^{th}$ | 22.7 | 19.7 | 32 | 22 | 15.7 | 0.32 | 1.21 | 1.53 | 1.32 | 0.71 |
| $90^{th}$ | 23.8 | 21.1 | 35.7 | 25 | 16.4 | 0.32 | 1.20 | 1.47 | 0.69 | 0.70 |

In order to perform the reliability analysis using FORM (see Chapter 1) for the 20 bridges in this study it was necessary to project the live load, i.e. moment, shear, and wheel load to 75 years as described below. If the live load data was used un-projected it would result in high reliability indices not really representative of the reliability over the bridge's design lifetime. Data projection is a technique commonly employed in reliability analyses and there are many different methods each with their own pros and cons. In NCHRP 368 (Nowak 1999) the live load data projection was done using a graphical technique.

Projection method

The WIM data files described in Table 2-2 contained limited information for each data point. The exact time of each truck was not known, however, the date of the measurement was known. It was not known how many days (or hours) of data the WIM datasets contained so it was necessary to calculate this as closely as possible using data from MDOT's planning division. Hence, average daily truck traffic (ADTT) was procured through MDOT's planning division for each functional classification of roadway. The statistics of the ADTT were determined for 1.) The entire state of Michigan by functional classification of roadway; and 2.) Region 7, Metro, by functional classification for all functional classes except FC02. A preliminary analysis was performed by the project manager and it was determined that Region 7 contained only a very small percentage of roadways designated as FC02, thus it was neglected.

Region 7 was analyzed separately because the WIM data used in this study was gathered from sites in and around Region 7, hence extrapolation of the conclusions to the entire state of Michigan may be construed as suspect or at the very least potentially biased. Professional opinion of the researchers was that the ADTT within Region 7 was larger than the state average; however there was either insufficient planning data to confirm this or it is not the case. As mentioned in Chapter 1, ADTT is very site-specific and caution should be used when making generalizations for areas larger than those measured.

From the ADTT statistics the following procedure was used to project the moment, shear, and wheel weight data to 75 years:

The equivalent days of data (EDD) for each functional class was determined based on the $50^{th}$ and $90^{th}$ percentile of the ADTT data for 1.) the entire state of Michigan; and 2.) Region 7, for a total of four (4) different EDD levels. The EDD was determined as

$$EDD = \frac{m}{ADTT} \tag{2-2}$$

where the numerator is the number of trucks in the dataset for that FC from Table 2-2, and the denominator in equation 2-2 is the ADTT corresponding to the $n^{th}$ percentile from the corresponding planning dataset. It was decided after discussion between the researchers and project manager to use $50^{th}$ and $90^{th}$ percentiles of the empirical cumulative distribution function (CDF) of the ADTT (from planning) for each FC. The $50^{th}$ percentile was chosen because it is a well-known representative statistic called the median. The median ($50^{th}$ percentile) is defined as the data point at which one-half of the data is below and one-half of the data is above. The $90^{th}$ percentile was chosen in order to serve as an indicator of the sensitivity of this parameter in the projection procedure and the overall reliability analysis. The $90^{th}$ percentile is defined as the data point having nine-tenths of the data below and one-tenth of the data above it. These CDF's were calculated by dividing the miles of roadway associated with each truck volume in the planning dataset into one-tenth mile segments. For example, if a particular segment of roadway was two miles long and had a small ADTT and another segment of roadway was one-half mile long but had a large ADTT, the new weighted data set would have twenty data points (2 miles/0.1 mile) with the small ADTT values and five points (0.5 miles/0.1 mile) with the large ADTT values. All these points would be generated and placed in a data set which makes up the weighted dataset from which the 50th and 90th percentiles were determined for the projection procedure.

The number of days to which the data must be projected, termed the required days of data (RDD), was calculated as

$$\begin{aligned} RDD &= 75 \text{ years} \times 365 \text{ days/year} \\ &= 27{,}375 \text{ days} \end{aligned} \tag{2-3}$$

where the right hand side of equation 2-3 is the number of days in 75 years.

An empirical cumulative distribution function is found by sorting the truck load effect (i.e. moment, shear, or wheel load) dataset from smallest to largest where $m$ is the length of the dataset. The corresponding value of the cumulative distribution function for the $i^{th}$ ranked load effect can be expressed as

$$F_i = \frac{i}{m} \tag{2-4}$$

In order to project the CDF from the *EDD* in each data set to the *RDD*, an $N$ value must be calculated as

$$N = \frac{RDD}{EDD} \tag{2-5}$$

The projected CDF, hereafter called $F_{75}$, can be calculated by making the assumption that each time period of duration EDD within the RDD time period (i.e. 75 years) are statistically independent from one another. Hence the projected CDF can be calculated as

$$F_{75} = F_i^N \tag{2-6}$$

Figure 2-1 presents an example of a histogram for the bending moment on a bridge and the corresponding plots of the CDF and the CDF projected to 75 years.

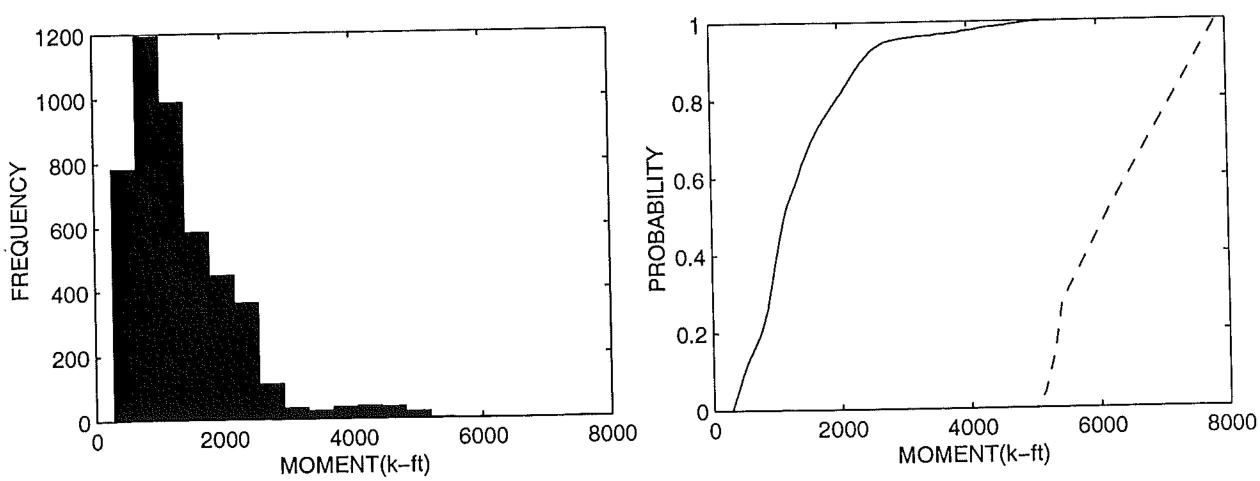


**Figure 2-1: Example of histogram for truck-induced moment, empirical distribution (solid line), and distribution projected to 75 years (dashed line).**

Once the data was projected, the mean value of the projected dataset can be read directly as the point on the abscissa corresponding to 0.5 on the CDF, $F_{75}$. A best-fit numerical technique was used to estimate the standard deviation of the projected dataset. Recall that the coefficient of variation (COV) of a random variable is defined as the ratio of its standard deviation to its mean. The COV is independent of units and is a good measure of variation for a random variable. Many equation in reliability are written in terms of the COV instead of the standard deviation. The dataset projection results for the bridge moments and shears for functional classes are presented in Appendix B. Recall that for the Region 7 projections, FC02 was not calculated.

It should be noted that during the projection procedure there were several data sets that did not contain a sufficient quantity of WIM data, particularly for the larger trucks that would result in larger moments and shears. This resulted in a very small standard deviation for the projected CDF, and in some cases it was zero. Theoretically, this is correct and can be explained practically by considering that within a 75 year period one may be relatively certain based on the known statistics as to the largest load effect that will occur.

## 2.2 Dead Loads

The dead loads were calculated from the bridge plans provided by the Michigan DOT. The dead load was assumed to act as a uniformly distributed load. The critical beam was assumed to be the girder adjacent to the fascia girder, i.e. first interior girder. Any loads that were the result of safety railing, safety barriers, etc. located on the edge were assumed to be distributed to the critical beam with a one-third factor. A 25 psf future wearing surface was included in the dead load for both the "as-designed" and "design-minimum" cases. The calculated dead load for each bridge is presented in Appendix C.

Each dead load has an associated bias and coefficient of variation (COV). The COV is defined as the ratio of the standard deviation to the mean value. The dead load bias, $D_{bias}$, can be expressed in terms of the nominal dead load, $D_n$, and mean dead load, $D_{mean}$, as

$$D_{bias} = \frac{D_{mean}}{D_n} \tag{2-7}$$

The bias and COV associated with each bridge type is presented later (see section 3.1).

## 2.3 Bridge Capacity Calculations

Capacities for moment and shear were determined for two different cases. The first case was the "as designed" case, in which the bridge plans used for construction were analyzed, and moment and shear capacities were computed based on engineering mechanics. The second case was the "design minimum" case, in which minimum capacities were computed based on the AASHTO bridge code (1996) required for the factored dead and live load (HS25) used in the State of Michigan. The axle loads and lane load associated with the HS25 truck load will be discussed later.

The bridge moment capacities were calculated at 24 different locations for the 20 bridges, for the "as-designed" case as well as the "design-minimum" case. The level of detail associated with the determination of the moment capacity was the same level of detail used in design. The bridge shear capacities were calculated at 48 different locations for the 20 bridges, for the "as-designed" case as well as the "design-minimum" case. Section 2-1 provides an explanation of the justification for checking multiple load effects on each bridge.

As-Designed Capacities for moment and shear

Basic principles of engineering structural analysis/structural mechanics were used to compute capacities. It should be noted that no resistance factors (i.e. strength reduction factors) of any sort were applied to the calculated capacities. The as-designed moment and shear capacities are presented in Appendix D using the same notation as described in Appendix A. In order to maintain consistency with NCHRP 368 (Nowak 1999), ultimate strengths were determined based on composite sections without regard to construction staging. In other words, the non-composite to composite behavior of the beam was neglected herein.

Design-Minimum Capacities for moment and shear

The design minimum capacity for moment and shear was computed using the following procedure. The HS25 bridge design loading consists of a live load using the HS25 axle weights shown in Figure 2-2, or a lane load of 0.8 k/ft + one or more point loads of 22.5 k (for moment) and 32.5 k (for shear), whichever results in a larger load effect. For example, in order to determine the "design-minimum" moment capacity for a simply supported bridge girder, one would compute 1.) the maximum moment from the HS25 truck axle weights shown in Figure 2-2; and 2.) the maximum moment from the combination of a 0.8 k/ft uniformly distributed load over the span + a 22.5 k point load at the center of the span. The live load moment is designated as whichever is larger.

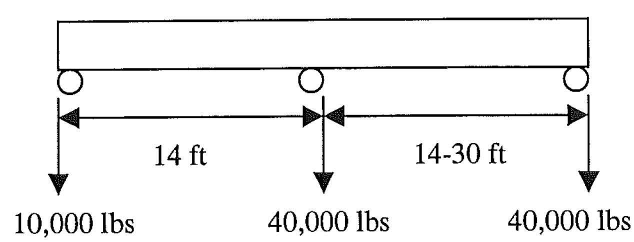


**Figure 2-2: Axle weights and spacing for HS25 bridge design load**

Once the HS25 load effect is determined from influence line analysis or tables, the nominal live load moment, $L_n$, can be computed as

$$L_n = M_{L_n} \frac{s}{11} I \tag{2-8}$$

where $s$ is the beam spacing in feet, $M_{L_n}$ is the nominal static moment, and the denominator, 11, is the AASHTO steel and prestressed concrete girder distribution factor (GDF) for the axle load. The value $I$ in equation 2-8 is the impact factor calibrated to account for dynamic amplification of load effect due to a moving vehicle. For the present study, an impact factor, $I = 1.3$, was used. It was reasoned that during the 75-year design life of a bridge the roadway surface would be significantly rough at one time or another, hence 1.3 was selected instead of 1.2 (which could be considered an average). The nominal moment capacity can then be calculated based on the AASHTO load factors as

$$M_n = 1.3D_n + 2.17L_n \tag{2-9}$$

The capacity for RC decks is modeled using the nominal strength given in the AASHTO standard code (1996) (AASHTO Article 8.16.6.6):

$$R_n = ( 2 + 4/ \alpha ) (f_c')^{1/2} b_0 d \gamma < 4 (f_c')^{1/2} b_0 d \gamma \qquad (2\text{-}10)$$

where $f_c'$ is the concrete compressive strength in psi; $\alpha$ is the ratio of the tire print long side to short side. It is set equal to 2.5 for a typical tire print of 20 in. by 8 in. for dual tires; d is the effective deck thickness equal to the total thickness minus the bottom cover; $b_0$ is the perimeter of the critical section, which is defined by the straight lines parallel to and at a distance d/2 from the edges of the tire print used; $\gamma$ is a model correction parameter, which is modeled by a random variable with a mean of 1.55 and COV of 23%, based on the test data in Perdikaris et al (1993).

## Chapter 3: Reliability Analysis and Results

The reliability index is a measure of the reserve capacity in a structural system. The First Order Reliability Method (FORM) was used to calculate the reliability indices in this study (see Chapter 1: Introduction).

As mentioned in the previous chapters, two different types of reliability indices were calculated for each bridge. The "as-designed" reliability calculated using the as-designed capacity and the "design-minimum" reliability calculated using the design-minimum capacity outlined in Chapters 1 and 2. The shears and moments were calculated at the points along the span(s) corresponding to the locations that the live load statistics were calculated, i.e. identified as critical locations. The "design-minimum" reliability served as a design load check, which was the primary objective of this study as outlined in Chapter 1. However, in order to determine the reliability of recently constructed bridges, actual bridge resistances were also used to help compute the reliability indices. The results of the later were termed the "as-designed" reliability indices and will always be greater than the "design-minimum" reliability indices, provided the bridge meets or exceeds the minimum design specifications. The reliability index, $\beta$, was determined using the following procedure:

The mean and COV of the live load moment (or shear) must be combined with the mean and COV of the dead load moment (or shear) to determine the total load effect (see section 1.3), *S*, on the girder.

1. Recall that the dead load moment must be computed as outlined in section 2.2. The bias and COV associated with the dead load for each bridge type was selected to be consistent with NCHRP 368 (Nowak 1999) as 1.0 and 0.1, respectively.

2. Recall that the steel and prestressed concrete Girder Distribution Factor (GDF) was equal to s/11 for the design-minimum capacity analysis (see equation 2-8). A single lane loading girder distribution factor *G* was used in this project for modeling the live load effect. For example, it's nominal value is *s*/14 for the cases of steel and prestressed concrete beams (AASHTO 1996), where *s* is the spacing between beams in feet. This selection was based on a previous research project of MDOT that found that the single lane girder distribution factor in the design code (AASHTO 1996) is more realistic for modeling effects of truck load. Since the goal of the reliability calculations was to estimate the $\beta$ value under realistic conditions a GDF of s/14 was believed to be more representative of the actual load distribution. The impact factor, *I*, was consistent with NCHRP 368 as with the design-minimum analysis, $I = 1.3$. The nominal live load moment was then calculated as

$$L = 0.9 M_L \frac{s}{14} I \tag{3-1}$$

where $M_L$ is now the mean value (projected to 75 years) of the truck-induced moment calculated from the WIM data and 0.9 is the bias for the s/14 GDF (AASHTO 1996). The values for $M_L$ are presented in Appendix B.

3. The COV of the live load, $V_L$, is also determined from the WIM data. The impact factor, $I$, and GDF are assigned COV's of $V_I = 0.10$ and $V_G = 0.13$, respectively (Moses and Verma 1987). Finally, in order to calculate the COV of the truck-induced live load, $V_L$, the COV's are combined as

$$V_L = \sqrt{V_G^2 + V_I^2 + V_T^2} \tag{3-2}$$

where $V_T$ indicates the COV of the truck load effect calculated from the 75-year statistical distribution described in section 2.1.

4. Then the standard deviation of the live load can be calculated from the result of equation 3-2 as

$$\sigma_L = LV_L \tag{3-3}$$

5. The total load COV, $V_S$, can be calculated by combining the dead and live load statistics as

$$V_S = \frac{\sqrt{\sigma_D^2 + \sigma_L^2}}{\mu_D + \mu_L} \tag{3-4}$$

where $\sigma_D$ is the standard deviation of $D$ and was determined as the product of the mean dead load and the COV of the dead load. Similarly, $\sigma_L$ is the standard deviation of $L$ determined as the product of the mean and COV of the live load effect. The mean value for the total load effect, $\mu_S$, is

$$\mu_S = \mu_D + \mu_L \tag{3-5}$$

where $\mu_D$ and $\mu_L$ are the mean of the dead and live load effect, respectively. If desired, the standard deviation of the total load effect could be expressed as

$$\sigma_S = SV_S \tag{3-6}$$

6. The nominal resistance, $R_n$, was determined as outlined in section 2.3 and was assigned a bias and COV consistent with NCHRP 368. Table 3-2 presents the associated bias and COV by bridge (girder) type. The mean resistance was calculated as

$$R = R_n \cdot bias \tag{3-7}$$

**Table 3-2: Bias and COV of Resistance by Bridge Type (Nowak 1999)**

| Bridge Type | Bias (Factor) | COV |
|---|---|---|
| Composite Steel (SC) | 1.12 | 0.10 |
| Prestressed I-Beam (PI) | 1.05 | 0.075 |
| Prestressed Box Adjacent (PCA) | 1.05 | 0.075 |
| Prestresed Box Spread (PCS) | 1.05 | 0.075 |

The reliability index was calculated based on the statistics of the load, $S$, and the resistance, $R$, as

$$\beta = \frac{\ln(R) - \ln(S)}{\sqrt{V_R^2 + V_S^2}} \tag{3-8}$$

where $R$ and $S$ represent the mean of the resistance and load, respectively; and $V_R$ and $V_S$ represent the coefficient of variation of the resistance and load, respectively. Note that equation 3-8 is for lognormally distributed random variables.

The reliability indices were calculated for ten different cases:

1.) The as-designed girder capacity for the 50th percentile ADTT for the state.
2.) The as-designed girder capacity for the 90th percentile ADTT for the state.
3.) The design-minimum girder capacity for the 50th percentile ADTT for the state.
4.) The design-minimum girder capacity for the 90th percentile ADTT for the state.
5.) The as-designed slab punching shear for the 50th percentile ADTT for the state.
6.) The as-designed slab punching shear for the 90th percentile ADTT for the state.

and

7.) The as-designed girder capacity for the 50th percentile ADTT for Region 7.
8.) The as-designed girder capacity for the 90th percentile ADTT for Region 7.
9.) The design-minimum girder capacity for the 50th percentile ADTT for Region 7.
10.) The design-minimum girder capacity for the 90th percentile ADTT for Region 7.

Appendix E presents the calculation results for these ten different reliability index calculations for each functional classification of roadway. The shading, which will be discussed later in more detail in Chapter 4, indicates a reliability index, $\beta$, value lower than 3.5. Recall from Chapter 1 that the value of 3.5 for $\beta$ was selected as a target reliability level since it was the value used in the calibration of the LRFD bridge design code (Nowak 1999). It should be noted that the reliability indices calculated using the 90th percentile of the ADTT should, in theory, always be equal to or lower than those calculated using the 50th percentile of the ADTT.

## Identification of Critical Reliability Indices

The controlling reliability index for shear or moment was determined for each bridge based on the weakest link in a chain logic. For example, if $n$ values of moment were calculated for a bridge then the reliability index for flexure for that bridge can be expressed mathematically as

$$\beta = \min[\beta_1, \beta_2, \ldots, \beta_n] \tag{3-9}$$

The values for the reliability indices for cases 1-4 and 7-10 described above are presented in Tables 3-3 through 3-6. The results for cases 5 and 6, the deck reliability indices, are presented in Table 3-7. As in Appendix E, tables 3-3 through 3-7 are shaded to indicate values of $\beta$ lower than 3.5.

The reliability index for each bridge type, $\beta_{bridgetype}$, was calculated as the average of the five reliability indices for each bridge type

$$\beta_{bridgetype} = \frac{1}{5}\sum_{i=1}^{5} \beta_{bridgetype,i} \tag{3-10}$$

where the double subscript on the $\beta$ in the summation indicates the bridge type, i.e. composite steel (SC), prestressed I-beam (PI) prestressed adjacent box (PCA), or prestressed spread box (PCS), and the $i$ indicates which of the five bridges. Figure 3-1 presents a flowchart summary for clarification of the overall procedure outlined in chapters 2 and 3 of this report to this point. Recall from chapter 1 that five bridges of each type were analyzed. Appendix F presents two examples that show the calculation of the reliability index for one of the steel composite bridges, B01-11072, using 1.) The "as-designed" resistance; and 2.) The "design-minimum" resistance.

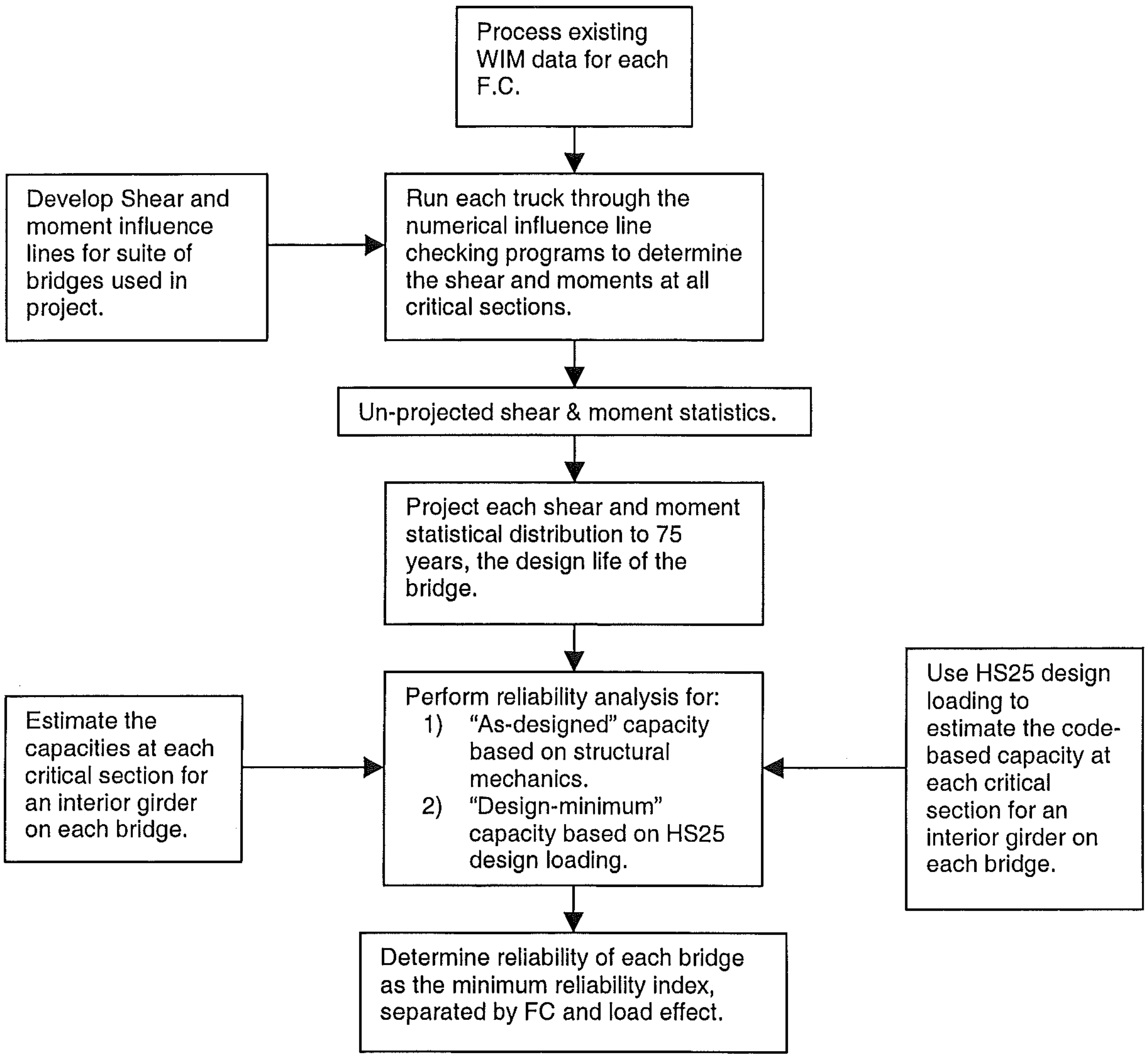


**Figure 3-1: Flowchart showing procedure used to calculate reliability indices in this study.**

Once the reliability index for each bridge is determined using equation 3-9, the average for each bridge type was calculated using equation 3-10. The reliability indices ranged from as low as near 1 to over 8. As mentioned, the target reliability index was 3.5 for this study, hence average reliability indices for each bridge type under 3.5 are shaded in Table 3-3 through Table 3-6. Comparison of Table 3-3 for the "as-designed" reliability indices to Table 3-4 for the "design-minimum" reliability indices shows that the over-design due to individual designers exercising conservatism is significant. In fact, on average for the bridges in this study, only the reliability of the shear for the adjacent prestressed concrete box beam bridges did not achieve the target reliability index of 3.5. However, inspection of Table 3-4 reveals that this is definitely not the case for the "design-minimum" reliability indices. This is particularly true for FC02, FC11, and FC12. Chapter 4 presents more discussion on Tables 3-3 through 3-6 and the individual reliability index values in Appendix E.

**Table 3-3: Reliability indices for as-designed girder capacity for entire state**

| Bridge Type | | Functional Classification | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 01 | | 02 | | 11 | | 12 | | 14 | |
| | | 50th | 90th | 50th | 90th | 50th | 90th | 50th | 90th | 50th | 90th |
| SC | shear | 7.0 | 7.0 | 5.9 | 5.6 | 5.0 | 5.0 | 4.9 | 4.8 | 7.4 | 7.4 |
| | moment | 5.5 | 5.5 | 4.7 | 4.6 | 4.0 | 3.9 | 3.9 | 3.8 | 5.7 | 5.7 |
| PI | shear | 8.1 | 8.1 | 7.2 | 7.0 | 6.5 | 6.5 | 6.5 | 6.4 | 8.3 | 8.2 |
| | moment | 5.8 | 5.8 | 4.6 | 4.4 | 3.6 | 3.5 | 3.6 | 3.48 | 6.0 | 6.0 |
| PCS | shear | 8.2 | 8.2 | 7.1 | 6.9 | 6.3 | 6.2 | 6.3 | 6.3 | 8.3 | 8.2 |
| | moment | 8.3 | 8.3 | 6.8 | 6.8 | 5.4 | 5.4 | 5.8 | 5.7 | 8.4 | 8.4 |
| PCA | shear | 4.9 | 4.9 | 3.8 | 3.6 | 2.9 | 2.9 | 3.1 | 3.1 | 5.0 | 4.9 |
| | moment | 6.1 | 6.1 | 4.9 | 4.7 | 3.8 | 3.8 | 4.0 | 4.0 | 6.2 | 6.2 |

**Table 3-4: Reliability indices for design-minimum girder capacity for entire state**

| Bridge Type | | Functional Classification | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 01 | | 02 | | 11 | | 12 | | 14 | |
| | | 50th | 90th | 50th | 90th | 50th | 90th | 50th | 90th | 50th | 90th |
| SC | shear | 4.3 | 4.3 | 3.1 | 3.0 | 2.3 | 2.3 | 2.2 | 2.1 | 4.6 | 4.6 |
| | moment | 4.1 | 4.1 | 3.3 | 3.2 | 2.4 | 2.4 | 2.4 | 2.3 | 4.4 | 4.4 |
| PI | shear | 3.5 | 3.5 | 2.7 | 2.5 | 2.0 | 2.0 | 2.0 | 1.9 | 3.6 | 3.6 |
| | moment | 4.3 | 4.3 | 3.2 | 3.0 | 2.1 | 2.0 | 2.1 | 2.0 | 4.5 | 4.5 |
| PCS | shear | 3.8 | 3.8 | 2.8 | 2.6 | 1.9 | 1.9 | 2.0 | 2.0 | 3.8 | 3.8 |
| | moment | 5.0 | 5.0 | 3.8 | 3.7 | 2.2 | 2.1 | 2.6 | 2.5 | 5.1 | 5.1 |
| PCA | shear | 3.1 | 3.1 | 2.1 | 1.9 | 1.2 | 1.2 | 1.4 | 1.4 | 3.2 | 3.2 |
| | moment | 5.6 | 5.6 | 4.5 | 4.3 | 3.2 | 3.1 | 3.5 | 3.4 | 5.7 | 5.7 |

**Table 3-5: Reliability indices for as-designed girder capacity for region 7**

| Functional Classification | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bridge Type | | 01 | | 02 | | 11 | | 12 | | 14 | |
| | | 50th | 90th | 50th | 90th | 50th | 90th | 50th | 90th | 50th | 90th |
| SC | shear | 7.0 | 7.0 | | | 5.1 | 5.0 | 4.9 | 4.8 | 7.4 | 7.4 |
| | moment | 5.5 | 5.5 | | | 3.9 | 3.9 | 3.9 | 3.8 | 5.7 | 5.7 |
| PI | shear | 8.1 | 8.1 | | | 6.6 | 6.5 | 6.5 | 6.4 | 8.3 | 8.2 |
| | moment | 5.8 | 5.8 | | | 3.6 | 3.5 | 3.6 | 3.5 | 6.0 | 6.0 |
| PCS | shear | 8.2 | 8.2 | | | 6.3 | 6.2 | 6.3 | 6.3 | 8.3 | 8.2 |
| | moment | 8.3 | 8.3 | | | 5.4 | 5.4 | 5.8 | 5.7 | 8.4 | 8.4 |
| PCA | shear | 4.9 | 4.9 | | | 2.9 | 2.9 | 3.1 | 3.1 | 5.0 | 4.9 |
| | moment | 6.1 | 6.1 | | | 3.8 | 3.8 | 4.0 | 4.0 | 6.2 | 6.2 |

**Table 3-6: Reliability indices for design-minimum girder capacity for region 7**

| Functional Classification | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bridge Type | | 01 | | 02 | | 11 | | 12 | | 14 | |
| | | 50th | 90th | 50th | 90th | 50th | 90th | 50th | 90th | 50th | 90th |
| SC | shear | 4.3 | 4.3 | | | 2.3 | 2.3 | 2.2 | 2.1 | 4.6 | 4.6 |
| | moment | 4.1 | 4.1 | | | 2.4 | 2.4 | 2.4 | 2.3 | 4.4 | 4.7 |
| PI | shear | 3.5 | 3.5 | | | 2.0 | 2.0 | 2.0 | 1.9 | 3.6 | 3.6 |
| | moment | 4.3 | 4.3 | | | 2.1 | 2.0 | 2.1 | 2.0 | 4.5 | 4.5 |
| PCS | shear | 3.8 | 3.8 | | | 2.0 | 1.9 | 2.0 | 2.0 | 3.8 | 3.8 |
| | moment | 5.0 | 5.0 | | | 2.2 | 2.1 | 2.6 | 2.5 | 5.1 | 5.1 |
| PCA | shear | 3.1 | 3.1 | | | 1.2 | 1.2 | 1.4 | 1.4 | 3.2 | 3.2 |
| | moment | 5.6 | 5.6 | | | 3.2 | 3.1 | 3.5 | 3.4 | 5.7 | 5.7 |

**Table 3-7: Reliability Indices for as-designed slab to punching shear for entire state**

| Functional Classification | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Bridge Type | 01 | | 02 | | 11 | | 12 | | 14 | |
| | 50th | 90th | 50th | 90th | 50th | 90th | 50th | 90th | 50th | 90th |
| SC | 8.7 | 8.6 | 8.8 | 8.8 | 8.1 | 7.9 | 8.7 | 8.5 | 9.1 | 9.1 |
| PI | 8.7 | 8.6 | 8.8 | 8.8 | 8.1 | 7.9 | 8.7 | 8.5 | 9.1 | 9.1 |
| PCA | 9.1 | 9.0 | 9.2 | 9.1 | 8.6 | 8.5 | 9.1 | 9.0 | 9.4 | 9.3 |
| PCS | 8.7 | 8.6 | 8.8 | 8.8 | 8.1 | 7.9 | 8.7 | 8.5 | 9.1 | 9.1 |

## Chapter 4: Discussion, Conclusions, and Recommendations

### Discussion

Appendix E shows the reliability indices calculated using the model described in equations 1-1 and 2-1 with the statistical parameters of the random variables presented in Chapters 2 and 3. As discussed earlier, the reliability index calculation model used here refers to only one failure mode: beam flexure, beam shear, or deck punching shear. There are four tables in Appendix E (E-1 to E-4) for flexure and shear, respectively, for the combinations of 50$^{th}$ and 90$^{th}$ percentiles of the ADTT and the entire state or the Metro Region (Region 7) only. Each table lists the type of construction in the first column and the bridge analyzed in the second column. The third column identifies the cross section and the failure mode, using m for flexural moment and v for shear. The remainder of the columns present the reliability index β for 5 different FC's of roadway for which WIM truck data were available and used in this study. For each functional class, two β values are listed – one for the "as designed" resistance as determined from the plans and the other for the "design minimum" based on the current AASHTO design code requirement (1996) adopted in Michigan.

Comparison of Tables E-1 and E-2 can show the effects of truck traffic volume. As discussed earlier, traffic volume varies, sometimes significantly, with bridge site. To reiterate from Chapter 2, a 50$^{th}$ percentile value of the traffic volume means that there is a 50 percent probability that this traffic volume is higher than the actual traffic volume. The 90$^{th}$ percentile means that there is a 90 percent probability that this traffic volume is higher than the actual traffic volume. Tables E-1 and E-2 indicate that the differences in $\beta$ due to the 50$^{th}$ and 90$^{th}$ percentiles of traffic volume are not significant. For example, the reliability index β for FC 01 for bridge S18-41064 with respect to the moment at midspan (point 1.5) is 4.1 for "as designed" in Table E-1 for 50$^{th}$ percentile traffic volume. It is also 4.1 in Table E-2 for 90$^{th}$ percentile traffic volume. There is a negligible difference (in the third digit after the decimal point) between these two β values. This small difference is the effect of traffic volume. Such a small difference is due to the fact that the 50$^{th}$ and 90$^{th}$ percentiles are both fairly large (approximately 3,400 and 4,200 trucks per day, respectively). The projection performed using these two values has resulted in very similar mean and standard deviation values for live load effect. In this particular example, the live load effect is the flexural moment at midspan. The mean and standard deviation are 5,054 and 14.4 k-ft for the 50$^{th}$ percentile case and 5,061 and 13.9 k-ft for the 90$^{th}$ percentile case (Tables B-1 and B-2 in Appendix B), showing very little difference. Note that comparison of Tables E-3 and E-4 also shows the same trend of little effect of traffic volume.

As discussed above, the traffic volumes (the 50$^{th}$ and 90$^{th}$ percentiles) synthesized using data from the entire state and from the Metro Region (Region 7) were used to compute corresponding reliability indices, in order to observe the effect of bridge site location in the state. Comparison of Tables E-1 versus E-3 as well as Tables E-2 versus Table E-4 permits such observation within the range of the input data used here. The comparison of these two pairs shows that bridge location has very little effect on the reliability index. For example, the same bridge example used above can be used here again for the purpose of comparison. The reliability index β for bridge S18-41064 with respect to the moment at midspan (m15) is 2.7 for the "as designed" case in Table E-1 for 50$^{th}$ percentile traffic volume. It is also 2.7 for the Metro Region (Region 7) as shown in Table E-3. This trend is attributed to the fact that for the entire state and Metro Region, the same load spectrum described by the WIM data was used to calculate the reliability indices for both cases. The only difference between those two computations was the ADTT used to project the data to 75 years. As discussed above, the traffic volume did not show significant effects, hence these values were close to each other. In fact, it can be concluded also from this comparison that more WIM data are needed from different areas around the state, in order to calculate reliability indices that are more representative of the entire state rather than any one region.

Recall that 3.5 was used as the target reliability index for component strength in the calibration of the AASHTO LRFD Bridge Design Specifications and was also used as the target reliability index for the present project. Using this reliability threshold, Tables 3-3 to 3-6 have those β values shaded if they are lower than 3.5, as do the Appendix Table E-1 to E-4. Based on the earlier discussion on the effect of bridge location in the state and in the Metro Region, we can focus our attention to the tables for Region 7 only since the values for the entire state were very similar. These are Tables 3-5 and 3-6 in Chapter 3 and Tables E-3 and E-4 in the appendix. They show consistently that β values for FC 11 and FC 12 represent the worst conditions for the bridges in the Metro Region (Region 7). Note that these two functional classes are respectively defined as "urban principal arterial – interstate" and "urban principal arterial – other freeways or expressways", according to the FHWA definition.

In Tables 3-3 and 3-4 as well as Tables E-1 and E-2, the next worst condition appears to be the functional class 2 (FC 02) defined as "rural principal arterial – other". Neither Tables 3-5 and 3-6 nor Tables E-3 and E-4 show values of $\beta$ for this FC since there was only a very small section of roadway designated as FC02 in Region 7, essentially an urban area.

It can also be seen that the majority of the prestressed concrete bridges in this study have reliability indices lower than 3.5 for the "design minimum" in Tables E-1 through E-4. This is also the case in Tables 3-4 and 3-6. While steel bridges have more values of β higher than 3.5, the lowest β value is seen for a steel bridge span. This value is 1.2 (Tables E-3 and E-4) for both the 50$^{th}$ and 90$^{th}$ percentiles of traffic volume, both for the shear of a simply supported span of steel bridge (S20-41064). These minimum $\beta$ values are much lower than the target level of 3.5. According to this criterion of $\beta$ equal to 3.5, the minimum strength requirement in the current design code (AASHTO 1996) does not provide the desired margin of safety (i.e., adequate design load), at least for bridges in the Metro Region. This conclusion should not be extrapolated to the entire state mainly because the WIM data is from in and around the Metro Region.

It is well known that structural engineers exercise conservatism in their design practice, which often results in additional reserve strength built into the structure. This reserve strength can sometimes be significant. Large differences in the reliability index β values between the "as designed" and "design minimum" provide evidence as to this fact in Tables 3-3 to 3-6 and appendix Tables E-1 to E-4. For example, the β value for support shear in bridge S18-41064 is 2.0 for FC12 for "design minimum" (Table E-3). In contrast, the "as designed" case has a β value as high as 6.7. It is clear that a large amount of additional reserve strength has been provided beyond what the code requires. While this conservatism is commonly observed as shown in this study, there is no measure in place to control and/or assure uniform conservatism. Instead, there is always some chance that the conservatism exercised is not adequate to cover the involved risk and supply a reliability index below 3.5. For example, for the 20 bridges analyzed in this project, 11 of them have a β value lower than the target 3.5 for the As Designed case in Table E-3 (for the 50$^{th}$ percentile) and 12 of them in Table E-4 (for the 90$^{th}$ percentile). This situation deserves adequate attention.

Table 3-7 shows the reliability indices for RC deck slabs. The failure mode considered here is punching shear because previous research has shown that this is usually the dominant failure mode for RC decks. Due to the fact that the "entire state" and the "Metro Region" cases use the same WIM data and result in similar β values, only the results for the entire state are shown in the table. Furthermore, the punching shear capacity is considered to be a function of the deck thickness according to the AASHTO code provisions, which is kept constant within each of the four types of bridges covered in this project.

Therefore, Table 3-7 lists the reliability index values for each bridge type, without identification for a particular bridge. Also note that these $\beta$ values are for the case of "as designed". This is because deck thickness is almost a constant now in the state for each of these types of bridges. Appendix E-5 shows that the $\beta$ values are around 8 to 9, with a minimum of 7.9 and a maximum of 9.4. In the calibration of the AASHTO LRFD Bridge Design Specifications, decks were not considered. Thus, there is no target $\beta$ value that can be directly taken from that experience and used here. However, the reliability indices of 8 to 9 are certainly adequate considering that it is much higher that the target value of 3.5 for primary members.

## Conclusions

The following conclusions were reached based on the results of this study.

1. The difference in the structural reliability index $\beta$ due to the traffic volumes taken as the $50^{th}$ and $90^{th}$ percentiles is negligible. The cases of "entire state" and "Metro Region" in this study did not result in significantly different $\beta$ values, because the only difference between the two cases was the traffic volumes representing respective areas. Note that the WIM data (i.e., the probabilistic distribution of truck weight) was the same in the analysis for these two cases, and they are collected from bridges in or very near the Metro Region. No other WIM data from other parts of the state were considered to be appropriate for use in this study.

2. The deck design load of HS20 is adequate for RC deck design, with respect to structural safety for strength. It should be noted that this conclusion is based on a target reliability index of 3.5.

3. Based on the randomly selected twenty bridges analyzed in this study the current Michigan design load of HS25 for design of bridge beams did not consistently achieve the target reliability index of 3.5. Hence, the HS25 design load may be inadequate for the Metro Region based on the analysis presented herein. This conclusion was reached based on the following observations. i.) A large number of cases of shear or moment for the 20 sample bridges used here had a $\beta$ value lower than the 3.5 target level, particularly for FC11 and FC12, which are typical for the Metro Region. Note that this comparison is based on the "design minimum" because the 3.5 target value is intended to be for this case. ii.) Based on the "as designed" strength, it has been found that there are still cases where the $\beta$ value falls below 3.5, with a minimum of about 2.2. This indicates that practice of convention or intentional conservatism certainly mitigates the situation considerably. Nevertheless it cannot guarantee that all designs will produce bridge components with reliability indices above the target level. iii.) The averaged minimum $\beta$ values (Tables 3-5 and 3-6) averaged over each bridge type also show similar trends as in Items i) and ii). It also should be noted that these averaged minima were obtained over the cases calculated here. They do not necessarily cover the entire bridge population in the Metro Region, because the sample bridges were not selected according to that population.

On the other hand, it should be pointed out that it has not been established that a reliability index $\beta$ value below 3.5 indicates an unsafe bridge. Particularly, the target level of 3.5 is used for single structural components and not the entire structural system. It is the system that dictates the safety of bridge, not a single component. Secondly, the target level of 3.5 was selected in the calibration process of the AASHTO LRFD code as the average of $\beta$ levels assured by the AASHTO design code at the time. Thus, it is not an absolute criterion but rather a relative norm.

4. More WIM truck weight data beyond what have been used in this study are needed to investigate whether the above conclusions are also valid for other regions in the state. The WIM datasets used in this

study were collected from bridges in or very near the Metro Region. These data were used for reliability analysis for other regions in the state but with traffic volumes from the corresponding areas. Resulting $\beta$ values are very similar to those for the Metro Region, as indicated in Conclusion 1 above. It is seen that the same WIM data used for both the "entire state" and the "Metro region" cases makes it difficult to draw reliable conclusions as to the entire state. Therefore, WIM data from other regions is required to draw definitive conclusions for the rest of the state.

Recommendations

Based on the results and conclusions presented, the following items are recommended for future study.

1. A research effort is recommended to develop a new bridge design load for beam design in the Metro Region. This design load should assure a level of structural reliability compatible for the Metro Region and other parts of the state with the rest of the country. This new design load is to accommodate higher truck loads commonly observed in the area. In other words, it is to cover potentially significantly different truck loads in the Metro Region.

2. Further effort is recommended to gather more WIM data from other bridge sites throughout the entire state. This information will assist in assessing the safety of new bridges in other areas of the state. As an economical alternative it is recommended to attempt to use available WIM data collected using means other than that of instrumented bridges. For example the WIM datan collected by the planning function of MDOT may be considered for this purpose. These truck load data may be less accurate than those obtained using instrumented bridges. However, it is possible and also is considered appropriate to develop a probabilistic model to account for the uncertainty introduced through the use of less accurate instrumentation.

3. The model used in this study to project the statistical distribution of the truck load effect to a long time period (e.g., 75 years) using data from a short period of time (e.g., a few days) needs to be studied further. This task should include the following steps. i.) Identify approaches that may produce more reliable results. Theoretical approaches should be considered in this step. ii.) Compare the results obtained from alternative approaches to examine consistency. Identify the approaches that produce consistent results. iii.) If possible, compare analysis results with measured data for identifying the confirmed reliable approach(es). This step depends on what WIM data are available and whether they are reliable to be used for this step's objective.

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## Appendix A: Un-Projected Moments and Shears

Each moment or shear location is identified in the following manner: The bridge ID in the leftmost column; In the column labeled "Load Eff.", an "m" indicates a moment and a "v" indicates a shear. The first number after the m or v indicates the span number, and the second number indicates how far from the leftmost support for that span in terms of percent of the span. For example, for bridge no. B01-11072, the m14 indicates the moment on the first span at a location 40% from the leftmost support. The v20 indicates the shear at the second support.

| | Bridge I.D. | Load Eff. | FC 01 | | FC 02 | | FC 11 | | FC 12 | | FC 14 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | Std | Mean | Std | Mean | Std | Mean | Std | Mean | Std |
| | S18-41064 | m15 | 1447.8 | 691.4 | 1607.3 | 990.8 | 1588 | 1268.2 | 1409.5 | 937.1 | 1065.6 | 735.8 |
| | | v10 | 42 | 19.8 | 46.2 | 28.1 | 45.7 | 35.9 | 40.6 | 26.4 | 30.7 | 20.8 |
| | S20-41064 | m15 | 1254.5 | 595.5 | 1395.4 | 856.6 | 1381.2 | 1101 | 1225.5 | 813.3 | 929.6 | 637.1 |
| | | v10 | 41.1 | 19.2 | 45.2 | 27.3 | 44.8 | 35.1 | 39.8 | 25.8 | 30.2 | 20.3 |
| | B01-11072 | m14 | 379.1 | 163.5 | 426.8 | 241 | 413.3 | 311.9 | 366.6 | 231.6 | 286.4 | 177.4 |
| | | m20 | 339.8 | 157 | 366.6 | 213.6 | 357.1 | 264.7 | 322.7 | 200.8 | 237.2 | 156 |
| | | v10 | 30.6 | 13 | 34.3 | 19.5 | 34.4 | 25.6 | 30.5 | 18.7 | 23.9 | 14.3 |
| | | v20 | 45.7 | 22.4 | 50.5 | 31.9 | 49.7 | 40.3 | 44.1 | 29.8 | 33 | 23.5 |
| | | m14 | 1170.9 | 554 | 1300.5 | 793.8 | 1285.3 | 1018.2 | 1141 | 752.3 | 864 | 590 |
| | | m20 | 767.4 | 378.5 | 846.1 | 534.6 | 829.8 | 673.1 | 737.2 | 497.8 | 550 | 394 |
| | | m26 | 1305.8 | 621.2 | 1448.5 | 888.1 | 1430 | 1136.1 | 1269.7 | 839.6 | 959.2 | 659.3 |
| | S19-63174 | v10 | 40.3 | 18.6 | 44.3 | 26.6 | 44 | 34.4 | 39.1 | 25.2 | 29.8 | 19.8 |
| SC | | v20l | 44.4 | 21.2 | 48.8 | 30.1 | 48.1 | 38.2 | 42.8 | 28.2 | 32.2 | 22.3 |
| | | v20r | 45.2 | 21.7 | 49.7 | 30.7 | 48.9 | 38.9 | 43.5 | 28.7 | 32.6 | 22.7 |
| | | v30 | 41 | 19.1 | 45.1 | 27.2 | 44.8 | 35 | 39.8 | 25.7 | 30.2 | 20.2 |
| | | m20 | 783.9 | 386 | 865 | 546.1 | 849 | 688.6 | 754 | 509.1 | 562.9 | 402.5 |
| | | m25 | 788.5 | 366.9 | 879.5 | 530.4 | 873.4 | 687.3 | 774.9 | 508.2 | 591.6 | 396.2 |
| | | m30 | 493.8 | 241.1 | 547 | 343.8 | 538.8 | 436.7 | 477.9 | 322.2 | 358.9 | 253.5 |
| | | m40 | 800.2 | 394.2 | 882.7 | 557.5 | 866.4 | 702.8 | 769.5 | 519.6 | 574.3 | 410.9 |
| | | v20l | 45 | 21.6 | 49.5 | 30.6 | 48.7 | 38.8 | 43.3 | 28.6 | 32.5 | 22.6 |
| | S03-19042 | v20r | 41.2 | 19.2 | 45.4 | 27.4 | 45 | 35.3 | 40 | 25.9 | 30.4 | 20.4 |
| | | v30l | 41.9 | 19.7 | 46.2 | 28 | 45.8 | 36 | 40.7 | 26.4 | 30.8 | 20.8 |
| | | v30r | 41.8 | 19.6 | 46.1 | 27.9 | 45.7 | 35.9 | 40.6 | 26.4 | 30.8 | 20.7 |
| | | v40l | 41.3 | 19.3 | 45.5 | 27.5 | 45.1 | 35.4 | 40.1 | 26 | 30.4 | 20.4 |
| | | v40r | 45.1 | 21.7 | 49.6 | 30.6 | 48.8 | 38.8 | 43.4 | 28.7 | 32.5 | 22.7 |
| | | v50 | 40.4 | 18.7 | 44.4 | 26.7 | 44.1 | 34.4 | 39.2 | 25.2 | 29.8 | 19.9 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PI | S11-19033 | m15 | 1235.1 | 585.8 | 1374.1 | 843.2 | 1360.4 | 1084.2 | 1207 | 800.9 | 915.9 | 627.2 |
| | | v10 | 40.9 | 19.1 | 45.1 | 27.2 | 44.7 | 35 | 39.7 | 25.7 | 30.1 | 20.2 |
| | B01-11052 | m15 | 852.4 | 396.7 | 954.5 | 578.2 | 951 | 753.8 | 842.5 | 556.8 | 646.6 | 432.6 |
| | | v10 | 38.2 | 17.4 | 42.2 | 25.2 | 42.1 | 32.7 | 37.3 | 23.9 | 28.6 | 18.7 |
| | B04-11057 | m15 | 1169.2 | 553.2 | 1301.9 | 797.5 | 1290 | 1027.2 | 1144.3 | 758.8 | 869.6 | 593.6 |
| | | v10 | 40.6 | 18.9 | 44.7 | 26.9 | 44.4 | 34.7 | 39.4 | 25.5 | 30 | 20 |
| | B02-11112 | m15 | 1103.6 | 520.7 | 1230 | 752 | 1219.8 | 970.6 | 1081.8 | 716.9 | 823.4 | 560.2 |
| | | m25 | 1078.3 | 508.2 | 1202.2 | 734.5 | 1192.7 | 948.7 | 1057.7 | 700.7 | 805.6 | 547.3 |
| | | v10 | 40.1 | 18.6 | 44.2 | 26.6 | 43.9 | 34.3 | 39 | 25.2 | 29.7 | 19.8 |
| | | v20 | 40 | 18.5 | 44 | 26.5 | 43.8 | 34.2 | 38.9 | 25 | 29.6 | 19.7 |
| | R01-19034 | m15 | 248 | 103.1 | 276 | 145.4 | 275.9 | 195.5 | 247.1 | 147.7 | 189.4 | 113.2 |
| | | m25 | 179.6 | 74.7 | 199.6 | 103.5 | 194.36 | 133.1 | 174.4 | 101.6 | 133.4 | 78.2 |
| | | v10 | 27.9 | 11.2 | 31.1 | 16.4 | 31 | 21.6 | 27.8 | 16.1 | 21.7 | 12.2 |
| | | v20 | 26.1 | 10.2 | 28.9 | 14.6 | 28.5 | 18.8 | 25.7 | 14.3 | 20 | 10.8 |
| PCS | B04-03072 | m15 | 342.3 | 144.2 | 382.4 | 208.1 | 383.8 | 281.5 | 342.5 | 211.3 | 264.3 | 160.8 |
| | | v10 | 29.9 | 12.7 | 33.6 | 18.9 | 33.8 | 25 | 29.9 | 18.3 | 23.5 | 14 |
| | R01-55011 | m15 | 537.8 | 241 | 607.4 | 358 | 612.5 | 480.2 | 541.1 | 354.5 | 423.6 | 272.9 |
| | | v10 | 34.2 | 15.2 | 38.2 | 22.5 | 38.3 | 29.5 | 33.9 | 21.4 | 26.3 | 16.5 |
| | S06-63081 | M15 | 146.9 | 60.9 | 163 | 83.9 | 161.4 | 108.6 | 144.9 | 836 | 110.8 | 63.7 |
| | | M25 | 549.6 | 247 | 620.7 | 366.8 | 625.7 | 491.4 | 552.8 | 362.7 | 432.5 | 279.3 |
| | | M35 | 153.9 | 63.9 | 170.9 | 88.1 | 169.5 | 114.6 | 152.1 | 87.5 | 116.3 | 67.2 |
| | | V10 | 24.9 | 9.7 | 27.6 | 13.7 | 27.2 | 17.5 | 24.6 | 13.4 | 19.1 | 10.1 |
| | | V20 | 34.4 | 15.3 | 38.4 | 22.6 | 38.5 | 29.6 | 34.1 | 21.5 | 26.5 | 16.6 |
| | | V30 | 25.2 | 9.8 | 27.9 | 13.9 | 27.6 | 17.8 | 24.9 | 13.6 | 19.3 | 10.3 |
| | S14-33084 | m15 | 226.54 | 94.2 | 248.2 | 130 | 251.6 | 176.8 | 225.5 | 134 | 172.7 | 102.9 |
| | | m25 | 515 | 229.4 | 581.4 | 340.6 | 586.5 | 458 | 518.4 | 338.2 | 406 | 260.1 |
| | | m35 | 198.3 | 82.5 | 220.5 | 114.9 | 211.5 | 146.2 | 189.9 | 111.4 | 145.3 | 85.9 |
| | | v10 | 27.4 | 10.9 | 30.5 | 15.8 | 30.4 | 20.8 | 27.2 | 15.6 | 21.3 | 11.8 |
| | | v20 | 33.8 | 15 | 37.8 | 22.2 | 37.9 | 29.1 | 33.5 | 21.2 | 26.1 | 16.3 |
| | | v30 | 26.7 | 10.5 | 29.6 | 15 | 29.1 | 19.4 | 26.2 | 14.7 | 20.4 | 11.1 |
| | B01-79031 | m15 | 295.4 | 123.1 | 329.4 | 176 | 329.8 | 237.6 | 295.1 | 178.9 | 226.5 | 136.2 |
| | | v10 | 28.9 | 11.9 | 32.4 | 17.6 | 32.5 | 23.4 | 28.9 | 17.3 | 22.7 | 13.2 |
| PCA | S05-82022 | m15 | 540.1 | 242.2 | 609.3 | 359.5 | 615 | 482.4 | 543.3 | 356.1 | 425.3 | 274.1 |
| | | v10 | 34.3 | 15.2 | 38.3 | 22.6 | 38.3 | 29.5 | 33.9 | 21.4 | 26.4 | 16.5 |
| | S06-82022 | m15 | 537.4 | 240.4 | 606.3 | 357.5 | 612 | 479.8 | 540.7 | 354.2 | 423.3 | 272.6 |
| | | v10 | 34.2 | 15.2 | 38.3 | 22.5 | 38.3 | 29.5 | 33.9 | 21.4 | 26.3 | 16.5 |
| | S25-82022 | m15 | 816.1 | 378.8 | 914 | 552.9 | 912.2 | 722.6 | 808 | 533.8 | 621 | 414.2 |
| | | v10 | 37.8 | 17.2 | 41.8 | 24.9 | 41.7 | 32.4 | 37 | 23.6 | 28.4 | 18.4 |
| | S01-11015 | m15 | 212.3 | 88.3 | 235.5 | 123.2 | 235.4 | 164.5 | 211.2 | 124.9 | 161.6 | 96.2 |
| | | v10 | 27.1 | 10.7 | 30.1 | 15.5 | 29.9 | 20.3 | 26.9 | 15.3 | 20.9 | 11.5 |
| | | m25 | 591.8 | 268.3 | 667.1 | 397.2 | 672 | 529.6 | 593.9 | 391.1 | 463.3 | 301.3 |
| | | v20 | 35.1 | 15.7 | 39.1 | 23.1 | 39.13 | 30.2 | 34.6 | 21.9 | 26.8 | 17 |
| | | m45 | 257.8 | 107.2 | 286.5 | 151.3 | 229.4 | 159.8 | 205.8 | 121.5 | 157.5 | 93.6 |
| | | v40 | 28.1 | 11.3 | 31.4 | 16.7 | 29.7 | 20 | 26.7 | 15.1 | 20.8 | 11.4 |
| | B02-46082 | M15 | 250.8 | 104.3 | 279.2 | 147.2 | 279 | 197.9 | 250 | 149.5 | 191.5 | 114.5 |
| | | V10 | 28 | 11.2 | 31.2 | 16.4 | 31.2 | 21.7 | 27.8 | 16.2 | 21.8 | 12.3 |

Notes: 1.) B04-11057, only calculate one span 123.75; 2.) B02-11052, only calculate one span 98.479; 3.) S06-63081, only calculate spans of 73, 28, and 29.

## Appendix B: Projected live load statistics for moment and shear

Each moment or shear location is identified in the following manner: The bridge ID in the leftmost column; In the column labeled "Load Eff.", and "m" indicates a moment and a "v" indicates a shear. The first number after the m or v indicates the span number, and the second number indicates how far from the leftmost support for that span in terms of percent of the span. For example, for bridge no. B01-11072, the m14 indicates the moment on the first span at a location 40% from the leftmost support. The v20 indicates the negative shear at the second support.

**Table B-1. Mean & Standard Deviation for projected 75-year data using 50th Percentile ADTT (Moment in k-ft, Shear in k) – Entire State**

| | Bridge I.D. | Load Eff. | FC 01 | | FC 02 | | FC 11 | | FC 12 | | FC 14 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | Std | Mean | Std | Mean | Std | Mean | Std | Mean | Std |
| | S18-41064 | m15 | 5054 | 14.4 | 5402.8 | 302 | 7544.6 | 16.4 | 7712.6 | 76.5 | 4610.8 | 45.1 |
| | | v10 | 140.28 | 0.12 | 177.68 | 5.62 | 212.6 | 2 | 220.9 | 1.91 | 130.8 | 1.26 |
| | S20-41064 | m15 | 4394.1 | 11.5 | 5499 | 221.9 | 6551.6 | 9.08 | 6692 | 68.9 | 4030.2 | 37.7 |
| | | v10 | 136.72 | 0.02 | 173 | 8.34 | 208.2 | 1.4 | 215.3 | 1.98 | 128.6 | 1.18 |
| | B01-11072 | m14 | 1273 | 2.94 | 1518 | 54.5 | 2001.4 | 5.3 | 1955.6 | 18.5 | 1222 | 3.42 |
| | | m20 | 1022.1 | 0.11 | 1313 | 58.1 | 1522 | 1.89 | 1588.1 | 33.2 | 975.3 | 4.04 |
| | | v10 | 96.8 | 0.24 | 124.8 | 4.38 | 158.7 | 0.23 | 158.4 | 1.86 | 97.6 | 0.24 |
| | | v20 | 159.8 | 0.49 | 211.2 | 13.4 | 240.6 | 0.91 | 244.5 | 1.57 | 143.3 | 1.62 |
| | | m14 | 4035.3 | 10.4 | 5061.3 | 188 | 6055.1 | 16.8 | 6169.2 | 28.4 | 3720 | 33 |
| | | m20 | 2703.8 | 6.14 | 3508.7 | 184.1 | 4015.8 | 20.4 | 4063.7 | 26 | 2388 | 26.6 |
| | | m26 | 4506.6 | 12.15 | 5668 | 198.8 | 6756.6 | 22.3 | 6862.7 | 32.4 | 4132.5 | 38.3 |
| | S19-63174 | v10 | 133.4 | 0.014 | 169.7 | 7.38 | 205.1 | 1.16 | 210.1 | 0.74 | 126.6 | 1.09 |
| | | v20l | 149.9 | 0.23 | 194.4 | 9.55 | 227.5 | 1.79 | 230 | 0.95 | 137.6 | 1.42 |
| SC | | v20r | 153 | 0.29 | 200.8 | 11.1 | 231.6 | 1.75 | 233.8 | 1.02 | 139.4 | 1.48 |
| | | v30 | 136.4 | 0.06 | 173.4 | 7.32 | 208.9 | 1.47 | 214.2 | 0.84 | 128.5 | 1.17 |
| | | m20 | 2751.7 | 7.12 | 3561.4 | 200 | 3995.4 | 56.1 | 4170.3 | 36 | 2443.4 | 27.4 |
| | | m25 | 2740 | 6.15 | 3340.3 | 87.4 | 4026.8 | 22.7 | 4131.5 | 47.3 | 2557.6 | 20.2 |
| | | m30 | 1727 | 5.12 | 2236.9 | 137.6 | 2535.3 | 35.9 | 2646.6 | 24.9 | 1560.7 | 17.04 |
| | | m40 | 2810.2 | 7.17 | 3632.9 | 200.2 | 4077.6 | 57.3 | 4254.8 | 36.6 | 2493.5 | 27.9 |
| | | v20l | 152.06 | 0.29 | 197.5 | 10.6 | 225.8 | 2.61 | 234.8 | 1.97 | 139 | 1.48 |
| | S03-19042 | v20r | 137.48 | 0.008 | 173.3 | 7.33 | 206.5 | 2.05 | 215 | 2.06 | 129.8 | 1.16 |
| | | v30l | 140.49 | 0.044 | 177.2 | 8.13 | 209.9 | 2.05 | 219.6 | 2.07 | 131.9 | 1.23 |
| | | v30r | 139.9 | 0.065 | 176.1 | 7.66 | 209.4 | 2.1 | 218.7 | 2.05 | 131.5 | 1.2 |
| | | v40l | 137.76 | 0.03 | 173.9 | 7.34 | 207 | 2.03 | 216.4 | 2.08 | 130.1 | 1.17 |
| | | v40r | 152.2 | 0.29 | 197.6 | 10.8 | 225.9 | 2.58 | 234.8 | 1.97 | 139.1 | 1.49 |
| | | v50 | 133.86 | 0.005 | 168.8 | 7.04 | 201.6 | 1.9 | 210.5 | 1.95 | 126.7 | 1.12 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PI | S11-19033 | m15 | 4324.5 | 11.5 | 5392.3 | 216.6 | 6329.3 | 57.6 | 6545.7 | 69.1 | 3975.5 | 36.7 |
| | | v10 | 136.8 | 0 | 172.3 | 7.63 | 204.5 | 2.13 | 213.6 | 2.01 | 128.4 | 1.21 |
| | B02-11052 | m15 | 3019.1 | 5.78 | 3640.4 | 27.6 | 4442.2 | 22.3 | 4562.1 | 54.6 | 2824.2 | 22.2 |
| | | v10 | 125.8 | 0.029 | 160.4 | 7.69 | 192 | 1.62 | 199.5 | 1.91 | 121.8 | 0.95 |
| | B04-11057 | m15 | 4099.9 | 10.51 | 5085.4 | 190 | 6002.7 | 50.8 | 6201 | 66.4 | 3777.6 | 34.2 |
| | | v10 | 134.77 | 0.016 | 170.6 | 7.93 | 202.8 | 2.08 | 211.8 | 1.95 | 127.4 | 1.13 |
| | B02-11112 | m15 | 3876.3 | 7.53 | 4780.4 | 166.3 | 5679.9 | 44.1 | 5860.8 | 63.9 | 3580.3 | 31.7 |
| | | m25 | 3789.9 | 9.15 | 4653.5 | 137.2 | 5555.3 | 41.5 | 5729.9 | 63 | 3504.1 | 30.8 |
| | | v10 | 132.58 | 0.051 | 168.3 | 7.75 | 201 | 1.87 | 208.7 | 2.02 | 126.4 | 1.1 |
| | | v20 | 131.98 | 0.05 | 167.3 | 7.24 | 200.2 | 1.85 | 207.8 | 2.03 | 126 | 1.09 |
| | R01-19034 | m15 | 742.2 | 0.2 | 939.9 | 58.5 | 1338.5 | 2.87 | 1210.8 | 18.9 | 754.3 | 1.57 |
| | | m25 | 501.4 | 0.63 | 631.3 | 35.5 | 928 | 6.16 | 814.4 | 14.1 | 508 | 1.6 |
| | | v10 | 81.4 | 0.35 | 109.3 | 5.64 | 144.2 | 0.6 | 135.9 | 1.23 | 81.4 | 0.15 |
| | | v20 | 70.96 | 0.12 | 91.8 | 4.09 | 131.5 | 0.36 | 116.4 | 0.4 | 68.5 | 0.21 |
| PCS | B04-03072 | m15 | 1092 | 0.55 | 1393.1 | 75.5 | 1873 | 0.8 | 1815.4 | 5.27 | 1114 | 0.038 |
| | | v10 | 94.6 | 0.37 | 124.6 | 6.4 | 156.5 | 0.16 | 154.5 | 1.3 | 95.7 | 0.12 |
| | R01-55011 | m15 | 1932.3 | 0.18 | 2420.2 | 126.1 | 2944.3 | 17 | 2976 | 34.2 | 1853.3 | 10.1 |
| | | v10 | 112.7 | 0.15 | 142 | 4.7 | 174.4 | 1.09 | 171.7 | 2.22 | 110.7 | 0.6 |
| | S06-63081 | m15 | 399.2 | 0.55 | 484.6 | 25.1 | 765.2 | 3.96 | 621 | 11.6 | 422.1 | 0.47 |
| | | M25 | 1979.4 | 0.13 | 2436.6 | 108.9 | 3030.4 | 17.1 | 2988.2 | 36.7 | 1895.4 | 10.5 |
| | | M35 | 418.9 | 0.78 | 517.5 | 28.2 | 806 | 4.63 | 664.9 | 12.3 | 447.7 | 0.04 |
| | | v10 | 65.8 | 0.11 | 87.5 | 6.5 | 125.9 | 0.37 | 105.6 | 0.31 | 64.1 | 0.14 |
| | | V20 | 112.9 | 0.13 | 143.8 | 4.5 | 177 | 0.93 | 171.4 | 2.27 | 111.5 | 0.69 |
| | | V30 | 67.2 | 0.1 | 89.5 | 6.9 | 127.4 | 0.43 | 108.3 | 0.28 | 64.7 | 0.2 |
| | S14-33084 | m15 | 668.69 | 0.07 | 830.8 | 49.5 | 1219.1 | 2.1 | 1113.9 | 18.4 | 675.2 | 2.14 |
| | | m25 | 1835.1 | 0.78 | 2275.6 | 105.8 | 2857.7 | 2.32 | 2895.9 | 30.1 | 1770.7 | 9.1 |
| | | m35 | 569.47 | 0.18 | 725.2 | 47 | 1021.1 | 3.9 | 914.6 | 15.4 | 547.8 | 2.66 |
| | | v10 | 78.8 | 0.2 | 103.9 | 6.7 | 142.3 | 0.51 | 132.05 | 0.02 | 77.9 | 0.11 |
| | | v20 | 110.36 | 0.163 | 141 | 4.6 | 174.5 | 1.19 | 181.4 | 0.32 | 109.6 | 0.57 |
| | | v30 | 73.6 | 0.264 | 96.7 | 4.9 | 135.4 | 0.24 | 121.69 | 0.16 | 71.8 | 0.17 |
| | B01-79031 | m15 | 911.3 | 0.58 | 1151.6 | 55.3 | 1607.7 | 1.68 | 1530.6 | 4.7 | 925.6 | 0.73 |
| | | v10 | 89.1 | 0.288 | 117.8 | 8.3 | 149.9 | 0.75 | 145.4 | 0.71 | 88.7 | 0.003 |
| PCA | S05-82022 | m15 | 1941.8 | 0.11 | 2401.1 | 97.7 | 2985.7 | 2.28 | 2900.9 | 19.6 | 1862.2 | 10.1 |
| | | v10 | 112.2 | 0.145 | 143.7 | 4.6 | 176.2 | 0.91 | 169 | 1.45 | 110.9 | 0.67 |
| | S06-82022 | m15 | 1930.6 | 0.18 | 2390.1 | 99.9 | 2950.7 | 16.85 | 2887.8 | 19.4 | 1856.3 | 9.72 |
| | | v10 | 112.3 | 0.15 | 143.6 | 4.7 | 174.7 | 1.08 | 169.1 | 1.45 | 111 | 0.58 |
| | S25-82022 | m15 | 2899.2 | 4.95 | 3608.7 | 134.6 | 4302 | 7.36 | 4260.8 | 30.8 | 2714.9 | 20.9 |
| | | v10 | 124.4 | 0.002 | 159.8 | 7 | 193.2 | 0.07 | 188.3 | 1.13 | 120.5 | 0.91 |
| | S01-11015 | m15 | 618.9 | 0.004 | 767.7 | 37.2 | 1139 | 2.27 | 979.2 | 9.87 | 622 | 2.54 |
| | | v10 | 76.4 | 0.28 | 101.4 | 6 | 140.5 | 0.19 | 125.2 | 0.35 | 76 | 0.04 |
| | | m25 | 2131.6 | 1.15 | 2626.9 | 101.4 | 3239 | 2.12 | 3144 | 24 | 2032.7 | 12.3 |
| | | v20 | 114.9 | 0.085 | 147.1 | 4.9 | 180.9 | 1.06 | 173.2 | 1.33 | 113.4 | 0.68 |
| | | m45 | 775.6 | 0.24 | 968.8 | 50.5 | 1109.3 | 2.67 | 950.7 | 9.61 | 601.7 | 2.72 |
| | | v40 | 84.5 | 0.23 | 113.3 | 8.7 | 138.7 | 0.28 | 123.3 | 0.33 | 74.7 | 0.15 |
| | B02-46082 | M15 | 751.68 | 0.21 | 930 | 45.6 | 1354.2 | 2.94 | 1285.2 | 4.05 | 764.4 | 1.44 |
| | | V10 | 82.9 | 0.24 | 110.7 | 8.78 | 144.8 | 0.65 | 136.7 | 0.29 | 81.4 | 0.14 |

See footnotes – Appendix A.

**Table B-2. Mean & Standard Deviation for projected 75-year data using 90th Percentile ADTT (Moment in k-ft, Shear in k) – Entire State**

| | Bridge I.D. | Load Eff. | FC 01 | | FC 02 | | FC 11 | | FC 12 | | FC 14 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | Std | Mean | Std | Mean | Std | Mean | Std | Mean | Std |
| | S18-41064 | m15 | 5061 | 13.9 | 6402.8 | 302 | 7572.7 | 16 | 7787.8 | 75.1 | 4635.8 | 43.3 |
| | | v10 | 140.34 | 0.12 | 177.68 | 5.62 | 216.5 | 1.96 | 223.6 | 1.88 | 131.5 | 1.21 |
| | S20-41064 | m15 | 4399.7 | 11.1 | 5499 | 221.9 | 6566.5 | 8.87 | 6754.5 | 67.7 | 4051.2 | 36.2 |
| | | v10 | 136.73 | 0.02 | 174 | 8.34 | 210.6 | 1.36 | 218 | 1.94 | 129.2 | 1.14 |
| | B01-11072 | m14 | 1273 | 2.94 | 1565.5 | 54.2 | 2009.7 | 5.22 | 1988.9 | 18.2 | 1224.4 | 3.25 |
| | | m20 | 1022.1 | 0.11 | 1361.2 | 57.7 | 1523.8 | 1.87 | 1615.3 | 32.8 | 978.1 | 3.83 |
| | | v10 | 96.8 | 0.24 | 130.7 | 4.36 | 158.9 | 0.23 | 161.3 | 1.84 | 97.7 | 0.23 |
| | | v20 | 159.8 | 0.49 | 222 | 13.2 | 241.5 | 0.9 | 248.1 | 1.54 | 144.4 | 1.54 |
| | | m14 | 4035.3 | 10.4 | 5268.7 | 186.9 | 6071.5 | 16.5 | 6265.9 | 27.9 | 3743.3 | 31.3 |
| | | m20 | 2703.8 | 6.14 | 3673.7 | 182.3 | 4035.7 | 20.1 | 4122.2 | 25.5 | 2406.8 | 25.3 |
| | | m26 | 4506.6 | 12.15 | 5901.9 | 197.6 | 6778.5 | 22 | 6966.4 | 31.9 | 4159.6 | 36.4 |
| | S19-63174 | v10 | 133.4 | 0.014 | 176.8 | 7.32 | 206.2 | 1.14 | 213.9 | 0.72 | 127.3 | 1.04 |
| SC | | v20l | 149.9 | 0.23 | 203.2 | 9.47 | 229.2 | 1.77 | 233.2 | 0.94 | 138.6 | 1.35 |
| | | v20r | 153 | 0.29 | 210.5 | 11 | 233.4 | 1.73 | 236.9 | 1 | 140.5 | 1.4 |
| | | v30 | 136.4 | 0.06 | 180.7 | 7.27 | 210.3 | 1.45 | 218 | 0.82 | 129.3 | 1.11 |
| | | m20 | 2753.7 | 6.98 | 3732.3 | 198 | 4109.1 | 19.8 | 4254.4 | 34.8 | 2455.8 | 26.5 |
| | | m25 | 2741.7 | 6.02 | 3464.2 | 87.1 | 4075.2 | 1.64 | 4197.9 | 45.8 | 2566.8 | 19.5 |
| | | m30 | 1728.5 | 5.02 | 2344.2 | 136.2 | 2609.4 | 9.35 | 2696.6 | 24.1 | 1568.4 | 16.48 |
| | | m40 | 2812.3 | 7.02 | 3806.2 | 198.2 | 4193.5 | 20.5 | 4340.5 | 35.4 | 2506.1 | 27 |
| | | v20l | 152.14 | 0.286 | 206.8 | 10.5 | 231.1 | 1.78 | 239.2 | 1.91 | 139.7 | 1.43 |
| | S03-19042 | v20r | 137.5 | 0.0079 | 180.4 | 7.28 | 210.7 | 1.22 | 219.7 | 1.99 | 130.3 | 1.12 |
| | | v30l | 140.51 | 0.043 | 184.4 | 8.07 | 214.1 | 1.49 | 224.5 | 2 | 132.4 | 1.19 |
| | | v30r | 139.92 | 0.064 | 183.3 | 7.6 | 213.8 | 1.43 | 223.6 | 1.98 | 132.1 | 1.16 |
| | | v40l | 137.77 | 0.028 | 181 | 7.29 | 211.1 | 1.16 | 221.5 | 2.01 | 130.6 | 1.13 |
| | | v40r | 152.3 | 0.288 | 206.9 | 10.7 | 231.1 | 1.76 | 239.2 | 1.91 | 139.7 | 1.44 |
| | | v50 | 133.9 | 0.0048 | 175.7 | 6.99 | 205.5 | 1.22 | 215.5 | 1.89 | 127.3 | 1.09 |
| | S11-19033 | m15 | 4327.7 | 11.3 | 5614.4 | 215.2 | 6457.5 | 8.26 | 6650.5 | 66.9 | 3992.2 | 35.5 |
| | | v10 | 136.8 | 0 | 179.4 | 7.57 | 208.9 | 1.59 | 218.5 | 1.95 | 128.9 | 1.17 |
| | B02-11052 | m15 | 3020.7 | 5.66 | 3771.8 | 27.6 | 4487.8 | 6 | 4636.5 | 52.9 | 2834.3 | 21.5 |
| | | v10 | 125.81 | 0.0286 | 167.2 | 7.63 | 195.4 | 0.38 | 204.7 | 1.85 | 122.2 | 0.92 |
| | B04-11057 | m15 | 4102.9 | 10.29 | 5288.7 | 188.9 | 6117.2 | 5.81 | 6298.5 | 64.4 | 3793.1 | 33.1 |
| | | v10 | 134.78 | 0.015 | 177.7 | 7.87 | 207.2 | 1.45 | 216.8 | 1.89 | 127.9 | 1.1 |
| PI | | m15 | 3879 | 9.34 | 4964.8 | 165.4 | 5778.3 | 3.37 | 5952.8 | 62 | 3594.7 | 30.7 |
| | B02-11112 | m25 | 3792.5 | 8.97 | 4830.6 | 136.6 | 5647.3 | 2.42 | 5820.2 | 61 | 3518.1 | 29.8 |
| | | v10 | 132.6 | 0.05 | 175.1 | 7.69 | 204.8 | 1.02 | 213.4 | 1.96 | 126.9 | 1.07 |
| | | v20 | 132 | 0.048 | 174.1 | 7.19 | 204 | 0.95 | 212.5 | 1.96 | 126.5 | 1.05 |
| | | m15 | 742.3 | 0.19 | 982.3 | 57.9 | 1342.3 | 1.64 | 1235.1 | 18.3 | 755 | 1.52 |
| | R01-19034 | m25 | 501.6 | 0.62 | 655.9 | 35.2 | 938.1 | 4.59 | 836.2 | 13.7 | 508.7 | 1.55 |
| | | v10 | 81.5 | 0.34 | 115.7 | 5.6 | 145.5 | 0.17 | 138.7 | 1.19 | 81.5 | 0.15 |
| | | v20 | 71 | 0.117 | 96.1 | 4.07 | 132.4 | 0.11 | 116.8 | 0.39 | 68.6 | 0.2 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PCS | B04-03072 | m15 | 1092 | 0.55 | 1440 | 37.3 | 1874.7 | 0.79 | 1818.6 | 5.18 | 1114 | 0.036 |
| | | v10 | 94.6 | 0.37 | 130.8 | 6.3 | 156.6 | 0.16 | 155.8 | 1.27 | 95.8 | 0.12 |
| | R01-55011 | m15 | 1932.4 | 0.17 | 2466.3 | 107.6 | 2982.6 | 2.25 | 3030.2 | 33.1 | 1857.8 | 9.74 |
| | | v10 | 112.24 | 0.148 | 148.3 | 4.7 | 176.6 | 1.06 | 173.4 | 2.16 | 111 | 0.58 |
| | S06-63081 | m15 | 399.2 | 0.55 | 518.9 | 21.1 | 773.4 | 3.43 | 628.8 | 11.4 | 422.4 | 0.45 |
| | | M25 | 1979.4 | 0.13 | 2542.7 | 108.2 | 3052.3 | 2.2 | 3013.8 | 36.1 | 1901.6 | 10.1 |
| | | M35 | 418.9 | 0.78 | 537.7 | 16.7 | 813.1 | 2.76 | 673.4 | 12.1 | 447.8 | 0.04 |
| | | v10 | 65.8 | 0.11 | 92.2 | 6.4 | 126.1 | 0.11 | 105.8 | 0.3 | 64.2 | 0.13 |
| | | V20 | 112.9 | 0.13 | 150.2 | 4.5 | 178.5 | 0.91 | 172.3 | 2.24 | 111.9 | 0.66 |
| | | V30 | 67.2 | 0.1 | 94.4 | 6.8 | 127.8 | 0.14 | 108.4 | 0.28 | 64.8 | 0.19 |
| | S14-33084 | m15 | 668.72 | 0.06 | 830.8 | 49.5 | 1221.5 | 2.06 | 1131.4 | 18.1 | 676.3 | 2.05 |
| | | m25 | 1835.5 | 0.75 | 2275.6 | 105.8 | 2874.9 | 2.26 | 2930 | 29.5 | 1775.7 | 8.7 |
| | | m35 | 569.55 | 0.17 | 725.2 | 47 | 1025.6 | 3.81 | 929 | 15.1 | 549.3 | 2.56 |
| | | v10 | 78.9 | 0.196 | 103.9 | 6.7 | 143.2 | 0.5 | 132.06 | 0.02 | 78 | 0.1 |
| | | v20 | 110.43 | 0.157 | 141 | 4.6 | 176.5 | 1.16 | 181.5 | 0.31 | 109.9 | 0.55 |
| | | v30 | 73.7 | 0.255 | 96.7 | 4.9 | 135.9 | 0.24 | 121.74 | 0.16 | 71.9 | 0.16 |
| | B01-79031 | m15 | 911.5 | 0.57 | 1154.5 | 44.2 | 1609.6 | 0.002 | 1532.9 | 4.53 | 925.9 | 0.71 |
| | | v10 | 89.2 | 0.282 | 124.1 | 8.2 | 151.5 | 0.31 | 145.8 | 0.68 | 88.8 | 0.003 |
| PCA | S05-82022 | m15 | 1941.8 | 0.11 | 2489.8 | 99.9 | 3004.5 | 2.22 | 2905.7 | 19.3 | 1868.2 | 9.67 |
| | | v10 | 112.2 | 0.145 | 150.3 | 4.6 | 177.8 | 0.89 | 169.4 | 1.43 | 111.3 | 0.64 |
| | S06-82022 | m15 | 1930.6 | 0.18 | 2477.1 | 99.7 | 2972.2 | 2.27 | 2892.5 | 19 | 1858.8 | 9.54 |
| | | v10 | 112.3 | 0.15 | 150 | 4.7 | 175.8 | 1.07 | 169.5 | 1.43 | 111.2 | 0.57 |
| | S25-82022 | m15 | 2899.2 | 4.95 | 3658.2 | 69.7 | 4309.2 | 7.26 | 4268.2 | 30.2 | 2729.6 | 19.8 |
| | | v10 | 124.4 | 0.002 | 166.6 | 7 | 193.3 | 0.06 | 188.6 | 1.11 | 121.1 | 0.87 |
| | S01-11015 | m15 | 618.9 | 0.004 | 823.9 | 47.2 | 1140.5 | 2.25 | 981.6 | 9.7 | 623.8 | 2.41 |
| | | v10 | 76.4 | 0.28 | 106.2 | 5.9 | 140.7 | 0.19 | 125.3 | 0.35 | 76.1 | 0.03 |
| | | m25 | 2131.6 | 1.15 | 2749.8 | 126.6 | 3246.9 | 2.09 | 3149.9 | 23.6 | 2041.4 | 11.7 |
| | | v20 | 114.9 | 0.085 | 153.6 | 4.9 | 182 | 1.05 | 173.5 | 1.31 | 113.9 | 0.65 |
| | | m45 | 775.6 | 0.24 | 1029.7 | 59.5 | 1110.9 | 2.64 | 953.1 | 9.44 | 603.6 | 2.58 |
| | | v40 | 84.5 | 0.23 | 119.6 | 8.6 | 139 | 0.28 | 123.4 | 0.32 | 74.8 | 0.14 |
| | B02-46082 | M15 | 751.74 | 0.2 | 992.5 | 58 | 1358.1 | 1.57 | 1287.2 | 3.91 | 765 | 1.39 |
| | | V10 | 82.96 | 0.23 | 116.9 | 8.7 | 146.4 | 0.46 | 136.8 | 0.28 | 81.5 | 0.14 |

See footnotes – Appendix A.

**Table B-3. Mean & Standard Deviation for projected 75-year data using 50th Percentile ADTT (Moment in k-ft, Shear in k) – Region 7**

| | Bridge I.D. | Load Eff. | FC 01 | | FC 02NC | | FC 11 | | FC 12 | | FC 14 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | Std | | | Mean | Std | Mean | Std | Mean | Std |
| | S18-41064 | m15 | 5049.9 | 14.7 | | | 7544.6 | 16.4 | 7712.6 | 76.5 | 4615.5 | 44.8 |
| | | v10 | 140.24 | 0.125 | | | 212.6 | 2 | 220.9 | 1.91 | 130.9 | 1.25 |
| | S20-41064 | m15 | 4390.8 | 11.8 | | | 6551.6 | 9.08 | 6692 | 68.9 | 4034.2 | 37.4 |
| | | v10 | 136.7 | 0.024 | | | 208.2 | 1.4 | 215.3 | 1.98 | 128.7 | 1.18 |
| | B01-11072 | m14 | 1270.6 | 3.11 | | | 2001.4 | 5.3 | 1955.6 | 18.5 | 1222.4 | 3.39 |
| | | m20 | 1022 | 0.113 | | | 1522 | 1.89 | 1588.1 | 33.2 | 975.8 | 4 |
| | | v10 | 96.6 | 0.26 | | | 158.7 | 0.23 | 158.4 | 1.86 | 97.6 | 0.24 |
| | | v20 | 159.6 | 0.51 | | | 240.6 | 0.91 | 244.5 | 1.57 | 143.5 | 1.61 |
| | | m14 | 4030.1 | 10.77 | | | 6055.1 | 16.8 | 6169.2 | 28.4 | 3724.1 | 32.7 |
| | | m20 | 2700.7 | 6.36 | | | 4015.8 | 20.4 | 4063.7 | 26 | 2391.3 | 26.4 |
| | | m26 | 4500.5 | 12.6 | | | 6756.6 | 22.3 | 6862.7 | 32.4 | 4137.2 | 38 |
| | S19-63174 | v10 | 133.3 | 0.015 | | | 205.1 | 1.16 | 210.1 | 0.74 | 126.7 | 1.08 |
| SC | | v20l | 149.8 | 0.24 | | | 227.5 | 1.79 | 230 | 0.95 | 137.8 | 1.41 |
| | | v20r | 152.8 | 0.3 | | | 231.6 | 1.75 | 233.8 | 1.02 | 139.6 | 1.46 |
| | | v30 | 136.4 | 0.07 | | | 208.9 | 1.47 | 214.2 | 0.84 | 128.6 | 1.16 |
| | | m20 | 2749 | 7.31 | | | 3975.3 | 56.5 | 4121 | 36.7 | 2443.4 | 27.4 |
| | | m25 | 2737.7 | 6.31 | | | 4019.9 | 22.8 | 4092.5 | 48.2 | 2557.6 | 20.2 |
| | | m30 | 1725.1 | 5.26 | | | 2522.8 | 36.1 | 2617.3 | 25.4 | 1560.7 | 17.04 |
| | | m40 | 2807.5 | 7.36 | | | 4057.1 | 57.6 | 4204.5 | 37.3 | 2493.5 | 27.9 |
| | | v20l | 151.9 | 0.3 | | | 224.9 | 2.63 | 232.2 | 2.01 | 139 | 1.48 |
| | S03-19042 | v20r | 137.47 | 0.008 | | | 205.9 | 2.06 | 212.3 | 2.1 | 129.8 | 1.16 |
| | | v30l | 140.48 | 0.05 | | | 209.3 | 2.06 | 216.8 | 2.11 | 131.9 | 1.23 |
| | | v30r | 139.87 | 0.067 | | | 208.8 | 2.11 | 215.9 | 2.09 | 131.5 | 1.2 |
| | | v40l | 137.74 | 0.03 | | | 206.3 | 2.04 | 213.4 | 2.12 | 130.1 | 1.17 |
| | | v40r | 152.11 | 0.3 | | | 225.1 | 2.59 | 232.3 | 2.01 | 139.1 | 1.49 |
| | | v50 | 133.85 | 0.005 | | | 201 | 1.92 | 207.6 | 1.99 | 126.7 | 1.12 |
| | S11-19033 | m15 | 4320.2 | 11.8 | | | 6299.4 | 57.9 | 6484.1 | 70.4 | 3975.5 | 36.7 |
| | | v10 | 136.76 | 0 | | | 203.9 | 2.14 | 210.7 | 2.06 | 128.4 | 1.21 |
| | B02-11052 | m15 | 3016.9 | 5.94 | | | 4434.2 | 22.4 | 4518.3 | 55.6 | 2824.2 | 22.2 |
| | | v10 | 125.77 | 0.031 | | | 191.5 | 1.63 | 196.5 | 1.95 | 121.8 | 0.95 |
| | B04-11057 | m15 | 4096 | 10.79 | | | 5976.1 | 51.1 | 6143.8 | 67.7 | 3777.6 | 34.2 |
| | | v10 | 134.76 | 0.016 | | | 202.2 | 2.09 | 208.8 | 1.99 | 127.4 | 1.13 |
| PI | | m15 | 3872.7 | 9.79 | | | 5657.2 | 44.3 | 5806.7 | 65.1 | 3580.3 | 31.7 |
| | B02-11112 | m25 | 3786.4 | 9.4 | | | 5534 | 41.7 | 5676.9 | 64.2 | 3504.1 | 30.8 |
| | | v10 | 132.56 | 0.052 | | | 200.4 | 1.89 | 205.9 | 2.06 | 126.4 | 1.1 |
| | | v20 | 131.96 | 0.051 | | | 199.6 | 1.86 | 205 | 2.07 | 126 | 1.09 |
| | | m15 | 742.1 | 0.2 | | | 1335.1 | 2.89 | 1196.5 | 19.2 | 754.3 | 1.57 |
| | R01-19034 | m25 | 501.1 | 0.65 | | | 926.3 | 6.19 | 801.6 | 14.4 | 508 | 1.6 |
| | | v10 | 81.27 | 0.36 | | | 143.9 | 0.61 | 134.2 | 1.25 | 81.4 | 0.15 |
| | | v20 | 70.92 | 0.122 | | | 131.3 | 0.37 | 116.2 | 0.41 | 68.5 | 0.21 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PCS | B04-03072 | m15 | 1091.5 | 0.58 | | | 1873 | 0.8 | 1815.4 | 5.27 | 1114 | 0.038 |
| | | v10 | 94.32 | 0.39 | | | 156.5 | 0.16 | 154.5 | 1.3 | 95.7 | 0.12 |
| | R01-55011 | m15 | 1932.2 | 0.187 | | | 2936.8 | 17.1 | 2944.2 | 34.9 | 1853.3 | 10.1 |
| | | v10 | 112.1 | 0.159 | | | 174 | 1.095 | 170.7 | 2.26 | 110.7 | 0.6 |
| | S06-63081 | m15 | 398.8 | 0.59 | | | 765.2 | 3.96 | 621 | 11.6 | 421.9 | 0.49 |
| | | M25 | 1979.3 | 0.14 | | | 3030.4 | 17.1 | 2988.2 | 36.7 | 1890.5 | 10.86 |
| | | M35 | 418.3 | 0.823 | | | 806 | 4.63 | 664.9 | 12.3 | 447.7 | 0.04 |
| | | v10 | 65.7 | 0.12 | | | 125.9 | 0.37 | 105.6 | 0.31 | 64 | 0.14 |
| | | V20 | 112.8 | 0.14 | | | 177 | 0.93 | 171.4 | 2.27 | 111.2 | 0.71 |
| | | V30 | 67.1 | 0.104 | | | 127.4 | 0.43 | 108.3 | 0.28 | 64.6 | 0.21 |
| | S14-33084 | m15 | 668.67 | 0.067 | | | 1219.1 | 2.1 | 1113.9 | 18.4 | 675.4 | 2.12 |
| | | m25 | 1834.9 | 0.8 | | | 2857.7 | 2.32 | 2895.9 | 30.1 | 1771.6 | 9.03 |
| | | m35 | 569.4 | 0.18 | | | 1021.1 | 3.9 | 914.6 | 15.4 | 548.1 | 2.64 |
| | | v10 | 78.7 | 0.21 | | | 142.3 | 0.51 | 132.05 | 0.02 | 77.9 | 0.11 |
| | | v20 | 110.31 | 0.166 | | | 174.5 | 1.19 | 181.4 | 0.32 | 109.6 | 0.56 |
| | | v30 | 73.49 | 0.27 | | | 135.4 | 0.24 | 121.69 | 0.16 | 71.8 | 0.17 |
| | B01-79031 | m15 | 911.2 | 0.6 | | | 1603 | 1.69 | 1530.5 | 12.6 | 925.6 | 0.73 |
| | | v10 | 89 | 0.296 | | | 149.7 | 0.75 | 146.6 | 2.15 | 88.7 | 0.003 |
| PCA | S05-82022 | m15 | 1941.7 | 0.117 | | | 2985.7 | 2.28 | 2900.9 | 19.6 | 1857.4 | 10.44 |
| | | v10 | 112.13 | 0.154 | | | 176.2 | 0.91 | 169 | 1.45 | 110.6 | 0.7 |
| | S06-82022 | m15 | 1930.4 | 0.2 | | | 2950.7 | 16.85 | 2887.8 | 19.4 | 1856.3 | 9.72 |
| | | v10 | 112.16 | 0.155 | | | 174.7 | 1.08 | 169.1 | 1.45 | 111 | 0.58 |
| | S25-82022 | m15 | 2895.2 | 5.24 | | | 4302 | 7.36 | 4260.8 | 30.8 | 2717.5 | 20.7 |
| | | v10 | 124.38 | 0.0016 | | | 193.2 | 0.07 | 188.3 | 1.13 | 120.6 | 0.9 |
| | S01-11015 | m15 | 618.9 | 0.004 | | | 1139 | 2.27 | 979.2 | 9.87 | 622.3 | 2.52 |
| | | v10 | 76.2 | 0.3 | | | 140.5 | 0.19 | 125.2 | 0.35 | 76.04 | 0.04 |
| | | m25 | 2130.7 | 1.22 | | | 3239 | 2.12 | 3144 | 24 | 2034.2 | 12.2 |
| | | v20 | 114.79 | 0.09 | | | 180.9 | 1.06 | 173.2 | 1.33 | 113.5 | 0.68 |
| | | m45 | 775.4 | 0.25 | | | 1109.3 | 2.67 | 950.7 | 9.61 | 602.06 | 2.69 |
| | | v40 | 84.3 | 0.25 | | | 138.7 | 0.28 | 123.3 | 0.33 | 74.7 | 0.15 |
| | B02-46082 | M15 | 751.6 | 0.21 | | | 1350.7 | 2.95 | 1242.3 | 26.7 | 764.4 | 1.44 |
| | | V10 | 82.8 | 0.25 | | | 144.4 | 0.66 | 134.4 | 1.69 | 81.4 | 0.14 |

NC: Not calculated (see section 2.1); In addition, see footnotes – Appendix A.

**Table B-4. Mean & Standard Deviation for projected 75-year data using 90th Percentile ADTT (Moment in k-ft, Shear in k) – Region 7**

| | Bridge I.D. | Load Eff. | FC 01 | | FC 02$^{NC}$ | | FC 11 | | FC 12 | | FC 14 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | Std | | | Mean | Std | Mean | Std | Mean | Std |
| SC | S18-41064 | m15 | 5054 | 14.4 | | | 7572.7 | 16 | 7787.8 | 75.1 | 4647.1 | 42.5 |
| | | v10 | 140.28 | 0.123 | | | 216.5 | 1.96 | 223.6 | 1.88 | 131.8 | 1.19 |
| | S20-41064 | m15 | 4394.1 | 11.5 | | | 6566.5 | 8.87 | 6754.5 | 67.7 | 4060.6 | 35.5 |
| | | v10 | 136.72 | 0.023 | | | 210.6 | 1.36 | 218 | 1.94 | 129.5 | 1.12 |
| | B01-11072 | m14 | 1272.3 | 2.98 | | | 2009.7 | 5.22 | 1988.9 | 18.2 | 1224.4 | 3.25 |
| | | m20 | 1022.1 | 0.108 | | | 1523.8 | 1.87 | 1615.3 | 32.8 | 978.1 | 3.83 |
| | | v10 | 96.7 | 0.25 | | | 158.9 | 0.23 | 161.3 | 1.84 | 97.7 | 0.23 |
| | | v20 | 159.7 | 0.5 | | | 241.5 | 0.9 | 248.1 | 1.54 | 144.4 | 1.54 |
| | S19-63174 | m14 | 4033 | 10.56 | | | 6071.5 | 16.5 | 6265.9 | 27.9 | 3743.3 | 31.3 |
| | | m20 | 2702.5 | 6.23 | | | 4035.7 | 20.1 | 4122.2 | 25.5 | 2406.8 | 25.3 |
| | | m26 | 4504 | 12.34 | | | 6778.5 | 22 | 6966.4 | 31.9 | 4159.6 | 36.4 |
| | | v10 | 133.3 | 0.014 | | | 206.2 | 1.14 | 213.9 | 0.72 | 127.3 | 1.04 |
| | | v20l | 149.9 | 0.23 | | | 229.2 | 1.77 | 233.2 | 0.94 | 138.6 | 1.35 |
| | | v20r | 153 | 0.294 | | | 233.4 | 1.73 | 236.9 | 1 | 140.5 | 1.4 |
| | | v30 | 136.4 | 0.06 | | | 210.3 | 1.45 | 218 | 0.82 | 129.3 | 1.11 |
| | S03-19042 | m20 | 2750.2 | 7.23 | | | 4109.1 | 19.8 | 4254.4 | 34.8 | 2455.8 | 26.5 |
| | | m25 | 2738.7 | 6.24 | | | 4075.2 | 1.64 | 4197.9 | 45.8 | 2566.8 | 19.5 |
| | | m30 | 1725.9 | 5.2 | | | 2609.4 | 9.35 | 2696.6 | 24.1 | 1568.4 | 16.48 |
| | | m40 | 2808.7 | 7.28 | | | 4193.5 | 20.5 | 4340.5 | 35.4 | 2506.1 | 27 |
| | | v20l | 151.99 | 0.297 | | | 231.1 | 1.78 | 239.2 | 1.91 | 139.7 | 1.43 |
| | | v20r | 137.47 | 0.008 | | | 210.7 | 1.22 | 219.7 | 1.99 | 130.3 | 1.12 |
| | | v30l | 140.49 | 0.045 | | | 214.1 | 1.49 | 224.5 | 2 | 132.4 | 1.19 |
| | | v30r | 139.89 | 0.066 | | | 213.8 | 1.43 | 223.6 | 1.98 | 132.1 | 1.16 |
| | | v40l | 137.75 | 0.029 | | | 211.1 | 1.16 | 221.5 | 2.01 | 130.6 | 1.13 |
| | | v40r | 152.16 | 0.3 | | | 231.1 | 1.76 | 239.2 | 1.91 | 139.7 | 1.44 |
| | | v50 | 133.86 | 0.0049 | | | 205.5 | 1.22 | 215.5 | 1.89 | 127.3 | 1.09 |
| PI | S11-19033 | m15 | 4322.1 | 11.7 | | | 6457.5 | 8.26 | 6650.5 | 66.9 | 3992.2 | 35.5 |
| | | v10 | 136.76 | 0 | | | 208.9 | 1.59 | 218.5 | 1.95 | 128.9 | 1.17 |
| | B02-11052 | m15 | 3017.9 | 5.87 | | | 4487.8 | 6 | 4636.5 | 52.9 | 2834.3 | 21.5 |
| | | v10 | 125.78 | 0.03 | | | 195.4 | 0.38 | 204.7 | 1.85 | 122.2 | 0.92 |
| | B04-11057 | m15 | 4097.7 | 10.66 | | | 6117.2 | 5.81 | 6298.5 | 64.4 | 3793.1 | 33.1 |
| | | v10 | 134.77 | 0.016 | | | 207.2 | 1.45 | 216.8 | 1.89 | 127.9 | 1.1 |
| | B02-11112 | m15 | 3874.3 | 9.67 | | | 5778.3 | 3.37 | 5952.8 | 62 | 3594.7 | 30.7 |
| | | m25 | 3788 | 9.29 | | | 5647.3 | 2.42 | 5820.2 | 61 | 3518.1 | 29.8 |
| | | v10 | 132.57 | 0.0052 | | | 204.8 | 1.02 | 213.4 | 1.96 | 126.9 | 1.07 |
| | | v20 | 131.97 | 0.05 | | | 204 | 0.95 | 212.5 | 1.96 | 126.5 | 1.05 |
| | R01-19034 | m15 | 742.2 | 0.2 | | | 1342.3 | 1.64 | 1235.1 | 18.3 | 755 | 1.52 |
| | | m25 | 501.25 | 0.64 | | | 938.1 | 4.59 | 836.2 | 13.7 | 508.7 | 1.55 |
| | | v10 | 81.33 | 0.35 | | | 145.5 | 0.17 | 138.7 | 1.19 | 81.5 | 0.15 |
| | | v20 | 70.94 | 0.121 | | | 132.4 | 0.11 | 116.8 | 0.39 | 68.6 | 0.2 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PCS | B04-03072 | m15 | 1091.7 | 0.569 | | | 1874.7 | 0.79 | 1818.6 | 5.18 | 1114 | 0.036 |
| | | v10 | 94.43 | 0.38 | | | 156.6 | 0.16 | 155.8 | 1.27 | 95.8 | 0.12 |
| | R01-55011 | m15 | 1932.3 | 0.184 | | | 2982.6 | 2.25 | 3030.2 | 33.1 | 1857.8 | 9.74 |
| | | v10 | 112.1 | 0.157 | | | 176.6 | 1.06 | 173.4 | 2.16 | 111 | 0.58 |
| | S06-63081 | m15 | 399 | 0.575 | | | 773.4 | 3.43 | 628.8 | 11.4 | 422.4 | 0.45 |
| | | M25 | 1979.4 | 0.134 | | | 3052.3 | 2.2 | 3013.8 | 36.1 | 1901.6 | 10.1 |
| | | M35 | 418.5 | 0.81 | | | 813.1 | 2.76 | 673.4 | 12.1 | 447.8 | 0.04 |
| | | v10 | 65.8 | 0.11 | | | 126.1 | 0.11 | 105.8 | 0.3 | 64.2 | 0.13 |
| | | V20 | 112.9 | 0.135 | | | 178.5 | 0.91 | 172.3 | 2.24 | 111.9 | 0.66 |
| | | V30 | 67.2 | 0.102 | | | 127.8 | 0.14 | 108.4 | 0.28 | 64.8 | 0.19 |
| | S14-33084 | m15 | 668.69 | 0.065 | | | 1221.5 | 2.06 | 1131.4 | 18.1 | 676.9 | 2 |
| | | m25 | 1835.1 | 0.78 | | | 2874.9 | 2.26 | 2930 | 29.5 | 1778 | 8.58 |
| | | m35 | 569.47 | 0.176 | | | 1025.6 | 3.81 | 929 | 15.1 | 550 | 2.51 |
| | | v10 | 78.8 | 0.2 | | | 143.2 | 0.5 | 132.06 | 0.02 | 78 | 0.103 |
| | | v20 | 110.35 | 0.163 | | | 176.5 | 1.16 | 181.5 | 0.31 | 110 | 0.54 |
| | | v30 | 73.57 | 0.26 | | | 135.9 | 0.24 | 121.74 | 0.16 | 71.9 | 0.16 |
| | B01-79031 | m15 | 911.2 | 0.59 | | | 1609.6 | 0.002 | 1532.9 | 4.53 | 925.9 | 0.71 |
| | | v10 | 89.06 | 0.29 | | | 151.5 | 0.31 | 145.8 | 0.68 | 88.8 | 0.003 |
| PCA | S05-82022 | m15 | 1941.7 | 0.114 | | | 3004.5 | 2.22 | 2905.7 | 19.3 | 1868.2 | 9.67 |
| | | v10 | 112.17 | 0.15 | | | 177.8 | 0.89 | 169.4 | 1.43 | 111.3 | 0.64 |
| | S06-82022 | m15 | 1930.5 | 0.19 | | | 2972.2 | 2.27 | 2892.5 | 19 | 1858.8 | 9.54 |
| | | v10 | 112.2 | 0.152 | | | 175.8 | 1.07 | 169.5 | 1.43 | 111.2 | 0.57 |
| | S25-82022 | m15 | 2896.7 | 5.13 | | | 4309.2 | 7.26 | 4268.2 | 30.2 | 2729.6 | 19.8 |
| | | v10 | 124.38 | 0.0016 | | | 193.3 | 0.06 | 188.6 | 1.11 | 121.1 | 0.87 |
| | S01-11015 | m15 | 618.9 | 0.004 | | | 1140.5 | 2.25 | 981.6 | 9.7 | 623.8 | 2.41 |
| | | v10 | 76.3 | 0.295 | | | 140.7 | 0.19 | 125.3 | 0.35 | 76.1 | 0.03 |
| | | m25 | 2131 | 1.2 | | | 3246.9 | 2.09 | 3149.9 | 23.6 | 2041.4 | 11.7 |
| | | v20 | 114.8 | 0.088 | | | 182 | 1.05 | 173.5 | 1.31 | 113.9 | 0.65 |
| | | m45 | 775.5 | 0.244 | | | 1110.9 | 2.64 | 953.1 | 9.44 | 603.6 | 2.58 |
| | | v40 | 84.4 | 0.24 | | | 139 | 0.28 | 123.4 | 0.32 | 74.8 | 0.14 |
| | B02-46082 | M15 | 751.64 | 0.208 | | | 1358.1 | 1.57 | 1287.2 | 3.91 | 765 | 1.39 |
| | | V10 | 82.85 | 0.24 | | | 146.4 | 0.46 | 136.8 | 0.28 | 81.5 | 0.14 |

NC: Not calculated (see section 2.1); In addition, see footnotes – Appendix A.

## Appendix C: Calculated dead load moment and shear effect for the bridges in this study

| | Bridge # | Load Eff. | Dead Load Effect (m: k-ft; v: k) |
|---|---|---|---|
| SC | S18-41064 | m15 | 6171 |
| | | v10 | 122.1 |
| | S20-41064 | m15 | 2831.95 |
| | | v10 | 74.8 |
| | B01-11072 | m14 | 376.5 |
| | | m20 | 669.33 |
| | | v10 | 25.6 |
| | | v20 | 47 |
| | S19-63174 | m14 | 2258.5 |
| | | m20 | 4960.8 |
| | | m26 | 3246.4 |
| | | v10 | 60.5 |
| | | v20l | 112.4 |
| | | v20r | 120.3 |
| | | v30 | 70.6 |
| | S03-19042 | m20 | 3841.5 |
| | | m25 | 754.9 |
| | | m30 | 1471.5 |
| | | m40 | 3918.5 |
| | | v20l | 94.5 |
| | | v20r | 85.3 |
| | | v30l | 67.1 |
| | | v30r | 67.1 |
| | | v40l | 85.3 |
| | | v40r | 94.5 |
| | | v50 | 69.3 |

| | | | |
|---|---|---|---|
| PI | S11-19033 | m15 | 3653 |
| | | v10 | 158.4 |
| | B01-11052 | m15 | 2204 |
| | | m25 | 2220 |
| | | m35 | 2220 |
| | | m45 | 2220 |
| | | v10 | 94 |
| | | v20 | 94.4 |
| | | v30 | 94.4 |
| | | v40 | 94.4 |
| | B04-11057 | m15 | 3731.7 |
| | | m25 | 3731.7 |
| | | v10 | 161.1 |
| | | v20 | 160.1 |
| | B02-11112 | m15 | 3145 |
| | | m25 | 3145 |
| | | m45 | 3145 |
| | | v10 | 154.2 |
| | | v20 | 151.3 |
| | | v40 | 152 |
| | R01-19034 | m15 | 328.25 |
| | | m25 | 210 |
| | | v10 | 34.7 |
| | | v20 | 27.5 |

| | Bridge # | Load Eff. | Dead Load Effect (m: k-ft; v: k) |
|---|---|---|---|
| PCS | B04-03072 | m15 | 439.4 |
| | | v10 | 42.3 |
| | R01-55011 | m15 | 1093.7 |
| | | v10 | 60.1 |
| | S06-63081 | m15 | 156.3 |
| | | m25 | 1054.5 |
| | | m35 | 167.4 |
| | | v10 | 22 |
| | | v20 | 57.1 |
| | | v30 | 22.8 |
| | S14-33084 | m15 | 277.7 |
| | | m25 | 937.2 |
| | | m35 | 229.4 |
| | | v10 | 28.9 |
| | | v20 | 53.1 |
| | | v30 | 26.3 |
| | B01-79031 | m15 | 466.8 |
| | | v10 | 40.1 |

| | Bridge # | Location | Dead Load Effect (m: k-ft; v: k) |
|---|---|---|---|
| PCA | s05-82022 | m15 | 601.1 |
| | | v10 | 33.6 |
| | s06-82022 | m15 | 601.1 |
| | | v10 | 33.6 |
| | s25-82022 | m15 | 1208.7 |
| | | v10 | 50.6 |
| | s01-11015 | m15 | 154.6 |
| | | v10 | 17 |
| | | m25 | 688.2 |
| | | v20 | 35.8 |
| | | m45 | 204.8 |
| | | v40 | 19.6 |
| | b02-46082 | m15 | 176.4 |
| | | v10 | 17.1 |

## Appendix D: As-designed and design-minimum moment and shear capacities

| | Bridge I.D. | Load eff. | As-Designed | Design Minimum | Governing load |
|---|---|---|---|---|---|
| SC | S18-41064 | m15 | 15015 | 14532 | Lane |
| | | v10 | 663.4 | 342.2 | Truck |
| | S20-41064 | m15 | 9380.3 | 7578.6 | Truck |
| | | v10 | 310.4 | 226.6 | Truck |
| | B01-11072 | m14 | 2532 | 1949.9 | Truck |
| | | m20 | 2480.8 | 2026.7 | Lane |
| | | v10 | 304.5 | 213 | Lane |
| | | v20 | 307 | 256.1 | Lane |
| | S19-63174 | m14 | 8828.8 | 6662.4 | Truck |
| | | m20 | 12076 | 11156.6 | Lane |
| | | m26 | 9504.8 | 8391 | Lane |
| | | v10 | 690.8 | 242.5 | Lane |
| | | v20l | 690.8 | 346.3 | Lane |
| | | v20r | 690.8 | 365.8 | Lane |
| | | v30 | 690.8 | 261.5 | Lane |
| | S03-19042 | m20 | 13130 | 10531.4 | Lane |
| | | m25 | 9783.4 | 4865 | Truck |
| | | m30 | 11645 | 5730.3 | Lane |
| | | m40 | 13094 | 10730.7 | Lane |
| | | v20l | 456.8 | 435.5 | Lane |
| | | v20r | 456.8 | 378.8 | Lane |
| | | v30l | 342.6 | 342.3 | Lane |
| | | v30r | 342.6 | 342.3 | Lane |
| | | v40l | 456.8 | 378.8 | Lane |
| | | v40r | 456.8 | 435.5 | Lane |
| | | v50 | 342.6 | 328.3 | Lane |

| | Bridge # | Location | As-Designed | Design Minimum | Governing load |
|---|---|---|---|---|---|
| PI | S11-19033 | m15 | 11465 | 9330 | Truck |
| | | v10 | 739.3 | 356.8 | Truck |
| | B01-11052 | m15 | 8214.1 | 6305.3 | Truck |
| | | m25 | 7904 | 6298.8 | Truck |
| | | m35 | 7904 | 6298.8 | Truck |
| | | m45 | 8214.1 | 6298.8 | Truck |
| | | v10 | 808.9 | 272.8 | Truck |
| | | v20 | 624 | 273.3 | Truck |
| | | v30 | 624 | 273.3 | Truck |
| | | v40 | 807.7 | 273.3 | Truck |
| | B04-11057 | m15 | 11554 | 9767 | Truck |
| | | m25 | 11554 | 9767 | Truck |
| | | v10 | 728.3 | 376.4 | Truck |
| | | v20 | 730.5 | 375.2 | Truck |
| | B02-11112 | m15 | 10310 | 8675.7 | Truck |
| | | m25 | 10310 | 8675.7 | Truck |
| | | m45 | 10310 | 8675.7 | Truck |
| | | v10 | 738.1 | 367.6 | Truck |
| | | v20 | 744.9 | 363.8 | Truck |
| | | v40 | 743.4 | 364.7 | Truck |
| | R01-19034 | m15 | 1690 | 1590 | Truck |
| | | m25 | 1175.9 | 1049 | Truck |
| | | v10 | 350 | 208.2 | Truck |
| | | v20 | 352.9 | 188 | Truck |

| | Bridge I.D. | Load eff. | As-Designed | Design Minimum | Governing load |
|---|---|---|---|---|---|
| PCS | B04-03072 | m15 | 2409.7 | 1667 | Truck |
| | | v10 | 360.7 | 192.5 | Truck |
| | R01-55011 | m15 | 3962.2 | 2534.8 | Truck |
| | | v10 | 490 | 192.8 | Truck |
| | S06-63081 | m15 | 1152.1 | 695.3 | Truck |
| | | m25 | 3940.4 | 2858.2 | Truck |
| | | m35 | 1152.1 | 732.1 | Truck |
| | | v10 | 476.3 | 137.2 | Truck |
| | | v20 | 424.9 | 192 | Truck |
| | | v30 | 470 | 139.3 | Truck |
| | S14-33084 | m15 | 1603.9 | 1065.4 | Truck |
| | | m25 | 4524.6 | 2672.9 | Truck |
| | | m35 | 1292 | 911.7 | Truck |
| | | v10 | 422.5 | 149.7 | Truck |
| | | v20 | 401.9 | 185.6 | Truck |
| | | v30 | 420.2 | 144.1 | Truck |
| | B01-79031 | m15 | 2185.5 | 1568.6 | Truck |
| | | v10 | 328.7 | 190.5 | Truck |

| | Bridge I.D. | Load eff. | As-Designed | Design Minimum | Governing load |
|---|---|---|---|---|---|
| PCA | S05-82022 | m15 | 1809.2 | 1767.2 | Truck |
| | | v10 | 156.7 | 127.9 | Truck |
| | S06-82022 | m15 | 1809.2 | 1767.2 | Truck |
| | | v10 | 156.7 | 127.9 | Truck |
| | S25-82022 | m15 | 3301.9 | 2981.4 | Truck |
| | | v10 | 252.3 | 151.2 | Truck |
| | S01-11015 | m15 | 909.6 | 698.4 | Truck |
| | | v10 | 170.9 | 106.2 | Truck |
| | | m25 | 2057.1 | 2010.9 | Truck |
| | | v20 | 166.3 | 132.2 | Truck |
| | | m45 | 909.6 | 861.9 | Truck |
| | | v40 | 167.1 | 111.3 | Truck |
| | B02-46082 | m15 | 779.6 | 704.2 | Truck |
| | | v10 | 141.4 | 102.4 | Truck |

## Appendix E: Reliability indices for the entire state and region 7

**Table E-1. Reliability Indices – 50th Percentile ADTT – Entire State**

| | Bridge I.D. | Load Eff. | F. C. 01 | | F. C. 02 | | F. C. 11 | | F. C. 12 | | F. C. 14 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | As Design | Design Min | As Design | Design Min | As Design | Design Min | As Design | Design Min | As Design | Design Min |
| SC | S18-41064 | m15 | 4.1 | 3.8 | 3.8 | 3.6 | 2.7 | 2.5 | 2.6 | 2.4 | 4.3 | 4.1 |
| | | v10 | 8.8 | 3.8 | 7.7 | 2.9 | 6.9 | 2.1 | 6.7 | 2.0 | 9.1 | 4.1 |
| | S20-41064 | m15 | 5.5 | 3.9 | 4.6 | 3.1 | 3.9 | 2.4 | 3.8 | 2.3 | 5.8 | 4.2 |
| | | v10 | 5.5 | 3.2 | 4.3 | 2.1 | 3.6 | 1.3 | 3.4 | 1.2 | 5.8 | 3.5 |
| | B01-11072 | m14 | 6.7 | 5.0 | 5.7 | 4.0 | 4.3 | 2.7 | 4.5 | 2.8 | 6.9 | 5.2 |
| | | m20 | 6.2 | 4.7 | 5.1 | 3.7 | 4.5 | 3.1 | 4.3 | 2.9 | 6.3 | 4.9 |
| | | v10 | 9.0 | 6.7 | 7.5 | 5.2 | 6.3 | 4.0 | 6.3 | 4.0 | 9.0 | 6.6 |
| | | v20 | 5.7 | 4.4 | 4.0 | 2.9 | 3.5 | 2.3 | 3.4 | 2.2 | 6.2 | 5.0 |
| | S19-63174 | m14 | 6.1 | 4.0 | 5.0 | 3.1 | 4.3 | 2.3 | 4.2 | 2.3 | 6.4 | 4.3 |
| | | m20 | 5.8 | 5.2 | 5.3 | 4.7 | 5.0 | 4.4 | 5.0 | 4.4 | 5.9 | 5.3 |
| | | m26 | 4.9 | 3.9 | 4.0 | 3.1 | 3.3 | 2.5 | 3.3 | 2.4 | 5.2 | 4.2 |
| | | v10 | 11.6 | 4.4 | 10.1 | 3.2 | 9.4 | 2.3 | 9.2 | 2.2 | 11.9 | 4.6 |
| | | v20l | 9.8 | 4.6 | 8.4 | 3.5 | 7.8 | 2.9 | 7.8 | 2.8 | 10.1 | 4.9 |
| | | v20r | 9.5 | 4.7 | 8.0 | 3.5 | 7.6 | 3.0 | 7.6 | 2.9 | 9.9 | 5.0 |
| | | v30 | 11.3 | 4.4 | 9.8 | 3.3 | 9.1 | 2.4 | 8.9 | 2.3 | 11.6 | 4.7 |
| | S03-19042 | m20 | 6.9 | 5.2 | 6.0 | 4.4 | 5.6 | 4.0 | 5.5 | 3.9 | 7.2 | 5.5 |
| | | m25 | 8.6 | 4.2 | 7.4 | 3.1 | 6.4 | 2.2 | 6.2 | 2.1 | 9.0 | 4.5 |
| | | m30 | 11.3 | 6.1 | 9.8 | 4.9 | 9.4 | 4.5 | 9.2 | 4.3 | 11.8 | 6.5 |
| | | m40 | 6.7 | 5.2 | 5.8 | 4.3 | 5.5 | 4.0 | 5.3 | 3.9 | 7.0 | 5.5 |
| | | v20l | 6.1 | 5.7 | 4.7 | 4.4 | 4.2 | 3.9 | 4.0 | 3.7 | 6.4 | 6.1 |
| | | v20r | 7.3 | 5.9 | 6.0 | 4.7 | 5.3 | 4.0 | 5.0 | 3.8 | 7.5 | 6.2 |
| | | v30l | 5.7 | 5.7 | 4.4 | 4.4 | 3.6 | 3.6 | 3.4 | 3.4 | 6.0 | 6.0 |
| | | v30r | 5.7 | 5.7 | 4.4 | 4.4 | 3.6 | 3.6 | 3.4 | 3.4 | 6.0 | 6.0 |
| | | v40l | 7.3 | 5.9 | 6.0 | 4.7 | 5.2 | 4.0 | 5.0 | 3.7 | 7.5 | 6.2 |
| | | v40r | 6.1 | 5.7 | 4.7 | 4.4 | 4.2 | 3.9 | 4.0 | 3.7 | 6.4 | 6.1 |
| | | v50 | 5.8 | 5.5 | 4.6 | 4.3 | 3.8 | 3.5 | 3.5 | 3.3 | 6.1 | 5.8 |
| PI | S11-19033 | m15 | 5.8 | 3.9 | 4.7 | 2.9 | 4.0 | 2.2 | 3.8 | 2.0 | 6.1 | 4.2 |
| | | v10 | 7.6 | 2.9 | 6.8 | 2.2 | 6.3 | 1.7 | 6.2 | 1.6 | 7.8 | 3.0 |
| | B02-11052 | m15 | 6.3 | 4.3 | 5.4 | 3.4 | 4.4 | 2.4 | 4.3 | 2.3 | 6.6 | 4.6 |
| | | v10 | 9.9 | 3.2 | 8.9 | 2.4 | 8.3 | 1.8 | 8.1 | 1.6 | 10.0 | 3.3 |
| | B04-11057 | m15 | 5.5 | 3.9 | 4.4 | 2.9 | 3.7 | 2.2 | 3.5 | 2.0 | 5.8 | 4.3 |
| | | v10 | 7.3 | 3.0 | 6.5 | 2.4 | 6.0 | 1.9 | 5.9 | 1.7 | 7.5 | 3.2 |
| | B02-11112 | m15 | 5.5 | 3.9 | 4.4 | 2.9 | 3.6 | 2.1 | 3.4 | 1.9 | 5.8 | 4.3 |
| | | m25 | 5.6 | 4.0 | 4.6 | 3.0 | 3.7 | 2.2 | 3.5 | 2.0 | 5.9 | 4.4 |
| | | v10 | 7.6 | 3.1 | 6.8 | 2.4 | 6.3 | 1.9 | 6.1 | 1.8 | 7.7 | 3.2 |
| | | v20 | 7.7 | 3.1 | 6.9 | 2.4 | 6.4 | 1.9 | 6.3 | 1.8 | 7.9 | 3.2 |
| | R01-19034 | m15 | 5.9 | 5.3 | 4.1 | 3.7 | 2.2 | 1.7 | 2.8 | 2.3 | 5.8 | 5.2 |
| | | m25 | 6.3 | 5.3 | 4.6 | 3.7 | 2.3 | 1.4 | 3.1 | 2.2 | 6.2 | 5.2 |
| | | v10 | 8.3 | 5.2 | 6.8 | 3.9 | 5.7 | 2.8 | 6.0 | 3.0 | 8.3 | 5.2 |
| | | v20 | 9.2 | 5.6 | 7.9 | 4.4 | 6.4 | 2.9 | 7.0 | 3.4 | 9.4 | 5.7 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PCS | B04-03072 | m15 | 9.0 | 5.9 | 7.3 | 4.4 | 5.9 | 2.9 | 6.1 | 3.1 | 8.9 | 5.8 |
| | | v10 | 8.2 | 4.5 | 6.9 | 3.3 | 6.0 | 2.4 | 6.1 | 2.5 | 8.2 | 4.4 |
| | R01-55011 | m15 | 7.8 | 3.4 | 6.4 | 2.4 | 5.6 | 1.6 | 5.6 | 1.5 | 7.9 | 3.6 |
| | | v10 | 8.8 | 3.1 | 7.8 | 2.2 | 7.0 | 1.5 | 7.0 | 1.5 | 8.8 | 3.1 |
| | S06-63081 | m15 | 9.4 | 5.4 | 7.9 | 4.1 | 5.5 | 1.6 | 6.7 | 2.9 | 9.1 | 5.1 |
| | | M25 | 8.1 | 5.0 | 6.9 | 4.0 | 5.9 | 3.0 | 6.0 | 3.1 | 8.3 | 5.2 |
| | | M35 | 9.1 | 5.5 | 7.5 | 4.1 | 5.2 | 1.7 | 6.3 | 2.8 | 8.7 | 5.1 |
| | | v10 | 11.9 | 5.1 | 10.3 | 3.7 | 9.1 | 2.3 | 10.0 | 3.0 | 11.9 | 5.2 |
| | | V20 | 8.2 | 3.4 | 7.2 | 2.5 | 6.4 | 1.7 | 6.5 | 1.8 | 8.3 | 3.4 |
| | | V30 | 11.7 | 5.1 | 10.0 | 3.6 | 9.0 | 2.3 | 9.8 | 3.0 | 11.8 | 5.2 |
| | S14-33084 | m15 | 9.1 | 5.7 | 7.4 | 4.3 | 5.6 | 2.3 | 6.1 | 2.8 | 9.0 | 5.6 |
| | | m25 | 10.4 | 5.5 | 9.0 | 4.4 | 8.0 | 3.4 | 7.9 | 3.3 | 10.6 | 5.6 |
| | | m35 | 8.4 | 5.5 | 6.6 | 4.0 | 5.0 | 2.3 | 5.6 | 2.9 | 8.6 | 5.7 |
| | | v10 | 10.7 | 4.7 | 9.1 | 3.4 | 8.0 | 2.2 | 8.4 | 2.5 | 10.7 | 4.7 |
| | | v20 | 8.3 | 3.5 | 7.2 | 2.6 | 6.4 | 1.8 | 6.2 | 1.7 | 8.3 | 3.6 |
| | | v30 | 11.0 | 4.9 | 9.6 | 3.6 | 8.3 | 2.3 | 8.8 | 2.7 | 11.1 | 5.0 |
| | B01-79031 | m15 | 8.4 | 5.4 | 6.9 | 4.1 | 5.2 | 2.5 | 5.5 | 2.7 | 8.3 | 5.4 |
| | | v10 | 7.7 | 4.5 | 6.3 | 3.2 | 5.5 | 2.3 | 5.6 | 2.5 | 7.7 | 4.5 |
| PCA | S05-82022 | m15 | 5.7 | 5.5 | 4.6 | 4.4 | 3.6 | 3.3 | 3.7 | 3.5 | 5.9 | 5.6 |
| | | v10 | 4.2 | 3.0 | 3.2 | 2.0 | 2.4 | 1.2 | 2.5 | 1.3 | 4.3 | 3.0 |
| | S06-82022 | m15 | 5.7 | 5.5 | 4.6 | 4.4 | 3.6 | 3.4 | 3.7 | 3.5 | 5.9 | 5.7 |
| | | v10 | 4.2 | 3.0 | 3.2 | 2.0 | 2.4 | 1.2 | 2.5 | 1.3 | 4.3 | 3.0 |
| | S25-82022 | m15 | 6.3 | 5.3 | 5.4 | 4.4 | 4.7 | 3.7 | 4.7 | 3.7 | 6.6 | 5.5 |
| | | v10 | 5.9 | 2.8 | 4.9 | 1.8 | 4.2 | 1.1 | 4.3 | 1.2 | 6.0 | 2.9 |
| | S01-11015 | m15 | 8.6 | 6.4 | 7.0 | 5.0 | 5.0 | 2.9 | 5.9 | 3.8 | 8.5 | 6.4 |
| | | v10 | 7.0 | 4.3 | 5.5 | 2.9 | 4.2 | 1.6 | 4.7 | 2.1 | 7.0 | 4.3 |
| | | m25 | 6.0 | 5.8 | 4.9 | 4.7 | 4.0 | 3.8 | 4.1 | 3.9 | 6.2 | 6.0 |
| | | v20 | 4.4 | 3.0 | 3.4 | 2.0 | 2.5 | 1.2 | 2.7 | 1.4 | 4.4 | 3.1 |
| | | m45 | 7.0 | 6.5 | 5.5 | 5.1 | 4.9 | 4.5 | 5.8 | 5.4 | 8.4 | 7.9 |
| | | v40 | 6.3 | 4.0 | 4.8 | 2.6 | 4.1 | 1.8 | 4.6 | 2.3 | 6.9 | 4.5 |
| | B02-46082 | M15 | 6.6 | 5.8 | 5.3 | 4.4 | 3.3 | 2.5 | 3.6 | 2.8 | 6.5 | 5.7 |
| | | V10 | 5.7 | 3.8 | 4.1 | 2.4 | 3.2 | 1.3 | 3.4 | 1.6 | 5.8 | 3.9 |

## Table E-2. Reliability Indices – 90th Percentile ADTT – Entire State

| | Bridge I.D. | Load Eff. | F. C. 01 | | F. C. 02 | | F. C. 11 | | F. C. 12 | | F. C. 14 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | As Design | Design Min | As Design | Design Min | As Design | Design Min | As Design | Design Min | As Design | Design Min |
| ST | S18-41064 | m15 | 4.1 | 3.8 | 3.8 | 3.6 | 2.7 | 2.5 | 2.6 | 2.4 | 4.3 | 4.1 |
| | | v10 | 8.8 | 3.8 | 7.7 | 2.9 | 6.8 | 2.1 | 6.7 | 1.9 | 9.1 | 4.1 |
| | S20-41064 | m15 | 5.5 | 3.9 | 4.6 | 3.1 | 3.9 | 2.4 | 3.8 | 2.3 | 5.8 | 4.2 |
| | | v10 | 5.5 | 3.2 | 4.3 | 2.1 | 3.5 | 1.3 | 3.4 | 1.1 | 5.8 | 3.4 |
| | B01-11072 | m14 | 6.7 | 5.0 | 5.6 | 3.9 | 4.3 | 2.7 | 4.4 | 2.7 | 6.9 | 5.2 |
| | | m20 | 6.2 | 4.7 | 5.0 | 3.5 | 4.5 | 3.1 | 4.3 | 2.8 | 6.3 | 4.8 |
| | | v10 | 9.0 | 6.7 | 7.2 | 5.0 | 6.3 | 4.0 | 6.2 | 3.9 | 9.0 | 6.6 |
| | | v20 | 5.7 | 4.4 | 3.8 | 2.6 | 3.5 | 2.3 | 3.3 | 2.1 | 6.2 | 4.9 |
| | S19-63174 | m14 | 6.1 | 4.0 | 4.9 | 2.9 | 4.3 | 2.3 | 4.1 | 2.2 | 6.4 | 4.3 |
| | | m20 | 5.8 | 5.2 | 5.2 | 4.6 | 5.0 | 4.4 | 4.9 | 4.3 | 5.9 | 5.3 |
| | | m26 | 4.9 | 3.9 | 3.9 | 3.0 | 3.3 | 2.4 | 3.2 | 2.3 | 5.1 | 4.2 |
| | | v10 | 11.6 | 4.4 | 9.9 | 3.0 | 9.3 | 2.3 | 9.1 | 2.1 | 11.9 | 4.6 |
| | | v20l | 9.8 | 4.6 | 8.2 | 3.3 | 7.8 | 2.8 | 7.7 | 2.7 | 10.1 | 4.9 |
| | | v20r | 9.5 | 4.7 | 7.8 | 3.3 | 7.6 | 2.9 | 7.5 | 2.9 | 9.8 | 5.0 |
| | | v30 | 11.3 | 4.4 | 9.6 | 3.1 | 9.0 | 2.4 | 8.9 | 2.2 | 11.5 | 4.6 |
| | S03-19042 | m20 | 6.9 | 5.2 | 5.8 | 4.2 | 5.5 | 3.9 | 5.4 | 3.8 | 7.2 | 5.5 |
| | | m25 | 8.6 | 4.2 | 7.2 | 2.9 | 6.3 | 2.1 | 6.2 | 2.0 | 8.9 | 4.5 |
| | | m30 | 11.3 | 6.1 | 9.6 | 4.7 | 9.3 | 4.4 | 9.1 | 4.2 | 11.7 | 6.5 |
| | | m40 | 6.7 | 5.2 | 5.7 | 4.2 | 5.4 | 3.9 | 5.2 | 3.8 | 7.0 | 5.5 |
| | | v20l | 6.1 | 5.7 | 4.5 | 4.2 | 4.1 | 3.8 | 4.0 | 3.6 | 6.4 | 6.1 |
| | | v20r | 7.3 | 5.9 | 5.8 | 4.6 | 5.2 | 3.9 | 4.9 | 3.7 | 7.5 | 6.2 |
| | | v30l | 5.7 | 5.7 | 4.2 | 4.2 | 3.5 | 3.5 | 3.3 | 3.3 | 5.9 | 5.9 |
| | | v30r | 5.7 | 5.7 | 4.2 | 4.2 | 3.5 | 3.5 | 3.3 | 3.3 | 6.0 | 6.0 |
| | | v40l | 7.3 | 5.9 | 5.8 | 4.5 | 5.1 | 3.9 | 4.9 | 3.6 | 7.5 | 6.2 |
| | | v40r | 6.0 | 5.7 | 4.5 | 4.2 | 4.1 | 3.8 | 4.0 | 3.6 | 6.4 | 6.1 |
| | | v50 | 5.8 | 5.5 | 4.4 | 4.2 | 3.7 | 3.4 | 3.4 | 3.1 | 6.1 | 5.8 |
| I | S11-19033 | m15 | 5.8 | 3.9 | 4.5 | 2.7 | 3.9 | 2.1 | 3.8 | 1.9 | 6.1 | 4.2 |
| | | v10 | 7.6 | 2.9 | 6.7 | 2.1 | 6.3 | 1.7 | 6.1 | 1.5 | 7.7 | 3.0 |
| | B02-11052 | m15 | 6.3 | 4.3 | 5.3 | 3.2 | 4.4 | 2.3 | 4.2 | 2.2 | 6.6 | 4.5 |
| | | v10 | 9.9 | 3.2 | 8.7 | 2.2 | 8.2 | 1.7 | 8.0 | 1.5 | 10.0 | 3.3 |
| | B04-11057 | m15 | 5.5 | 3.9 | 4.3 | 2.8 | 3.6 | 2.1 | 3.4 | 1.9 | 5.8 | 4.3 |
| | | v10 | 7.3 | 3.0 | 6.4 | 2.3 | 6.0 | 1.8 | 5.8 | 1.7 | 7.4 | 3.2 |
| | B02-11112 | m15 | 5.5 | 3.9 | 4.2 | 2.7 | 3.5 | 2.0 | 3.3 | 1.8 | 5.8 | 4.2 |
| | | m25 | 5.6 | 4.0 | 4.4 | 2.9 | 3.6 | 2.1 | 3.5 | 1.9 | 5.9 | 4.3 |
| | | v10 | 7.6 | 3.1 | 6.7 | 2.3 | 6.2 | 1.8 | 6.1 | 1.7 | 7.7 | 3.2 |
| | | v20 | 7.7 | 3.1 | 6.8 | 2.3 | 6.3 | 1.8 | 6.2 | 1.7 | 7.9 | 3.2 |
| | R01-19034 | m15 | 5.9 | 5.3 | 3.9 | 3.4 | 2.2 | 1.7 | 2.7 | 2.2 | 5.8 | 5.2 |
| | | m25 | 6.2 | 5.3 | 4.3 | 3.4 | 2.3 | 1.4 | 3.0 | 2.1 | 6.2 | 5.2 |
| | | v10 | 8.3 | 5.2 | 6.6 | 3.7 | 5.7 | 2.7 | 5.9 | 3.0 | 8.3 | 5.2 |
| | | v20 | 9.2 | 5.6 | 7.7 | 4.2 | 6.4 | 2.9 | 7.0 | 3.4 | 9.4 | 5.7 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PCS | B04-03072 | m15 | 9.0 | 5.9 | 7.3 | 4.3 | 5.9 | 2.9 | 6.1 | 3.1 | 8.9 | 5.8 |
| | | v10 | 8.2 | 4.5 | 6.7 | 3.1 | 6.0 | 2.4 | 6.1 | 2.4 | 8.1 | 4.4 |
| | R01-55011 | m15 | 7.8 | 3.4 | 6.4 | 2.3 | 5.6 | 1.5 | 5.5 | 1.4 | 7.9 | 3.6 |
| | | v10 | 8.8 | 3.1 | 7.6 | 2.1 | 6.9 | 1.4 | 7.0 | 1.5 | 8.8 | 3.1 |
| | S06-63081 | m15 | 9.4 | 5.4 | 7.6 | 3.8 | 5.4 | 1.6 | 6.7 | 2.8 | 9.1 | 5.1 |
| | | M25 | 8.1 | 5.0 | 6.7 | 3.8 | 5.9 | 3.0 | 5.9 | 3.0 | 8.2 | 5.2 |
| | | M35 | 9.1 | 5.5 | 7.5 | 4.0 | 5.1 | 1.7 | 6.3 | 2.7 | 8.7 | 5.1 |
| | | v10 | 11.9 | 5.1 | 10.1 | 3.5 | 9.1 | 2.2 | 10.0 | 3.0 | 11.9 | 5.2 |
| | | V20 | 8.2 | 3.4 | 7.0 | 2.3 | 6.3 | 1.7 | 6.5 | 1.8 | 8.2 | 3.4 |
| | | V30 | 11.7 | 5.1 | 9.9 | 3.4 | 9.0 | 2.4 | 9.8 | 3.0 | 11.8 | 5.2 |
| | S14-33084 | m15 | 9.1 | 5.7 | 7.4 | 4.3 | 5.6 | 2.3 | 6.0 | 2.7 | 9.0 | 5.6 |
| | | m25 | 10.4 | 5.5 | 9.0 | 4.4 | 8.0 | 3.3 | 7.8 | 3.2 | 10.5 | 5.6 |
| | | m35 | 8.4 | 5.5 | 6.6 | 4.0 | 5.0 | 2.2 | 5.6 | 2.8 | 8.6 | 5.7 |
| | | v10 | 10.7 | 4.7 | 9.1 | 3.4 | 8.0 | 2.1 | 8.4 | 2.5 | 10.7 | 4.7 |
| | | v20 | 8.2 | 3.5 | 7.2 | 2.6 | 6.3 | 1.8 | 6.2 | 1.7 | 8.3 | 3.6 |
| | | v30 | 11.0 | 4.9 | 9.6 | 3.6 | 8.2 | 2.2 | 8.8 | 2.7 | 11.1 | 5.0 |
| | B01-79031 | m15 | 8.4 | 5.4 | 6.9 | 4.2 | 5.2 | 2.5 | 5.5 | 2.7 | 8.3 | 5.4 |
| | | v10 | 7.7 | 4.5 | 6.1 | 3.0 | 5.4 | 2.3 | 5.6 | 2.5 | 7.7 | 4.5 |
| PCA | S05-82022 | m15 | 5.7 | 5.5 | 4.4 | 4.2 | 3.5 | 3.3 | 3.7 | 3.5 | 5.9 | 5.6 |
| | | v10 | 4.2 | 3.0 | 3.0 | 1.8 | 2.3 | 1.1 | 2.5 | 1.3 | 4.2 | 3.0 |
| | S06-82022 | m15 | 5.7 | 5.5 | 4.4 | 4.2 | 3.6 | 3.4 | 3.7 | 3.5 | 5.9 | 5.7 |
| | | v10 | 4.2 | 3.0 | 3.0 | 1.8 | 2.4 | 1.2 | 2.5 | 1.3 | 4.3 | 3.0 |
| | S25-82022 | m15 | 6.3 | 5.3 | 5.4 | 4.4 | 4.6 | 3.7 | 4.7 | 3.7 | 6.6 | 5.5 |
| | | v10 | 5.9 | 2.8 | 4.7 | 1.7 | 4.2 | 1.1 | 4.3 | 1.2 | 6.0 | 2.8 |
| | S01-11015 | m15 | 8.6 | 6.4 | 6.5 | 4.6 | 5.0 | 2.9 | 5.8 | 3.8 | 8.5 | 6.4 |
| | | v10 | 7.0 | 4.3 | 5.3 | 2.8 | 4.2 | 1.5 | 4.7 | 2.1 | 7.0 | 4.3 |
| | | m25 | 6.0 | 5.8 | 4.7 | 4.5 | 4.0 | 3.7 | 4.1 | 3.9 | 6.2 | 6.0 |
| | | v20 | 4.4 | 3.0 | 3.2 | 1.9 | 2.5 | 1.2 | 2.7 | 1.4 | 4.4 | 3.0 |
| | | m45 | 7.0 | 6.5 | 5.1 | 4.7 | 4.9 | 4.5 | 5.8 | 5.4 | 8.3 | 7.9 |
| | | v40 | 6.3 | 4.0 | 4.6 | 2.4 | 4.1 | 1.8 | 4.6 | 2.3 | 6.9 | 4.5 |
| | B02-46082 | M15 | 6.6 | 5.8 | 4.8 | 4.0 | 3.3 | 2.5 | 3.6 | 2.8 | 6.5 | 5.7 |
| | | V10 | 5.7 | 3.8 | 3.9 | 2.2 | 3.1 | 1.3 | 3.4 | 1.6 | 5.8 | 3.9 |

**Table E-3. Reliability Indices – 50th Percentile ADTT – Region 7**

| | Bridge I.D. | Load Eff. | F. C. 01 | | F. C. 02 | | F. C. 11 | | F. C. 12 | | F. C. 14 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | As Design | Design Min | As Design | Design Min | As Design | Design Min | As Design | Design Min | As Design | Design Min |
| SC | S18-41064 | m15 | 4.1 | 3.8 | | | 2.7 | 2.5 | 2.6 | 2.4 | 4.3 | 4.1 |
| | | v10 | 8.8 | 3.8 | | | 6.9 | 2.1 | 6.7 | 2.0 | 9.1 | 4.1 |
| | S20-41064 | m15 | 5.5 | 3.9 | | | 3.9 | 2.4 | 3.8 | 2.3 | 5.8 | 4.2 |
| | | v10 | 5.5 | 3.2 | | | 3.6 | 1.3 | 3.4 | 1.2 | 5.8 | 3.4 |
| | B01-11072 | m14 | 6.7 | 5.0 | | | 4.3 | 2.7 | 4.5 | 2.8 | 6.9 | 5.2 |
| | | m20 | 6.2 | 4.7 | | | 4.5 | 3.1 | 4.3 | 2.9 | 6.3 | 4.8 |
| | | v10 | 9.0 | 6.7 | | | 6.3 | 4.0 | 6.3 | 4.0 | 9.0 | 6.6 |
| | | v20 | 5.7 | 4.4 | | | 3.5 | 2.3 | 3.4 | 2.2 | 6.2 | 5.0 |
| | S19-63174 | m14 | 6.1 | 4.0 | | | 4.3 | 2.3 | 4.2 | 2.3 | 6.4 | 4.3 |
| | | m20 | 5.8 | 5.2 | | | 5.0 | 4.4 | 5.0 | 4.4 | 5.9 | 5.3 |
| | | m26 | 4.9 | 4.0 | | | 3.3 | 2.5 | 3.3 | 2.4 | 5.2 | 4.2 |
| | | v10 | 11.6 | 4.4 | | | 9.4 | 2.3 | 9.2 | 2.2 | 11.9 | 4.6 |
| | | v20l | 9.8 | 4.6 | | | 7.8 | 2.9 | 7.8 | 2.8 | 10.1 | 4.9 |
| | | v20r | 9.5 | 4.7 | | | 7.6 | 3.0 | 7.6 | 2.9 | 9.9 | 5.0 |
| | | v30 | 11.3 | 4.4 | | | 9.1 | 2.4 | 8.9 | 2.3 | 11.6 | 4.7 |
| | S03-19042 | m20 | 6.9 | 5.2 | | | 5.7 | 4.0 | 5.5 | 3.9 | 7.2 | 5.5 |
| | | m25 | 8.6 | 4.2 | | | 6.4 | 2.2 | 6.3 | 2.1 | 9.0 | 4.5 |
| | | m30 | 11.3 | 6.1 | | | 9.5 | 4.5 | 9.3 | 4.3 | 11.8 | 6.5 |
| | | m40 | 6.7 | 5.2 | | | 5.5 | 4.0 | 5.4 | 3.9 | 7.0 | 5.5 |
| | | v20l | 6.1 | 5.7 | | | 4.3 | 3.9 | 4.1 | 3.8 | 6.4 | 6.1 |
| | | v20r | 7.3 | 5.9 | | | 5.3 | 4.0 | 5.1 | 3.8 | 7.5 | 6.2 |
| | | v30l | 5.7 | 5.7 | | | 3.6 | 3.6 | 3.5 | 3.5 | 6.0 | 6.0 |
| | | v30r | 5.7 | 5.7 | | | 3.7 | 3.6 | 3.5 | 3.5 | 6.0 | 6.0 |
| | | v40l | 7.3 | 5.9 | | | 5.3 | 4.0 | 5.1 | 3.8 | 7.5 | 6.2 |
| | | v40r | 6.1 | 5.7 | | | 4.2 | 3.9 | 4.1 | 3.8 | 6.4 | 6.1 |
| | | v50 | 5.8 | 5.5 | | | 3.8 | 3.5 | 3.6 | 3.3 | 6.1 | 5.8 |
| PI | S11-19033 | m15 | 5.8 | 3.9 | | | 4.0 | 2.2 | 3.9 | 2.0 | 6.1 | 4.2 |
| | | v10 | 7.6 | 2.9 | | | 6.4 | 1.8 | 6.2 | 1.7 | 7.8 | 3.0 |
| | B02-11052 | m15 | 6.3 | 4.3 | | | 4.4 | 2.4 | 4.3 | 2.3 | 6.6 | 4.6 |
| | | v10 | 9.9 | 3.2 | | | 8.3 | 1.8 | 8.2 | 1.7 | 10.0 | 3.3 |
| | B04-11057 | m15 | 5.5 | 3.9 | | | 3.7 | 2.2 | 3.6 | 2.1 | 5.8 | 4.3 |
| | | v10 | 7.3 | 3.0 | | | 6.0 | 1.9 | 5.9 | 1.8 | 7.5 | 3.2 |
| | B02-11112 | m15 | 5.5 | 3.9 | | | 3.6 | 2.1 | 3.5 | 1.9 | 5.8 | 4.3 |
| | | m25 | 5.6 | 4.0 | | | 3.7 | 2.2 | 3.6 | 2.1 | 5.9 | 4.4 |
| | | v10 | 7.6 | 3.1 | | | 6.3 | 1.9 | 6.2 | 1.8 | 7.7 | 3.2 |
| | | v20 | 7.7 | 3.1 | | | 6.4 | 1.9 | 6.3 | 1.8 | 7.9 | 3.2 |
| | R01-19034 | m15 | 5.9 | 5.3 | | | 2.2 | 1.7 | 2.9 | 2.4 | 5.8 | 5.2 |
| | | m25 | 6.3 | 5.3 | | | 2.3 | 1.4 | 3.2 | 2.3 | 6.2 | 5.2 |
| | | v10 | 8.3 | 5.2 | | | 5.7 | 2.8 | 6.0 | 3.1 | 8.3 | 5.2 |
| | | v20 | 9.2 | 5.6 | | | 6.4 | 2.9 | 7.0 | 3.4 | 9.4 | 5.7 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PCS | B04-03072 | m15 | 9.0 | 5.9 | | | 5.9 | 2.9 | 6.1 | 3.1 | 8.9 | 5.8 |
| | | v10 | 8.2 | 4.5 | | | 6.0 | 2.4 | 6.1 | 2.5 | 8.2 | 4.4 |
| | R01-55011 | m15 | 7.8 | 3.4 | | | 5.7 | 1.6 | 5.6 | 1.6 | 7.9 | 3.6 |
| | | v10 | 8.8 | 3.1 | | | 7.0 | 1.5 | 7.1 | 1.5 | 8.8 | 3.1 |
| | S06-63081 | m15 | 9.4 | 5.4 | | | 5.5 | 1.6 | 6.7 | 2.9 | 9.1 | 5.1 |
| | | M25 | 8.1 | 5.0 | | | 5.9 | 3.0 | 6.0 | 3.1 | 8.3 | 5.2 |
| | | M35 | 9.1 | 5.5 | | | 5.2 | 1.7 | 6.3 | 2.8 | 8.7 | 5.1 |
| | | v10 | 11.9 | 5.1 | | | 9.1 | 2.3 | 10.0 | 3.0 | 11.9 | 5.2 |
| | | V20 | 8.2 | 3.4 | | | 6.4 | 1.7 | 6.5 | 1.8 | 8.3 | 3.4 |
| | | V30 | 11.7 | 5.1 | | | 9.0 | 2.3 | 9.8 | 3.0 | 11.8 | 5.2 |
| | S14-33084 | m15 | 9.1 | 5.7 | | | 5.6 | 2.3 | 6.1 | 2.8 | 9.0 | 5.6 |
| | | m25 | 10.4 | 5.5 | | | 8.0 | 3.4 | 7.9 | 3.3 | 10.6 | 5.6 |
| | | m35 | 8.4 | 5.5 | | | 5.0 | 2.3 | 5.6 | 2.9 | 8.6 | 5.7 |
| | | v10 | 10.7 | 4.7 | | | 8.0 | 2.2 | 8.4 | 2.5 | 10.7 | 4.7 |
| | | v20 | 8.3 | 3.5 | | | 6.4 | 1.8 | 6.2 | 1.7 | 8.3 | 3.6 |
| | | v30 | 11.0 | 4.9 | | | 8.3 | 2.3 | 8.8 | 2.7 | 11.1 | 5.0 |
| | B01-79031 | m15 | 8.4 | 5.4 | | | 5.2 | 2.5 | 5.5 | 2.7 | 8.3 | 5.4 |
| | | v10 | 7.7 | 4.5 | | | 5.5 | 2.3 | 5.6 | 2.4 | 7.7 | 4.5 |
| PCA | S05-82022 | m15 | 5.7 | 5.5 | | | 3.6 | 3.3 | 3.7 | 3.5 | 5.9 | 5.7 |
| | | v10 | 4.2 | 3.0 | | | 2.4 | 1.2 | 2.5 | 1.3 | 4.3 | 3.1 |
| | S06-82022 | m15 | 5.7 | 5.5 | | | 3.6 | 3.4 | 3.7 | 3.5 | 5.9 | 5.7 |
| | | v10 | 4.2 | 3.0 | | | 2.4 | 1.2 | 2.5 | 1.3 | 4.3 | 3.0 |
| | S25-82022 | m15 | 6.3 | 5.3 | | | 4.7 | 3.7 | 4.7 | 3.7 | 6.6 | 5.5 |
| | | v10 | 5.9 | 2.8 | | | 4.2 | 1.1 | 4.3 | 1.2 | 6.0 | 2.9 |
| | S01-11015 | m15 | 8.6 | 6.4 | | | 5.0 | 2.9 | 5.9 | 3.8 | 8.5 | 6.4 |
| | | v10 | 7.0 | 4.3 | | | 4.2 | 1.6 | 4.7 | 2.1 | 7.0 | 4.3 |
| | | m25 | 6.0 | 5.8 | | | 4.0 | 3.8 | 4.1 | 3.9 | 6.2 | 6.0 |
| | | v20 | 4.4 | 3.0 | | | 2.5 | 1.2 | 2.7 | 1.4 | 4.4 | 3.1 |
| | | m45 | 7.0 | 6.5 | | | 4.9 | 4.5 | 5.8 | 5.4 | 8.3 | 7.9 |
| | | v40 | 6.4 | 4.0 | | | 4.1 | 1.8 | 4.6 | 2.3 | 6.9 | 4.5 |
| | B02-46082 | M15 | 6.6 | 5.8 | | | 3.3 | 2.5 | 3.8 | 2.9 | 6.5 | 5.7 |
| | | V10 | 5.7 | 3.9 | | | 3.2 | 1.4 | 3.5 | 1.7 | 5.8 | 3.9 |

## Table E-4. Reliability Indices – 90th Percentile ADTT – Region 7

| | Bridge I.D. | Load Eff. | F. C. 01 | | F. C. 02 | | F. C. 11 | | F. C. 12 | | F. C. 14 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | As Design | Design Min | As Design | Design Min | As Design | Design Min | As Design | Design Min | As Design | Design Min |
| SC | S18-41064 | m15 | 4.1 | 3.8 | | | 2.7 | 2.5 | 2.6 | 2.4 | 4.3 | 4.1 |
| | | v10 | 8.8 | 3.8 | | | 6.8 | 2.1 | 6.7 | 1.9 | 9.1 | 4.0 |
| | S20-41064 | m15 | 5.5 | 3.9 | | | 3.9 | 2.4 | 3.8 | 2.3 | 5.8 | 4.2 |
| | | v10 | 5.5 | 3.2 | | | 3.5 | 1.3 | 3.4 | 1.1 | 5.8 | 3.4 |
| | B01-11072 | m14 | 6.7 | 5.0 | | | 4.3 | 2.7 | 4.4 | 2.7 | 6.9 | 5.2 |
| | | m20 | 6.2 | 4.7 | | | 4.5 | 3.1 | 4.3 | 2.8 | 6.3 | 4.8 |
| | | v10 | 9.0 | 6.7 | | | 6.3 | 4.0 | 6.2 | 3.9 | 9.0 | 6.6 |
| | | v20 | 5.7 | 4.4 | | | 3.5 | 2.3 | 3.3 | 2.1 | 6.2 | 4.9 |
| | S19-63174 | m14 | 6.1 | 4.0 | | | 4.3 | 2.3 | 4.1 | 2.2 | 6.4 | 4.3 |
| | | m20 | 5.8 | 5.2 | | | 5.0 | 4.4 | 4.9 | 4.3 | 5.9 | 5.3 |
| | | m26 | 4.9 | 3.9 | | | 3.3 | 2.4 | 3.2 | 2.3 | 5.1 | 4.2 |
| | | v10 | 11.6 | 4.4 | | | 9.3 | 2.3 | 9.1 | 2.1 | 11.9 | 4.6 |
| | | v20l | 9.8 | 4.6 | | | 7.8 | 2.8 | 7.7 | 2.7 | 10.1 | 4.9 |
| | | v20r | 9.5 | 4.7 | | | 7.6 | 2.9 | 7.5 | 2.9 | 9.8 | 5.0 |
| | | v30 | 11.3 | 4.4 | | | 9.0 | 2.4 | 8.9 | 2.2 | 11.5 | 4.6 |
| | S03-19042 | m20 | 6.9 | 5.2 | | | 5.5 | 3.9 | 5.4 | 3.8 | 7.2 | 5.5 |
| | | m25 | 8.6 | 4.2 | | | 6.3 | 2.1 | 6.2 | 2.0 | 8.9 | 4.5 |
| | | m30 | 11.3 | 6.1 | | | 9.3 | 4.4 | 9.1 | 4.2 | 11.7 | 6.5 |
| | | m40 | 6.7 | 5.2 | | | 5.4 | 3.9 | 5.2 | 3.8 | 7.0 | 5.5 |
| | | v20l | 6.1 | 5.7 | | | 4.1 | 3.8 | 4.0 | 3.6 | 6.4 | 6.1 |
| | | v20r | 7.3 | 5.9 | | | 5.2 | 3.9 | 4.9 | 3.7 | 7.5 | 6.2 |
| | | v30l | 5.7 | 5.7 | | | 3.5 | 3.5 | 3.3 | 3.3 | 5.9 | 5.9 |
| | | v30r | 5.7 | 5.7 | | | 3.5 | 3.5 | 3.3 | 3.3 | 6.0 | 6.0 |
| | | v40l | 7.3 | 5.9 | | | 5.1 | 3.9 | 4.9 | 3.6 | 7.5 | 6.2 |
| | | v40r | 6.1 | 5.7 | | | 4.1 | 3.8 | 4.0 | 3.6 | 6.4 | 6.1 |
| | | v50 | 5.8 | 5.5 | | | 3.7 | 3.4 | 3.4 | 3.1 | 6.1 | 5.8 |
| PI | S11-19033 | m15 | 5.8 | 3.9 | | | 3.9 | 2.1 | 3.8 | 1.9 | 6.1 | 4.2 |
| | | v10 | 7.6 | 2.9 | | | 6.3 | 1.7 | 6.1 | 1.5 | 7.7 | 3.0 |
| | B02-11052 | m15 | 6.3 | 4.3 | | | 4.4 | 2.3 | 4.2 | 2.2 | 6.6 | 4.5 |
| | | v10 | 9.9 | 3.2 | | | 8.2 | 1.7 | 8.0 | 1.5 | 10.0 | 3.3 |
| | B04-11057 | m15 | 5.5 | 3.9 | | | 3.6 | 2.1 | 3.4 | 1.9 | 5.8 | 4.3 |
| | | v10 | 7.3 | 3.0 | | | 6.0 | 1.8 | 5.8 | 1.7 | 7.4 | 3.2 |
| | B02-11112 | m15 | 5.5 | 3.9 | | | 3.5 | 2.0 | 3.3 | 1.8 | 5.8 | 4.2 |
| | | m25 | 5.6 | 4.0 | | | 3.6 | 2.1 | 3.5 | 1.9 | 5.9 | 4.3 |
| | | v10 | 7.6 | 3.1 | | | 6.2 | 1.8 | 6.1 | 1.7 | 7.7 | 3.2 |
| | | v20 | 7.7 | 3.1 | | | 6.3 | 1.8 | 6.2 | 1.7 | 7.9 | 3.2 |
| | R01-19034 | m15 | 5.9 | 5.3 | | | 2.2 | 1.7 | 2.7 | 2.2 | 5.8 | 5.2 |
| | | m25 | 6.3 | 5.3 | | | 2.3 | 1.4 | 3.0 | 2.1 | 6.2 | 5.2 |
| | | v10 | 8.3 | 5.2 | | | 5.7 | 2.7 | 5.9 | 3.0 | 8.3 | 5.2 |
| | | v20 | 9.2 | 5.6 | | | 6.4 | 2.9 | 7.0 | 3.4 | 9.4 | 5.7 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PCS | B04-03072 | m15 | 9.0 | 5.9 | | | 5.9 | 2.9 | 6.1 | 3.1 | 8.9 | 5.8 |
| | | v10 | 8.2 | 4.5 | | | 6.0 | 2.4 | 6.1 | 2.4 | 8.1 | 4.4 |
| | R01-55011 | m15 | 7.8 | 3.4 | | | 5.6 | 1.5 | 5.5 | 1.4 | 7.9 | 3.6 |
| | | v10 | 8.8 | 3.1 | | | 6.9 | 1.4 | 7.0 | 1.5 | 8.8 | 3.1 |
| | S06-63081 | m15 | 9.4 | 5.4 | | | 5.4 | 1.6 | 6.7 | 2.8 | 9.1 | 5.1 |
| | | M25 | 8.1 | 5.0 | | | 5.9 | 3.0 | 5.9 | 3.0 | 8.2 | 5.2 |
| | | M35 | 9.1 | 5.5 | | | 5.1 | 1.7 | 6.3 | 2.7 | 8.7 | 5.1 |
| | | v10 | 11.9 | 5.1 | | | 9.1 | 2.2 | 10.0 | 3.0 | 11.9 | 5.2 |
| | | V20 | 8.2 | 3.4 | | | 6.3 | 1.7 | 6.5 | 1.8 | 8.2 | 3.4 |
| | | V30 | 11.7 | 5.1 | | | 9.0 | 2.4 | 9.8 | 3.0 | 11.8 | 5.2 |
| | S14-33084 | m15 | 9.1 | 5.7 | | | 5.6 | 2.3 | 6.0 | 2.7 | 9.0 | 5.6 |
| | | m25 | 10.4 | 5.5 | | | 8.0 | 3.3 | 7.8 | 3.2 | 10.5 | 5.6 |
| | | m35 | 8.4 | 5.5 | | | 5.0 | 2.2 | 5.6 | 2.8 | 8.6 | 5.7 |
| | | v10 | 10.7 | 4.7 | | | 8.0 | 2.1 | 8.4 | 2.5 | 10.7 | 4.7 |
| | | v20 | 8.3 | 3.5 | | | 6.3 | 1.8 | 6.2 | 1.7 | 8.3 | 3.6 |
| | | v30 | 11.0 | 4.9 | | | 8.2 | 2.2 | 8.8 | 2.7 | 11.1 | 5.0 |
| | B01-79031 | m15 | 8.4 | 5.4 | | | 5.2 | 2.5 | 5.5 | 2.7 | 8.3 | 5.4 |
| | | v10 | 7.7 | 4.5 | | | 5.4 | 2.3 | 5.6 | 2.5 | 7.7 | 4.5 |
| PCA | S05-82022 | m15 | 5.7 | 5.5 | | | 3.5 | 3.3 | 3.7 | 3.5 | 5.9 | 5.6 |
| | | v10 | 4.2 | 3.0 | | | 2.3 | 1.1 | 2.5 | 1.3 | 4.2 | 3.0 |
| | S06-82022 | m15 | 5.7 | 5.5 | | | 3.6 | 3.4 | 3.7 | 3.5 | 5.9 | 5.7 |
| | | v10 | 4.2 | 3.0 | | | 2.4 | 1.2 | 2.5 | 1.3 | 4.3 | 3.0 |
| | S25-82022 | m15 | 6.3 | 5.3 | | | 4.6 | 3.7 | 4.7 | 3.7 | 6.6 | 5.5 |
| | | v10 | 5.9 | 2.8 | | | 4.2 | 1.1 | 4.3 | 1.2 | 6.0 | 2.8 |
| | S01-11015 | m15 | 8.6 | 6.4 | | | 5.0 | 2.9 | 5.8 | 3.8 | 8.5 | 6.4 |
| | | v10 | 7.0 | 4.3 | | | 4.2 | 1.5 | 4.7 | 2.1 | 7.0 | 4.3 |
| | | m25 | 6.0 | 5.8 | | | 4.0 | 3.7 | 4.1 | 3.9 | 6.2 | 6.0 |
| | | v20 | 4.4 | 3.0 | | | 2.5 | 1.2 | 2.7 | 1.4 | 4.4 | 3.0 |
| | | m45 | 7.0 | 6.5 | | | 4.9 | 4.5 | 5.8 | 5.4 | 8.3 | 7.9 |
| | | v40 | 6.3 | 4.0 | | | 4.1 | 1.8 | 4.6 | 2.3 | 6.9 | 4.5 |
| | B02-46082 | M15 | 6.6 | 5.8 | | | 3.3 | 2.5 | 3.6 | 2.8 | 6.5 | 5.7 |
| | | V10 | 5.7 | 3.8 | | | 3.1 | 1.3 | 3.4 | 1.6 | 5.8 | 3.9 |

## Appendix F: Example reliability index calculations

The following examples are intended to assist the reader in following along with the calculations of the reliability indices presented in this report. Please note that these are Mathcad calculation files and some of the notation may be different than the body of this report; this notation is defined to the right of each equation.

## PART 1: "As-designed" Reliability Index Sample Calculation for m14 on bridge B01-11072 using FC 01 50th Percentile Data for Region 7.

| | |
|---|---|
| $S := 6.25$ | Girder Spacing (ft) |
| $I := 1.3$ | Impact Factor |
| $Ln := 1273$ | Nominal Live Load(K-ft) |
| $L := Ln \cdot \frac{S}{14} \cdot I \cdot 0.9$ | Mean of Live Load(K-ft), 0.9 bias for GDF |
| $Dn := 376.5$ | Nominal Dead Load(K-ft) from bridge plans |
| $Dbias := 1.0$ | Bias of Dead Load |
| $D := Dn \cdot Dbias$ | |
| $D = 376.5$ | Mean of Dead Load(K-ft) |
| $Dcov := 0.1$ | Coefficient of Variation of Dead Load |
| $GDFcov := 0.13$ | Coefficient of Variation of Girder Distribution Factor |
| $Icov := 0.10$ | Coefficient of Variation of Impact Factor |
| $\sigma L := 2.94$ | Standard Deviation of Live Load |
| $MLcov := \frac{\sigma L}{1273}$ | Coefficient of Variation of Live Load Moment |
| $MLcov = 0.0023$ | |
| $Lcov := \sqrt{GDFcov^2 + Icov^2 + MLcov^2}$ | |
| $Lcov = 0.164$ | Coefficient of Variation of Live Load is square-root-of-the-sum-of-the-sqaures (SRSS) |
| $\sigma D := Dcov \cdot Dn$ | |
| $\sigma D = 37.65$ | Standard deviation of Dead Load(K-ft) |
| $\sigma L := Lcov \cdot L$ | |
| $\sigma L = 109.065$ | Standard deviation of Live Load(K-ft) |
| $VQ := \frac{\sqrt{(\sigma D)^2 + (\sigma L)^2}}{D + L}$ | |
| $VQ = 0.111$ | Coefficient of Variation of Total Load, Q |

**Get Resistance statistics:**

| | |
|---|---|
| $Mn := 2532$ | Nominal Resistance (K-ft) |
| $bias := 1.12$ | Bias of Nominal Moment Capacity |
| $VR := 0.10$ | Coefficient of Resistance Capacity |
| $R := Mn \cdot 1.12$ | |
| $R = 2836$ | Resistance Capacity(K-ft) |

**The load and resistance are lognormal; calculate the reliability index:**

$$\beta := \frac{\ln(R) - \ln(D + L)}{\sqrt{VR^2 + VQ^2}}$$

$\beta = 6.712$

**PART 2: "Design-minimum" Reliability Index Sample Calculation for m14 on bridge B01-11072 using FC 01 50th Percentile Data for Region 7.**

| | |
|---|---|
| $S := 6.25$ | Girder Spacing (ft) |
| $I := 1.3$ | Impact Factor |
| $Ln := 1273$ | Nominal Live Load(K-ft) |
| $L := Ln\cdot\frac{S}{14}\cdot I\cdot 0.9$ | Mean of Live Load(K-ft), 0.9 is the bias for GDF |
| $Dn := 376.5$ | Nominal Dead Load(K-ft) |
| $Dbias := 1.0$ | Bias of Dead Load |
| $D := Dn\cdot Dbias$ <br> $D = 376.5$ | Mean of Dead Load(K-ft) |
| $Dcov := 0.1$ | Coefficient of Variation of the Dead Load |
| $GDFcov := 0.13$ | Coefficient of Variation of the GDF |
| $Icov := 0.10$ | Coefficient of Variation of the Impact Factor |
| $\sigma L := 2.94$ | Standard Deviation of Live Load |
| $MLcov := \frac{\sigma L}{1273}$ | Coefficient of Variation of the Live Load Moment |

$MLcov = 0.0023$

$Lcov := \sqrt{GDFcov^2 + Icov^2 + MLcov^2}$

| | |
|---|---|
| $Lcov = 0.164$ | Coefficient of Variation of Live Load |
| $\sigma D := Dcov\cdot Dn$ <br> $\sigma D = 37.65$ | Standard deviation of Dead Load(K-ft) |

| | |
|---|---|
| $\sigma L := Lcov\cdot L$ <br> $\sigma L = 109.065$ | Standard deviation of Live Load(K-ft) |

$$VQ := \frac{\sqrt{(\sigma D)^2 + (\sigma L)^2}}{D + L}$$

$VQ = 0.111$ Coefficient of Variation of Total Load

**Get Resistance statistics:**

$LLn := 911.2$ HS25 Live Load(K-ft) from influence line analysis

$Mn := 1.3 \cdot Dn + 2.17 \cdot LLn \cdot S \cdot \frac{I}{11}$ Design Minimum Capacity(K-ft)

$bias := 1.12$ Bias of Nominal Moment Capacity

$VR := 0.10$ Coefficient of variation for the Resistance

$R := Mn \cdot 1.12$

$R = 2184$ Resistance (K-ft)

**The load and resistance are lognormal; calculate the reliability index:**

$$\beta := \frac{\ln(R) - \ln(D + L)}{\sqrt{VR^2 + VQ^2}}$$

$\beta = 4.962$