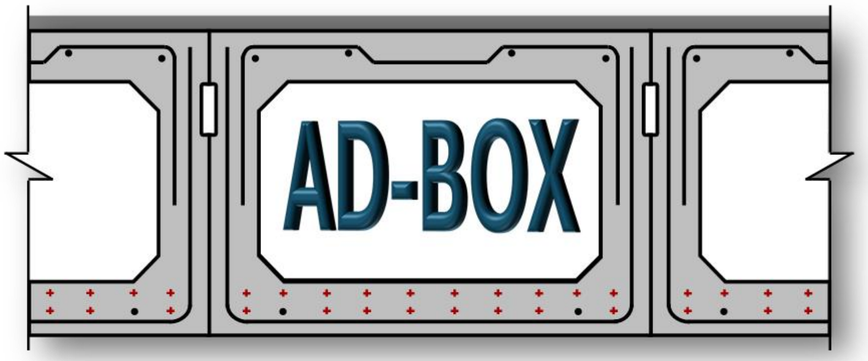
Innovative Evaluation of Precast, Prestressed Adjacent Box Beam Bridges



Prepared by:

Yugesh Maharjan

Suraj Dhungel

Dr. Serhan Guner

Prepared for:

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THE UNIVERSITY OF TOLEDO

OHIO DEPARTMENT OF TRANSPORTATION RESEARCH

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16. Abstract

The availability of automated tools for the load rating of adjacent box beam bridges lags behind those for other types of bridges. The use of hand calculations or general-purpose load rating tools is complex and time-consuming. This project has developed a specialized computer tool, aimed at automating and simplifying the load rating process for simply supported adjacent box beam bridges. The tool is named AD-BOX, which stands for Adjacent Box Beam Bridge Analysis and Rating. AD-BOX is developed using the Visual Basic for Applications programming language and is included in a user-friendly spreadsheet. This approach is intended to provide a familiar working environment without the need to install and learn a new computer program.

The project objectives include the development of AD-BOX, verification of its accuracy through independent hand calculations, and comparison of its reliability against general-purpose bridge rating software. 18 bridges are used in the verification. These bridges are load rated for 15 vehicle types required by the ODOT Bridge Design Manual and custom vehicles with up to 35 axles. The verification results with independent hand calculations provide a mean of 1.0 with a coefficient of variation (CV) of nearly equal to 0% for the rating factor (RF) ratios of AD-BOX divided by hand calculations. The comparison with the general-purpose bridge rating software provides a mean of 1.0 with a CV of up to 3.72% for the RF ratios of AD-BOX divided by the bridge rating software.

AD-BOX determines the maximum moment due to vehicular loadings at the exact maximum moment location instead of the conventional one-tenth-of-the-span method. The research results indicate that this approach provides approximately 3% more accurate maximum moments. In addition, it dramatically reduces the output produced and the associated burden on the users to process the output.

AD-BOX performs the shear load rating for all potential shear critical locations, including the critical sections near the supports and other points where shear reinforcement details change. In addition, AD-BOX has the capability to load rate the older box beam sections with multicell configurations. To consider the future needs for vehicles beyond the 15 vehicle types, AD-BOX has been developed with the capability to include custom vehicles with up to 35 axles.

To allow engineers to use the developed tool for any type of simply supported bridge, a capability is developed to calculate moment and shear envelopes due to one of the 15 vehicle types and a custom vehicle. AD-BOX presents the envelope values in both tabular and chart formats.

The result of this study demonstrates the accuracy and reliability of AD-BOX for the load rating of simply supported precast prestressed adjacent box beam bridges for the vehicle types noted above. It is expected that AD-BOX will reduce the time and effort required for the load rating of adjacent box beam bridges.

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Yugesh Maharjan

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The University of Toledo

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The contents of this report reflect the views of the author(s) who is (are) responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Ohio Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

The authors made every reasonable effort to prepare an error-free project report. Out of an abundance of caution, the readers are recommended to cross check the equations and code clauses with the source documents.

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Extended Abstract

Precast prestressed adjacent box beam bridges are a common component of national bridge infrastructure. In the State of Ohio, for example, there are approximately 8,000 such bridges, accounting for 27% of the state's bridge inventory. They offer rapid construction, ease of installation, and strength needed for short to medium spans. As with any type of bridge, the accurate load rating of adjacent box beam bridges is essential for determining the safe load capacities, posting requirements, and making informed permit decisions. Load rating is the process of evaluation of the existing bridges carried out to provide a basis for the safe live load-carrying capacity of bridges based on its design and prevailing site conditions. Despite their popularity, the availability of automated tools for the load rating of adjacent box beam bridges lags behind those for other types of bridges. The use of hand calculations or general-purpose load rating tools is complex and time-consuming due to the large number of box beam sections used over the years and the extensive calculations required for shear, flexure, and stress limits.

To address this need, this project has developed a specialized computer tool, aimed at automating and simplifying the load rating process for simply supported adjacent box beam bridges. The tool is named AD-BOX, which stands for **Ad**jacent **Box** Beam Bridge Analysis and Rating. AD-BOX is developed using the Visual Basic for Applications (VBA) programming language and is included in a user-friendly Microsoft Excel spreadsheet. This approach is intended to provide engineers and researchers with a familiar working environment without the need to install and learn a new computer program.

The project objectives include developing AD-BOX, verifying its accuracy through independent hand calculations, and comparing its performance against established, general-purpose bridge rating software. 18 sample bridges are load rated for 15 vehicle types required by the ODOT Bridge Design Manual (BDM, 2020) and custom vehicles with up to 35 axles, using AD-BOX, independent hand calculations, and the general-purpose bridge rating software. The bridge samples consist of seven non-skewed bridges and eleven skewed bridges. All non-skewed bridges consist of single-cell box beams, while nine skewed bridges consist of single-cell box beams, and the remaining two skewed bridges consist of multicell box beams. Eight have non-composite sections while the remaining ten have composite sections. The 15 vehicle types include the Design Vehicle (HL-93), Ohio legal loads (2F1, 3F1, 5C1), AASHTO legal loads (Type 3, Type 3S2, Type 3-3), special hauling vehicles (SU4, SU5, SU6, SU7), emergency vehicles (EV2, EV3), permit loads (PL 60T, PL 65T).

The verification results with independent hand calculations provide a mean of approximately 1.0 with a coefficient of variation (CV) nearly equal to 0% for the rating factor (RF) ratios of AD-BOX divided by hand calculations. The comparison results with the general-purpose bridge rating software provide a mean of approximately 1.0 with a CV up to 3.72% for the RF ratios of AD-BOX divided by the bridge rating software.

AD-BOX uses the maximum moment capacity calculations due to vehicular loadings at the exact maximum moment location instead of the conventional one-tenth-of-the-span method. The research results indicate that this approach provides approximately 3% more accurate maximum moments. In addition, it dramatically reduces the output produced and the associated burden on the users to process the output.

AD-BOX performs shear load rating for all potential shear critical locations, including the point at a distance equal to the effective shear depth (d_v) away from the internal face of the bearing at the support and other points where shear reinforcement details change. In addition, AD-BOX has the capability to load rate the older box beam sections with multicell configurations. To consider the future needs for vehicles beyond the 15 vehicle types listed in the ODOT BDM (2020), AD-BOX has been developed with the capability to include custom vehicles with up to 35 axles. A high axle count is selected to consider vehicles that may emerge in the future.

To allow engineers to use the developed tool for any type of simply supported bridge, a capability is developed to calculate moment and shear envelopes due to one of the 15 vehicle types and a custom vehicle. AD-BOX presents the envelope values in both tabular and chart formats. The tabular format allows engineers to copy and use the values in other analysis software or hand calculations, while the chart format offers a visual representation of the variation of the envelopes along with their peak values.

The result of this study demonstrates the accuracy and reliability of AD-BOX for load rating simply supported precast prestressed adjacent box beam bridges for the vehicle types noted above. It is expected that AD-BOX will reduce the time and effort required for load rating adjacent box beam bridges.

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1. Problem Statement

Precast prestressed adjacent box beam bridges are a common component of the national bridge inventory. They offer the advantage of rapid construction, low cost, and strength and serviceability performance required for short to medium spans. As with any type of bridge, accurate load rating of adjacent box beam bridges is essential for determining the safe load capacities, posting requirements, and making informed permit decisions. Load rating is the process of evaluation of the existing bridges carried out to provide a basis for the safe live load-carrying capacity of bridges based on its design and prevailing site conditions.

The load rating of bridges has numerous challenges, as engineers must perform rigorous calculations for many types of vehicles according to various standards. Despite their popularity, the availability of automated tools for the load rating of adjacent box beam bridges lags behind those for other types of bridges. The use of hand calculations or general-purpose load rating tools is complex and time-consuming due to the large number of box beam sections used over the years and the extensive calculations required for shear, flexure, and stress limits.

2. Research Background

2.1. Research Objectives

The project objectives include the development of a specialized computer tool, aimed at automating and simplifying the load rating process for simply supported adjacent box beam bridges, verification of its accuracy through independent hand calculations, and comparison of its performance against established, general-purpose bridge rating software. Named AD-BOX, the computer tool is developed using Visual Basic for Applications (VBA) programming language and included in a user-friendly Microsoft Excel spreadsheet. The project objectives are designed to ensure that AD-BOX meets the necessary standards for reliability and usability in the load rating of precast prestressed adjacent box beam bridges.

2.2. Literature Review

Among Ohio's approximately 30,000 bridges, around 8,000, or 27% of the state's bridge inventory, are precast, prestressed adjacent box beam bridges (Abu-Hajar 2023). These bridges are simply supported, either skewed or non-skewed, which may be composite or non-composite. A typical cross-section is shown in Figure 2-1. Primarily used for short to medium spans, box beam bridges offer advantages due to their favorable span-to-depth ratio, making them suitable where clearance is limited. Additionally, their aesthetic appeal and rapid construction make prestressed box beams a popular choice. Given the growing number of box beam bridges, ensuring the safety and proper evaluation of this infrastructure is crucial. The evaluation of box beam bridges is conducted through load rating, guided by the AASHTO Manual for Bridge Evaluation (MBE 2018) and specific guidelines set by the Department of Transportation responsible for the bridges. AASHTO MBE (2018) outlines methodologies, criteria, and requirements for load rating while the essential design criteria in the AASHTO MBE (2018) are derived from the AASHTO LRFD Bridge Design Specification (LRFD 2024). Since 2007, the Federal Highway Administration (FHWA) has required all new bridges to be designed using the LRFD method. Consequently, bridge load rating is conducted per MBE guidelines, adhering to LRFD and the specific Department of Transportation requirements.

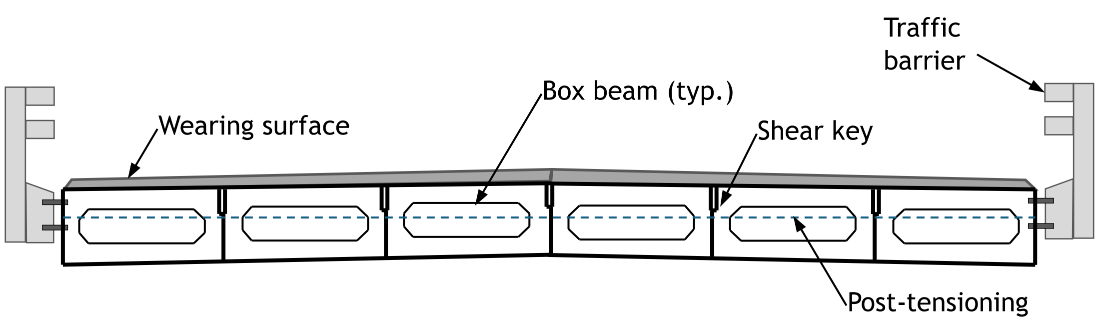


Figure 2-1 Typical cross section of a prestressed precast adjacent box beam bridge.

The evaluation of the existing bridges carried out using load rating provides a basis for the safe live load-carrying capacity of bridges. It is usually expressed as a Rating Factor (RF) or as a gross tonnage for each vehicle axle configuration. Load rating is generally conducted for the following reasons:

- As required by the Federal government,
- To monitor the safety of structures over time,
- To help determine when rehabilitation or replacement is needed,
- To determine if a bridge needs to be posted for a load restriction as required by the state code,
- To have a consistent summary of load-carrying capacities of all state bridges, and
- To assist the Office of Permits in their processing of Permits and Super loads.

2.2.1. AASHTO LRFD Bridge Design Specifications (LRFD 2024)

The AASHTO LRFD Bridge Design Specifications (LRFD 2024) is the primary standard that provides comprehensive criteria and guidelines for bridge design across its 15 sections. Section 3 specifically addresses the requirements for loads and forces, including load factors and their combinations. This section outlines load combinations for various conditions, such as live loads, dead loads, and environmental loads. LRFD Article 3.4.1 within this section details critical load combinations, while Table 3.4.1-1 presents standard load combinations and associated load factors for different limit states. These limit states: strength, service, and fatigue are adopted based on the type of structure and the category of vehicle loading applied to the bridge. As specified in AASHTO LRFD Article 5.5.3.1, evaluating the fatigue limit state is optional for prestressed beam bridges.

The dead load and live load requirements are covered in AASHTO LRFD Articles 3.5 and 3.6, respectively. Dead loads include the self-weight of beams, barriers, diaphragms, and wearing surfaces, calculated using material unit weights from Table 3.5.1.1. For the design of new bridges, the HL-93 vehicular model is used as the design vehicle. This standardized HL-93 load model defines a specific set of loads that produce similar extreme effects on bridges by considering all types of vehicles individually. Figure 2-2(a) presents the representative diagram for the HL-93 truck with a design lane load of 0.64 kips/ft and Figure 2-2(b) presents the representative diagram for the HL-93 tandem with a design lane load of 0.64 kips/ft. The maximum effect due to the HL-93 design truck with a design lane load or HL-93 tandem with the design lane load on the bridge is adopted for the design of the bridge.

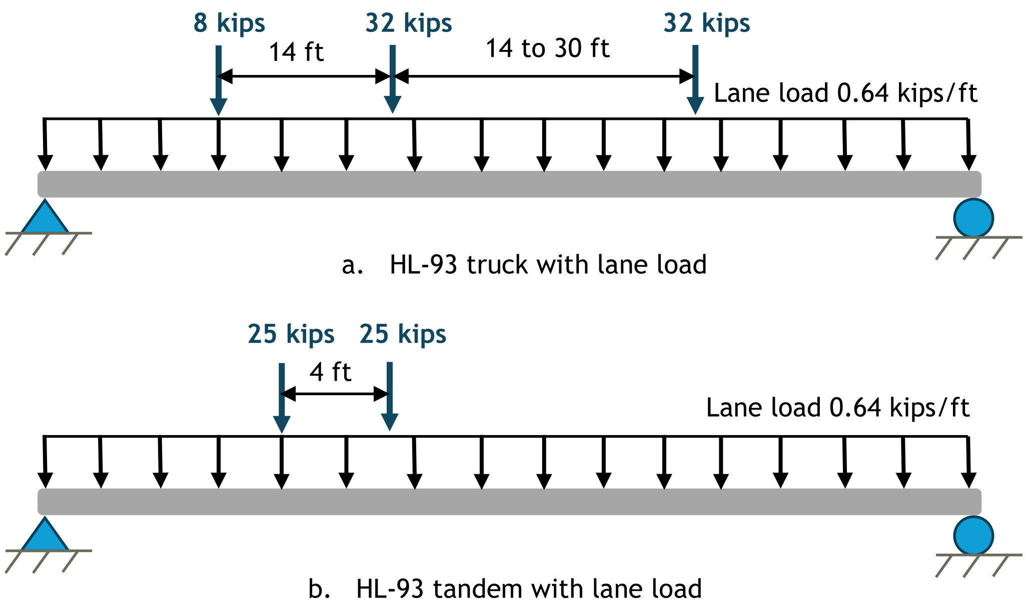


Figure 2-2 Design vehicle HL-93.

The structural analysis and evaluation criteria, which are also applicable to precast, prestressed box beam bridges are specified in AASHTO LRFD Section 4. This section comprises 9 sub-sections, AASHTO LRFD Article 4.6 provides information about static analysis. AASHTO LRFD Article 4.6.2.2.2. discusses the distribution factor method for moment and shear. Live load distribution factors for moment in interior beam are given in Table 4.6.2.2.2b-1 and for shear force are given in Table 4.6.2.2.3a-1. Similarly, live load distribution factors for the moment in the exterior beam are given in Table 4.6.2.2.2d-1 and for shear are given in Table 4.6.2.2.3b-1.

The distribution factors should be corrected for skewed bridges. Skew in bridges occurs when the span direction is not perpendicular to the supports, often due to space constraints or obstacles. Skewed bridges have load paths angled more than 90°, causing increased shear forces at exterior girders compared to straight bridges (Nouri and Ahmadi 2011). When the difference between the skew angles of two adjacent lines of support does not exceed 10 degrees, the bending moment in the beams is reduced in accordance with AASHTO LRFD Article 4.6.2.2.2e. Additionally, the shear force in the bridge is adjusted in accordance with AASHTO LRFD Article 4.6.2.2.3c for the skewed bridges. This adjustment in the moment and shear distribution factors has been studied by various authors, including Ebeido and Kennedy (1995, 1996) and Theoret et al. (2011). Ebeido and Kennedy (1995, 1996) investigated the influence of skew, along with other design parameters, on the shear and reaction distribution factors in continuous two-span composite steel-concrete bridges, emphasizing the increased complexity in the distribution of reactions and shears when the bridge is skewed. Similarly, Theoret et al. (2012) investigated the behavior of skewed slab bridges, noting that the development of transverse and secondary moments is influenced by the skew angle. Their work suggests that increased skew angles lead to a decrease in longitudinal moments while simultaneously increasing transverse moments, highlighting the intricate balance of forces in skewed bridge designs.

The design requirements for concrete structures are specified in AASHTO LRFD Section 5, with 15 sub-sections providing information about material properties, limit states, and design methodologies. AASHTO LRFD Article 5.5.4 gives the strength design requirements at the strength limit state applicable to precast, prestressed concrete box beams. The strength limit state ensures that the bridge can safely carry the applied loads without experiencing failure.

The flexural design of precast, prestressed box beam bridges at the strength limit state is performed according to AASHTO LRFD Article 5.6.3. This article provides a calculation procedure for nominal flexural resistance (M_n) and factored flexural resistance (M_r). The nominal flexural resistance of a beam is calculated according to an approximate method using rectangular stress distribution as specified in AASHTO LRFD Article 5.6.3.2. Alternatively, the strain compatibility approach may also be used for the calculation of flexural resistance. The strain compatibility method is necessary only when a significant number of prestressing strands are at the compression side of the neutral axis. As the box beams have a significant number of prestressing strands at the tension side, the approximate method provides an acceptable value of flexural resistance of the evaluated beam. The resistance factor (ϕ) for calculation factored flexural resistance is found based on the strain condition of the tension reinforcement as specified in AASHTO LRFD Article 5.5.4.2. At any section, the amount of prestressed and non-prestressed tensile reinforcement must be adequate to develop the factored flexural resistance.

For composite beams where the neutral axis lies below both the deck and the beam, the nominal moment capacity is determined using the same equation, incorporating the compressive strength of the deck. According to test results by Rizkalla et al. (2007), rather than performing a detailed analysis using two different concrete compressive strengths in the compression zone, employing the lower compressive strength of the deck provides a sufficiently accurate and conservative estimate of the nominal flexural resistance.

The criteria for minimum reinforcement limits are outlined in AASHTO LRFD Article 5.6.3.3. Minimum reinforcement provisions are intended to reduce the probability of brittle failure by providing flexural capacity greater than the cracking moment.

The shear design requirements for the adjacent box beam at the strength limit state are detailed in AASHTO LRFD Article 5.7.3. The shear analysis is based on the Modified Compression Field Theory by Vecchio and Collins (1986) as specified in AASHTO LRFD Article 5.7.3.3, which accounts for the effects of shear stress, axial stress, and tension stiffening on the concrete contribution to the shear resistance**.** The limit in determining the nominal shear capacity in AASHTO LRFD Article 5.7.3.3 has been validated by numerous experiments on prestressed and non-prestressed concrete members by Saleh and Tadros (1997) and Lee and Hwang (2010). The upper limit of the nominal shear resistance is given by Eq. 5.7.3.3-2 in AASHTO LRFD Article 5.7.3.3. This upper limit is intended to ensure that the concrete in the web of the beam does not crush before the yield of the transverse reinforcement.

The performance of a bridge during its service life is governed by the service limit states, which are addressed in AASHTO LRFD Article 5.5.2. These service limits ensure that the bridge meets certain criteria related to stress, cracking control, and deflection under live loads. In addition to the serviceability requirements, AASHTO LRFD Article 5.6.3.5.2 provides guidelines for computing deflections and camber due to several factors, including dead load, live load, prestressing, erection loads, concrete creep and shrinkage, and steel relaxation. These calculations are crucial for predicting the long-term behavior of the bridge and ensuring that it meets the desired performance criteria throughout its service life. Prestressing design considerations are specified in AASHTO LRFD Article 5.9, which includes stress limitations and prestressing losses. AASHTO LRFD Article 5.9.3 provides guidelines for calculating losses due to factors like elastic shortening, concrete creep and shrinkage, and relaxation. Stress limitations specify maximum allowable stress values in the prestressed reinforcement as well as limits on compressive and tensile stresses in the concrete at transfer and service limit states.

2.2.2. AASTHO Manual for Bridge Evaluation (MBE 2018)

The AASHTO Manual for Bridge Evaluation (MBE 2018) is the prevailing standard that provides guidelines for the inspection and evaluation of existing bridges. The evaluation of the existing bridge is performed using load rating. The practice of load-rating bridges began as early as 1941 when the American Standard Specification for Highway Bridges introduced provisions for evaluating existing structures. The Manual for Bridge Evaluation (MBE) was first adopted by the AASHTO Highways Subcommittee on Bridges and Structures in 2005. The MBE combined the Manual for Condition Evaluation of Bridges with the Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges to provide owners with a single document for evaluating and load rating bridges.

The AASHTO MBE (2018) has been divided into eight sections, with each section representing a distinct phase of an overall bridge inspection and evaluation program. AASHTO MBE Section 6 provides nationally recognized specifications for the load rating of bridges which includes the Load and Resistance Factor (LRFR) method, the Allowable Stress method, and the Load Factor method. AASHTO MBE Section 6 is further categorized into two parts. Part A incorporates provisions specific to the LRFR method while Part B provides safety criteria and procedures for the Allowable Stress and Load Factor Methods of Evaluation. The LRFR method, discussed in Part A is used for load rating using strength limit states, and the Allowable Stress method as discussed in Part B is used for load rating using Service limit states. The limit states for the load rating are selected based on the type of bridge and vehicle loading condition, according to AASHTO MBE Table 6A.4.2.2.1.

The following general load rating equation, provided in AASHTO MBE Article 6A.4.2 is used in determining the load rating factor of each component and connection subjected to a single force effect i.e., flexure, shear, or axial force.

$$RF = \frac{C - (\gamma_{DC})(DC) - (\gamma_{DW})(DW) \pm (\gamma_p)(P) - (\gamma_{PL})(PL)}{(\gamma_{LL})(LL)(1 + IM/100)}$$

For strength limit states:

$$C = \phi_c \phi_s \phi R_n$$

where the following lower limit shall apply:

$$\phi_c \phi_s \geq 0.85$$

For the service limit states:

$$C = f_R$$

where:

C = Capacity,
DC = Dead load effect due to structural components and attachments,
DW = Dead load effect due to wearing surface and utilities,
f_R = Allowable stress specified in AASHTO LRFD,
IM = Dynamic load allowance expressed as a percentage,
LL = Live load effect,
P = Permanent loads other than dead loads, such as earth pressure, shrinkage, etc.,
PL = Pedestrian load effect only to be applied when a sidewalk is present,
RF = Rating factor,
R_n = Nominal member resistance,
γ_{DC} = Load factor for DC load
γ_{DW} = Load factor for DW load
γ_p = Load factor for permanent load = 1.0
γ_{LL} = Evaluation of live load factor

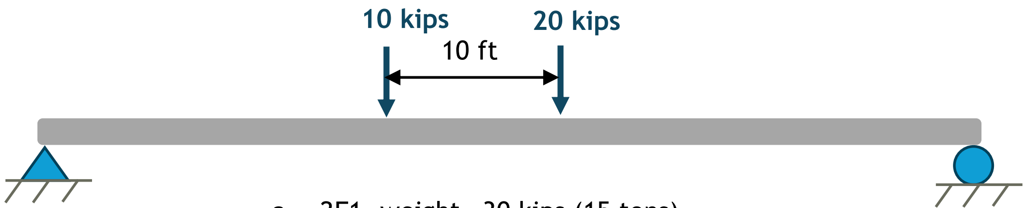
γ_{PL} = Load factor for sidewalk load = 1.0
ϕ_c = Condition factor
ϕ_s = System factor
ϕ = Resistance factor

The computation of load rating using this equation requires the calculation of the load effects for each dead load and live load, capacities of the rated component according to AASHTO LRFD as explained in Section 2.2.1 of this report. Dynamic load allowance is the factor that accounts for the dynamic effect of the moving vehicle, according to AASHTO MBE Article 6A.4.3.3, applied to the calculated static force effect due to the vehicle. The detailed calculation methodologies specific to the precast prestressed box beam bridges are discussed in detail in Section 3.1.3 of this report.

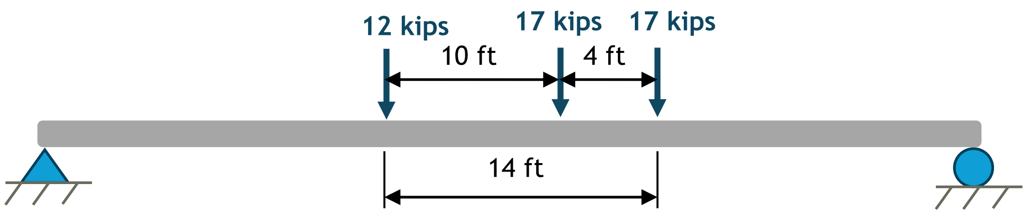
2.2.3. ODOT Bridge Design Manual (BDM 2020)

The Ohio Department of Transportation Bridge Design Manual (BDM 2020) is developed for the State of Ohio and supplements AASHTO LRFD and AASHTO MBE. It comprises 10 sections, from Sections 100 to 1000, each addressing critical aspects of bridge design. Out of these sections, Section 300 provides Ohio-specific guidelines for design, and 900 provides guidelines for load rating the bridges in Ohio. Section 308.2.3.3 provides design standards specific to precast, prestressed box beam bridges designed over Ohio. It incorporates ODOT's design standards and standard box beam sections. The ODOT box beam sections are either 36 in. or 48 in. wide and of varying depth from 12 in. to 42 in. The box beams used in Ohio bridges should comply with the prevailing standard bridge drawing PSBD 02-07. The PSBD 02-07 provides detailed drawings and notes for the design of a new box beam design in Ohio. These beams may be non-composite or composite with skewed or non-skewed spans. The minimum thickness of the composite reinforced deck slabs shall be 6 in. and reinforced with #6 bars. The skew limitation according to ODOT BDM (2020) is a maximum of 30 degrees for box beam bridges. Section 900 provides supplementary guidelines for load rating of the bridges, implementing the procedures provided in AASHTO MBE, and following the AASHTO LRFD specifications. These sections include ODOT's methodologies for describing requirements, load cases and combinations, calculating rating factors, and recommendations for postings or load capacity adjustments based on the AASHTO MBE provisions.

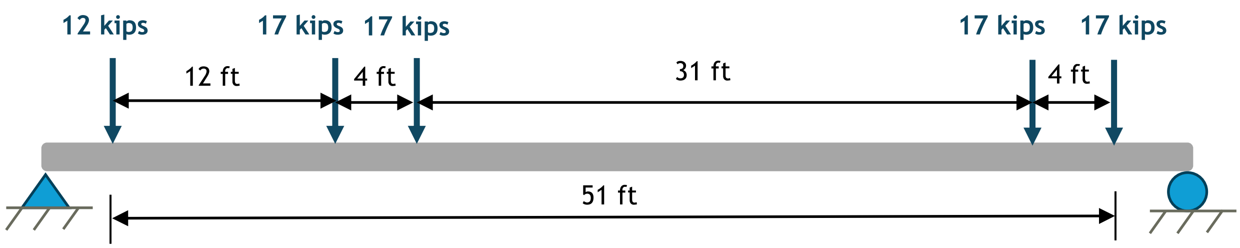
Section 908.2 of ODOT BDM provides the required vehicles for rating the bridges in Ohio. Bridges in Ohio are load rated for Design Vehicle (HL-93) at inventory and operating conditions, for Ohio Legal Vehicles (2F1, 3F1, 5C1), AASHTO Legal Vehicles (Type 3, Type 3S2, Type 3-3), Specialized Hauling Vehicles (SU4, SU5, SU6, SU7) at operating condition. Emergency vehicles (EV2, EV3) shall also be rated at operating conditions with load factors as defined in the Fixing America's Surface Transportation ACT (FAST Act). ODOT bridges shall also be rated for permit loads. Owners of non-ODOT bridges may or may not decide to rate bridges for permit loads of their choice. Agencies that are issuing routine permits are required to rate their bridges for Permit Loads (PL 60T, PL 65T) according to the Federal Highway Administration (FHWA) rules. The representative diagrams of the Ohio legal vehicles, AASHTO legal vehicles, specialized hauling vehicles, emergency vehicles, and permit loads are shown in Figure 2-3, Figure 2-4, Figure 2-5, Figure 2-6, and Figure 2-7, respectively.



a. 2F1, weight= 30 kips (15 tons)

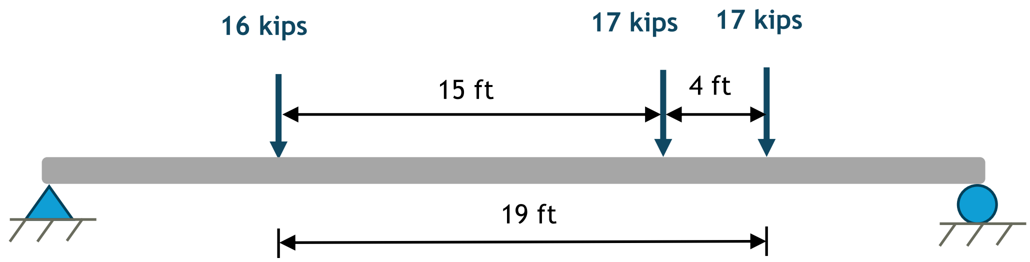


b. 3F1, weight= 46 kips (23 tons)

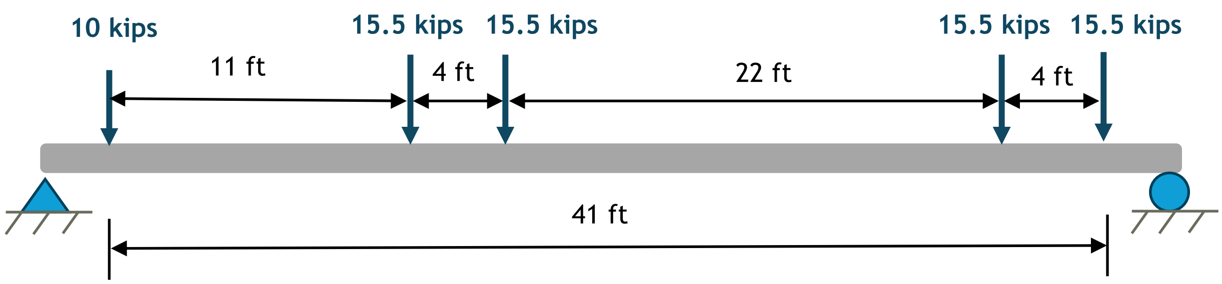


c. 5C1, weight= 80 kips (40 tons)

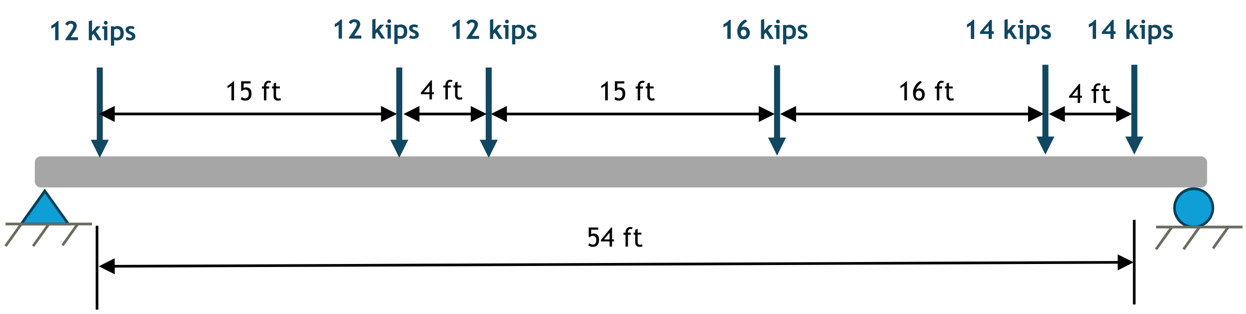
Figure 2-3 Ohio legal vehicles.



a. Type 3, weight= 50 kips (25 tons)

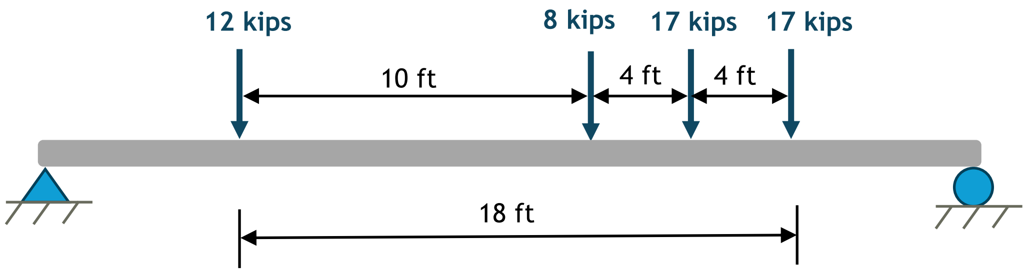


b. Type 3S2, weight= 72 kips (36 tons)

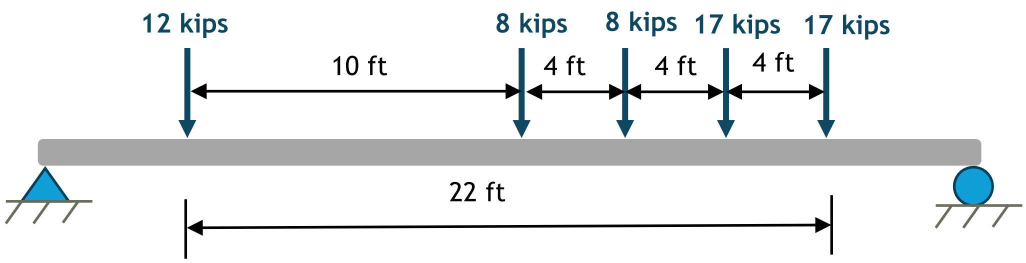


c. Type 3-3, weight= 80 kips (40 tons)

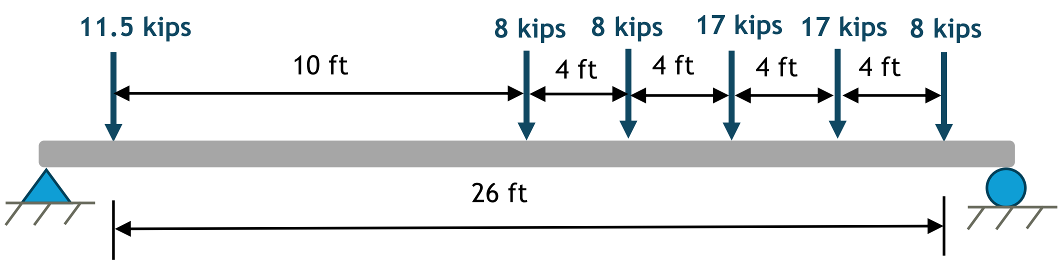
Figure 2-4 AASHTO legal vehicles.



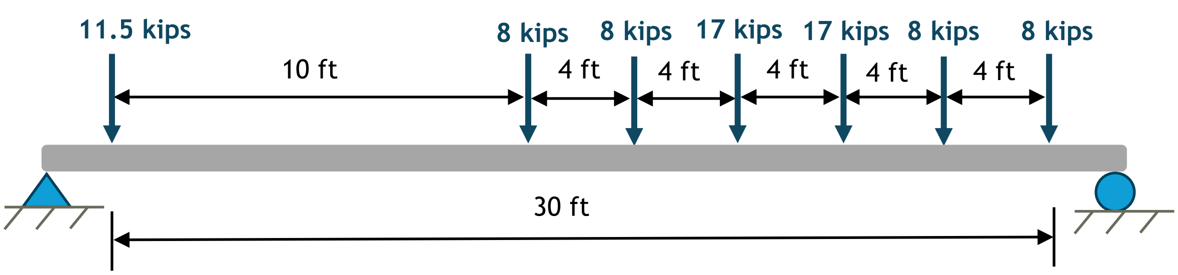
a. SU4, weight= 54 kips (27 tons)



b. SU5, weight= 62 kips (31 tons)

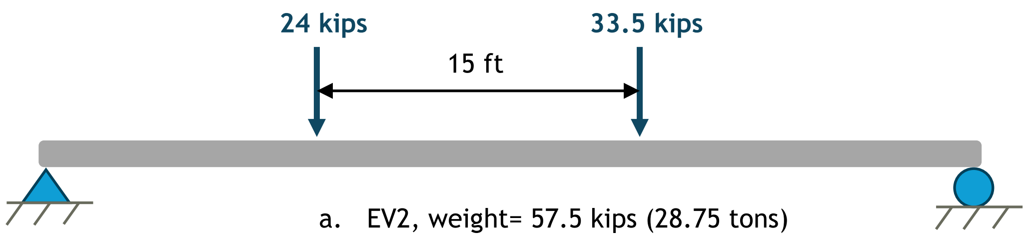


c. SU6, weight= 69.5 kips (34.5 tons)

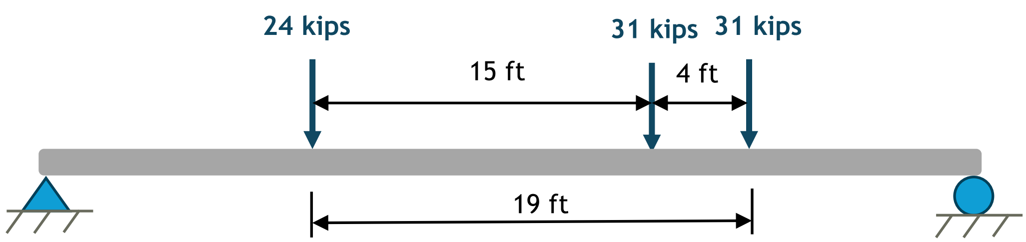


d. SU7, weight= 77.5 kips (38.75 tons)

Figure 2-5 Special hauling vehicles.

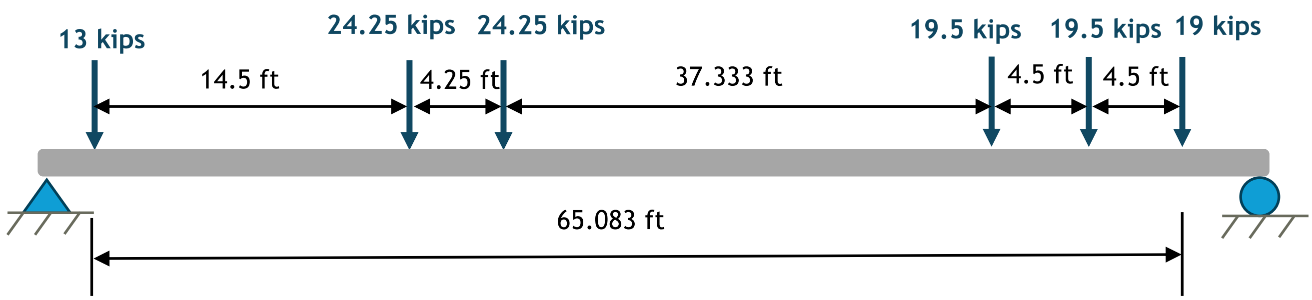


a. EV2, weight= 57.5 kips (28.75 tons)

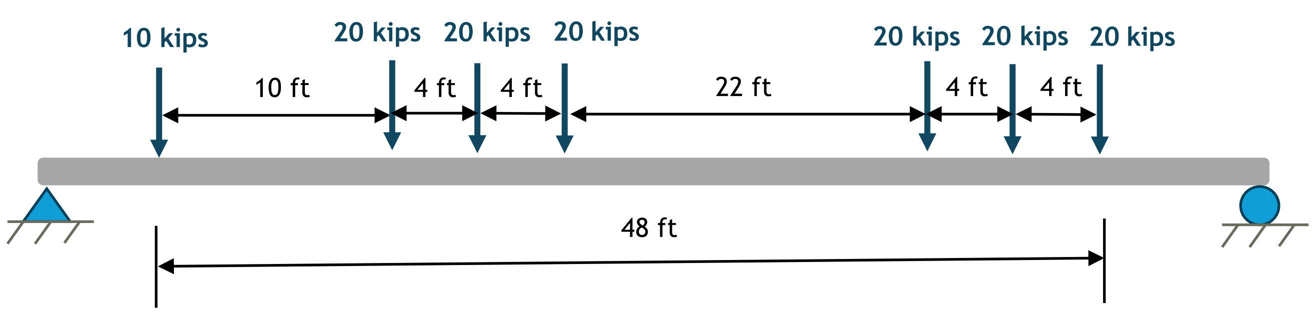


b. EV3, weight= 86 kips (43 tons)

Figure 2-6 Emergency vehicles.



a. PL 60T, weight= 120 kips (60 tons)



b. PL 65T, weight= 130 kips (65 tons)

Figure 2-7 Permit loads.

2.2.4. PCI Bridge Design Manual (PCI BDM 2014)

The PCI Bridge Design Manual (2014) provides guidance and resources in the design process of new adjacent box beam bridges according to the AASHTO LRFD Specifications. It has two design examples 9.4 and 9.5 of precast, prestressed box beams for composite and non-composite sections, respectively. These examples illustrate in detail the design of a typical interior beam.

2.3. Report Outline

The report includes six chapters and three appendices. Chapter 1 introduces box beam bridges and discusses the problem statement. Chapter 2 outlines the project objectives and reviews the research literature in the context of precast, prestressed box beam bridges. Chapter 3 presents the research approach, including the development, verification, application, and limitations of the developed load rating tool. Chapter 4 includes the research findings and conclusions. Chapter 5 presents the recommendations for implementation of the developed tool. Appendix A presents details of comprehensive shear check, Appendix B presents independent hand calculations for the load rating of a sample bridge, and Appendix C presents AD-BOX solved examples.

3. Research Approach

3.1. Development of AD-BOX

3.1.1. Introduction

AD-BOX is an innovative computer tool specialized in the load rating of precast prestressed adjacent box beam bridges. It is developed using the Visual Basic for Applications (VBA) programming language and implemented into a Microsoft Excel spreadsheet. Approximately 3,000 lines of VBA code are written to automate AD-BOX. It uses the Load and Resistance Factor Rating (LRFR) method for the strength limit state and the Allowable Stress Method (ASD) for the service limit state, according to the AASHTO LRFD Bridge Design Specifications (LRFD 2024) and the AASHTO Manual for Bridge Evaluation (MBE 2018). This tool accommodates 15 vehicle types required by the ODOT Bridge Design Manual (BDM 2020) which includes the Design Vehicle (HL-93), Ohio legal loads (2F1, 3F1, 5C1), AASHTO legal loads (Type 3, Type 3S2, Type 3-3), special hauling vehicles (SU4, SU5, SU6, SU7), emergency vehicles (EV2, EV3), permit loads (PL 60T, PL 65T). To consider the future needs for vehicles beyond the 15 vehicle types listed in the ODOT BDM (2020), AD-BOX has been developed with the capability to include custom vehicles with up to 35 axles. A high axle count is selected to consider vehicles that may emerge in the future.

3.1.2. Structure of the Spreadsheet

For a user-friendly interface, AD-BOX is developed with two primary tabs (Main and Calculation Summary) and one optional tab (Envelopes). In addition, hidden, on-demand tabs are available for displaying the detailed calculations if the user requests. Section 3.3 of this report provides detailed guidance for the application of these tabs in AD-BOX.

3.1.2.1. Primary Tabs

The primary tabs in AD-BOX are as follows.

a. Main Tab

This tab is developed to facilitate the input of bridge data and obtain load rating results. It is further divided into four sections: bridge information, material properties, box beam section properties, and load rating. For load rating, a 'Compute Load Rating' button is provided in the load rating section. It computes the load rating for the evaluated bridges with a single click. All necessary calculations and iterations are performed automatically.

b. Calculation Summary Tab

This tab provides a summary of all detailed calculations involved in the bridge's load rating. Various buttons are embedded in the spreadsheet to allow users to show or hide detailed calculations if the user requests. Detailed explanations of the calculations involved in the load rating are discussed in Section 3.1.3.

3.1.2.2. On-demand Tabs

The on-demand tabs are hidden tabs, which are available if the user requests. The on-demand tabs are developed to display the detailed calculations discussed in Section 3.1.3 of this report. In AD-BOX, the on-demand tabs include one tab each for the calculations of distribution factors, capacity, prestress losses, load rating for interior beams, load rating for exterior beams, and 17 tabs for the calculation of unfactored maximum moment and shear force due to the vehicle types. Out of the 17 tabs, two tabs are for the design vehicle HL-93 (HL-93 and HL-93 Tandem), three tabs are for Ohio legal loads (2F1, 3F1, 5C1), three tabs are for AASHTO legal loads (Type 3, Type 3S2, Type 3-3), four tabs are for special hauling vehicles (SU4, SU5, SU6, SU7), two tabs are for emergency vehicles (EV2, EV3), two tabs are for permit loads (PL 60T, PL 65T), and one tab is for the custom vehicle. Using a separate tab for each purpose provides improved organization by keeping calculations distinct, enhanced usability by allowing users to access only the necessary functions, and customization flexibility to focus on specific calculations as needed. Section 3.3 provides detailed guidance for the application of these tabs in AD-BOX.

3.1.2.3. Optional Tab

In AD-BOX, an optional tab (Envelopes) is developed as a standalone feature, independent of other tabs. This tab is designed to present moment and shear envelopes for the selected vehicle type on any single span, simply supported bridge. Section 3.1.4 of this report provides details of the envelope calculation method and Section 3.3.3 provides guidance for the application of this tab.

3.1.3. Detailed Calculations

The load rating process initiates with the input of essential bridge information, design data, material properties, and load rating settings. Then, it involves calculations for loads, live load distribution factors, maximum bending moments, and shear forces resulting from both dead and live loads, along with the assessment of beam capacities. The maximum moment and shear due to each vehicle on the bridge is calculated using the influence line method as explained in Section 3.1.3.4 of this report. Finally, the load rating values are calculated, which are categorized into three types based on vehicle types: design load rating, legal load rating, and permit load rating, using the limit states based on the type of structure and vehicle as outlined in AASHTO MBE Table 6A.4.2.2-1. The flow chart for each input and calculation involved is presented in Figure 3-1.

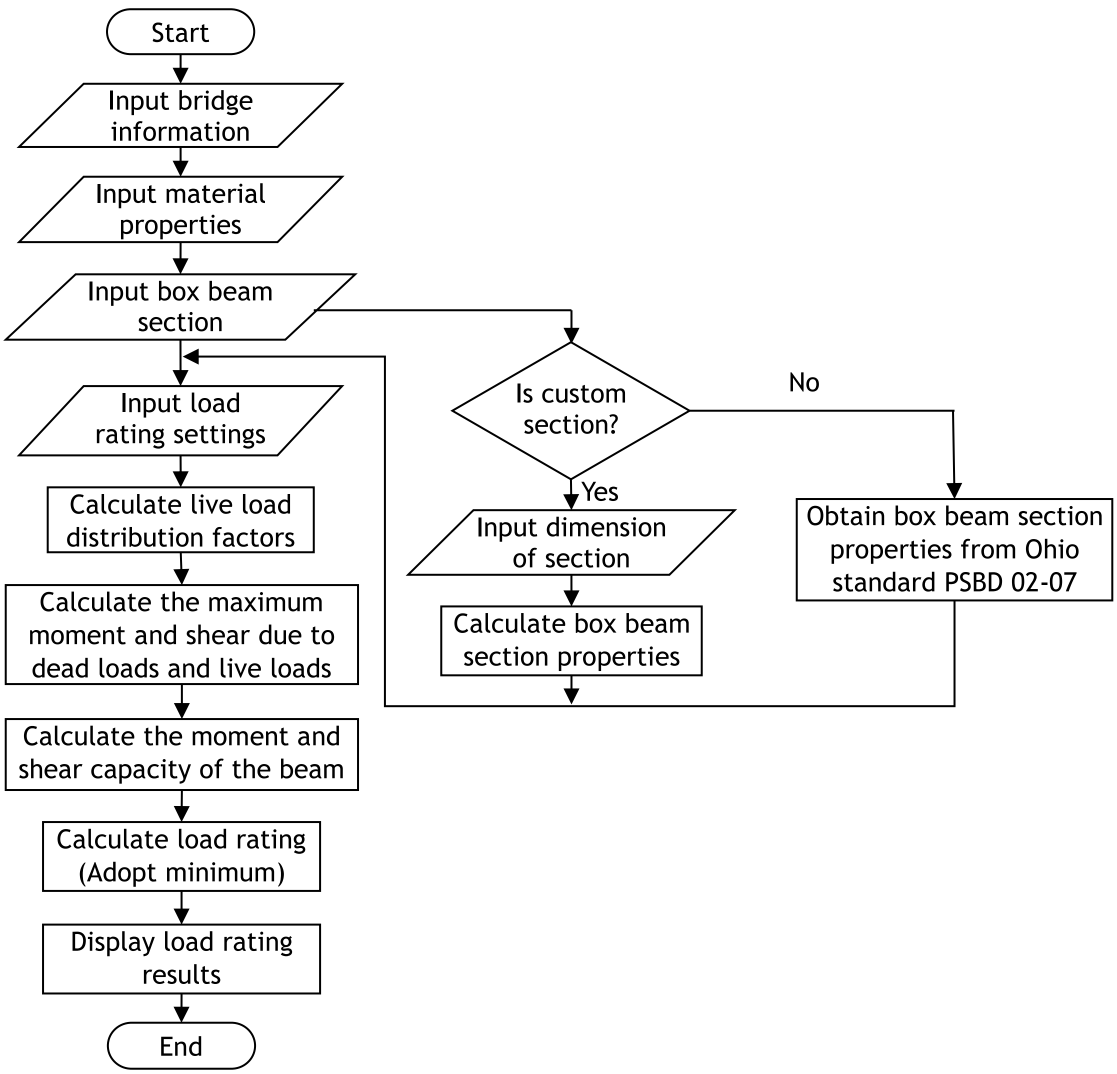


Figure 3-1 Flow chart for load rating in AD-BOX.

3.1.3.1. Loads

The loads to be used for the load rating of the bridges include dead loads and vehicular live loads. Environmental loads such as wind, ice, temperature, streamflow, and earthquake are usually not considered in load rating.

3.1.3.1.1 Dead loads

The load due to structural components and attachments, wearing surface, and utilities on the bridge span are dead load acting on the bridge. The dead loads are further classified into two categories: DW and DC, to supplement the use of different load factors as specified in AASHTO MBE Table 6A.4.2.2-1. The details of load factors specific to precast prestressed adjacent box beam bridges are presented in Section 3.1.3.6 of this report.

DW includes structural components, and attachment loads which include the self-weight of the beam, including the deck slab for composite beams, diaphragm weight, and weight due to barrier or railing.

DC includes weight due to the wearing surface and utilities.

Dead loads are equally distributed on each beam of the bridge when the conditions are satisfied as specified below, according to AASHTO LRFD Article 4.6.2.2.1.

- The width of the deck is constant.
- The number of beams is not less than four.
- Beams are parallel and have approximately the same stiffness.
- The roadway part of the overhang, $d_e \leq 3.0$ ft.
- The curvature in the plan is less than specified in the LRFD Specifications.

Section B1.2 of Appendix B presents the detailed calculation of the dead loads for a sample bridge.

3.1.3.1.2 Live loads

The live loads for the load rating of bridges include vehicle loads as categorized in AASHTO MBE Article 6A.2.3.1. These live loads consist of Design Loads, Legal Loads, and Permit Loads. As this research project is conducted in accordance with the ODOT BDM, the live loads have been selected based on ODOT BDM (2020), Section 908.3. The detailed configuration of these vehicles is presented in Section 2.2 of this report. The vehicles included for load rating in AD-BOX are listed below:

a. **Design Vehicle:** HL-93
b. **Legal Vehicles:**
   - Ohio Legal Loads: 2F1, 3F1, 5C1
   - Specialized Hauling Vehicles: SU4, SU5, SU6, SU7
   - AASHTO Legal Loads: Type 3, Type 3S2, Type 3-3
   - Emergency Vehicles: EV2, EV3
c. **Permit Vehicles:** PL60T, PL65T
d. **Custom Vehicle**: with up to 35 axles

To consider the future needs for vehicles beyond the 15 vehicle types listed in the ODOT BDM (2020), AD-BOX has been developed with the capability to include custom vehicles with up to 35 axles. A high axle count is selected to consider vehicles that may emerge in the future. The custom vehicle is treated as a permit load, and permit load conditions are adopted for its load rating using AD-BOX. Details on custom vehicle load rating are provided in Section 3.2.2.3.4 of this report.

The Maximum moment and shear due to live load are calculated and are distributed to each beam of the bridge according to AASHTO LRFD Table 4.6.2.2.2d-1. The live load distribution factors specific to box beam bridges is presented in Section 3.1.3.2 of this report.

3.1.3.2. Live Load Distribution Factors

The distribution factor method is used to distribute the moment and shear due to live load among all beams across the bridge section according to AASHTO LRFD Article 4.6.2.2.2. Live load distribution factors specific to box beam bridges for moment and shear for interior and exterior beams are presented in subsequent sections.

3.1.3.2.1 Live Load Distribution Factor for Interior Beam

For a typical interior box beam, the live load distribution factors for the moment are presented in Table 3-1, and for shear is presented in Table 3-2. These factors are valid for non-skewed bridges and should be corrected for skewed bridges using correction factors as specified in Section 3.1.3.2.3 of this report.

The live load distribution factors are inclusive of a multiple presence factor of 1.2 as specified in AASHTO LRFD Table 4.6.2.2.2b-1. The multiple presence factor is the factor defined to incorporate the effect of other vehicles within the bridge, along with the evaluated vehicle. Refer to AASHTO LRFD Article 4.6.2.2 for the details of multiple presence factors considered for the evaluation of the bridge.

Table 3-1 Live load distribution factors for the moment in a typical interior box beam.

Distribution factors	Range of applicability
One design lane loaded: $k\left(\frac{b}{33.3L}\right)^{0.5}\left(\frac{I}{J}\right)^{0.25}$ Two or more design lanes loaded: $k\left(\frac{b}{305}\right)^{0.6}\left(\frac{b}{12.0L}\right)^{0.2}\left(\frac{I}{J}\right)^{0.06}$ where: $k = 2.5\,(N_b^{-0.2}) \geq 1.5$	$35 \leq b \leq 60$ $20 \leq L \leq 120$ $5 \leq N_b \leq 20$

Table 3-2 Live load distribution factors for the shear in a typical interior box beam.

Distribution factors	Range of applicability
One design lane loaded: $\left(\frac{b}{130L}\right)^{0.15}\left(\frac{I}{J}\right)^{0.05}$ Two or more design lanes loaded: $\left(\frac{b}{156}\right)^{0.4}\left(\frac{b}{12.0L}\right)^{0.1}\left(\frac{I}{J}\right)^{0.05}\left(\frac{b}{48}\right)$ where: $\frac{b}{48} \geq 1.0$	$35 \leq b \leq 60$ $20 \leq L \leq 120$ $5 \leq N_b \leq 20$ $25{,}000 \leq J \leq 610{,}000$ $40{,}000 \leq I \leq 610{,}000$

where:

b = Width of box beam (in.)
L = Design span of the bridge (ft)
N_b = Number of box beams
I = Moment of inertia of the beam (in^4)
J = St. Venant's torsional constant (in^4)

The St. Venant's equation for calculating the torsional constant of single hollow box beams is specified in AASHTO LRFD Article 5.7.2.1. To illustrate the relevant dimensions and variables of St. Venant's equation, Figure 3-2 presents a thin-walled, single-cell box beam section. A small section, *ds*, is considered, and by integrating the shear stress from 0 to l_m (mid-length perimeter), the value of the torsional constant is determined.

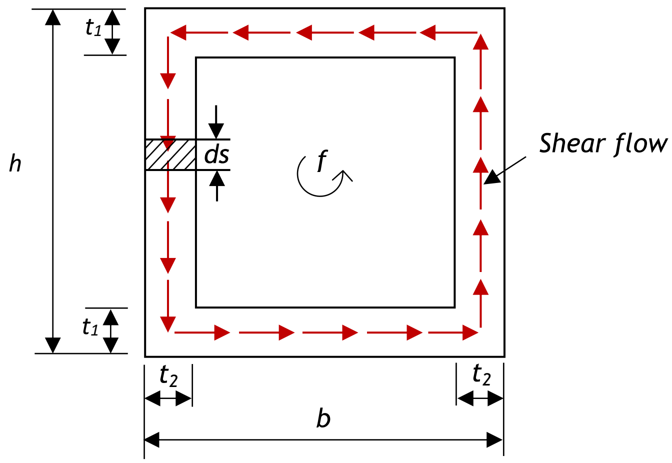


Figure 3-2 Typical single-cell box beam section.

in figure:

b = Width of beam section,
h = Height of beam section,
t_1 = Thickness of beam flange section, and
t_2 = Thickness of beam web section.

The St. Venant's equation is given by:

$$J = \frac{4A_o^2}{\sum \frac{s}{t}}$$

where:

J = Torsional constant,
A_o = The area enclosed by the centerline of elements of the beam, A_o = (b-t) *(h-t)
s = Length of side element,

$$s = 2\left(\frac{h - \left(\frac{t_1}{2} + \frac{t_1}{2}\right)}{t_2}\right) + 2\left(\frac{b - \left(\frac{t_2}{2} + \frac{t_2}{2}\right)}{t_1}\right)$$

The earlier box beam standards from the ODOT contain multicell box beam sections, which have more than two webs. The AASHTO LRFD specifications only provide a calculation procedure for the torsional constant of box beam sections with two webs. Multicell box beams introduce additional complexity due to the multiple compartments formed by the webs. This complexity requires a more detailed approach to determining the torsional constant, as the same equation used for single-cell box beams cannot be directly applied. Therefore, a study is necessary to determine a methodology for calculating the torsional constant of multicell box beam sections.

In multicell box beams, shear flow is essential for understanding the distribution of torsional stresses across compartments. It describes how these stresses vary along the closed sections of the beam. Boresi and Schmidt (2003), provide a framework for calculating the torsional constant in multicell box beams, assuming consistent shear flow in each compartment and uniform angles of twist.

Figure 3-3 illustrates the shear flow distribution in multicell box beams. According to Boresi and Schmidt (2003), each cell in a box beam exhibits a distinct shear flow, represented as f_1 and f_2 for cells 1 and 2, respectively. The shear flow in the adjacent cell affects the calculation of the twist in each cell, which is assumed to be uniform throughout. In the shared webs between cells 1 and 2, the shear flows act in opposite directions. If the areas of both cells sharing a web are equal, these opposite shear flows cancel out, resulting in no effect on the torsion due to the middle web.

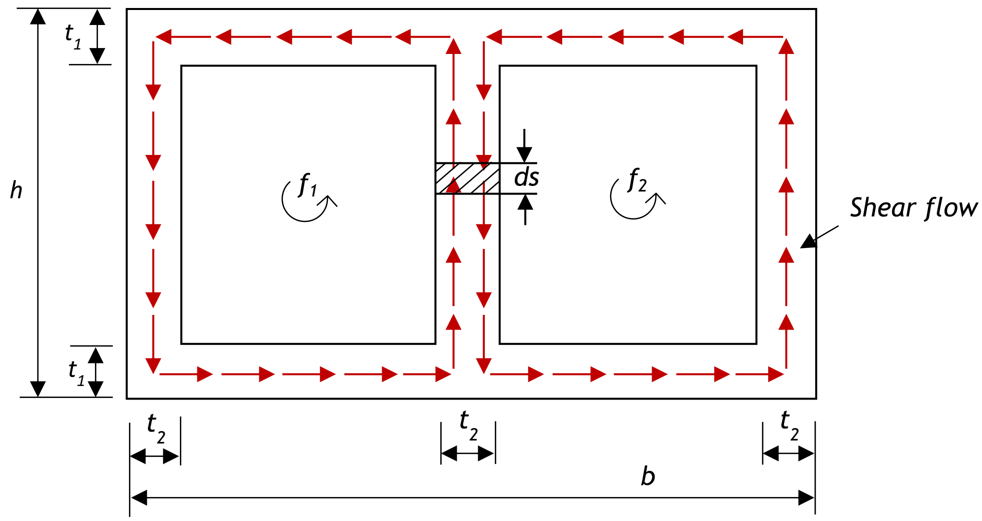


Figure 3-3 Typical multicell box beam section.

in figure:

b = Width of beam section,
h = Height of beam section,
t_1 = Thickness of beam flange section, and
t_2 = Thickness of beam web section.

The detailed procedure for calculating the torsional constant of a multicell box beam is outlined below: The total torque carried by a cross-section with i-compartments is given by

$$T = \sum_{i=1}^{n} 2 f_i A_{mi}$$

where:

T = Total torque
f_i = Shear flow in a compartment
A_{mi} = Centerline area of a compartment, and

Twist per unit length in each compartment is given by

$$\theta = \frac{1}{2GA_{mi}} \int_0^{l_{mi}} \frac{f_i - f_j}{t} ds,\ i = 1,2,\ldots,n$$

where:

l_{mi} = Length of the mean perimeter of i^{th} cell,
G = Shear Modulus,
f_j = Shear flow of the cell adjacent to the i^{th} cell where ds is located, 0 at the outer boundary

t = Thickness where ds is located.

The unknowns $f_1, f_2, f_3, \ldots,$ *and* f_i are determined by equating the twists from each cell. Then the torsional constant is calculated using the following equations.

$$J = \frac{T}{\theta G}$$

where:

J = Torsional constant.

In the multicell box beams, if the areas of cells sharing the common web are equal (identical cells), the shear flows cancel each other, resulting in no effect of torsion in the middle-shared web. Therefore, St. Venant's equation can be used to calculate the torsional constant of multicell box beams, disregarding the middle web's effect on torsion.

3.1.3.2.2 Live Load Distribution Factor for Exterior Beam

The live load distribution factors for a typical exterior box beam for the moment are presented in Table 3-3, and for shear is presented in Table 3-4. These factors are valid for non-skewed bridges and should be corrected for skewed bridges using correction factors as specified in Section 3.1.3.2.3 of this report

Same as for the interior beam, the distribution factors for the exterior beam are also inclusive of a multiple presence factor of 1.2 as specified in AASHTO LRFD Table 4.6.2.2.2b-1.

Table 3-3 Live load distribution factors for the moment in a typical exterior box beam.

Distribution factors	Range of applicability
One design lane loaded: $g = e\, g_{interior}$ $e = 1.125 + \frac{d_e}{30} \geq 1.0$ Two or more design lanes loaded: $g = e\, g_{interior}$ $e = 1.04 + \frac{d_e}{25} \geq 1.0$	$d_e \leq 2.0$

Table 3-4 Live load distribution factors for the shear in a typical exterior box beam.

Distribution factors	Range of applicability
One design lane loaded: $g = e\, g_{interior}$ $e = 1.25 + \frac{d_e}{20} \geq 1.0$ Two or more design lanes loaded: $g = e\, g_{interior}\left(\frac{48}{b}\right)$ where, $\left(\frac{48}{b}\right) \leq 1.0$ $e = 1 + \left(\frac{d_e + \frac{b}{12} - 2.0}{40}\right)^{0.5} \geq 1.0$	$d_e \leq 2.0$ $35 \leq b \leq 60$

where:

$g_{interior}$ = live load distribution factor for an interior beam

g = live load distribution factor for an exterior beam
b = width of the box beam section (in.)
d_e = horizontal distance from the centerline of the exterior web to the interior edge of the curb or traffic barrier (ft)

3.1.3.2.3 Effect of Skew

In the case of skewed bridges, when the difference in skew angles of the adjacent support is less than 10 degrees, the live load distribution factors for the moment in the beams are reduced according to AASHTO LRFD Table 4.6.2.2.2e-1. AASHTO LRFD (2024) has a range of applicability up to skew angles of 60 degrees, and ODOT BDM (2020) permits a maximum skew of 30 degrees. Hence, the skew angle is capped between 0 and 30 degrees in the development of AD-BOX. Reduction factors of live load distribution factor for the moment in skewed bridges specific to box beam bridges are presented in Table 3-5.

Table 3-5 Reduction factor of live load distribution factor for the moment in skewed box beam bridges.

Reduction factor	Range of applicability
$1.05 - 0.25 \tan\theta \leq 1.0$ If $\theta > 60°$, use $\theta = 60°$	$0° \leq \theta \leq 60°$

The live load distribution factors for the shear in the beams are reduced according to AASHTO LRFD Table 4.6.2.2.3c-1. Reduction factors of live load distribution factor for the shear force in skewed bridges specific to box beam bridges are presented in Table 3-6.

Table 3-6 Reduction factor of live load distribution factor for the shear force in skewed box beam bridges.

Reduction factor	Range of applicability
$1+\frac{12.0L}{90d}\sqrt{\tan\theta}$	$0° \leq \theta \leq 60°$ $20 \leq L \leq 120$ $17 \leq d \leq 60$ $35 \leq b \leq 60$ $5 \leq N_b \leq 20$

Section B1.3 of Appendix B presents the detailed calculation of the live load distribution factors, including the skew effects for a sample bridge.

3.1.3.3. Moment and Shear Critical Locations

3.1.3.3.1 Moment Critical Location

Using the conventional one-tenth-of-the-span method for calculating the moment due to vehicular load on simply supported bridges, the maximum moment occurs at the mid-span of the bridge. However, the exact location of the maximum moment can be determined by applying the absolute maximum method. This method states that the maximum moment location, for any vehicle configuration on the bridge, occurs where the axle closest to the resultant of all axles within the bridge is positioned equidistant from the resultant and the center of the bridge. An illustration of this method is provided below.

Suppose a three-axled vehicle is moving on a bridge with a span of L = 50 ft, as shown in Figure 3-4. Point C is the center of the bridge span. F_r represents the resultant of the vehicle's axles on the bridge. The maximum moment occurs at point Z, located at L_z = 22.67 ft, where the axle closest to the resultant force F_r is positioned equidistant from the center and the resultant.

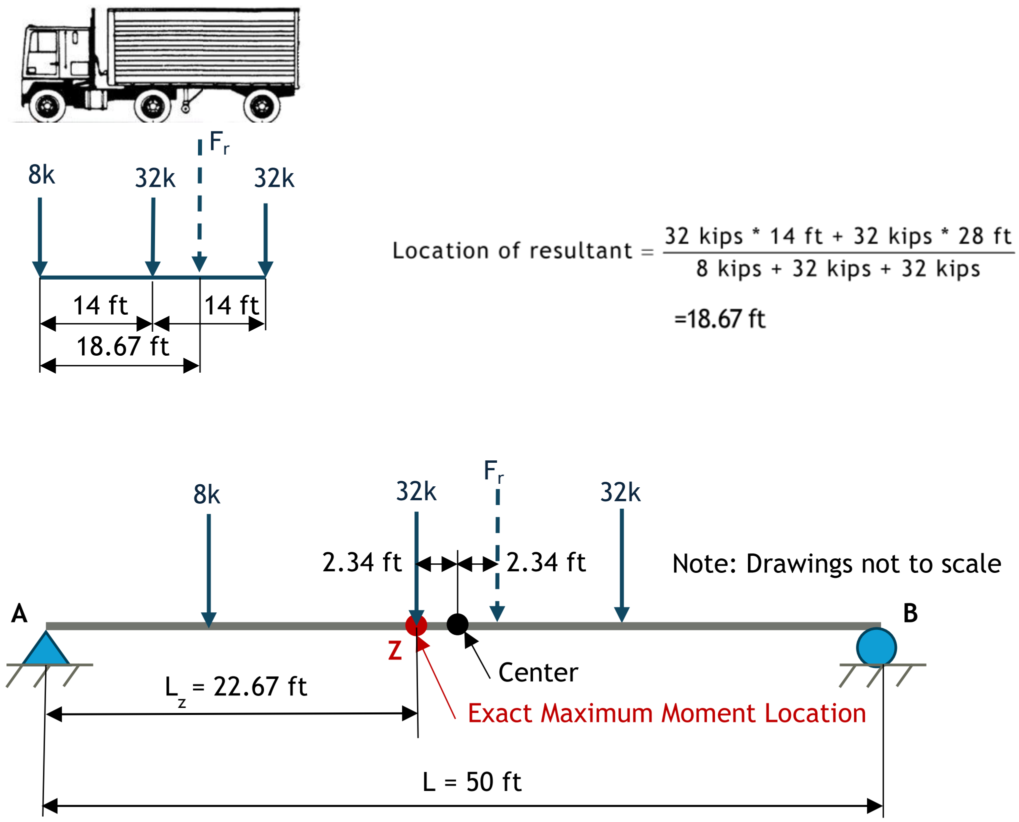


Figure 3-4 Exact maximum moment location due to a vehicle on a simply supported bridge.

3.1.3.3.2 Shear Critical Location

The typical shear critical point on the simply supported bridge is located at a point at a distance equal to the effective shear depth d_v away from the face of bearings at the supports as shown in Figure 3-5. The shear check is typically performed at this location. The maximum moment and shear force due to the vehicle on the bridge is calculated at this location using the influence line as discussed in Section 3.1.3.3 and shear capacity using the modified filed theory as discussed in Section 3.1.3.5.2 of this report.

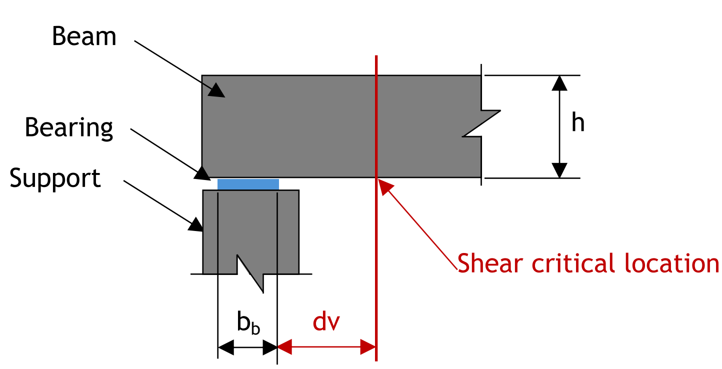


Figure 3-5 Typical shear critical location on a simply supported beam.

The distance d_v is given by:

$$d_v = d_e - \frac{a}{2}, \text{ but} > (0.9d_e) \text{ or } (0.72h)$$

where:

d_v	= Shear critical location from the face of the bearing at the supports
d_e	= Effective depth from the extreme compression fiber to the centroid of the tensile force in the tensile reinforcement
a	= Depth of compression block
h	= Depth of beam

The shear check should also be performed at other points, particularly where the shear reinforcement details change, to check if the shear is governing at any other location than the typical shear check point. In Figure 3-6, the provided shear reinforcement varies across different sections. The reinforcement provided in Regions 1 and 2 is not the same. Region 1 is provided with a complete set of U bars, i.e., both top and bottom U bars, as shown in Section A-A, with a lap length greater than or equal to 1.3 times the development length l_d. Region 2 is provided with a complete set of U bars and only the top U bar at alternate locations as shown in Section B-B. This top U bar does not act as shear reinforcement due to insufficient development length. This results in a reduced nominal shear capacity due to the increased spacing of the stirrups in this region. Consequently, it is necessary to evaluate the shear at points where the reinforcement and its spacing change.

Appendix A presents a detailed study for shear checks at different locations where shear reinforcement and its spacing change, including the typical shear check point along the bridge.

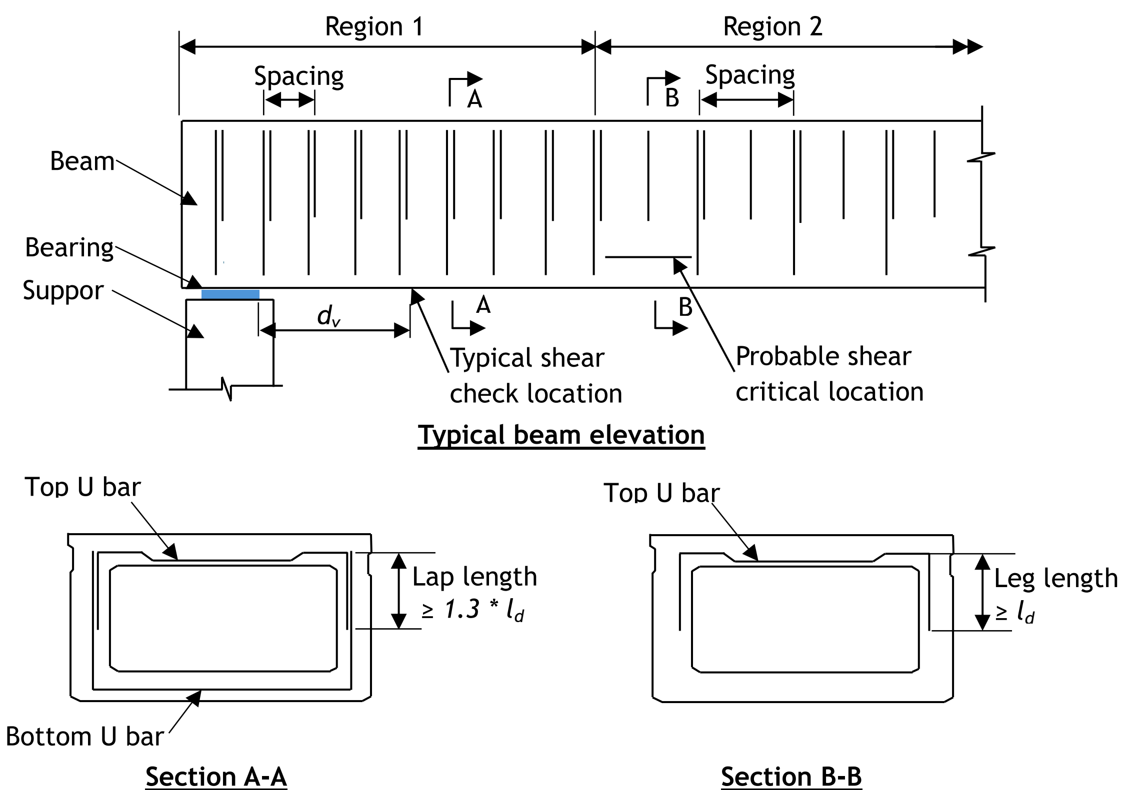


Figure 3-6 Typical beam elevation and section showing typical shear check location and probable shear critical location.

3.1.3.4. Maximum Moment and Shear Calculations

The load effect due to dead and live loads is expressed in bending moment and shear force, which are calculated at each section of the bridge span. For simply supported spans, the bending moment and shear forces due to specific loads, either point loads or uniformly distributed loads, are determined using the influence line equation as presented in the following subsections.

3.1.3.4.1 Moment and Shear Influence Lines for Point Load

For the point load P at a distance x from support A on the simply supported bridge span *L*, the bending moment M_z at any section Z at the distance L_z from the same support A is determined using the influence line equations. The schematic representation of the point load on the beam is shown in Figure 3-7.

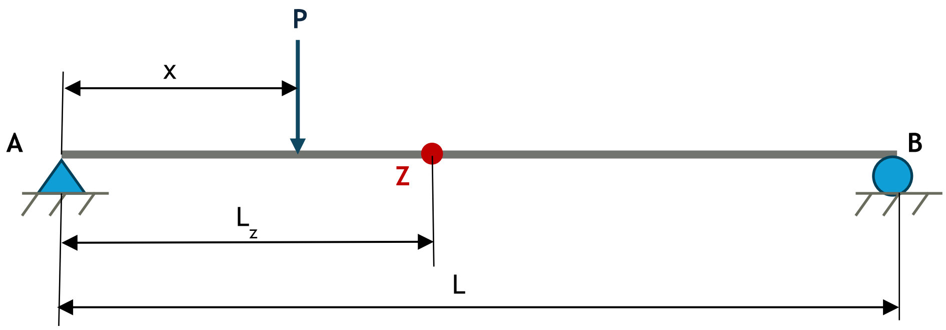


Figure 3-7 Schematic diagram for point load on a simply supported beam.

$$M_z = P\times\left[\left(1-\frac{x}{L}\right)\times L_z-\left(L_z-x\right)\right];\ \text{for}\ \ 0<x\le L_z$$

$$M_z = P\times\left[\left(1-\frac{x}{L}\right)\times L_z\right];\ \text{for}\ L_z\le x<L$$

The shear force V_z at section Z due to point load P is determined using the following influence line equations.

$$V_z = P\times\left(-\frac{x}{L}\right);\ \text{for}\ \ 0<x<L_z$$

$$V_z = P\times\left(1-\frac{x}{L}\right);\ \text{for}\ L_z\le x<L$$

3.1.3.4.2 Moment and Shear Influence Lines for Uniformly Distributed Load

For uniformly distributed load *w* on the bridge span *L*, the bending moment M_z at any section Z at the distance L_z from the support A is determined using the following influence line equation. The schematic representation of the uniformly distributed load on the beam is shown in Figure 3-8.

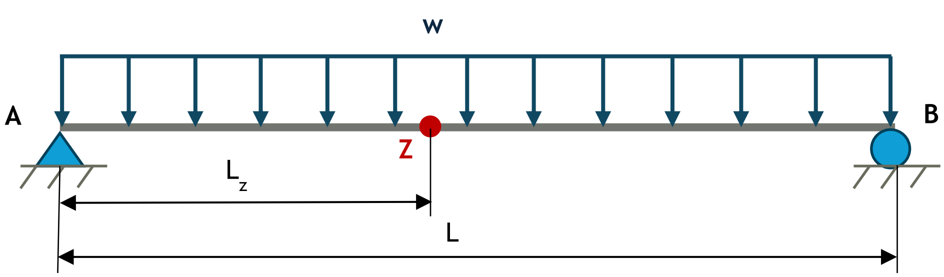


Figure 3-8 Schematic diagram for uniformly distributed load on a simply supported beam.

$$M_z = \frac{w \times L_z}{2} \times (L - L_z); \text{for } 0 \le L_z \le L$$

Similarly, the shear force V_z at section Z due to point load P is determined using the following influence line.

$$V_z = w \times \left(\frac{L}{2} - L_z\right); \text{ for } 0 \le L_z \le L$$

3.1.3.4.3 Maximum Moment Calculations

The maximum moment due to a vehicle crossing a simply supported bridge may be accurately determined by positioning the vehicle on the bridge by using the absolute maximum method, as described in Section 3.1.3.3.1 of this report. The moment generated by each axle at the maximum moment location is calculated using the influence line equations. The sum of these moments gives the maximum moment due to the vehicle at the exact maximum moment location on the bridge. When vehicle length is shorter than the bridge span, all axles are within the bridge span for calculating the moment at the exact maximum location. For vehicles longer than the bridge span, the vehicle is positioned on the bridge by eliminating some axles, which lie outside the bridge span. The detailed procedure for positioning the vehicle lying outside the bridge span is explained in Section 3.1.3.4.3.3 of this report.

An illustration of the maximum moment calculation due to the HL-93 truck on a 50 ft span bridge is presented in subsequent sections.

3.1.3.4.3.1 Moment at the Exact Maximum Point

Let the axles be denoted as a, b, and c, corresponding to 8 kips, 32 kips, and 32 kips, located at 0 ft, 14 ft, and 28 ft, respectively. The exact maximum moment location, Z, for this vehicle configuration on a 50 ft span bridge is at L_z = 22.67 ft, when axle b is positioned at location Z, as shown in Figure 3-9. The distances of each axle from the left support are as follows:

Axle	Distance from left Support
Axle a, P_a = 8 kips	x_a = 8.67 ft
Axle b, P_b = 32 kips	x_b = 22.67 ft
Axle c, P_c = 32 kips	x_c = 36.67 ft

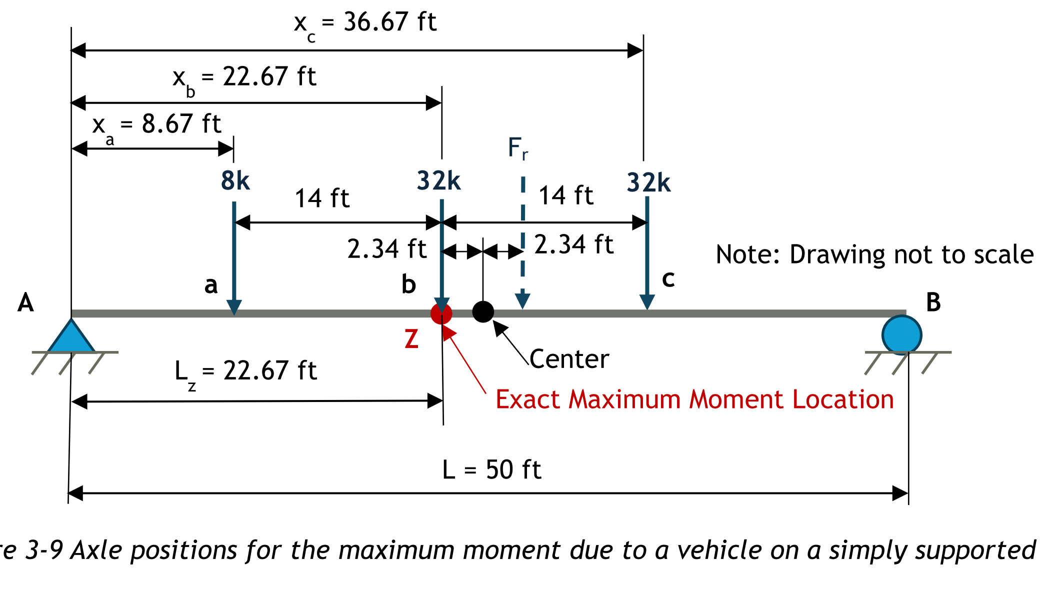


Figure 3-9 Axle positions for the maximum moment due to a vehicle on a simply supported bridge.

Moment due to each axle at the maximum moment location Z is determined using influence line equations:

Axle a

P_a = 8 kips

$$M_{z\_a} = P_a \times \left[\left(1 - \frac{x_a}{L}\right) \times L_z - \left(L_z - x_a\right) \right]; \text{ for } 0 < x_a = 8.67 \text{ ft} \le L_z$$

$$M_{z\_a} = 8 \times \left[\left(1 - \frac{8.67}{50}\right) \times 22.67 - \left(22.67 - 8.67\right) \right] = 37.91 \text{ kips-ft}$$

Axle b

P_b = 32 kips

$$M_{z\_b} = P_b \times \left[\left(1 - \frac{x_b}{L}\right) \times L_z \right]; \text{ for } x_b = 22.67 \text{ ft} = L_z$$

$$M_{z\_b} = 32 \times \left[\left(1 - \frac{22.67}{50}\right) \times 22.67 \right] = 396.53 \text{ kips-ft}$$

Axle c

P_c = 32 kips

$$M_{z\_c} = P_c \times \left[\left(1 - \frac{x_c}{L}\right) \times L_z \right]; \text{ for } L_z < x_a = 36.67 \text{ ft}$$

$$M_{z\_c} = 32 \times \left[\left(1 - \frac{36.67}{50}\right) \times 22.67 \right] = 193.40 \text{ kips-ft}$$

Finally, the sum of the moments due to each axle gives the maximum moment due to the vehicle configuration at the exact maximum moment location Z on the bridge.

$$M_z = M_{z\_a} + M_{z\_b} + M_{z\_c}$$

M_z= (37.91 + 396.53 + 193.40) kips-ft

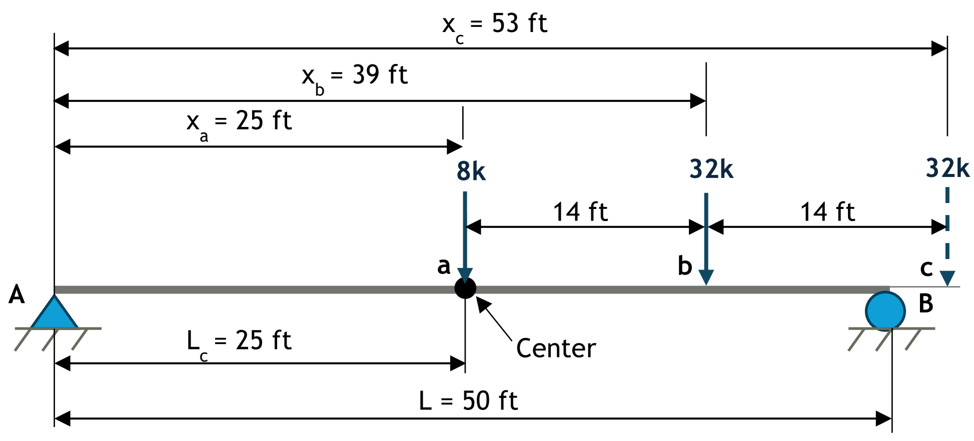
M_z= 627.84 kips-ft

The moment due to the HL-93 truck on the 50 ft span bridge at the exact maximum moment location is found to be 627.84 kips-ft. this value is then distributed among the adjacent box beams using distribution factors as explained in Section 3.1.3.2 and factored based on the vehicle type and condition of load rating as explained in Section 3.1.3.6 of this report.

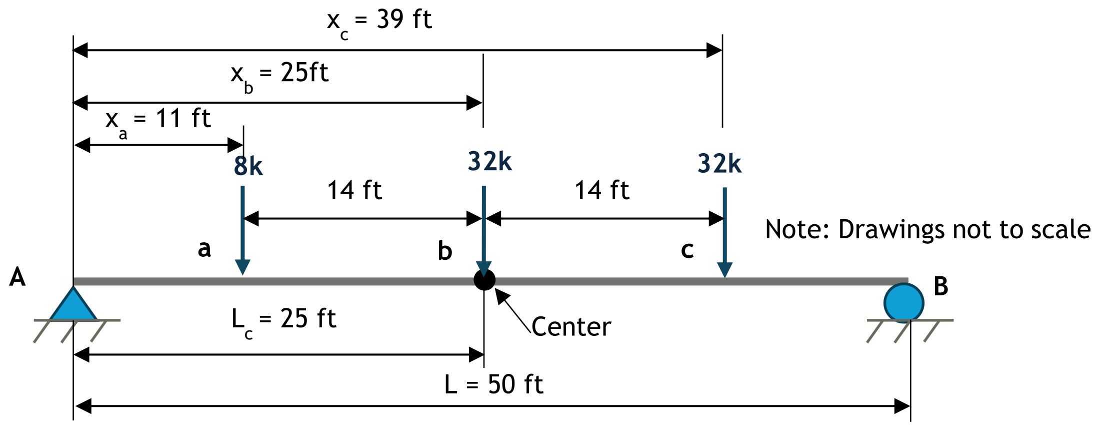
3.1.3.4.3.2 *Moment at the Center*

To conclude that the moment at point Z is the exact maximum location, a calculation is conducted using the same vehicle by positioning its axle a, b, and c at center C simultaneously as shown in Figure 3-10.

i. When axle a = 8 kips is placed at the center



ii. When axle b = 32 kips is placed at the center



iii. When axle c = 32 kips is placed at the center

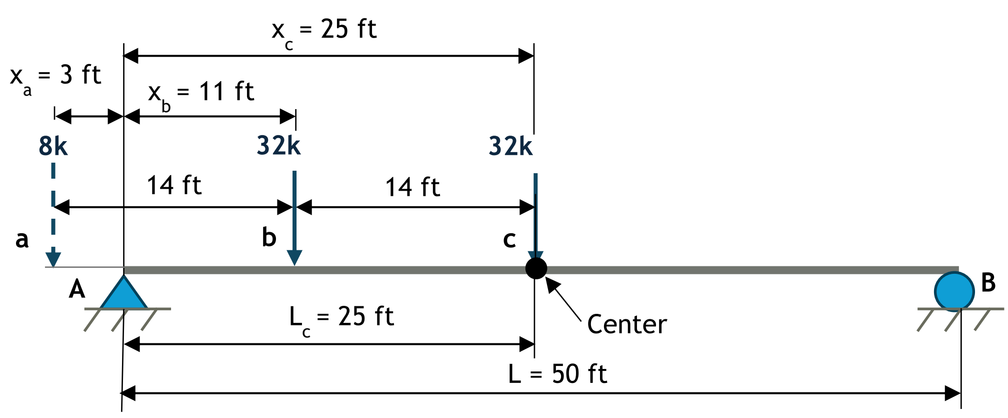


Figure 3-10 Axle positions for the moment at center due to a vehicle on a simply supported bridge.

The moment due to each axle with axles a, b, and c positioned at the center C is determined using the influence line equations. The maximum moment due to the vehicle, when axles a, b, and c are positioned at the center of the bridge, is found to be 276 kips-ft, 620 kips-ft, and 576 kips-ft, respectively. In contrast, the maximum moment due to the vehicle at the exact maximum location using the absolute maximum method is found to be 627 kips-ft, which is greater than that calculated at the center of the bridge.

These moment values are then distributed among the adjacent box beams using distribution factors as explained in Section 3.1.3.2 of this report and factored based on the vehicle type and condition of load rating as explained in Section 3.1.3.6 of this report.

3.1.3.4.3.3 Maximum Moment Due to Vehicles Lying Outside the Bridge Span

When a very long vehicle passes over the bridge, to obtain the maximum moment, the vehicle is positioned on the bridge by eliminating some axles lying outside the bridge span. Only the axles lying within the bridge span must be considered for the calculation. Multiple iterations are required to obtain the exact maximum location and the maximum moment due to the vehicle. AD-BOX is developed with the algorithm presented in the flow chart as shown in Figure 3-11 to obtain the maximum moment at the exact maximum location. Calculations are performed by replicating the vehicle moving on the bridge in both forward and backward directions. Iterations are performed by eliminating the axles lying outside the bridge span while moving the vehicle in both directions on the bridge.

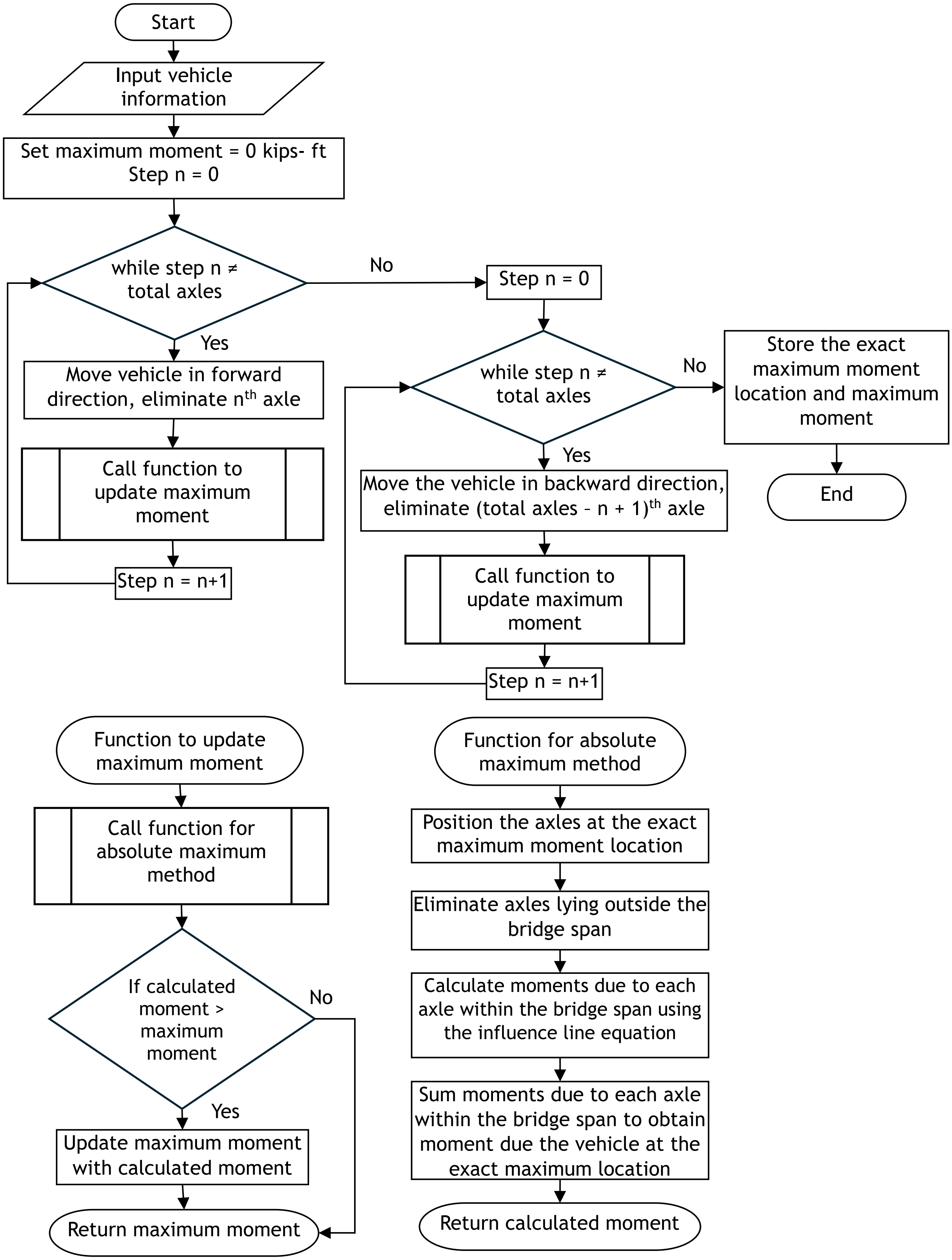


Figure 3-11 Flow chart to determine the maximum moment due to a vehicle on a bridge.

As an illustration, AD-BOX results for a vehicle 'Type 3-3' with some of its axles lying outside the 50 ft span bridge presented in Table 3-7. Among the six axles of Type 3-3, axles a, b, and c are eliminated to obtain the maximum moment at the exact maximum location on the bridge as shown in Figure 3-12. The exact maximum location for the vehicle configuration is found to be at Z = 27.27 ft. The vehicle positioned with the axle e at the exact maximum location Z gives the maximum moment due to the vehicle on the bridge.

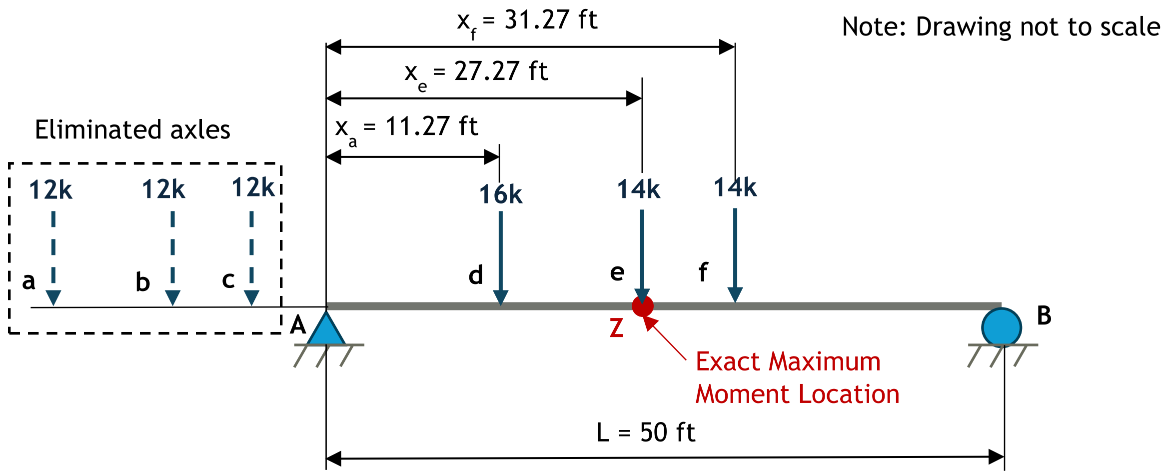


Figure 3-12 Axle positions for the maximum moment due to vehicle Type 3-3 on a 50 ft span bridge.

Table 3-7 AD-BOX results for the maximum moment due to vehicle Type 3-3 on a 50 ft span bridge.

Axle	Load (kips)	Position form first axle (ft)	Position from support A (ft)	Moment (kips-ft)
a	12.00	-34.00	-22.73	0.00
b	12.00	-19.00	-7.73	0.00
c	12.00	-15.00	-3.73	0.00
d	16.00	0.00	11.27	81.98
Fr	44.00	11.45	22.73	-
e	14.00	16.00	27.27	173.55
f	14.00	20.00	31.27	143.01
			Total	**398.55**

The maximum moment due to the vehicle Type 3-3 is found to be 398.55 kips-ft, which is then distributed among the adjacent box beams using distribution factors as explained in Section 3.1.3.2 and factored based on the load rating conditions as explained in Section 3.1.3.6 of this report.

3.1.3.4.4 Maximum Shear Calculations

The maximum shear force due to a vehicle passing over the bridge is calculated at the shear-critical location, which is situated a distance equal to the effective shear depth d_v from the face of the bearing at the supports, as explained in Section 3.1.3.3.2 of this report. This maximum shear force is achieved when the vehicle is positioned such that its heaviest axle among the extreme ends is at the shear-critical location. The influence line equations can determine the shear force contributed by each axle within the bridge span. The total maximum shear at the shear-critical point is then calculated by summing the shear forces from all axles located within the span.

An illustration for the calculation of the maximum shear due to the HL-93 truck on a 50 ft span bridge is presented here. Let the axles be denoted as a, b, and c, corresponding to 8 kips, 32 kips, and 32 kips, located at 0 ft, 14 ft, and 28 ft, respectively. Assuming the shear critical location S is at d_v = 2.5 ft for the bridge beam, the position of each axle for obtaining maximum shear due to the vehicle on the bridge is presented in Figure 3-13.

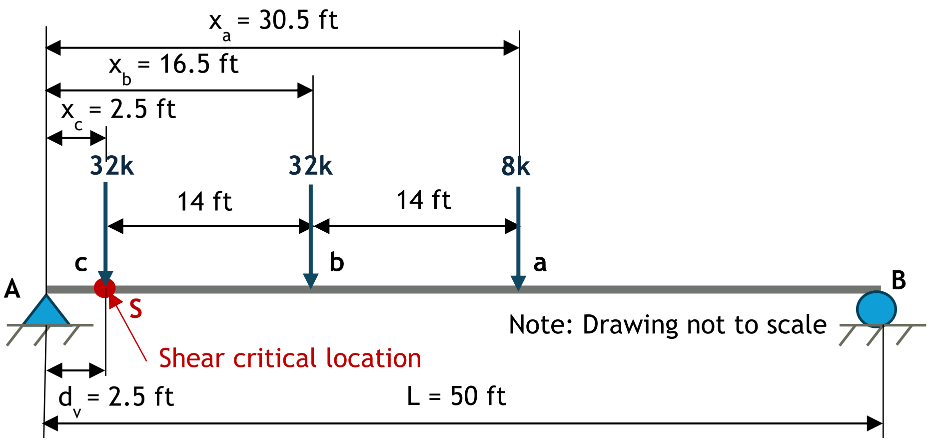


Figure 3-13 Axle positions for the maximum shear due to a vehicle on a simply supported bridge.

The shear force due to each axle at the shear critical location S is determined using influence line equations as follows:

Axle a

P_a = 8 kips

$$V_{S\_a} = P \times \left(1 - \frac{x_a}{L}\right); \text{ for } L_S < x_a = 30.5 \text{ ft} < L$$

$$V_{S\_a} = 8 \times \left(1 - \frac{30.5}{50}\right) = 3.12 \text{ kips}$$

Axle b

P_b= 32 kips

$$V_{S\_b} = P \times \left(1 - \frac{x_b}{L}\right); \text{ for } L_S < x_b = 16.5 \text{ ft} < L$$

$$V_{S\_b} = 32 \times \left(1 - \frac{16.5}{50}\right) = 21.44 \text{ kips}$$

Axle c

P_c= 32 kips

$$V_{S\_c} = P \times \left(1 - \frac{x_c}{L}\right); \text{ for } L_S = x_c = 2.5 \text{ ft} < L$$

$$V_{S\_c} = 32 \times \left(1 - \frac{2.5}{50}\right) = 30.40 \text{ kips}$$

Then, the sum of shear due to each axle gives the maximum shear due to the vehicle configuration on the bridge.

$$V_S = V_{S\_a} + V_{S\_b} + V_{S\_c}$$

V_S= (3.12 + 21.44 + 30.40) kips = 54.96 kips

The maximum shear due to the HL-93 truck on the 50 ft span bridge is found to be 54.96 kips. This value is then distributed among the adjacent box beams using distribution factors as explained in Section 3.1.3.2 and factored based on the vehicle type and condition of load rating as explained in Section 3.1.3.6 of this report.

The maximum shear may occur at other points along the span of the bridge, including the typical shear check location (distance d_v, from the internal face of the support) and other points where the shear reinforcement and its spacing change. The details of the shear critical locations are presented in Section 3.1.3.3.2 of this report and the detailed study for shear checks at different locations, including the typical shear check point along the bridge is presented in Appendix A.

3.1.3.5. Moment and Shear Capacity

3.1.3.5.1 Moment Capacity

The moment capacity of the beams is calculated using an approximate method or rectangular stress blocks method according to AASHTO LRFD Article 5.6.3.2. The strain compatibility method may also be used as explained in AASHTO LRFD Article 5.6.3.2.5. The moment capacity calculated using the equations of the approximate method is found to be sufficient for load rating purposes, which is further discussed in Section 3.2.2.1 of this report. These equations are valid for normal-weight concrete with design compressive strengths up to 15.0 ksi and lightweight concrete up to 10.0 ksi.

The factored moment capacity M_r is given by:

$$M_r = \phi M_n$$

where:

M_r = Factored moment capacity (kips-in)

M_n = Nominal moment capacity (kips-in)

ϕ = Resistance factor

In AD-BOX, the box beam is distinguished as having T-section behavior or rectangular section behavior based on the depth of the compression block of the beam. If the depth of the compression block is less than the depth of the top flange (h_f), then the beam is considered to have rectangular section behavior and if the depth of the compression block is greater than the depth of the top flange of the beam, the beam is considered to have T-section behavior.

The depth of compression block (a) is calculated as:

$$a = \beta_1 c$$

where:

c = Distance from the extreme compression fiber to the neutral axis (in.)

β_1 = Stress block factor specified in AASHTO LRFD Article 5.6.2.2

The distance from the extreme compression fiber to the neutral axis (c) is determined using the following equations:

For T-section behavior (when $a > h_f$)

$$c = \frac{A_{ps} f_{pu} + A_s f_s - A_s' f_s' - \alpha_1 f_c' (b - b_w) h_f}{\alpha_1 f_c' \beta b_w + k A_{ps} \dfrac{f_{pu}}{d_p}}$$

For rectangular section behavior (when $a \le h_f$)

$$c = \frac{A_{ps} f_{pu} + A_s f_s - A_s' f_s'}{\alpha_1 f_c' \beta p + k A_{ps} \dfrac{f_{pu}}{d_p}}$$

where:

A_{ps} = Area of prestressing steel (in^2)

f_{pu} = Specified tensile strength of prestressing steel (ksi)

f_{py} = Yield strength of prestressing steel (ksi)

$k = f_{pu} / f_{py}$

A_s = Area of non-prestressed tension reinforcement (in^2)

A_s' = Area of compression reinforcement (in^2)

f_s = Stress in the non-prestressed tension reinforcement at nominal flexural resistance (ksi)

f_s' = Stress in the non-prestressed compression reinforcement at nominal flexural resistance (ksi)

b = Width of the compression face of the member (in.)

b_w = Web width (in.)

h_f = Compression flange depth (in.)

d_p = Distance from extreme compression fiber to the centroid of the prestressing force (in.)

C = distance from the extreme compression fiber to the neutral axis (in.)

a_1 = Stress block factor specified in AASHTO LRFD Article 5.6.2.2

B_1 = Stress block factor specified in AASHTO LRFD Article 5.6.2.2

The stress block factor (α_1) is determined according to AASHTO LRFD Article 5.6.2.2. The values of α_1 vary according to the design compressive strength (f_c') of the concrete, which is calculated as follows:

$$\alpha_1 = 0.85;\ \text{for } f_c' < 10.0 \text{ ksi}$$
$$= 0.85 - 0.02(f_c' - 10) \geq 0.75;\ \text{for } f_c' \geq 10.0 \text{ ksi}$$

The stress block factor (β_1) is determined according to AASHTO LRFD Article 5.6.2.2. The values of β_1 vary according to the compressive strength (f_c') of the concrete, which is calculated as follows:

$$\beta_1 = 0.85;\ \text{for } f_c' < 4.0 \text{ ksi}$$
$$= 0.85 - 0.05(fc' - 4) \geq 0.65;\ \text{for } f_c' \geq 4.0 \text{ ksi}$$

The nominal moment capacity is determined using the following equation. This equation is basically for the beam with T-section behavior. In the case of beams with rectangular section behavior, the width of the web (b_w) is taken equal to the width of the compression face *(b)* of the beam i.e., $b = b_w$.

$$M_n = A_{ps} f_{ps}\left(d_p - \frac{a}{2}\right) + A_s f_s\left(d_s - \frac{a}{2}\right) - A_s' f_s'\left(d_s' - \frac{a}{2}\right) + \alpha_1 f_c'\left(b - b_w\right) h_f\left(\frac{a}{2} - \frac{h_f}{2}\right)$$

where:

A_{ps} = Area of prestressing steel (in^2)

f_{ps} = Average stress in prestressing steel at nominal bending resistance, as specified in AASHTO LRFD Article 5.6.3.1.1-1(ksi)

d_p = Distance from extreme compression fiber to the centroid of prestressing tendons (in.)

A_s = Area of non-prestressed tension reinforcement (in^2)

f_s = Stress in the non-prestressed tension reinforcement at nominal flexural resistance (ksi), as specified in AASHTO LRFD Article 5.6.2.1

d_s = Distance from extreme compression fiber to the centroid of non-prestressed tensile reinforcement (in.)

A_s' = Area of compression reinforcement (in^2)

f_s' = Stress in the non-prestressed compression reinforcement at nominal flexural resistance (ksi), as specified in AASHTO LRFD Article 5.6.2.1

d_s' = Distance from extreme compression fiber to the centroid of compression reinforcement (in.)

fc' = Design concrete compressive strength (ksi)

For composite beams where the neutral axis lies below both the deck and the beam, the nominal moment capacity is determined using the same equation, incorporating the compressive strength of the deck. According to test results by Rizkalla et al. (2007), rather than performing a detailed analysis using two different concrete compressive strengths in the compression zone, employing the lower compressive strength of the deck provides a sufficiently accurate and conservative estimate of the nominal flexural resistance. AD-BOX calculates the moment capacity of composite beams by using the lower compressive strength between the deck concrete and the beam concrete.

The resistance factor (ϕ) is determined according to the AASHTO LRFD Article 5.5.4.2. The resistance factor accounts for ensuring a ductile failure occurs in the designed section and maximum reinforcement is not exceeded. The beam sections are classified as tension-controlled, transition, or compression-controlled based on net tensile strain (ε_t) in extreme tension steel. Compression-controlled and tension-controlled sections are those sections that have net tensile strain in the extreme tension steel at nominal strength less than or equal to the compression-controlled strain limit (ε_{cl}), and equal to or greater than the tension-controlled strain limit (ε_{tl}), respectively. For prestressed concrete beams, the compression-controlled strain limit ε_{cl} = 0.002 and the tension-controlled strain limit ε_{tl} = 0.005. The sections with net tensile strain in between these limits are transition sections. Classifying sections as tension-controlled, transition or compression-controlled, and linearly varying, the resistance factor in the transition zone between reasonable values for the two extremes provides a rational approach for determining φ and limiting the capacity of over-reinforced sections. The value of φ for the prestressed section is calculated using the following relation:

$$0.75 \le \phi = 0.75 + \frac{0.25\left(\varepsilon_t - (\varepsilon_{cl} = 0.002)\right)}{\left((\varepsilon_{tl} = 0.005) - (\varepsilon_{cl} = 0.002)\right)} \le 1.0$$

AD-BOX also checks for minimum reinforcement in the evaluated beam. The amount of prestressed and non-prestressed tensile reinforcement shall be adequate to develop the following conditions:

$$M_r \ge \min(1.33M_u, M_{cr})$$

where:

M_u = factored moment required by the applicable strength load combination

M_{cr} = cracking moment of the beam (kips-in)

The cracking moment (M_{cr}) is calculated using the AASHTO LRFD Eqn. 5.6.3.3-1, which is given by:

$$M_{cr} = \gamma_3\left[\left(\gamma_1 f_r + \gamma_2 f_{cpe}\right)S_c - M_{dnc}\left(\frac{S_c}{S_{nc}} - 1\right)\right]$$

where:

M_{cr} = Cracking moment (kips-in)
f_r = Modulus of rupture of concrete specified in AASHTO LRFD Article 5.4.2.6
f_{cpe} = Compressive stress in concrete due to effective prestress forces only (after allowance for all prestress losses) at the extreme fiber of section where tensile stress is caused by externally applied loads (ksi)

S_c = Section modulus for the extreme fiber of the composite section where tensile stress is caused by externally applied loads (in^3)

M_{dnc} = Total unfactored dead load moment acting on the monolithic or non-composite section (kips-in)

S_{nc} = Section modulus for the extreme fiber of the monolithic or non-composite section where tensile stress is caused by externally applied loads (in^3)

γ_1 = Flexural cracking variability factor = 1.2 for precast segmental structure

γ_2 = Prestress variability factor = 1.1 for bonded tendons

γ_3 = 1.0 for prestressing steel

Section B1.7 of Appendix B presents the detailed calculation of the nominal moment capacity for a sample bridge.

3.1.3.5.2 Shear Capacity

The nominal shear capacity is calculated using the sectional method according to AASHTO LRFD Article 5.7.3.3 derived from Modified Compression Field Theory by Vecchio and Collins (1986). The nominal shear resistance (V_n) is determined as lesser of the following:

$$V_n = V_c + V_s + V_p$$

$$V_n = 0.25 f_c' b_v d_v + V_p$$

in which:

V_p = component of prestressing force in the direction of the shear force; positive if resisting the applied shear, which is equal to zero for box beams because all prestressing strands are along the longitudinal axis.

$$V_c = 0.0316 \beta \lambda \sqrt{f_c'} b_v d_v$$

$$V_s = \frac{A_v f_y d_v (\cot\theta + \cot\alpha)\sin\alpha}{s} \lambda_{duct}$$

For box beam bridges, the angle of inclination of the traverse reinforcement to the longitudinal axis (α) is equal to 90 degrees. So, the equation for V_s reduces to:

$$V_s = \frac{A_v f_y d_v \cot\theta}{s} \lambda_{duct}$$

where:

b_v = Effective web width (in.)

d_v = Effective shear depth (in.)

λ = Concrete density modification factor

s = Spacing of transverse reinforcement measured in a direction parallel to the longitudinal reinforcement (in.)

A_v = Area of transverse reinforcement within a distance s (in^2)

λ_{duct} = Shear strength reduction factor taken as 1.0 because of the use of ungrouted post-tensioning in box beam bridges

β = Factor indicating the ability of diagonally cracked concrete to transmit tension and shear

θ = Angle of inclination of diagonal compressive stresses (degrees)

The values of β and θ parameters are found according to the general procedure specified in AASHTO LRFD Article 5.7.3.4.2.

The longitudinal reinforcement should be checked to ensure that the tensile capacity of the member is sufficient to resist the tension induced by the shear force, according to AASHTO LRFD 5.7.3.5-1 as presented in the following equilibrium equation. This check is required to ensure the longitudinal tension flexural reinforcement is adequate to achieve the calculated shear capacity.

$$A_s f_y + A_{ps} f_{ps} \geq \frac{|M_u|}{d_v \phi_f} + 0.5\frac{N_u}{\phi_c} + \left(\left|\frac{V_u}{\phi_v} - V_p\right| - 0.5V_s\right)\cot\theta$$

where:

A_s = Area of non-prestressed tension reinforcement (in^2)

A_{ps} = Area of prestressing steel (in^2)

f_y = Yield strength of non-prestressed tension reinforcement (ksi)

f_{ps} = Effective stress in prestressing strands (ksi)

ϕ_f, ϕ_v, ϕ_c = resistance factors taken from AASHTO LRFD Article 5.5.4.2 as appropriate for the moment, shear, and axial resistance

V_u = Shear demand (kips)

M_u = Concurrent bending moment (kips-in.)

N_u = Axial force in the member (kips)

d_v = Effective shear depth (in.)

V_p = Component of prestressing force in the direction of the shear force (kips)

V_s = Shear strength due to shear reinforcement (kips)

θ = Angle of inclination of diagonal compressive stresses (degrees)

This longitudinal reinforcement criterion may govern for bridges that were not designed according to this criterion. If the equilibrium is not satisfied, the shear capacity of the beam should be reduced based on the maximum shear demand (V_u) that can be applied on the beam. This is an iterative process performed with the assumption of reduced shear demand and concurrent moment until the equilibrium is satisfied. The detailed procedure for calculating the shear capacity considering the longitudinal reinforcement criterion is proposed by the Federal Highway Administration (FHWA) report, FHWA-HIF-22-025 (Holt et al. 2022).

AD-BOX checks the longitudinal reinforcement criterion to confirm that the longitudinal reinforcement provided is adequate to achieve the shear capacity calculated using the sectional method. However, if the equilibrium is not satisfied, AD-BOX informs the user to perform this check manually using an appropriate method, such as the one proposed in the FHWA report.

Section B1.8 of Appendix B presents the detailed calculation of the nominal shear capacity for a sample bridge.

3.1.3.6. Load Rating

The Load rating of the bridge is performed according to the methods incorporated in AASHTO MBE Section 6. This section incorporates two parts: Part A provides specifics to the Load and Resistance Factor Rating (LRFR) method and Part B provides specifics to allowable stress and load factor methods. AD-BOX uses the LRFR method using the strength limit states to load rate the vehicles listed in Section 3.1.3.1.2 of this report. For inventory condition for design vehicle HL-93, the service limit state is also checked using the allowable stress method as specified in AASHTO MBE (2018). Based on load types, the load rating is comprised of three distinct procedures: design load rating, legal load rating, and permit load rating.

The load rating of a bridge is performed based on the structural condition, material properties, loads, and traffic conditions at the bridge site. Prior to the load rating, the condition information of the bridge is collected from the site inspection record. The structural design information and the material properties are collected from the drawings. The vehicular loads and traffic conditions are selected as per the specific standards of the load rating department. The following general expression is used in determining the load rating of the bridges.

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

For strength limit states:

$C = \phi_c \phi_s \phi R_n$ where: $\phi_c \phi_s \geq 0.85$

For the service limit states:

$C = f_r$

where:

RF = Rating factor

C = Capacity

f_r = Allowable stress

R_n = Nominal member resistance

D_c = Dead load effect due to structural components and attachments

D_W = Dead load effect due to wearing surface and utilities

P = Permanent loads other than dead loads

LL = Live load effect

IM = Dynamic load allowance

γ_{DC} = Load factor for structural components and attachments

γ_{DW} = Load factor for wearing surfaces and utilities

γ_p = Load factor for permanent loads other than dead loads = 1.0

γ_{LL} = Live load factor

ϕ_c= Condition factor

ϕ_s = System factor

ϕ = Resistance factor

The load rating is carried out to each applicable limit state and load effect. The lowest factor amongst the applicable limit states is the controlling rating factor. The load factors are applied to each load effect according to the limit states as specified in AASHTO MBE Table 6A.4.2.2.2-1. The limit states and load factors specific to each of the three procedures are specified in the subsequent sections of this report.

The condition factor (ϕ_c) is provided to account for the uncertainty in the resistance of the deteriorated beams and likely increased future deterioration. This factor is tied to the structural condition of the member and only accounts for the member's deterioration due to natural causes (e.g., atmospheric corrosion). THE Damage caused by accidents is specifically not considered. In AD-BOX, the condition factor should be selected based on the information collected from the site inspection and according to AASHTO MBE Table C6A.4.2.3-1, as presented herein Table 3-8.

Table 3-8 Condition factors.

Superstructure condition rating	Structural condition of member	ϕ_c
6 or higher	Good or Satisfactory	1.00
5	Fair	0.95
4 or lower	Poor	0.85

The system factor (ϕ_s) is a multiplier applied to the nominal resistance to account for the redundancy of the complete superstructure. The structural members of a bridge do not behave independently; they interact with one another to form a unified system. Bridge redundancy refers to the capability of a bridge's structural system to carry loads even after damage to or failure of one or more of its members. The system factors are selected according to AASHTO MBE Article 6A.4.2.4. In AD-BOX, for box beam bridges, the system factor is set at 1.00.

3.1.3.6.1 Design Load Rating

The design load rating is for the assessment of the bridge using the design loading (HL-93). The design load rating is performed for the inventory and operating level for the HL-93 loading. The design-load rating is performed using dimensions and properties for the bridge in its present condition, obtained from a recent field inspection. For the inventory level, the design load rating shall be performed for Strength-I as well as Service-III limit states. For the operating level, the design load rating shall be performed for the Strength-I limit state. The limit states and load factors for design load rating are adopted according to AASHTO MBE Table 6A.4.2.2.2-1. The load factors specific to the design load rating of prestressed concrete bridges are presented in Table 3-9.

Table 3-9 Limit states and load factors for the design vehicle.

Limit state	Dead load	Dead load	Design Vehicle (HL-93)	
			Inventory	Operating
	γ_{DC}	γ_{DW}	γ_{LL}	γ_{LL}
Strength-I	1.25	1.50	1.75	1.35
Service-III	1.00	1.00	0.80	-

The dynamic allowance (*IM*) for design load rating is adopted according to AASHTO LRFD Article 3.6.2. The load effects due to the HL-93 truck increased by IM = 33% to account for the dynamic effects due to moving vehicles. The dynamic allowance is not applied to the lane load.

Section B1.10 of Appendix B presents the detailed calculation of the design load rating for a sample bridge.

3.1.3.6.2 Legal Load Rating

The primary purpose of legal load rating is to assess bridges that lack sufficient capacity under design load rating. The legal load rating establishes ratings for the AASHTO family of legal loads and state-specific legal loads. In AD-BOX, the legal load rating includes three Ohio legal loads (3F1, 4F1, and 5C1), three AASHTO legal vehicles (Type 3, Type 3S2, and Type 3-3), and four specialized hauling vehicles (SU4, SU5, SU6, and SU7). The legal load ratings shall be conducted using the Strength-I limit state, and the Service-III limit state which is optional.

The load factor for Strength-I limit states shall be adopted according to AASHTO MBE Table 6A.4.2.2.2-1, as presented in Table 3-10. The load factors are based on the average daily truck traffic (ADTT) of the bridge. A linear interpolation is permitted for ADTT values between 1000 and 5000. For the Service-III limit state, the load factors are taken 1.00 for both the dead load and live loads.

Table 3-10 Live load factors for legal vehicles.

Traffic volume (one direction)	**Load factor (γ_{LL})** [a]
Unknown	1.45
ADTT ≥ 5000	1.45
ADTT ≤ 1000	1.30

Note:
a Linear interpolation is permitted for ADTT values between 1000 and 5000

The dynamic allowance (*IM*) for legal load rating is adopted according to AASHTO LRFD Article 3.6.2, where the load effects from legal vehicles are increased by 33% to account for dynamic effects. The bridge's response to moving vehicles is influenced by the pavement conditions and the dynamic characteristics of both the bridge and the vehicle. Most bridge load tests indicate that roadway imperfections significantly impact bridge responses to traffic loads. The 33% dynamic load allowance is intentionally conservative, reflecting conditions that may arise with distressed approaches or bridge decks featuring bumps, sags, or other surface irregularities. In AD-BOX, an IM of 33% is used by default for all legal vehicles. Moreover, for longitudinal members with spans greater than 40 feet and less severe conditions, the dynamic load allowance (*IM*) may be reduced according to AASHTO MBE Table C6A.4.4.3-1, as presented in Table 3-11.

Table 3-11 Dynamic allowance based on riding surface conditions.

Riding Surface Conditions	**IM**
Smooth riding surface at approaches, bridge deck, and expansion joints	10%
Minor surface deviations or depressions	20%

Section B1.11 of Appendix B presents the detailed calculation of the permit load rating for a sample bridge.

3.1.3.6.3 Permit Load Rating

Bridge owners have established procedures for permitting vehicles that exceed legal weight limits. This usually involves issuing a permit that outlines the vehicle's specifications and the approved travel routes. The permit load rating procedure enables bridge owners to determine the load rating factor necessary to issue permits for rated bridges. The permit load rating is performed for the Strength-II state, and Service-I limit state which is optional for prestressed concrete bridges. Permits are further categorized as routine or annual permit and special or limited permit.

a. Routine or Annual Permit

The routine permits generally allow unlimited trips for vehicles within specified weight limits over a year. These permit vehicles may mix in the traffic stream and move at normal speeds without any movement restrictions.

b. Special or Limited Permit

The special permits are typically valid for a single trip or a limited number of trips, often for heavier vehicles than those with routine permits. The single-trip permits are valid for a specified period (usually 3–5 days), while multiple-trip permits allow overweight shipments over 30–90 days.

The single trip permits for excessively heavy loads may include conditions to mitigate load effects, such as:

- Escort requirements to restrict other traffic on the bridge.
- Specific positioning of the permit vehicle on the bridge to reduce stress on critical components.
- Crawling speed (<10 mph) to minimize dynamic load effects.

Based on the type of permit loads, the load factors for the permit vehicle are adopted according to the AASHTO MBE Table 6A.4.5.4.2a.1, as presented herein Table 3-12.

Table 3-12 Live load factors for permit vehicles.

Permit type	Frequency	Loading condition	DF[a]	ADTT (one direction)	Load factor by permit weight ratio[b]		
					GVW / AL < 2.0 (kip/ft)		
					GVW / AL < 2.0 (kip/ft)	2.0 < GVW / AL < 3.0 (kip/ft)	GVW / AL >3.0 (kip/ft)
Routine or annual	Unlimited crossings	Mix with traffic (other vehicles may be on the bridge)	Two or more lanes	> 5000	1.40	1.35	1.30
				=1000	1.35	1.25	1.20
				<100	1.30	1.25	1.15
	Unlimited crossings (Reinforced concrete box culverts)[c]	Mix with traffic (other vehicles may be on the bridge)	One lane	All ADTTs	1.40		
					All weights		
Special or limited crossing	Single trip	Escorted with no other vehicles on the bridge	One lane	N/A	1.10		
	Single trip	Mix with traffic (other vehicles may be on the bridge)	One lane	All ADTTs	1.20		
	Multiple trips (less than 100 crossings)	Mix with traffic (other vehicles may be on the bridge)	One lane	All ADTTs	1.40		

Notes:

a DF = LRFD-distribution factor. When a one-lane distribution factor is used, the built-in multiple presence factor should be divided out.

b Permit Weight Ratio = GVW/AL; GVW = Gross Vehicle Weight; AL = Front axle to rear axle length; Use only axles on the bridge.

c Refer to AASHTO MBE Article 6A.5.12.

The dynamic load allowance to be applied to the permit load rating is specified in Section 3.1.3.6.2 of this report. For slow-moving (≤10 mph) permit vehicles, the dynamic load allowance may be eliminated.

Section B1.12 of Appendix B presents the detailed calculation of the permit load rating for a sample bridge.

3.1.4. Presentation of Envelopes

In AD-BOX, an optional tab (Envelopes) is developed as a standalone feature to present bending moment and shear force envelopes due to a selected vehicle type on any single span simply supported bridge, including box beam bridges. Envelopes for bending moment and shear force represent the maximum possible values of these forces at different locations along the bridge span due to moving loads. The envelopes are calculated at 12 intermediate points on the bridge span including the exact maximum location, providing a detailed representation of force distribution along the bridge. The calculated values do not include any distribution or impact factors. Appropriate distribution and impact factors should be applied. The value of moment and shear force at each location is the maximum of moment and shear force due to the vehicle with all possible axle positioning, calculated using the influence line method as specified in Section 3.1.3.4 of this report. These envelopes, providing pre-calculated maximum forces, can be independently used in the design and evaluation process of bridges. Combination with dead loads and multiple vehicles is not included to maintain the simplicity of the AD-BOX interface.

The envelopes for bending moments are presented in both tabular and graphical formats, where the bending moments due to the selected vehicle type are plotted on the y-axis, and the distance from the support of the bridge is plotted on the x-axis, as shown in Figure 3-14. This graph helps visualize how bending moments vary along the bridge span, making it easier to identify the maximum bending moments and their specific locations on the bridge span.

Similarly, the envelopes for shear forces are also presented in both tabular and graphical formats, where the shear forces due to the selected vehicle type are plotted on the y-axis, and the distance from the support of the bridge is plotted on the x-axis, as shown in Figure 3-15. Figure 3-15 is an example of a shear envelope for the vehicle Type 3-3 on a 65.50 ft simply supported bridge. This graph helps visualize how shear forces vary along the bridge span, making it easier to identify the maximum shear forces and their specific locations on the bridge span. Only positive shear force is shown in the graph. The negative shear force also acts on the simply supported bridge, which is the exact mirror of the presented values.

These envelopes provide critical moment and shear values to use independently for the design and evaluation of any single span, simply supported bridges.

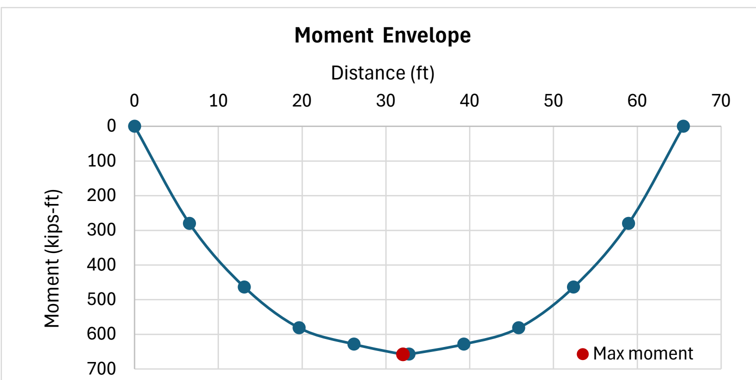


Figure 3-14 Moment envelope for vehicle Type 3-3 on a 65.50 ft simply supported bridge span.

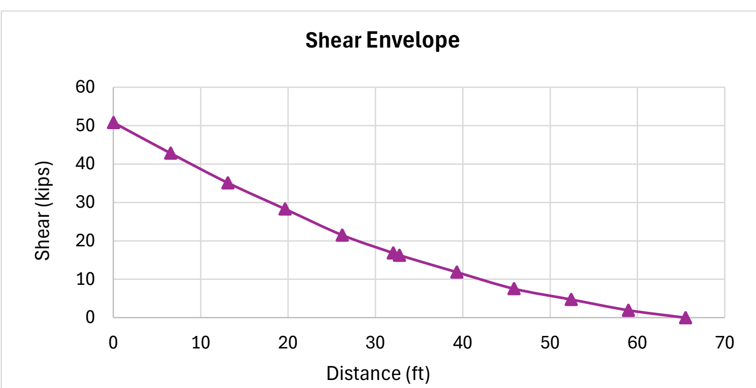


Figure 3-15 Shear envelope for vehicle Type 3-3 on a 65.50 ft simply supported bridge span.

3.1.5. Notes, Warnings, and Error Messages

Notes, warnings, and error messages are added to the AD-BOX interface. Notes are information for the users. Warning messages indicate that something is unusual, and the users should check the input. Error messages indicate that there is an error in the input and terminate the execution until the error is corrected. The list of the notes, warnings, and error messages is presented in Table 3-13, Table 3-14, and Table 3-15 respectively.

Table 3-13 List of notes in AD-BOX.

	Particulars	**Notes**
1.	Bridge span	Input bridge span between 20 and 120 ft.
2.	End offset	Input distance from the edge of beam to the center of bearing.
3.	Thickness of deck slab	Thickness must include hunch and deck slab.
4.	Skew angle	Input skew angle between 0 and 30.
5.	Appraisal rating	Input appraisal rating from 0 to 9.
6.	ADTT	Input average daily traffic in one direction. Input 'unknown,' if data is not available.
7.	Average annual humidity	Input average annual humidity between 0% and 100%.
8.	Additional beam weight	Miscellaneous load added to beam self-weight.
9.	Additional barrier weight	Miscellaneous load added to barrier weight.
10.	Input for service limit states	Long-term prestress losses are based on refined analysis according to AASHTO LRFD Article 5.9.3.4.
11.	Box beam section used	The listed Sections are from ODOT standard PSBD 02-07. Select 'Custom' to input other sections.
12.	Concrete compressive strength at transfer	Input concrete compressive strength up to 10 ksi.
13.	Concrete compressive strength in design	Input concrete compressive strength up to 10 ksi.
14.	Concrete compressive strength of the deck concrete	Input concrete compressive strength up to 10 ksi.
15.	Unit weight of concrete	Input unit weight of normal weight concrete between 0.135 and 0.155 kcf.
16.	Reinforcement bars	Input reinforcement bars at the bottom flange only.
17.	Shear reinforcement	Region 1: Zone near the Support. Region 2: Zone away from support towards the center.
18.	Add custom vehicle	Custom vehicles are treated as permit vehicles. Input a maximum of 35 axles.

Table 3-14 List of warning messages in AD-BOX.

	Particulars	Warning Messages
1.	Change of input	Click on the 'COMPUTE LOAD RATING' button. Some input values have been changed.
2.	Negative total width	Unusual total width detected. Check input.
3.	Negative end offset	Unusual end offset detected. Check input.
4.	Negative width of bearing	Unusual width of bearing detected. Check input.
5.	Negative width of the barrier	Unusual width of the barrier detected. Check input.
6.	Negative thickness of the deck slab	Unusual thickness of the deck slab detected. Check input.
7.	Unusual additional beam weight	Unusual additional beam weight detected. Check input.
8.	Unusual additional barrier weight	Unusual additional barrier weight detected. Check input.
9.	Negative ADTT	Unusual ADTT detected. Check input.
10.	Unusual thickness of diaphragms	Unusual thickness of diaphragms detected. Check input.
11.	Unusual yield strength	Unusual yield strength detected. Check input.
12.	Unusual modulus of elasticity	Unusual modulus of elasticity detected. Check input.
13.	Unusual unit weights of surfacing material	Unusual unit weights of surfacing material detected. Check input.
14.	Unusual unit weights of the barrier	Unusual unit weights of the barrier detected. Check input.
15.	Unusual dynamic load allowance	Unusual dynamic load allowance detected. Check input.

Table 3-15 List of error messages in AD-BOX.

	Particulars	Error Messages
1.	Invalid bridge span	Invalid bridge span.
2.	Invalid appraisal rating	Invalid appraisal rating.
3.	Invalid position of diaphragms	Invalid position of diaphragms.
4.	Invalid average annual humidity	Invalid average annual humidity.
5.	Invalid number of box beams	Invalid number of box beams.
6.	Invalid number of prestressing strands	Invalid number of prestressing strands.
7.	Invalid concrete compressive strength at transfer	Invalid concrete compressive strength at transfer.
8.	Invalid concrete compressive strength in design	Invalid concrete compressive strength in design.
9.	Invalid concrete compressive strength of the deck concrete	Invalid concrete compressive strength of the deck concrete.
10.	Invalid unit weight of concrete	Invalid unit weight of concrete.
11.	Negative load rating results	Unusual load rating results. Check the input.
12.	Load rating cannot be completed	Load rating cannot be completed. Some input values are either invalid or undefined.

3.2. Verification of AD-BOX

3.2.1. Verification with Independent Hand Calculations

To check the accuracy and reliability of AD-BOX, independent hand calculations are performed, and the load rating results are compared. A total of 18 sample bridges, including 16 with single-cell box beams and two with multicell box beams, are load-rated using independent hand calculations and AD-BOX. These sample bridges are existing bridges located in Ohio and are provided for research purposes by ODOT. The general information on bridges used for the verification with independent hand calculations is presented in Table 3-16.

The bridges selected for this study include a mix of skewed and non-skewed bridges, which have either non-composite or composite beams. The samples include a total of seven non-skewed bridges (three with non-composite and four with composite cross sections) and eleven skewed bridges (five with non-composite and six with composite cross sections). Among the skewed bridges, nine have single-cell box beams, while two have multicell box beams. This diverse selection of bridge types allowed for a thorough examination of rating factors for different bridge types under the required vehicular loading conditions.

Table 3-16 List of sample bridges used for verification.

Sample no	Year of Construction	Design Span (ft)	Composite/ Non-composite	Box Beam Section	Skew/ Non-skew	Skew (Degrees)
Single-cell Box Beam Bridges						
1	2024	30	Non-composite	B17-48	Non-skew	0
2	2018	50	Non-composite	B21-48	Non-skew	0
3	1982	62	Non-composite	B33-48	Non-skew	0
4	2023	25	Composite	CB17-36	Non-skew	0
5	2021	45	Composite	CB17-48	Non-skew	0
6	2018	55	Composite	CB17-48	Non-skew	0
7	2021	80	Composite	CB27-48	Non-skew	0
8	2018	42	Non-composite	B21-48	Skew	28
9	1984	65	Non-composite	B27-48	Skew	5
10	2009	65.5	Non-composite	B21-48	Skew	12
11	1985	74.85	Non-composite	B33-36	Skew	30
12	2016	75	Non-composite	B33-36	Skew	10
13	2021	26	Composite	CB17-48	Skew	30
14	2022	47.71	Composite	CB21-48	Skew	19
15	2018	60	Composite	CB27-48	Skew	24
16	2019	83	Composite	CB33-48	Skew	20
Multicell Box Beam Bridges						
17	1996	35	Composite	CB17-48	Skew	30
18	2007	45	Composite	CB21-48	Skew	10

The bridges are load rated for 15 vehicle types required by ODOT BDM, including the Design Vehicle (HL-93), Ohio legal loads (2F1, 3F1, 5C1), AASHTO legal loads (Type 3, Type 3S2, Type 3-3), special hauling vehicles (SU4, SU5, SU6, SU7), emergency vehicles (EV2, EV3), and permit loads (PL 60T, PL 65T). The load rating procedure is based on the guidelines specified in the AASHTO MBE (2018) and AASHTO LRFD (2024), with specific details from ODOT BDM (2020), as reviewed in Section 2.2 of this report.

The RF values obtained from AD-BOX are verified with independent hand calculations. Verifications of the rating factors are based on the ratio of RFs from AD-BOX to those from hand calculations. The mean and coefficient of variation (CV) of these ratios are computed to evaluate the accuracy and reliability of AD-BOX calculations. Separate verifications are conducted for non-skewed and skewed bridges for each vehicle type, ensuring verification across various bridge configurations and vehicular loading conditions.

Figure 3-16 presents the results of the verification of AD-BOX with independent hand calculations. The RFs obtained from AD-BOX for 15 vehicle types across 18 sample bridges are plotted against the ratio of RFs from AD-BOX to independent hand calculations. A mean line is drawn, which is found to be approximately equal to 1.0. Table 3-17 presents the CVs obtained from the verification for each vehicle type. The CVs for each vehicle type are found to be approximately 0%. The mean of the ratios of approximately 1.0 with a CV of approximately 0% confirms the accuracy and reliability of AD-BOX. The detailed results of the verification are presented in the subsequent sections.

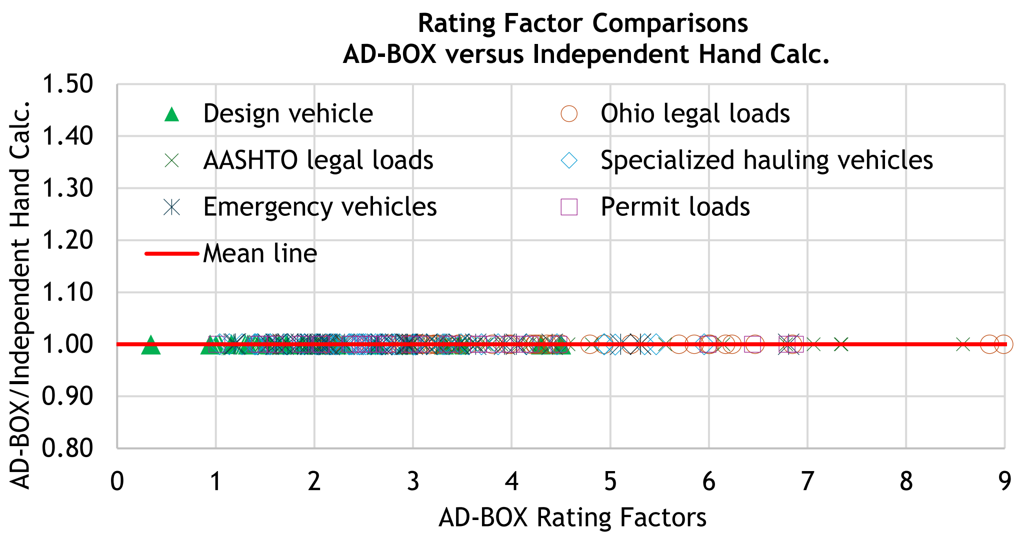


Figure 3-16 Rating factor comparisons for AD-BOX versus independent hand calculations.

Table 3-17 Coefficient of variations for verification for AD-BOX versus independent hand calculations.

Vehicle types		Coefficient of variation (CV) AD-BOX/Hand calc.		
		Non skewed bridges	Skewed bridges	
		Single-cell box beam bridges	Single-cell box beam bridges	Multicell box beam bridges
Design vehicle HL-93	Inventory	0.01%	0.05%	0.03%
	Operating	0.01%	0.01%	0.03%
Ohio legal loads	2F1	0.01%	0.01%	0.01%
	3F1	0.01%	0.01%	0.02%
	5C1	0.02%	0.01%	0.02%
AASHTO legal loads	Type 3	0.01%	0.02%	0.03%
	Type 3S2	0.01%	0.01%	0.02%
	Type 3-3	0.02%	0.01%	0.03%
Specialized hauling vehicles	SU4	0.03%	0.01%	0.02%
	SU5	0.01%	0.01%	0.02%
	SU6	0.02%	0.01%	0.03%
	SU7	0.02%	0.02%	0.03%
Emergency vehicles	EV2	0.02%	0.02%	0.03%
	EV3	0.02%	0.02%	0.02%
Permit loads	PL60T	0.02%	0.00%	0.02%
	PL65T	0.02%	0.00%	0.02%

Appendix B presents the detailed hand calculations for sample bridge 15 as a representative sample and the results for all other sample bridges. Refer to Appendix C for the input values and AD-BOX results for all sample bridges.

3.2.1.1. Non-Skewed Bridges

The verification is performed using seven non-skewed bridges comprising three non-composite and four composite cross sections. The design vehicle HL-93, at the inventory condition, is load rated for the Strength-I and Service-III limit states. At the operating condition, HL-93, Ohio legal vehicles, AASHTO legal vehicles, specialized hauling vehicles, and emergency vehicles are load rated using the Strength-I limit state, as discussed in Section 3.1.3.6 of this report. The verification results are detailed in Table 3-18 through Table 3-27 , which presents the comparison of rating factors obtained from independent hand calculations and AD-BOX. The load rating results from the independent hand calculations for the non-skewed sample bridges are presented in Section B2.1 of Appendix B.

Table 3-18 presents a comparison of the RF ratios for non-skewed sample bridges for the design vehicle, HL-93 at inventory, and operating conditions for the Strength-I limit state. The mean of the ratios is found to be 1.000, with a CV of nearly equal to 0.00%, indicating that AD-BOX computes RF values for HL-93 that are well aligned with independent hand calculations.

Table 3-18 AD-BOX versus independent hand calculations of non-skewed bridges for the design vehicle.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Design load (HL-93)					
				Inventory			Operating		
				AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
1	Non-composite	2024	31	1.703	1.703	1.000	2.207	2.207	1.000
2	Non-composite	2018	50	1.546	1.546	1.000	2.005	2.004	1.000
3	Non-composite	1982	62	1.036	1.036	1.000	1.343	1.343	1.000
4	Composite	2023	28	2.258	2.258	1.000	2.928	2.928	1.000
5	Composite	2021	45	1.548	1.548	1.000	2.007	2.007	1.000
6	Composite	2018	55	1.183	1.183	1.000	1.876	1.876	1.000
7	Composite	2021	80	1.769	1.769	1.000	2.293	2.293	1.000
					Mean	**1.000**		**Mean**	**1.000**
					CV	**0.01%**		**CV**	**0.01%**

HL-93 at the inventory condition is also checked using the Service-III limit state. The governing load rating factor is the minimum value of the rating factor at Strength-I and Service-III limit states. Table 3-19 presents verification for seven non-skewed bridges for HL-93 at inventory condition.

Table 3-19 AD-BOX versus independent hand calculations of non-skewed bridges for the design vehicle.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Design Vehicle (HL-93)			Governing Limit State
				Inventory			
				AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	
1	Non-composite	2024	31	1.703	1.703	1.000	**Strength-I**
2	Non-composite	2018	50	1.546	1.546	1.000	**Strength-I**
3	Non-composite	1982	62	1.036	1.036	1.000	**Strength-I**
4	Composite	2023	28	2.258	2.258	1.000	**Strength-I**
5	Composite	2021	45	1.495	1.495	1.000	**Service-III**
6	Composite	2018	55	1.183	1.183	1.000	**Service-III**
7	Composite	2021	80	1.395	1.395	1.000	**Service-III**
					Mean	**1.000**	
					CV	**0.01%**	

Table 3-20 and Table 3-21 present a comparison of the RF ratios for non-skewed sample bridges for Ohio legal vehicles: 2F1, 3F1, and 5C1. The RF values for these vehicles are calculated using Strength-I limit states as explained in Section 3.1.3.6.2 of this report. The mean of the ratios is found to be 1.000, with a CV of nearly equal to 0.00%, indicating that AD-BOX computes RF values for Ohio legal vehicles that are well aligned with those calculated by independent hand calculation.

Table 3-20 AD-BOX versus independent hand calculations of non-skewed bridges for Ohio legal loads.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Ohio legal loads					
				2F1			3F1		
				AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
1	Non-composite	2024	31	4.411	4.411	1.000	3.107	3.107	1.000
2	Non-composite	2018	50	4.430	4.429	1.000	3.001	3.001	1.000
3	Non-composite	1982	62	3.214	3.214	1.000	2.157	2.157	1.000
4	Composite	2023	28	5.853	5.853	1.000	4.237	4.237	1.000
5	Composite	2021	45	4.243	4.243	1.000	2.888	2.888	1.000
6	Composite	2018	55	4.794	4.794	1.000	3.234	3.234	1.000
7	Composite	2021	80	5.994	5.994	1.000	3.993	3.993	1.000
					Mean	**1.000**		**Mean**	**1.000**
					CV	**0.01%**		**CV**	**0.01%**

Table 3-21 AD-BOX versus independent hand calculations of non-skewed bridges for Ohio legal load.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Ohio legal load		
				5C1		
				AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
1	Non-composite	2024	31	3.257	3.257	1.000
2	Non-composite	2018	50	3.077	3.075	1.001
3	Non-composite	1982	62	2.199	2.199	1.000
4	Composite	2023	28	4.501	4.501	1.000
5	Composite	2021	45	2.971	2.971	1.000
6	Composite	2018	55	3.306	3.306	1.000
7	Composite	2021	80	3.557	3.557	1.000
					Mean	**1.000**
					CV	**0.02%**

Table 3-22 and Table 3-23 present a comparison of the RF ratios for non-skewed sample bridges for AASHTO legal vehicles: Type 3, Type 3S2, and Type 3-3. The RF values for these vehicles are calculated using Strength-I limit states as explained in Section 3.1.3.6.2 of this report. The mean of the ratios is found to be 1.000, with a CV of nearly equal to 0.00%, indicating that AD-BOX computes RF values for AASHTO legal vehicles that are well aligned with those calculated by independent hand calculations.

Table 3-22 AD-BOX versus independent hand calculations of non-skewed bridges for AASHTO legal loads.

Sample No.	Types of beams	Year of constr.	Design span (ft)	AASHTO legal loads					
				Type 3		Ratio (a/b)	Type 3S2		Ratio (a/b)
				AD-BOX (a)	Independent hand calcs. (b)		AD-BOX (a)	Independent hand calcs. (b)	
1	Non-composite	2024	31	3.472	3.472	1.000	3.520	3.520	1.000
2	Non-composite	2018	50	3.054	3.053	1.000	3.301	3.300	1.000
3	Non-composite	1982	62	2.147	2.147	1.000	2.062	2.062	1.000
4	Composite	2023	28	4.575	4.575	1.000	4.814	4.814	1.000
5	Composite	2021	45	2.982	2.982	1.000	3.514	3.513	1.000
6	Composite	2018	55	3.255	3.255	1.000	3.319	3.319	1.000
7	Composite	2021	80	3.896	3.896	1.000	3.405	3.405	1.000
					Mean	**1.000**		**Mean**	**1.000**
					CV	**0.01%**		**CV**	**0.01%**

Table 3-23 AD-BOX versus independent hand calculations of non-skewed bridges for AASHTO legal load.

Sample No.	Types of beams	Year of constr.	Design span (ft)	AASHTO legal load		
				Type 3-3		Ratio (a/b)
				AD-BOX (a)	Independent hand calcs. (b)	
1	Non-composite	2024	31	4.276	4.276	1.000
2	Non-composite	2018	50	3.638	3.636	1.001
3	Non-composite	1982	62	2.232	2.232	1.000
4	Composite	2023	28	5.555	5.554	1.000
5	Composite	2021	45	3.579	3.579	1.000
6	Composite	2018	55	3.634	3.634	1.000
7	Composite	2021	80	3.501	3.501	1.000
					Mean	**1.000**
					CV	**0.02%**

Table 3-24 and Table 3-25 present a comparison of the RF ratios for non-skewed sample bridges for specialized hauling vehicles: SU4, SU5, SU6, and SU7. The RF values for these vehicles are calculated using Strength-I limit states as explained in Section 3.1.3.6.2 of this report. The mean of the ratios is found to be 1.000, with a CV of nearly equal to 0.00%, indicating that AD-BOX computes RF values for specialized hauling vehicles that are well aligned with those calculated by independent hand calculations.

Table 3-24 AD-BOX versus independent hand calculations of non-skewed bridges for specialized hauling vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Specialized hauling vehicles					
				SU4			SU5		
				AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
1	Non-composite	2024	31	2.860	2.860	1.000	2.664	2.664	1.000
2	Non-composite	2018	50	2.665	2.664	1.000	2.456	2.456	1.000
3	Non-composite	1982	62	1.898	1.898	1.000	1.728	1.728	1.000
4	Composite	2023	28	3.863	3.863	1.000	3.564	3.563	1.000
5	Composite	2021	45	2.579	2.579	1.000	2.397	2.397	1.000
6	Composite	2018	55	2.858	2.858	1.001	2.619	2.619	1.000
7	Composite	2021	80	3.486	3.486	1.000	3.138	3.138	1.000
					Mean	**1.000**		**Mean**	**1.000**
					CV	**0.03%**		**CV**	**0.01%**

Table 3-25 AD-BOX versus independent hand calculations of non-skewed bridges for specialized hauling vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Specialized hauling vehicles					
				SU6			SU7		
				AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
1	Non-composite	2024	31	2.432	2.432	1.000	2.333	2.333	1.000
2	Non-composite	2018	50	2.213	2.212	1.000	2.053	2.052	1.000
3	Non-composite	1982	62	1.552	1.552	1.000	1.427	1.427	1.000
4	Composite	2023	28	3.305	3.305	1.000	3.250	3.250	1.000
5	Composite	2021	45	2.163	2.163	1.000	2.017	2.017	1.000
6	Composite	2018	55	2.356	2.356	1.000	2.176	2.176	1.000
7	Composite	2021	80	2.812	2.812	1.000	2.569	2.568	1.000
					Mean	**1.000**		**Mean**	**1.000**
					CV	**0.02%**		**CV**	**0.02%**

Table 3-26 presents a comparison of RF values for seven non-skewed bridges for Emergency vehicles (EV2 and EV3). The RF values for these vehicles are calculated using Strength-I limit states, and load factors according to the FAST act as explained in Section 2.2.3. The mean of the ratios is found to be 1.000, with a CV of nearly equal to 0.00%, indicating that AD-BOX computes RF values for emergency vehicles that are well aligned with those calculated by independent hand calculations.

Table 3-26 AD-BOX versus independent hand calculations of non-skewed bridges for emergency vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Emergency vehicles					
				EV2			EV3		
				AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
1	Non-composite	2024	31	2.932	2.932	1.000	2.060	2.060	1.000
2	Non-composite	2018	50	2.644	2.643	1.000	1.730	1.729	1.000
3	Non-composite	1982	62	1.868	1.868	1.000	1.612	1.612	1.000
4	Composite	2023	28	3.926	3.925	1.000	3.637	3.637	1.000
5	Composite	2021	45	2.582	2.582	1.000	1.682	1.682	1.000
6	Composite	2018	55	2.824	2.824	1.000	2.002	2.002	1.001
7	Composite	2021	80	4.469	4.469	1.000	2.940	2.940	1.000
					Mean	**1.000**		**Mean**	**1.000**
						0.02%		**CV**	**0.02%**

Table 3-27 presents the verification of AD-BOX with independent hand calculations for seven non-skewed bridges for permit loads. Permit loads are rated using the Strength-II limit states. For permit loads also, the mean of the ratios is found to be 1.000, with a CV of nearly equal to 0.00%, indicating that AD-BOX computes RF values for permit vehicles that are well aligned with those calculated by independent hand calculations.

Table 3-27 AD-BOX versus independent hand calculations of non-skewed bridges for permit loads.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Permit loads					
				PL 60T			PL 65T		
				AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
1	Non-composite	2024	31	2.573	2.573	1.000	2.468	2.468	1.000
2	Non-composite	2018	50	2.596	2.595	1.000	2.369	2.368	1.000
3	Non-composite	1982	62	1.887	1.887	1.000	1.513	1.513	1.000
4	Composite	2023	28	4.478	4.476	1.000	4.187	4.186	1.000
5	Composite	2021	45	2.707	2.707	1.000	2.490	2.490	1.000
6	Composite	2018	55	3.921	3.921	1.000	3.350	3.350	1.000
7	Composite	2021	80	3.759	3.759	1.000	2.630	2.630	1.000
					Mean	**1.000**		**Mean**	**1.000**
					CV	**0.02%**		**CV**	**0.02%**

These verification tables for the seven non-skewed bridges, for all vehicle types required by ODOT BDM, show a mean of 1.000 and a CV of nearly equal to 0.00%. This indicates that the calculations from AD-BOX are well aligned with the independent hand calculations for load rating non-skewed precast prestressed adjacent box beam bridges with composite and non-composite cross sections.

3.2.1.2. Skewed Bridges

The verification is further carried out for the eleven skewed bridges with five non-composite and six composite cross sections. Load rating is performed for these bridges for 15 vehicle types required by ODOT BDM. A separate verification is carried out for nine single-cell and two multicell box beam cross sections. The verification results for nine skewed box beam bridges having single-cell box beam configurations are detailed from Table 3-28 through Table 3-37, which compares the RF values obtained from independent hand calculations and AD-BOX. Section B2.2 of Appendix B presents the load rating results from the independent hand calculations for the skewed sample bridges.

Table 3-28 presents a comparison of the RF ratios for nine skewed sample bridges for the design vehicle, HL-93 at inventory, and operating conditions for the Strength-I limit state. The mean of the ratios is found to be 1.000, with a CV of nearly equal to 0.00%, indicating that AD-BOX computes RF values for HL-93 that are well aligned with those calculated by independent hand calculations.

Table 3-28 AD-BOX versus independent hand calculations of skewed bridges for the design vehicle.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Design Vehicle (HL-93)					
					Inventory			Operating		
					AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
8	Non-composite	2020	42	28	1.639	1.639	1.000	2.124	2.124	1.000
9	Non-composite	1984	65	5	1.004	1.004	1.000	1.301	1.301	1.000
10	Non-composite	2021	65.5	12	1.022	1.022	1.000	1.325	1.325	1.000
11	Non-composite	1985	74.85	30	0.726	0.726	1.000	0.941	0.941	1.000
12	Non-composite	2016	76	10	1.718	1.717	1.001	2.228	2.228	1.000
13	Composite	2021	27	30	3.473	3.473	1.000	4.502	4.502	1.000
14	Composite	2022	50	19	3.314	3.313	1.000	4.296	4.295	1.000
15	Composite	2018	60	24	2.032	2.032	1.000	2.634	2.634	1.000
16	Composite	2019	83	20	1.517	1.517	1.000	1.966	1.966	1.000
						Mean	**1.000**		**Mean**	**1.000**
						CV	**0.01%**		**CV**	**0.01%**

HL-93 at inventory condition is also checked using the Service-III limit state, and the governing load rating factor is adopted as the minimum value of the rating factors between the Strength-I and Service-III limit states. Table 3-29 presents verification of AD-BOX at inventory condition at the Strength-I and Service-III limit states for nine skewed bridges.

Table 3-29 AD-BOX versus independent hand calculations of skewed bridges for inventory loading.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Design Vehicle (HL-93)			Governing limit states
					Inventory			
					AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	
8	Non-composite	2020	42	28	1.639	1.639	1.000	**Strength-I**
9	Non-composite	1984	65	5	1.004	1.003	1.000	**Strength-I**
10	Non-composite	2021	65.5	12	1.004	1.003	1.001	**Service-III**
11	Non-composite	1985	74.85	30	0.341	0.341	1.000	**Service-III**
12	Non-composite	2016	76	10	1.718	1.718	1.000	**Strength-I**
13	Composite	2021	27	30	3.473	3.473	1.000	**Strength-I**
14	Composite	2022	50	19	3.314	3.313	1.000	**Strength-I**
15	Composite	2018	60	24	2.023	2.023	1.000	**Strength-I**
16	Composite	2019	83	20	1.001	1.002	0.999	**Service-III**
						Mean	**1.000**	
						CV	**0.05%**	

Table 3-30 and Table 3-31 present a comparison of the RF ratios for nine skewed sample bridges for Ohio legal vehicles: 2F1, 3F1, and 5C1. The RF values for these vehicles are calculated using Strength-I limit states as explained in Section 3.1.3.6.2 of this report. The mean of the ratios is found to be 1.000, with a CV of nearly equal to 0.00%, indicating that AD-BOX computes RF values for Ohio legal vehicles that are well aligned with those calculated by independent hand calculations.

Table 3-30 AD-BOX versus independent hand calculations of skewed bridges for Ohio legal loads.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Ohio legal loads					
					2F1			3F1		
					AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
8	Non-composite	2020	42	28	4.359	4.359	1.000	2.982	2.982	1.000
9	Non-composite	1984	65	5	3.165	3.166	1.000	2.120	2.120	1.000
10	Non-composite	2021	65.5	12	3.234	3.234	1.000	2.165	2.165	1.000
11	Non-composite	1985	74.85	30	2.406	2.406	1.000	1.605	1.605	1.000
12	Non-composite	2016	76	10	5.697	5.697	1.000	3.803	3.803	1.000
13	Composite	2021	27	30	8.988	8.987	1.000	6.467	6.466	1.000
14	Composite	2022	50	19	8.846	8.846	1.000	6.011	6.011	1.000
15	Composite	2018	60	24	6.235	6.235	1.000	4.193	4.193	1.000
16	Composite	2019	83	20	5.209	5.209	1.000	3.466	3.466	1.000
						Mean	**1.000**		**Mean**	**1.000**
						CV	**0.01%**		**CV**	**0.01%**

Table 3-31 AD-BOX versus independent hand calculations of skewed bridges for Ohio legal load.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Ohio legal load		
					5C1		
					AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
	Non-composite	2020	42	28	3.075	3.075	1.000
9	Non-composite	1984	65	5	2.160	2.160	1.000
10	Non-composite	2021	65.5	12	2.206	2.206	1.000
11	Non-composite	1985	74.85	30	1.512	1.512	1.000
12	Non-composite	2016	76	10	3.520	3.520	1.000
13	Composite	2021	27	30	6.847	6.847	1.000
14	Composite	2022	50	19	6.171	6.170	1.000
15	Composite	2018	60	24	4.277	4.277	1.000
16	Composite	2019	83	20	3.036	3.036	1.000
						Mean	**1.000**
						CV	**0.01%**

Table 3-32 and Table 3-33 present a comparison of the RF ratios for nine skewed sample bridges for AASHTO legal vehicles: Type 3, Type 3S2, and Type 3-3. The RF values for these vehicles are calculated using Strength-I limit states as explained in Section 3.1.3.6.2 of this report. The mean of the ratios is found to be 1.000, with a CV of nearly equal to 0.00%, indicating that AD-BOX computes RF values for AASHTO legal vehicles that are well aligned with those calculated by independent hand calculations.

Table 3-32 AD-BOX versus independent hand calculations of skewed bridges for AASHTO legal loads.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	AASHTO legal loads					
					Type 3			Type 3S2		
					AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
8	Non-composite	2020	42	28	3.108	3.108	1.000	3.367	3.367	1.000
9	Non-composite	1984	65	5	2.102	2.102	1.000	1.982	1.982	1.000
10	Non-composite	2021	65.5	12	2.146	2.146	1.000	2.018	2.018	1.000
11	Non-composite	1985	74.85	30	1.574	1.574	1.000	1.413	1.413	1.000
12	Non-composite	2016	76	10	3.726	3.724	1.001	3.320	3.319	1.000
13	Composite	2021	27	30	7.063	7.063	1.000	7.343	7.343	1.000
14	Composite	2022	50	19	6.148	6.148	1.000	6.781	6.781	1.000
15	Composite	2018	60	24	4.182	4.182	1.000	4.069	4.069	1.000
16	Composite	2019	83	20	3.375	3.375	1.000	2.917	2.917	1.000
						Mean	**1.000**		**Mean**	**1.000**
						CV	**0.02%**		**CV**	**0.01%**

Table 3-33 AD-BOX versus independent hand calculations of skewed bridges for AASHTO legal load.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	AASHTO legal load		
					Type 3-3		
					AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
8	Non-composite	2020	42	28	3.745	3.745	1.000
9	Non-composite	1984	65	5	2.134	2.134	1.000
10	Non-composite	2021	65.5	12	2.170	2.170	1.000
11	Non-composite	1985	74.85	30	1.469	1.469	1.000
12	Non-composite	2016	76	10	3.468	3.468	1.000
13	Composite	2021	27	30	8.577	8.577	1.000
14	Composite	2022	50	19	7.339	7.339	1.000
15	Composite	2018	60	24	4.428	4.428	1.000
16	Composite	2019	83	20	2.980	2.980	1.000
						Mean	**1.000**
						CV	**0.01%**

Table 3-34 and Table 3-35 present a comparison of ratios of RF values for nine skewed sample bridges for specialized hauling vehicles: SU4, SU5, SU6, and SU7. The RF values for these vehicles are calculated using Strength-I limit states as explained in Section 3.1.3.6.2 of this report. The mean of the ratios is found to be 1.000, with CV of nearly equal to 0.00%, indicating that AD-BOX computes RF values for specialized hauling vehicles that are well aligned with those calculated by independent hand calculations.

Table 3-34 AD-BOX versus independent hand calculations of skewed bridges for specialized hauling vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Specialized hauling vehicles					
					SU4			SU5		
					AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
8	Non-composite	2020	42	28	2.673	2.673	1.000	2.496	2.496	1.000
9	Non-composite	1984	65	5	1.863	1.863	1.000	1.693	1.693	1.000
10	Non-composite	2021	65.5	12	1.902	1.902	1.000	1.728	1.728	1.000
11	Non-composite	1985	74.85	30	1.404	1.404	1.000	1.268	1.268	1.000
12	Non-composite	2016	76	10	3.325	3.325	1.000	3.000	3.000	1.000
13	Composite	2021	27	30	5.953	5.953	1.000	5.466	5.466	1.000
14	Composite	2022	50	19	5.348	5.348	1.000	4.941	4.941	1.000
15	Composite	2018	60	24	3.693	3.693	1.000	3.366	3.366	1.000
16	Composite	2019	83	20	3.023	3.023	1.000	2.720	2.720	1.000
						Mean	**1.000**		**Mean**	**1.000**
						CV	**0.01%**		**CV**	**0.01%**

Table 3-35 AD-BOX versus independent hand calculations of skewed bridges for specialized hauling vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Specialized hauling vehicles					
					SU6			SU7		
					AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
8	Non-composite	2020	42	28	2.258	2.258	1.000	2.116	2.116	1.000
9	Non-composite	1984	65	5	1.519	1.519	1.000	1.394	1.394	1.000
10	Non-composite	2021	65.5	12	1.550	1.550	1.000	1.422	1.422	1.000
11	Non-composite	1985	74.85	30	1.136	1.136	1.000	1.039	1.039	1.000
12	Non-composite	2016	76	10	2.690	2.691	1.000	2.461	2.460	1.000
13	Composite	2021	27	30	5.050	5.050	1.000	4.935	4.935	1.000
14	Composite	2022	50	19	4.460	4.461	1.000	4.148	4.149	1.000
15	Composite	2018	60	24	3.025	3.025	1.000	2.786	2.786	1.000
16	Composite	2019	83	20	2.435	2.435	1.000	2.221	2.221	1.000
						Mean	**1.000**		**Mean**	**1.000**
						CV	**0.01%**		**CV**	**0.02%**

Table 3-36 presents a comparison of RF values for nine skewed bridges for Emergency vehicles (EV2 and EV3). The RF values for these vehicles are calculated using Strength-I limit states, and load factors according to the FAST act as explained in Section 2.2.3 of this report. The mean of the ratios is found to be 1.000, with a CV of nearly equal to 0.00%, indicating that AD-BOX computes RF values for emergency vehicles that are well aligned with those calculated by independent hand calculations.

Table 3-36 AD-BOX versus independent hand calculations of skewed bridges for emergency vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Emergency vehicles					
					EV2			EV3		
					AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
8	Non-composite	2020	42	28	2.679	2.679	1.000	2.306	2.306	1.000
9	Non-composite	1984	65	5	1.831	1.830	1.001	1.199	1.198	1.000
10	Non-composite	2021	65.5	12	2.085	2.085	1.000	1.613	1.613	1.000
11	Non-composite	1985	74.85	30	1.532	1.532	1.000	1.186	1.186	1.000
12	Non-composite	2016	76	10	3.240	3.240	1.000	2.131	2.131	1.000
13	Composite	2021	27	30	6.808	6.808	1.000	5.106	5.106	1.000
14	Composite	2022	50	19	5.307	5.307	1.000	3.468	3.468	1.000
15	Composite	2018	60	24	4.048	4.048	1.000	3.138	3.138	1.000
16	Composite	2019	83	20	2.944	2.944	1.000	1.933	1.933	1.000
						Mean	**1.000**		**Mean**	**1.000**
						CV	**0.02%**		**CV**	**0.02%**

Table 3-37 presents verification of AD-BOX with independent hand calculations for nine skewed sample bridges for permit loads. Permit loads are rated using the Strength-II limit states. For permit loads also, the mean of the ratios is found to be 1.000, with a CV of nearly equal to 0.00%, indicating that AD-BOX computes RF values for permit vehicles that are well aligned with those calculated by independent hand calculations.

Table 3-37 AD-BOX versus independent hand calculations of skewed bridges for permit loads.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Permit loads					
					PL 60T			PL 65T		
					AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
8	Non-composite	2020	42	28	2.551	2.551	1.000	2.358	2.358	1.000
9	Non-composite	1984	65	5	1.859	1.859	1.000	1.444	1.444	1.000
10	Non-composite	2021	65.5	12	2.071	2.071	1.000	1.602	1.602	1.000
11	Non-composite	1985	74.85	30	1.406	1.406	1.000	1.011	1.011	1.000
12	Non-composite	2016	76	10	3.996	3.996	1.000	2.740	2.740	1.000
13	Composite	2021	27	30	6.878	6.878	1.000	6.443	6.443	1.000
14	Composite	2022	50	19	6.792	6.792	1.000	5.990	5.990	1.000
15	Composite	2018	60	24	3.662	3.662	1.000	2.998	2.998	1.000
16	Composite	2019	83	20	2.966	2.966	1.000	2.061	2.061	1.000
						Mean	**1.000**		**Mean**	**1.000**
						CV	**0.00%**		**CV**	**0.00%**

These verification tables for nine skewed bridges, for 15 vehicles required by ODOT BDM, show a mean of 1.000 and a CV of nearly equal to 0.00%. This indicates that the calculations from AD-BOX are well aligned with the independent hand calculations for load rating skewed precast prestressed adjacent box beam bridges with composite and non-composite cross sections.

3.2.1.3. Multicell Box Beam Bridges

The verification is further conducted for two skewed multicell box beam bridges among the eleven skewed sample bridges presented in Table 3-16. According to AASHTO MBE Table 6A.4.2.2.2-1, design vehicle, HL-93 at inventory condition, are load rated for Strength-I and Service-III limit states, while HL-93 at operating condition, Ohio legal vehicles, AASHTO legal vehicles, specialized hauling vehicles, and emergency vehicles are load rated using the Strength-I limit state as discussed in Section 3.1.3.6 of this report. Section B2.3 of Appendix B presents the load rating results from the independent hand calculations for the sample multicell box beam bridges.

The verification results of RF values for two skewed multicell box beam bridges are presented in Table 3-7 through Table 3-45. The comparison is based on the ratio of results from AD-BOX to independent hand calculations. The mean and coefficient of variation (CV) of the ratio are calculated to assess the reliability and accuracy of the results.

Table 3-38 AD-BOX versus independent hand calculations for multicell box beam bridges for the design vehicle.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Design Vehicle (HL-93)					
					Inventory			Operating		
					AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
17	Composite	1996	35	30	1.159	1.158	1.000	1.947	1.946	1.000
18	Composite	2007	45	10	1.428	1.428	1.000	2.090	2.090	1.000
						Mean	**1.000**		**Mean**	**1.000**
						CV	**0.03%**		**CV**	**0.03%**

Table 3-39 AD-BOX versus independent hand calculations for multicell box beam bridges for Ohio legal loads.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Ohio legal loads					
					2F1			3F1		
					AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
17	Composite	1996	35	30	3.962	3.961	1.000	2.745	2.744	1.000
18	Composite	2007	45	10	4.936	4.936	1.000	3.364	3.364	1.000
						Mean	**1.000**		**Mean**	**1.000**
						CV	**0.01%**		**CV**	**0.02%**

Table 3-40 AD-BOX versus independent hand calculations for multicell box beam bridges for Ohio legal load.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Ohio legal load		
					5C1		
					AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
17	Composite	1996	35	30	2.853	2.853	1.000
18	Composite	2007	45	10	3.460	3.460	1.000
						Mean	**1.000**
						CV	**0.02%**

Table 3-41 AD-BOX versus independent hand calculations for multicell box beam bridges for AASHTO legal loads.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	AASHTO legal loads					
					Type 3			Type 3S2		
					AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
17	Composite	1996	35	30	2.960	2.960	1.000	3.104	3.103	1.000
18	Composite	2007	45	10	3.469	3.468	1.000	3.796	3.795	1.000
						Mean	**1.000**		**Mean**	**1.000**
						CV	**0.03%**		**CV**	**0.02%**

Table 3-42 AD-BOX versus independent hand calculations for multicell box beam bridges for AASHTO legal load.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	AASHTO legal load		
					Type 3-3		
					AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
17	Composite	1996	35	30	3.627	3.628	1.000
18	Composite	2007	45	10	4.158	4.157	1.000
						Mean	**1.000**
						CV	**0.03%**

Table 3-43 AD-BOX versus independent hand calculations for multicell box beam bridges for specialized hauling vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Specialized hauling vehicles					
					SU4			SU5		
					AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
17	Composite	1996	35	30	2.493	2.494	1.000	2.373	2.372	1.000
18	Composite	2007	45	10	3.002	3.002	1.000	2.787	2.787	1.000
						Mean	**1.000**		**Mean**	**1.000**
						CV	**0.02%**		**CV**	**0.02%**

Table 3-44 AD-BOX versus independent hand calculations for multicell box beam bridges for specialized hauling vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Specialized hauling vehicles					
					SU6			SU7		
					AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)	AD-BOX (a)	Independent hand calcs. (b)	Ratio (a/b)
17	Composite	1996	35	30	2.153	2.152	1.000	2.034	2.033	1.000
18	Composite	2007	45	10	2.518	2.519	1.000	2.350	2.349	1.000
						Mean	**1.000**		**Mean**	**1.000**
						CV	**0.03%**		**CV**	**0.03%**

Table 3-45 AD-BOX versus independent hand calculations for multicell box beam bridges for emergency vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Emergency vehicles					
					EV2		Ratio (a/b)	EV3		Ratio (a/b)
					AD-BOX (a)	Independent hand calcs. (b)		AD-BOX (a)	Independent hand calcs. (b)	
17	Composite	1996	35	30	2.789	2.790	1.000	2.148	2.149	1.000
18	Composite	2007	45	10	2.994	2.994	1.000	1.958	1.958	1.000
						Mean	**1.000**		**Mean**	**1.000**
						CV	**0.03%**		**CV**	**0.02%**

Table 3-46 AD-BOX versus independent hand calculations for multicell box beam bridges for emergency vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Permit vehicles					
					PL60T		Ratio (a/b)	PL65T		Ratio (a/b)
					AD-BOX (a)	Independent hand calcs. (b)		AD-BOX (a)	Independent hand calcs. (b)	
17	Composite	1996	35	30	3.393	3.392	1.000	3.081	3.080	1.000
18	Composite	2007	45	10	4.135	4.135	1.000	3.664	3.664	1.000
						Mean	**1.000**		**Mean**	**1.000**
						CV	**0.02%**		**CV**	**0.02%**

The verification tables for the multicell box beam bridges indicate that AD-BOX calculates RF values with high accuracy and reliability for 15 vehicle types required by the ODOT BDM. This is confirmed by the mean ratio of approximately 1.0 and the coefficient of variation (CV) of nearly 0.00% compared to independent hand calculations.

3.2.1.4. Conclusions

Considering 18 sample bridges, a mean of 1.000 and a coefficient of variation of approximately 0.00% are obtained for the rating factor values calculated by AD-BOX divided by those calculated by the independent hand calculations for 15 vehicle types.

These verification studies, encompassing skewed, non-skewed, composite, and non-composite bridges, including both single-cell and multicell box beam configurations, demonstrate the accuracy and reliability of AD-BOX for the load rating of the simply supported adjacent box beam bridges considered in this study.

3.2.2. Comparison with AASHTOWare BrR

To evaluate the reliability of AD-BOX, its results are compared with those obtained from AASHTOWare BrR, as summarized in the BR100 summary sheet provided by the ODOT. The input parameters and output criteria for load rating using AD-BOX is used same as that used for load rating using AASHTOWare BrR. A total of 18 sample bridges, the same ones used for the verification in Section 3.2.1 of this report are used for the comparison.

Figure 3-17 presents the comparisons of RFs obtained from AD-BOX with RFs from AASHTOWare BrR. The RFs obtained from AD-BOX for 15 vehicle types across 18 sample bridges are plotted against the ratio of RFs from AD-BOX to BrR. A mean line is drawn, which is found to be approximately equal to 1.0. Table 3-47 presents the CVs obtained from the comparison for each vehicle type. The maximum CV obtained is 3.72%. The mean of the ratios are approximately 1.0, with a CV of up to 3.72%, which confirms the reliability of AD-BOX. The detailed results of the comparison are presented in the subsequent sections.

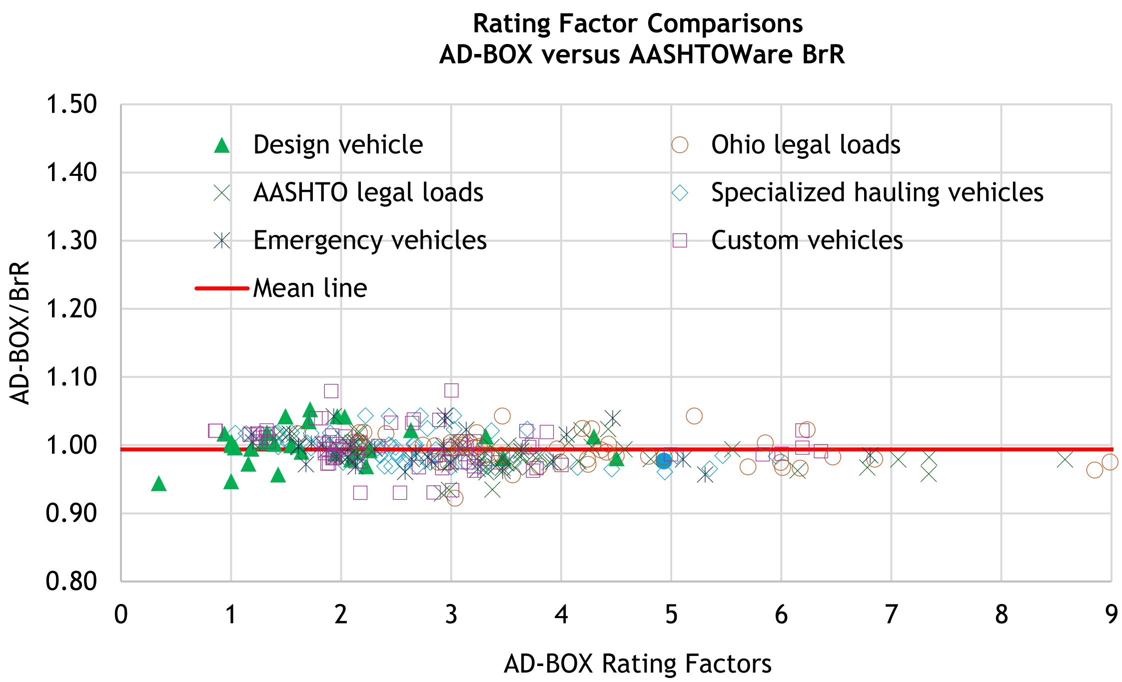


Figure 3-17 Rating factor comparisons for AD-BOX versus AASHTOWare BrR.

Table 3-47 Coefficient of variations for verification for AD-BOX versus independent hand calculations.

Vehicle types		Coefficient of variation (CV) AD-BOX/BrR		
		Non skewed bridges	Skewed bridges	
		Single-cell box beam bridges	Single-cell box beam bridges	Multicell box beam bridges
Design vehicle HL93	Inventory	2.05%	**3.72%**	1.17%
	Operating	2.16%	2.27%	0.60%
Ohio legal loads	2F1	1.27%	2.73%	0.86%
	3F1	1.26%	2.58%	1.02%
	5C1	1.65%	3.38%	0.99%
AASHTO legal loads	Type 3	1.13%	3.01%	0.74%
	Type 3S2	1.19%	2.82%	1.00%
	Type 3-3	1.27%	3.11%	0.47%
Specialized hauling vehicles	SU4	1.16%	2.61%	0.91%
	SU5	1.35%	2.70%	1.22%
	SU6	1.37%	2.61%	1.19%
	SU7	1.13%	2.66%	0.86%
Emergency vehicles	EV2	2.57%	2.69%	0.58%
	EV3	2.07%	2.63%	0.06%
Custom vehicles	12-axle	0.97%	2.18%	1.16%
	15-axle	0.98%	2.06%	0.87%
	19-axle	2.71%	2.15%	0.22%
	35-axle	2.69%	2.13%	0.22%

Appendix B presents the input and AD-BOX results for all sample bridges used for the comparison.

3.2.2.1. Flexural Capacity Comparisons

To check the reliability of flexure capacity calculation in AD-BOX, the flexural capacities calculated by AD-BOX and AASHTOWare BrR are compared, with separate comparisons for composite and non-composite beams. The comparison, based on the ratio of AD-BOX results to BrR, is presented for non-composite beams in Table 3-48 and composite beams in Table 3-49. The mean and CV of these ratios are calculated to quantify deviation.

AD-BOX calculates the flexural capacity of box beams using an approximate method with a rectangular compression block as specified in Section 3.1.3.5.1 of this report. According to AASHTO LRFD Article 5.6.3.2.5, a more complex, iterative strain compatibility method may also be used. AASHTOWare BrR employs this method to calculate beam flexural capacities. Before the comparison of AD-BOX rating factor results with AASHTOWare BrR, its flexural capacity is first compared with that from AASHTOWare BrR.

Table 3-48 Comparison of flexure capacity of non-composite beams using AD-BOX and AASHTOWare BrR.

Sample no.	Year of construction	Design Span (ft)	Beam section	Flexure Capacity		Ratio (AD-BOX/BrR)
				AD-BOX (kips-ft)	BrR (kips-ft)	
1	2024	30	B17-48	693.31	697.75	0.994
2	2018	50	B21-48	1266.16	1264.03	1.002
3	1982	62	B33-48	1571.11	1571.3	1.000
8	2018	42	B33-48	1571.11	1571.3	1.000
9	1984	65	B27-48	1641.06	1643.63	0.998
10	2009	65.5	B21-48	1680.55	1685.27	0.997
11	1985	74.85	B33-48	1687.07	1686.29	1.000
12	2016	75	B33-36	2086.94	2108.44	0.990
					Mean	**0.998**
					CV	**0.40%**

Table 3-49 Comparison of flexure capacity of composite beams using AD-BOX and AASHTOWare BrR.

Sample no.	Year of construction	Design Span (ft)	Beam section	Flexure Capacity		Ratio (AD-BOX/BrR)
				AD-BOX (kips-ft)	BrR (kips-ft)	
4	2023	25	CB17-36	569.38	598.52	0.951
5	2021	45	CB17-48	1164.04	1132.86	1.028
6	2018	55	CB17-48	1549.99	1533.42	1.011
7	2021	80	CB27-48	3115.47	3161.57	0.985
13	2021	26	CB17-48	920.79	935.1	0.985
14	2022	47.71	CB21-48	2019.36	2016.49	1.001
15	2018	60	CB27-48	2121.87	2052.02	1.034
16	2019	83	CB33-48	3341.57	3272.3	1.021
					Mean	**1.002**
					CV	**2.74%**

As shown in Table 3-48, the non-composite flexural capacity exhibits minor deviation, with a mean of 0.998 and CV of 0.40%, indicating that both methods yield similar values. For composite beams, as shown in Table 3-49, the deviation is higher, with a mean of 1.002 and CV of 2.74%, possibly due to the unaccounted differences in concrete strength between the deck slab and beam in the approximate method. The mean of 0.998 for non-composite beams indicates flexural capacity calculated by AD-BOX is slightly lower than those calculated by BrR, while the mean of 1.002 indicates the flexural capacity calculated by AD-BOX is slightly higher than that calculated by BrR for the composite beams. The CV of the ratios, which is less than or equal to 2.74%, confirms that the flexural capacity calculated by AD-BOX is reliable for the load rating of adjacent box beam bridges.

3.2.2.2. Maximum Moment Comparisons

AD-BOX uses the maximum moment capacity calculations due to the vehicular loading at the exact maximum moment location, as presented in Section 3.1.3.4 of this report. AASHTOWare BrR calculates the moments due to vehicular loading using the conventional one-tenth-of-the-span of the span method, which gives the maximum moment at the center of the bridge span, which may not be accurate. To quantify the deviation between AD-BOX and BrR's maximum moment calculations, the unfactored maximum moments from both tools are compared using sample bridge 15 as a representative sample, among the 18 sample bridges, across 13 vehicle types. The comparison is conducted based on the percentage deviation of AD-BOX results from the theoretical values and AD-BOX with BrR, which is presented in Table 3-50.

Table 3-50 Comparison of maximum moments for sample bridge 15 using AD-BOX and AASHTOWare BrR.

	Vehicle Type	AD-BOX (kips-ft)	Theoretical (kips-ft)	BrR (kips-ft)	% Deviation (AD-BOX with Theoretical)	% Deviation (AD-BOX with BrR)
1	HL-93 truck	322.12	322.12	319.63	0.00%	0.78%
2	2F1	160.31	160.31	159.82	0.00%	0.31%
3	3F1	238.14	238.14	238.13	0.00%	0.00%
4	5C1	233.46	233.46	233.33	0.00%	0.05%
5	SU4	270.53	270.53	270.09	0.00%	0.16%
6	SU5	297.15	297.15	295.66	0.00%	0.50%
7	SU6	330.20	330.20	329.62	0.00%	0.18%
8	SU7	358.38	358.38	358.39	0.00%	0.00%
9	EV2	276.34	276.34	272.69	0.00%	1.34%
10	EV3	419.64	419.64	418.72	0.00%	0.22%
11	Type 3	239.02	239.02	238.13	0.00%	0.38%
12	Type 3S2	246.98	246.98	240.53	0.00%	2.68%
13	Type 3-3	225.48	225.48	225.34	0.00%	0.06%

As shown in Table 3-50, AD-BOX calculated the maximum moments exactly the same as the theoretical maximum values. BrR, on the other end, provided consistently smaller values with a maximum deviation of up to 2.68% from the theoretical value for vehicle Type 3S2. This indicates the importance of calculating the maximum moment at the exact location and AD-BOX's improved accuracy in calculating maximum moments for load rating.

3.2.2.3. Rating Factor Comparisons

3.2.2.3.1 Non-skewed Bridges

The comparison of RF values from AD-BOX and AASHTOWare BrR values from the BR100 summary sheet provided by ODOT is performed separately for seven non-skewed bridges, among the sample bridges presented in Table 3-16, which consists of three non-composite and four composite beams. According to AASHTO MBE Table 6A.4.2.2.2-1, Design vehicle, HL-93 at inventory condition, are load rated for strength-I and Service-III limit states, while HL-93 at operating condition, Ohio legal vehicles, AASHTO legal vehicles, specialized hauling vehicles, and emergency vehicles are load rated using the Strength-I limit state as discussed in Section 3.1.3.6 of this report. The RF value for HL-93 at inventory is the adopted minimum value of the results from Strength-I and Service-III limit states.

The comparison results of RF values for the non-skewed bridges are presented through Table 3-51 through Table 3-58. The comparison is based on the ratio of results from AD-BOX to BR100. All input parameters are taken the same while calculating the RF values using AD-BOX and AASHTOWare BrR. The mean and CV of the ratios are calculated to check the reliability of the results. Section C1 of Appendix C presents the input and AD-BOX results for the non-skewed sample bridges.

Table 3-51 presents a comparison of the RF ratios for the HL-93 design vehicle under inventory and operating conditions. For the inventory condition, the minimum RF values from the Strength-I and Service-III limit states are applied, while the RF values for the operating condition are calculated using the Strength-I limit state. The mean of the ratios is found to be approximately 1.0, with a CV of up to 2.16%, indicating that AD-BOX computes RF values for HL-93 that closely align with those calculated by AASHTOWare BrR.

Table 3-51 AD-BOX versus AASHTOWare BrR for non-skewed bridges for the design vehicle.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Design Vehicle (HL-93)					
				Inventory		Ratio (a/b)	Operating		Ratio (a/b)
				AD-BOX (a)	BrR (b)		AD-BOX (a)	BrR (b)	
1	Non-composite	2024	31	1.703	1.645	1.035	2.207	2.132	1.035
2	Non-composite	2018	50	1.546	1.546	1.000	2.005	2.004	1.000
3	Non-composite	1982	62	1.036	1.039	0.997	1.343	1.346	0.998
4	Composite	2023	28	2.258	2.275	0.993	2.928	2.95	0.993
5	Composite	2021	45	1.495	1.434	1.043	2.007	2.068	0.971
6	Composite	2018	55	1.183	1.189	0.995	1.876	1.907	0.984
7	Composite	2021	80	1.395	1.392	1.002	2.293	2.351	0.975
					Mean	**1.009**		**Mean**	**0.994**
					CV	**2.05%**		**CV**	**2.16%**

Table 3-52 and Table 3-53 present a comparison of the ratios of RF values for the non-skewed sample bridges for Ohio legal vehicles: 2F1, 3F1, and 5C1. The RF values for these vehicles are calculated using Strength-I limit states as explained in Section 3.1.3.6.2 of this report. The mean of the ratios is found to be slightly less than 1.0, with a CV of up to 1.65%, indicating that AD-BOX computes RF values for Ohio legal vehicles that closely align with those calculated by AASHTOWare BrR. The mean of less than 1.0 confirms the effect of the greater maximum moment calculated at the exact maximum location rather than at the center span of the bridge.

Table 3-52 AD-BOX versus AASHTOWare BrR of non-skewed bridges for Ohio legal loads.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Ohio legal loads					
				2F1		Ratio (a/b)	3F1		Ratio (a/b)
				AD-BOX (a)	BrR (b)		AD-BOX (a)	BrR (b)	
1	Non-composite	2024	31	4.411	4.457	0.990	3.107	3.107	1.000
2	Non-composite	2018	50	4.430	4.424	1.001	3.001	2.989	1.004
3	Non-composite	1982	62	3.214	3.224	0.997	2.157	2.161	0.998
4	Composite	2023	28	5.853	5.832	1.004	4.237	4.326	0.979
5	Composite	2021	45	4.243	4.365	0.972	2.888	2.963	0.975
6	Composite	2018	55	4.794	4.872	0.984	3.234	3.28	0.986
7	Composite	2021	80	5.994	6.148	0.975	3.993	4.094	0.975
					Mean	**0.989**		**Mean**	**0.988**
					CV	**1.27%**		**CV**	**1.26%**

Table 3-53 AD-BOX versus AASHTOWare BrR of non-skewed bridges for Ohio legal load.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Ohio legal load		
				5C1		Ratio (a/b)
				AD-BOX (a)	BrR (b)	
1	Non-composite	2024	31	3.257	3.263	0.998
2	Non-composite	2018	50	3.077	3.065	1.004
3	Non-composite	1982	62	2.199	2.204	0.998
4	Composite	2023	28	4.501	4.571	0.985
5	Composite	2021	45	2.971	3.047	0.975
6	Composite	2018	55	3.306	3.354	0.986
7	Composite	2021	80	3.557	3.718	0.957
					Mean	**0.986**
					CV	**1.65%**

Table 3-54 and Table 3-55 present a comparison of the RF ratios for non-skewed sample bridges for AASHTO legal loads: Type3, Type3S2, and Type3-3. The RF values for these vehicles are calculated using Strength-I limit states as explained in Section 3.1.3.6.2 of this report. For AASHTO legal loads also, the mean of the ratios is found slightly less than 1.0, with a CV of up to 1.27%, indicating that AD-BOX computes RF values for AASHTO legal loads that closely align with those calculated by AASHTOWare BrR. The mean of less than 1.0 confirms the effect of the greater maximum moment calculated at the exact maximum location rather than at the center span of the bridge.

Table 3-54 AD-BOX versus AASHTOWare BrR of non-skewed bridges for AASHTO legal loads.

Sample No.	Types of beams	Year of constr.	Design span (ft)	AASHTO legal loads					
				Type 3		Ratio (a/b)	Type 3S2		Ratio (a/b)
				AD-BOX (a)	BrR (b)		AD-BOX (a)	BrR (b)	
1	Non-composite	2024	31	3.472	3.529	0.984	3.520	3.521	1.000
2	Non-composite	2018	50	3.054	3.052	1.001	3.301	3.330	0.991
3	Non-composite	1982	62	2.147	2.154	0.997	2.062	2.097	0.984
4	Composite	2023	28	4.575	4.603	0.994	4.814	4.915	0.979
5	Composite	2021	45	2.982	3.070	0.971	3.259	3.342	0.975
6	Composite	2018	55	3.255	3.310	0.983	3.319	3.428	0.968
7	Composite	2021	80	3.896	3.997	0.975	3.405	3.515	0.969
					Mean	**0.986**		**Mean**	**0.981**
					CV	**1.13%**		**CV**	**1.19%**

Table 3-55 AD-BOX versus AASHTOWare BrR of non-skewed bridges for AASHTO legal load.

Sample No.	Types of beams	Year of constr.	Design span (ft)	AASHTO legal load		
				Type 3-3		Ratio (a/b)
				AD-BOX (a)	BrR (b)	
1	Non-composite	2024	31	4.276	4.285	0.998
2	Non-composite	2018	50	3.638	3.649	0.997
3	Non-composite	1982	62	2.232	2.237	0.998
4	Composite	2023	28	5.555	5.589	0.994
5	Composite	2021	45	3.579	3.699	0.967
6	Composite	2018	55	3.634	3.687	0.986
7	Composite	2021	80	3.501	3.597	0.973
					Mean	**0.988**
					CV	**1.27%**

Table 3-56 and Table 3-57 present a comparison of the RF ratios for non-skewed sample bridges for Specialized hauling vehicles: SU4, SU5, SU6, and SU7. The RF values for these vehicles are calculated using Strength-I limit states as explained in Section 3.1.3.6.2 of this report. For specialized hauling vehicles also, the mean of the ratios is found to be slightly less than 1.000, with a CV of up to 1.37%, indicating that AD-BOX computes RF values for specialized hauling vehicles that closely align with those calculated by AASHTOWare BrR. The mean of less than 1.0 confirms the effect of the greater maximum moment calculated at the exact maximum location rather than at the center span of the bridge.

Table 3-56 AD-BOX versus AASHTOWare BrR of non-skewed bridges for specialized hauling vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Special hauling vehicles					
				SU4		Ratio (a/b)	SU5		Ratio (a/b)
				AD-BOX (a)	BrR (b)		AD-BOX (a)	BrR (b)	
1	Non-composite	2024	31	2.860	2.878	0.994	2.664	2.662	1.001
2	Non-composite	2018	50	2.665	2.657	1.003	2.456	2.458	0.999
3	Non-composite	1982	62	1.898	1.903	0.997	1.728	1.735	0.996
4	Composite	2023	28	3.863	3.939	0.981	3.564	3.66	0.974
5	Composite	2021	45	2.579	2.65	0.973	2.397	2.473	0.969
6	Composite	2018	55	2.858	2.902	0.985	2.619	2.666	0.982
7	Composite	2021	80	3.486	3.574	0.975	3.138	3.22	0.975
					Mean	**0.987**		**Mean**	**0.985**
					CV	**1.16%**		**CV**	**1.35%**

Table 3-57 AD-BOX versus AASHTOWare BrR of non-skewed bridges for specialized hauling vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Special hauling vehicles					
				SU6			SU7		
				AD-BOX (a)	BrR (b)	Ratio (a/b)	AD-BOX (a)	BrR (b)	Ratio (a/b)
1	Non-composite	2024	31	2.432	2.43	1.001	2.333	2.342	0.996
2	Non-composite	2018	50	2.213	2.208	1.002	2.053	2.044	1.004
3	Non-composite	1982	62	1.552	1.556	0.997	1.427	1.43	0.998
4	Composite	2023	28	3.305	3.400	0.972	3.250	3.289	0.988
5	Composite	2021	45	2.163	2.223	0.973	2.017	2.069	0.975
6	Composite	2018	55	2.356	2.393	0.984	2.176	2.207	0.986
7	Composite	2021	80	2.812	2.884	0.975	2.568	2.632	0.976
					Mean	**0.986**		**Mean**	**0.989**
					CV	**1.37%**		**CV**	**1.13%**

Table 3-58 presents a comparison of the RF ratios for non-skewed sample bridges for emergency vehicles EV2 and EV3. The RF values for these vehicles are calculated using Strength-I limit states, and load factors according to FAST act. For emergency vehicles, the mean of the ratios is found slightly less than 1.0, with a CV of up to 2.57%, indicating that AD-BOX computes RF values for emergency vehicles that closely align with those calculated by AASHTOWare BrR. The mean of less than 1.0 confirms the effect of the greater maximum moment calculated at the exact maximum location rather than at the center span of the bridge.

Table 3-58 AD-BOX versus AASHTOWare BrR of non-skewed bridges for emergency vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Emergency vehicles					
				EV2			EV3		
				AD-BOX (a)	BrR (b)	Ratio (a/b)	AD-BOX (a)	BrR (b)	Ratio (a/b)
1	Non-composite	2024	31	2.932	2.935	0.999	2.060	2.097	0.982
2	Non-composite	2018	50	2.644	2.699	0.980	1.730	1.726	1.002
3	Non-composite	1982	62	1.868	1.881	0.993	1.612	1.616	0.997
4	Composite	2023	28	3.926	4.023	0.976	3.637	3.668	0.992
5	Composite	2021	45	2.582	2.688	0.961	1.682	1.730	0.972
6	Composite	2018	55	2.824	2.892	0.976	2.002	2.034	0.984
7	Composite	2021	80	4.469	4.299	1.039	2.940	2.838	1.036
					Mean	**0.989**		**Mean**	**0.995**
					CV	**2.57%**		**CV**	**2.07%**

The comparison tables for non-skewed sample bridges indicate that AD-BOX calculates RF values with reliability for all vehicle types required by the ODOT BDM, which is confirmed by the mean ratio of approximately 1.0 and a CV of up to 2.57%.

3.2.2.3.2 Skewed Bridges

The comparison is further carried out for the eleven skewed bridges with five non-composite and six composite cross sections. Load rating is performed for these bridges for all vehicle types required by ODOT BDM. A separate comparison is made for nine single-cell and two multicell box beam cross sections. According to AASHTO MBE Table 6A.4.2.2.2-1, Design vehicle, HL-93 at inventory condition, are load rated for Strength-I and Service-III limit states, while HL-93 at operating condition, Ohio legal vehicles, AASHTO legal vehicles, specialized hauling vehicles, and emergency vehicles are load rated using the Strength-I limit state as discussed in Section 3.1.3.6 of this report. RF value for HL-93 at inventory is adopted minimum value of the results from Strength-I and Service-III limit states.

The comparison of RF values from AD-BOX and AASHTOWare BrR values from the BR100 summary sheet provided by ODOT for nine skewed bridges are detailed through Table 3-59 to Table 3-66. The comparison is based on the ratio of results from AD-BOX to BR100. All input parameters are taken the same while calculating the RF values using AD-BOX and AASHTOWare BrR. Mean and CV of the ratio are calculated, to check the reliability of the results. Section C2 of Appendix C presents the input and AD-BOX results for the skewed sample bridges.

Table 3-59 presents a comparison of the RF ratios for skewed bridges for the HL-93 design vehicle under inventory and operating conditions. For the inventory condition, the minimum RF values from the Strength-I and Service-III limit states are applied, while the RF values for the operating condition are calculated using the Strength-I limit state. The mean of the ratios is found to be approximately 1.0, with a CV of up to 3.72%, indicating that AD-BOX computes RF values for HL-93 that closely align with those calculated by AASHTOWare BrR.

Table 3-59 AD-BOX versus AASHTOWare BrR for skewed bridges for the design vehicle.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Design Vehicle (HL-93)					
					Inventory		Ratio (a/b)	Operating		Ratio (a/b)
					AD-BOX (a)	BrR (b)		AD-BOX (a)	BrR (b)	
8	Non-composite	2020	42	28	1.639	1.655	0.990	2.124	2.146	0.990
9	Non-composite	1984	65	5	1.004	0.999	1.005	1.301	1.295	1.005
10	Non-composite	2021	65.5	12	1.004	1.004	1.000	1.325	1.301	1.018
11	Non-composite	1985	74.85	30	0.341	0.361	0.945	0.941	0.925	1.018
12	Non-composite	2016	76	10	1.718	1.632	1.053	2.228	2.299	0.969
13	Composite	2021	27	30	3.473	3.541	0.981	4.502	4.590	0.981
14	Composite	2022	50	19	3.314	3.271	1.013	4.296	4.241	1.013
15	Composite	2018	60	24	2.032	1.950	1.042	2.634	2.577	1.022
16	Composite	2019	83	20	1.001	1.057	0.947	1.966	1.886	1.042
						Mean	**0.997**		**Mean**	**1.006**
						CV	**3.72%**		**CV**	**2.27%**

Table 3-60 and Table 3-61 present a comparison of the RF ratios for skewed sample bridges for Ohio legal vehicles: 2F1, 3F1, and 5C1. The RF values for these vehicles are calculated using Strength-I limit states as explained in Section 3.1.3.6.2 of this report. The mean of the ratios is found approximately 1.0, with a CV of up to 3.38%, indicating that AD-BOX computes RF values for Ohio legal vehicles that closely align with those calculated by AASHTOWare BrR.

Table 3-60 AD-BOX versus AASHTOWare BrR of skewed bridges for Ohio legal loads.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Ohio legal loads					
					2F1			3F1		
					AD-BOX (a)	BrR (b)	Ratio (a/b)	AD-BOX (a)	BrR (b)	Ratio (a/b)
8	Non-composite	2020	42	28	4.359	4.389	0.993	2.982	2.990	0.997
9	Non-composite	1984	65	5	3.165	3.153	1.004	2.120	2.111	1.004
10	Non-composite	2021	65.5	12	3.234	3.176	1.018	2.165	2.126	1.018
11	Non-composite	1985	74.85	30	2.406	2.366	1.017	1.605	1.578	1.017
12	Non-composite	2016	76	10	5.697	5.883	0.968	3.803	3.923	0.969
13	Composite	2021	27	30	8.987	9.214	0.975	6.467	6.581	0.983
14	Composite	2022	50	19	8.846	9.18	0.964	6.011	6.215	0.967
15	Composite	2018	60	24	6.235	6.098	1.022	4.193	4.092	1.025
16	Composite	2019	83	20	5.209	4.994	1.043	3.466	3.323	1.043
						Mean	**1.001**		**Mean**	**1.003**
						CV	**2.73%**		**CV**	**2.58%**

Table 3-61 AD-BOX versus AASHTOWare BrR of skewed bridges for Ohio legal load.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Ohio legal load		
					5C1		
					AD-BOX (a)	BrR (b)	Ratio (a/b)
8	Non-composite	2020	42	28	3.075	3.085	0.997
9	Non-composite	1984	65	5	2.160	2.150	1.005
10	Non-composite	2021	65.5	12	2.206	2.165	1.019
11	Non-composite	1985	74.85	30	1.512	1.501	1.007
12	Non-composite	2016	76	10	3.520	3.688	0.954
13	Composite	2021	27	30	6.847	6.990	0.980
14	Composite	2022	50	19	6.171	6.384	0.967
15	Composite	2018	60	24	4.277	4.176	1.024
16	Composite	2019	83	20	3.036	3.291	0.923
						Mean	**0.986**
						CV	**3.38%**

Table 3-62 and Table 3-63 present a comparison of the RF ratios for skewed sample bridges for AASHTO legal loads: Type3, Type3S2, and Type3-3. The RF values for these vehicles are calculated using Strength-I limit states as explained in Section 3.1.3.6.2 of this report. For AASHTO legal loads also, the mean of the ratios is found slightly less than 1.0, with a CV of up to 3.11%, indicating that AD-BOX computes RF values for AASHTO legal loads that closely align with those calculated by AASHTOWare BrR.

Table 3-62 AD-BOX versus AASHTOWare BrR of skewed bridges for AASHTO legal loads.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	AASHTO legal loads					
					Type 3		Ratio (a/b)	Type 3S2		Ratio (a/b)
					AD-BOX (a)	BrR (b)		AD-BOX (a)	BrR (b)	
8	Non-composite	2020	42	28	3.108	3.135	0.991	3.367	3.376	0.997
9	Non-composite	1984	65	5	2.102	2.095	1.003	1.982	1.993	0.994
10	Non-composite	2021	65.5	12	2.146	2.108	1.018	2.018	1.999	1.010
11	Non-composite	1985	74.85	30	1.574	1.548	1.017	1.413	1.392	1.015
12	Non-composite	2016	76	10	3.726	3.848	0.968	3.320	3.458	0.960
13	Composite	2021	27	30	7.063	7.214	0.979	7.343	7.474	0.982
14	Composite	2022	50	19	6.148	6.388	0.962	6.781	7.011	0.967
15	Composite	2018	60	24	4.182	4.092	1.022	4.069	4.052	1.004
16	Composite	2019	83	20	3.375	3.610	0.935	2.917	3.139	0.929
						Mean	**0.988**		**Mean**	**0.984**
						CV	**3.01%**		**CV**	**2.82%**

Table 3-63 AD-BOX versus AASHTOWare BrR of skewed bridges for AASHTO legal load.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	AASHTO legal load		
					Type 3-3		Ratio (a/b)
					AD-BOX (a)	BrR (b)	
8	Non-composite	2020	42	28	3.745	3.801	0.985
9	Non-composite	1984	65	5	2.134	2.125	1.004
10	Non-composite	2021	65.5	12	2.170	2.131	1.018
11	Non-composite	1985	74.85	30	1.469	1.446	1.016
12	Non-composite	2016	76	10	3.468	3.589	0.966
13	Composite	2021	27	30	8.577	8.760	0.979
14	Composite	2022	50	19	7.339	7.662	0.958
15	Composite	2018	60	24	4.428	4.325	1.024
16	Composite	2019	83	20	2.980	3.189	0.935
						Mean	**0.987**
						CV	**3.11%**

Table 3-64 and Table 3-65 present a comparison of the RF ratios for skewed sample bridges for Specialized hauling vehicles: SU4, SU5, SU6, and SU7. The RF values for these vehicles are calculated using Strength-I limit states as explained in Section 3.1.3.6.2 of this report. For specialized hauling vehicles also, the mean of the ratios is found approximately 1.0, with a CV of up to 2.70%, indicating that AD-BOX computes RF values for Specialized Hauling Vehicles that closely align with those calculated by AASHTOWare BrR.

Table 3-64 AD-BOX versus AASHTOWare BrR of skewed bridges for specialized hauling vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Special hauling vehicles					
					SU4			SU5		
					AD-BOX (a)	BrR (b)	Ratio (a/b)	AD-BOX (a)	BrR (b)	Ratio (a/b)
8	Non-composite	2020	42	28	2.673	2.686	0.995	2.496	2.523	0.989
9	Non-composite	1984	65	5	1.863	1.855	1.004	1.693	1.687	1.004
10	Non-composite	2021	65.5	12	1.902	1.868	1.018	1.728	1.698	1.018
11	Non-composite	1985	74.85	30	1.404	1.380	1.017	1.268	1.247	1.017
12	Non-composite	2016	76	10	3.325	3.432	0.969	3.000	3.100	0.968
13	Composite	2021	27	30	5.953	6.050	0.984	5.466	5.552	0.985
14	Composite	2022	50	19	5.348	5.54	0.965	4.941	5.142	0.961
15	Composite	2018	60	24	3.693	3.608	1.024	3.366	3.296	1.021
16	Composite	2019	83	20	3.023	2.898	1.043	2.720	2.607	1.043
						Mean	**1.002**		**Mean**	**1.001**
						CV	**2.61%**		**CV**	**2.70%**

Table 3-65 AD-BOX versus AASHTOWare BrR of skewed bridges for specialized hauling vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Special hauling vehicles					
					SU6			SU7		
					AD-BOX (a)	BrR (b)	Ratio (a/b)	AD-BOX (a)	BrR (b)	Ratio (a/b)
8	Non-composite	2020	42	28	2.258	2.270	0.995	2.116	2.121	0.998
9	Non-composite	1984	65	5	1.519	1.513	1.004	1.394	1.388	1.004
10	Non-composite	2021	65.5	12	1.550	1.522	1.018	1.422	1.396	1.019
11	Non-composite	1985	74.85	30	1.136	1.117	1.017	1.039	1.021	1.018
12	Non-composite	2016	76	10	2.690	2.777	0.969	2.461	2.539	0.969
13	Composite	2021	27	30	5.050	5.130	0.984	4.935	5.053	0.977
14	Composite	2022	50	19	4.460	4.621	0.965	4.148	4.289	0.967
15	Composite	2018	60	24	3.025	2.956	1.023	2.786	2.719	1.025
16	Composite	2019	83	20	2.435	2.335	1.043	2.221	2.129	1.043
						Mean	**1.002**		**Mean**	**1.002**
						CV	**2.61%**		**CV**	**2.66%**

Table 3-66 presents a comparison of the RF ratios for skewed sample bridges for Emergency vehicles EV2 and EV3. The RF values for these vehicles are calculated using Strength-I limit states and load factors according to the FAST Act. For Emergency Vehicles, the mean of the ratios is found slightly less than 1.0 with a CV of up to 2.69%, indicating that AD-BOX computes RF values for Emergency vehicles that closely align with those calculated by AASHTOWare BrR.

Table 3-66 AD-BOX versus AASHTOWare BrR of skewed bridges for emergency vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Emergency vehicles					
					EV2		Ratio (a/b)	EV3		Ratio (a/b)
					AD-BOX (a)	BrR (b)		AD-BOX (a)	BrR (b)	
8	Non-composite	2020	42	28	2.679	2.709	0.989	2.306	2.319	0.994
9	Non-composite	1984	65	5	1.831	1.828	1.002	1.199	1.194	1.004
10	Non-composite	2021	65.5	12	2.085	2.091	0.997	1.613	1.614	0.999
11	Non-composite	1985	74.85	30	1.532	1.506	1.017	1.186	1.167	1.016
12	Non-composite	2016	76	10	3.240	3.357	0.965	2.131	2.200	0.969
13	Composite	2021	27	30	6.808	6.910	0.985	5.106	5.215	0.979
14	Composite	2022	50	19	5.307	5.545	0.957	3.468	3.605	0.962
15	Composite	2018	60	24	4.048	3.986	1.016	3.138	3.068	1.023
16	Composite	2019	83	20	2.944	2.822	1.043	1.933	1.854	1.043
						Mean	**0.997**		**Mean**	**0.999**
						CV	**2.69%**		**CV**	**2.63%**

The comparison tables for skewed sample bridges indicate that AD-BOX calculates RF values with reliability for skewed bridges for all vehicle types required by the ODOT BDM, which is confirmed by the mean ratio of approximately 1.0 and a CV of up to 3.72%.

3.2.2.3.3 Multicell Box Beam Bridges

The comparison of RF values from AD-BOX with AASHTOWare BrR values, obtained from the BR100 summary sheet provided by ODOT, is performed separately for two skewed multicell box beam bridges, among the sample bridges presented in Table 3-16.

The comparison results of RF values for the two skewed multicell box beam bridges are presented through Table 3-67 to Table 3-72. The comparison is based on the ratio of results from AD-BOX to BR100. All input parameters are taken the same while calculating the RF values using AD-BOX and AASHTOWare BrR. The mean and CV of the ratio are calculated to check the reliability of the results. Section C3 of Appendix C presents the input and AD-BOX results for the sample multicell box beam bridges.

Table 3-67 AD-BOX versus AASHTOWare BrR for multicell box beam bridges for the design vehicle.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Design Vehicle (HL-93)					
					Inventory		Ratio (a/b)	Operating		Ratio (a/b)
					AD-BOX (a)	BrR (b)		AD-BOX (a)	BrR (b)	
17	Composite	1996	35	30	1.159	1.191	0.973	1.947	1.972	0.987
18	Composite	2007	45	10	1.428	1.492	0.957	2.090	2.135	0.979
						Mean	**0.965**		**Mean**	**0.983**
						CV	**1.17%**		**CV**	**0.60%**

Table 3-68 AD-BOX versus AASHTOWare BrR for multicell box beam bridges for Ohio legal loads.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Ohio legal loads					
					2F1			3F1		
					AD-BOX (a)	BrR (b)	Ratio (a/b)	AD-BOX (a)	BrR (b)	Ratio (a/b)
17	Composite	1996	35	30	3.962	3.984	0.994	2.745	2.744	1.000
18	Composite	2007	45	10	4.936	5.025	0.982	3.364	3.412	0.986
						Mean	**0.988**		**Mean**	**0.993**
						CV	**0.86%**		**CV**	**1.02%**

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Ohio legal load		
					5C1		
					AD-BOX (a)	BrR (b)	Ratio (a/b)
17	Composite	1996	35	30	2.853	2.855	0.999
18	Composite	2007	45	10	3.460	3.511	0.985
						Mean	**0.992**
						CV	**0.99%**

Table 3-69 AD-BOX versus AASHTOWare BrR for multicell box beam bridges for AASHTO legal loads.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	AASHTO legal loads					
					Type 3			Type 3S2		
					AD-BOX (a)	BrR (b)	Ratio (a/b)	AD-BOX (a)	BrR (b)	Ratio (a/b)
17	Composite	1996	35	30	2.959	2.986	0.991	3.104	3.104	1.000
18	Composite	2007	45	10	3.469	3.537	0.981	3.796	3.850	0.986
						Mean	**0.986**		**Mean**	**0.993**
						CV	**0.74%**		**CV**	**1.00%**

Table 3-70 AD-BOX versus AASHTOWare BrR for multicell box beam bridges for AASHTO legal loads.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	AASHTO legal load		
					Type 3-3		
					AD-BOX (a)	BrR (b)	Ratio (a/b)
17	Composite	1996	35	30	3.627	3.693	0.982
18	Composite	2007	45	10	4.158	4.262	0.976
						Mean	**0.979**
						CV	**0.47%**

Table 3-71 AD-BOX versus AASHTOWare BrR for multicell box beam bridges for specialized hauling vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Specialiazed hauling vehicles					
					SU4		Ratio (a/b)	SU5		Ratio (a/b)
					AD-BOX (a)	BrR (b)		AD-BOX (a)	BrR (b)	
17	Composite	1996	35	30	2.493	2.501	0.997	2.373	2.382	0.996
18	Composite	2007	45	10	3.002	3.051	0.984	2.787	2.847	0.979
						Mean	**0.990**		**Mean**	**0.987**
						CV	**0.91%**		**CV**	**1.22%**

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Specialized hauling vehicles					
					SU6		Ratio (a/b)	SU7		Ratio (a/b)
					AD-BOX (a)	BrR (b)		AD-BOX (a)	BrR (b)	
17	Composite	1996	35	30	2.153	2.152	1.000	2.034	2.038	0.998
18	Composite	2007	45	10	2.518	2.560	0.984	2.350	2.383	0.986
						Mean	**0.992**		**Mean**	**0.992**
						CV	**1.19%**		**CV**	**0.86%**

Table 3-72 AD-BOX versus AASHTOWare BrR for multicell box beam bridges for emergency vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Emergency vehicles					
					EV2		Ratio (a/b)	EV3		Ratio (a/b)
					AD-BOX (a)	BrR (b)		AD-BOX (a)	BrR (b)	
17	Composite	1996	35	30	2.789	2.838	0.983	2.148	2.186	0.982
18	Composite	2007	45	10	2.994	3.071	0.975	1.958	1.991	0.983
						Mean	**0.979**		**Mean**	**0.983**
						CV	**0.58%**		**CV**	**0.06%**

The comparison tables for sample multicell box beam bridges indicate that AD-BOX calculates RF values with reliability for all vehicle types required by the ODOT BDM, which is confirmed by the mean ratio of approximately 1.0 and a CV of up to 1.22%.

3.2.2.3.4 Custom Vehicles

To consider the future needs for vehicles beyond the 15 vehicle types listed in the ODOT BDM (2020), AD-BOX has been developed with the capability to include custom vehicles with up to 35 axles. A high axle count is selected to consider vehicles that may emerge in the future.

To check the reliability of load rating for custom vehicles using AD-BOX, four custom vehicles with 12, 15, 19, and 35 axles are tested across 18 sample bridges. The axle configurations and load rating results for the 12-, 15-, and 19-axle vehicles, calculated using AASHTOWare BrR, are provided by ODOT. The 35-axle vehicle is a hypothetical model configured for the comparison. The axle configurations of the 12-, 15-, 19-, and 35-axle custom vehicles used for comparison are presented in Table 3-73, Table 3-74, Table 3-75, and Table 3-76, respectively.

Table 3-73 Axle configuration for 12-axle custom vehicle.

Axle	a	b	c	d	e	f	g	h	i	j	k	l
Load (kips)	16.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00
Spacing (ft)	0.00	16.25	1.00	4.50	2.00	5.00	3.00	40.17	4.00	5.00	5.00	5.17
Distance from first axle (ft)	0.00	16.25	20.75	25.25	41.00	46.00	51.00	91.17	96.17	101.17	117.42	122.58

Table 3-74 Axle configuration for 15-axle custom vehicle.

Axle	a	b	c	d	e	f	g	h	i	j	k	l
Load (kips)	14.00	18.00	18.00	18.00	18.00	18.00	18.00	20.00	20.00	18.00	18.00	18.00
Spacing (ft)	0.00	12.17	4.50	4.50	15.67	5.00	5.00	76.92	5.00	12.50	5.00	5.00
Distance from first axle (ft)	0.00	12.17	16.67	21.17	36.83	41.83	46.83	123.75	128.75	141.25	146.25	151.25

Axle	m	n	o
Load (kips)	18.00	18.00	18.00
Spacing (ft)	14.00	5.00	5.00
Distance from first axle (ft)	165.25	170.25	175.25

Table 3-75 Axle configuration for 19-axle custom vehicle.

Axle	a	b	c	d	e	f	g	h	i	j	k	l
Load (kips)	20.00	20.00	20.00	20.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00
Spacing (ft)	0.00	13.50	5.00	5.00	15.00	5.00	5.00	14.67	5.00	5.00	4.50	5.00
Distance from first axle (ft)	0.00	13.50	18.50	23.50	38.50	43.50	48.50	63.17	68.17	73.17	77.67	82.67

Axle	m	n	o	p	q	r	s
Load (kips)	19.00	19.00	19.00	19.00	19.00	19.00	19.00
Spacing (ft)	5.00	4.50	5.00	5.00	14.08	5.00	5.00
Distance from first axle (ft)	87.67	92.17	97.17	102.17	116.25	121.25	126.25

Table 3-76 Axle configuration for 35-axle custom vehicle.

Axle	a	b	c	d	e	f	g	h	i	j	k	l
Load (kips)	20.00	20.00	20.00	20.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00
Spacing (ft)	0.00	13.50	5.00	5.00	15.00	5.00	5.00	14.67	5.00	5.00	4.50	5.00
Distance from first axle (ft)	0.00	13.50	18.50	23.50	38.50	43.50	48.50	63.17	68.17	73.17	77.67	82.67

Axle	m	n	o	p	q	r	s	t	u	v	w	x
Load (kips)	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00
Spacing (ft)	5.00	4.50	5.00	5.00	4.50	5.00	5.00	4.50	5.00	5.00	4.50	5.00
Distance from first axle (ft)	87.67	92.17	97.17	102.17	106.67	111.67	116.67	121.17	126.17	131.17	135.67	140.67

Axle	y	z	aa	ab	ac	ad	ae	af	ag	ah	ai
Load (kips)	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00
Spacing (ft)	5.00	4.50	5.00	5.00	4.50	5.00	5.00	4.50	14.08	5.00	5.00
Distance from first axle (ft)	145.67	150.17	155.17	160.17	164.67	169.67	174.67	179.17	193.25	198.25	203.25

The RF values for these vehicles are calculated using the Strength-II limit state, considering the custom vehicles as permit vehicles, and load factors for load conditions presented in Table 3-77, according to AASHTO MBE Table 6A.4.5.4.2a.1.

Table 3-77 Custom vehicle load conditions used for the comparison.

Permit type	Special or Limited crossing
Frequency	Multiple trips (<100 crossings)
Loading condition	Mixed with traffic
DF using	One lane

Table 3-78 and Table 3-79 present a comparison of the RF ratios for 16 sample bridges for 12-, 15-, 19-, and 35-axle custom vehicles. For custom vehicles, the mean of the ratios is found slightly less than 1.0 with a CV of up to 3.29%, indicating that AD-BOX computes RF values for custom vehicles that closely align with those calculated by AASHTOWare BrR. The mean of less than 1.0 confirms the effect of the greater maximum moment calculated at the exact maximum location rather than at the center span of the bridge.

Table 3-78 AD-BOX versus AASHTOWare BrR for custom vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Custom Vehicles					
					12-Axle		Ratio (a/b)	15-Axle		Ratio (a/b)
					AD-BOX (a)	BrR (b)		AD-BOX (a)	BrR (b)	
Single-Cell Box Beam Bridges										
1	Non- composite	2024	30	0	2.840	3.051	0.931	3.008	3.220	0.934
2	Non- composite	2018	50	0	3.139	3.151	0.996	3.083	3.065	1.006
3	Non- composite	1982	62	0	1.978	1.991	0.993	1.873	1.883	0.995
4	Composite	2023	25	0	3.776	3.907	0.966	4.004	4.124	0.971
5	Composite	2021	45	0	3.083	3.161	0.975	2.999	3.015	0.995
6	Composite	2018	55	0	2.883	2.923	0.986	3.003	2.779	1.081
7	Composite	2021	80	0	3.426	3.515	0.975	3.157	3.238	0.975
8	Non- composite	2018	42	28	3.306	3.373	0.980	3.212	3.193	1.006
9	Non- composite	1984	65	5	1.958	1.955	1.002	1.842	1.838	1.002
10	Non- composite	2009	65.5	12	2.042	2.016	1.013	1.920	1.893	1.014
11	Non- composite	1985	74.85	30	1.335	1.313	1.017	1.237	1.216	1.017
12	Non- composite	2016	75	10	2.920	3.021	0.967	2.707	2.797	0.968
13	Composite	2021	26	30	6.001	6.078	0.987	6.361	6.416	0.991
14	Composite	2022	47.71	19	6.191	6.214	0.996	6.191	6.060	1.022
15	Composite	2018	60	24	3.869	3.796	1.019	3.683	3.608	1.021
16	Composite	2019	83	20	2.893	2.789	1.037	2.660	2.563	1.038
Multicell Box Beam Bridges										
17	Composite	1996	35	30	2.860	2.905	0.985	2.945	3.022	0.975
18	Composite	2007	45	10	3.209	3.311	0.969	3.128	3.169	0.987
						Mean	**0.989**		**Mean**	**1.000**
						CV	**2.47%**		**CV**	**3.18%**

Table 3-79 AD-BOX versus AASHTOWare BrR for custom vehicles.

Sample No.	Types of beams	Year of constr.	Design span (ft)	Skew angle (degree)	Custom Vehicles					
					19-Axle			35-Axle		
					AD-BOX (a)	BrR (b)	Ratio (a/b)	AD-BOX (a)	BrR (b)	Ratio (a/b)
Single-Cell Box Beam Bridges										
1	Non- composite	2024	30	0	2.174	2.337	0.930	2.536	2.726	0.930
2	Non- composite	2018	50	0	1.896	1.888	1.004	2.177	2.168	1.004
3	Non- composite	1982	62	0	1.266	1.259	1.006	1.344	1.337	1.006
4	Composite	2023	25	0	3.210	3.335	0.963	3.745	3.891	0.963
5	Composite	2021	45	0	1.851	1.873	0.988	2.148	2.174	0.988
6	Composite	2018	55	0	1.911	1.770	1.080	1.946	1.973	0.986
7	Composite	2021	80	0	2.180	2.233	0.976	2.130	2.182	0.976
8	Non- composite	2018	42	28	2.013	2.016	0.999	2.337	2.340	0.999
9	Non- composite	1984	65	5	1.268	1.254	1.011	1.318	1.303	1.011
10	Non- composite	2009	65.5	12	1.323	1.295	1.022	1.168	1.150	1.016
11	Non- composite	1985	74.85	30	0.862	0.844	1.021	0.856	0.838	1.021
12	Non- composite	2016	75	10	1.889	1.941	0.973	1.874	1.926	0.973
13	Composite	2021	26	30	4.997	5.065	0.987	5.830	5.909	0.987
14	Composite	2022	47.71	19	3.735	3.735	1.000	3.709	3.719	0.997
15	Composite	2018	60	24	2.453	2.375	1.033	2.647	2.563	1.033
16	Composite	2019	83	20	1.821	1.752	1.039	1.769	1.702	1.039
Multicell Box Beam Bridges										
17	Composite	1996	35	30	1.927	1.959	0.984	1.927	1.959	0.984
18	Composite	2007	45	10	1.931	1.968	0.981	1.922	1.959	0.981
						Mean	**1.000**		**Mean**	**0.994**
						CV	**3.30%**		**CV**	**2.62%**

The comparison tables for custom vehicles indicate that AD-BOX calculates RF values with reliability, which is confirmed by the mean ratio of approximately 1.0 and a CV of up to 3.30%.

3.2.2.4. Conclusions

Considering 18 sample bridges, a mean of approximately 1.0 and a CV of up to 3.72% are obtained for the ratio of the rating factors from AD-BOX divided by the rating factors from AASHTOWare BrR.

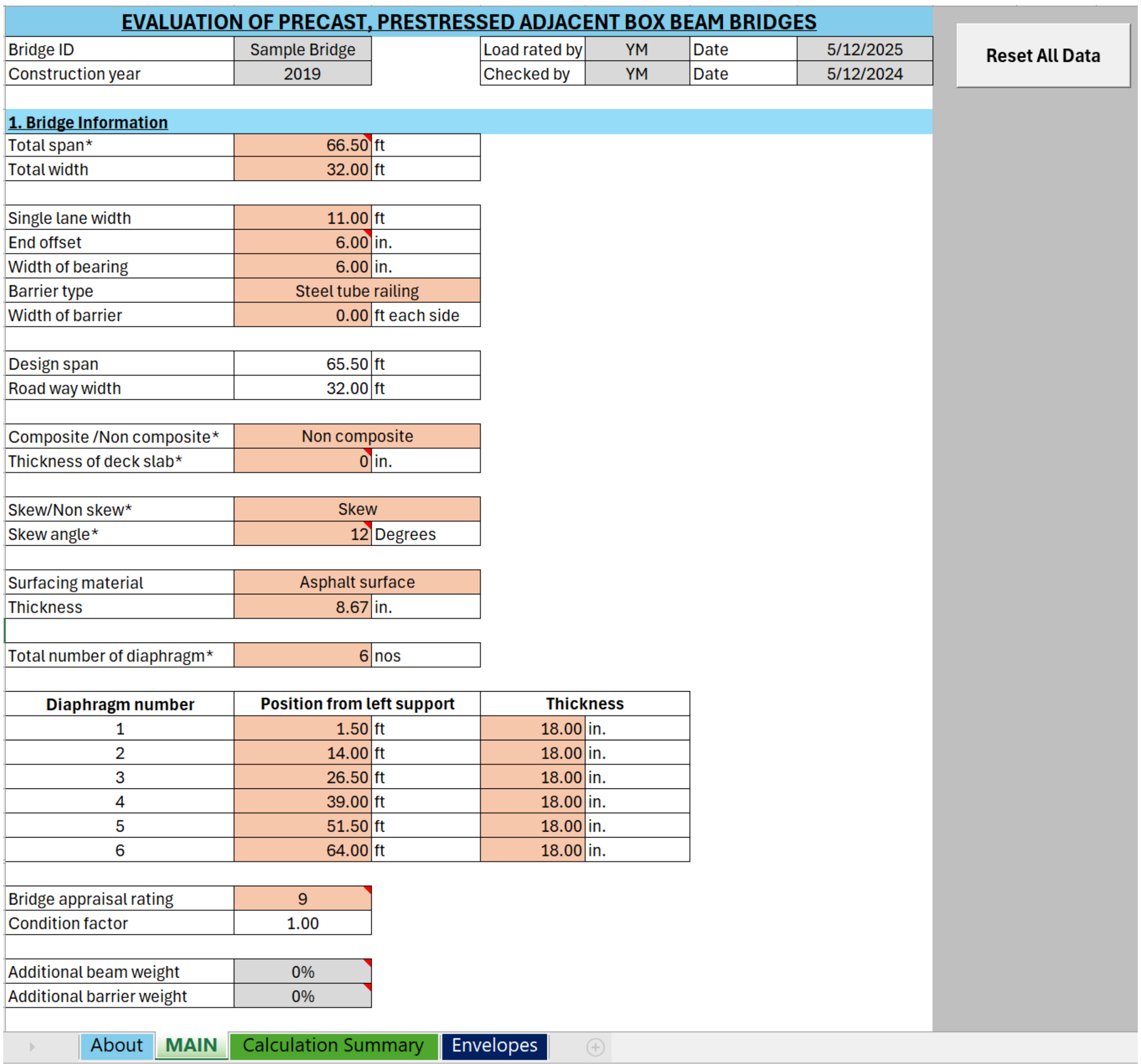
Due to the influence of moving loads, the maximum moment may not occur at the center of the bridge span. While dead loads generally create maximum moments at the center, the moving loads shift these moments slightly away from the centerline. Consequently, the moment values generated by AD-BOX are slightly higher than those obtained from the center, resulting in a more accurate load rating.

These comparisons, encompassing skewed, non-skewed, composite, and non-composite bridges, including both single-cell and multicell box beam configurations, demonstrate the reliability of AD-BOX for the load rating of the simply supported adjacent box beam bridges considered in this study.

3.3. Application of AD-BOX

The AD-BOX interface is developed with two primary tabs (Main and Calculation Summary) and one optional tab (Envelopes). In addition, hidden, on-demand tabs are available for displaying the detailed calculations if the user requests. All user activities for load rating a box beam bridge are conducted within the main tab, which serves as the primary workspace. The calculation summary tab provides a concise overview of all calculations performed within AD-BOX and includes buttons that allow users to unhide specific on-demand tabs to view the detailed calculations if the user requests. In essence, the calculation summary tab functions as a navigation tab for accessing detailed calculations. The optional envelopes tab is developed as a standalone feature, independent of other tabs in AD-BOX, to present the moment and shear envelopes for a selected vehicle type on any single span, simply supported bridge.

A sample image of the AD-BOX interface is presented in Figure 3-18. A 'reset all data' button is provided at the top of the main tab, allowing users to clear all input data and start fresh for a new bridge load rating.



EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample Bridge	Load rated by	YM	Date	5/12/2025
Construction year	2019	Checked by	YM	Date	5/12/2024

Reset All Data

1. Bridge Information

Total span*	66.50	ft
Total width	32.00	ft
Single lane width	11.00	ft
End offset	6.00	in.
Width of bearing	6.00	in.
Barrier type	Steel tube railing	
Width of barrier	0.00	ft each side
Design span	65.50	ft
Road way width	32.00	ft
Composite /Non composite*	Non composite	
Thickness of deck slab*	0	in.
Skew/Non skew*	Skew	
Skew angle*	12	Degrees
Surfacing material	Asphalt surface	
Thickness	8.67	in.
Total number of diaphragm*	6	nos

Diaphragm number	Position from left support		Thickness	
1	1.50	ft	18.00	in.
2	14.00	ft	18.00	in.
3	26.50	ft	18.00	in.
4	39.00	ft	18.00	in.
5	51.50	ft	18.00	in.
6	64.00	ft	18.00	in.

Bridge appraisal rating	9
Condition factor	1.00
Additional beam weight	0%
Additional barrier weight	0%

About | MAIN | Calculation Summary | Envelopes

Figure 3-18 Sample image of AD-BOX interface.

As shown in Figure 3-18, cells in the AD-BOX interface are color-coded to distinguish between input and output. The following color coding is used consistently throughout the interface.

a. Essential input: Light orange

Input Cell

b. Default Built-in input: Light orange with asterisks in the description

Input Cell*

c. Optional input: Light grey

Input Cell

d. Calculated values: white (output)

Output Cell

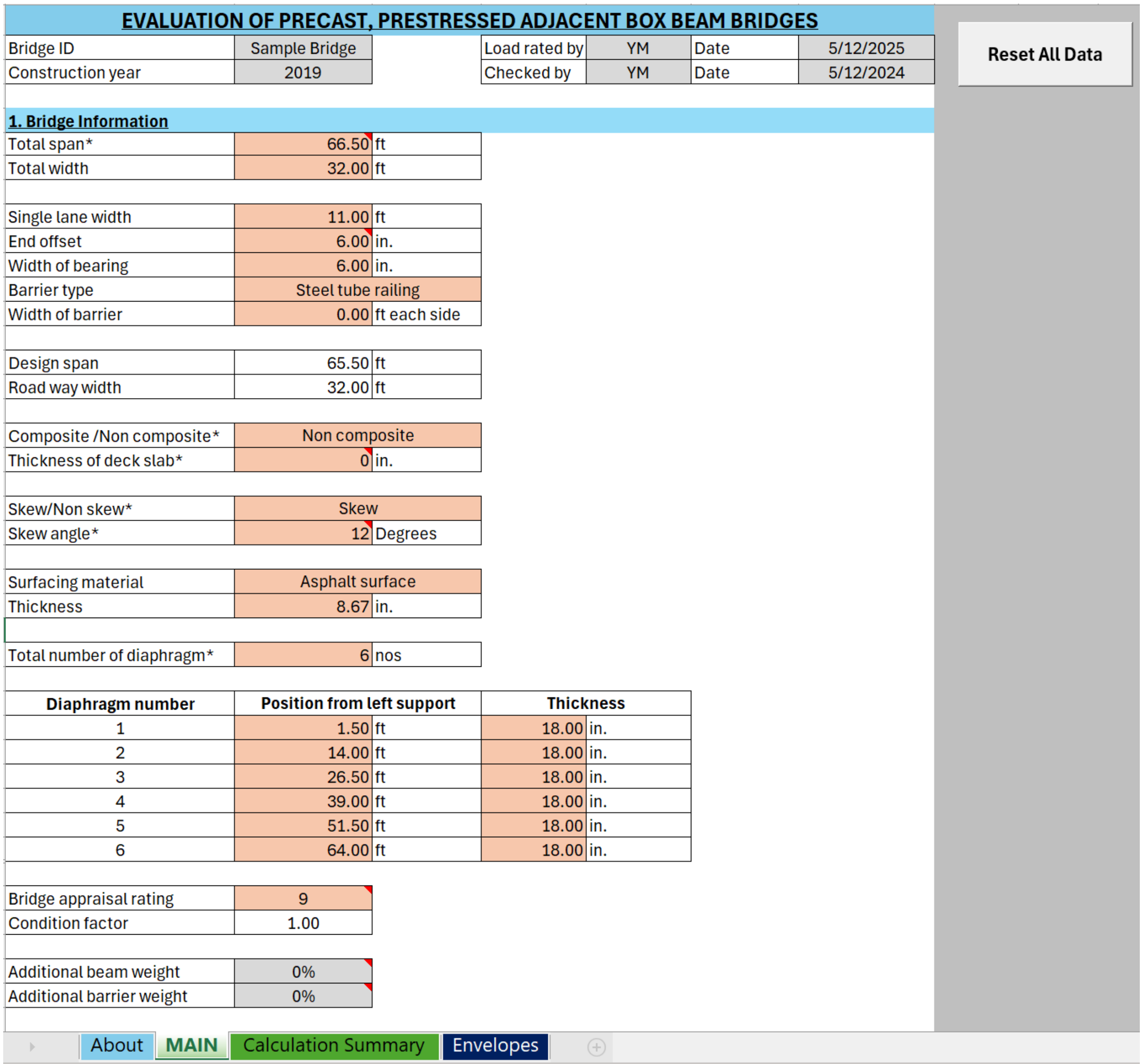
The following sections provide a detailed explanation of how to use AD-BOX.

3.3.1. Main Tab

The main tab is developed to facilitate the input of bridge data and obtain load rating results. It is further divided into four sections: bridge information, material properties, box beam section properties, and load rating.

3.3.1.1. Bridge Information

This is the first section of the main tab. The general bridge information such as bridge span, width of the bridge, barrier type and its width, box beam section type (composite or non-composite), skew angles, surfacing material information, and diaphragm dimensions are input in this section. A sample image of AD-BOX Section 1 of the main tab is shown in Figure 3-19. Users can also input the bridge appraisal rating in this section. Users can also optionally include additional weight for the beam and barrier.



EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample Bridge		Load rated by	YM	Date	5/12/2025
Construction year	2019		Checked by	YM	Date	5/12/2024

Reset All Data

1. Bridge Information

Total span*	66.50	ft
Total width	32.00	ft
Single lane width	11.00	ft
End offset	6.00	in.
Width of bearing	6.00	in.
Barrier type	Steel tube railing	
Width of barrier	0.00	ft each side
Design span	65.50	ft
Road way width	32.00	ft
Composite /Non composite*	Non composite	
Thickness of deck slab*	0	in.
Skew/Non skew*	Skew	
Skew angle*	12	Degrees
Surfacing material	Asphalt surface	
Thickness	8.67	in.
Total number of diaphragm*	6	nos

Diaphragm number	Position from left support		Thickness	
1	1.50	ft	18.00	in.
2	14.00	ft	18.00	in.
3	26.50	ft	18.00	in.
4	39.00	ft	18.00	in.
5	51.50	ft	18.00	in.
6	64.00	ft	18.00	in.

Bridge appraisal rating	9
Condition factor	1.00
Additional beam weight	0%
Additional barrier weight	0%

About | MAIN | Calculation Summary | Envelopes

Figure 3-19 AD-BOX main tab, Section 1 bridge information

The input cells include notes to guide users, indicated by a red triangle marker in the top right corner of each cell. Notes can be viewed by hovering over these cells. A sample of such a cell is shown in Figure 3-20. A complete list of all notes in AD-BOX is provided in Section 3.1.5 of this report.

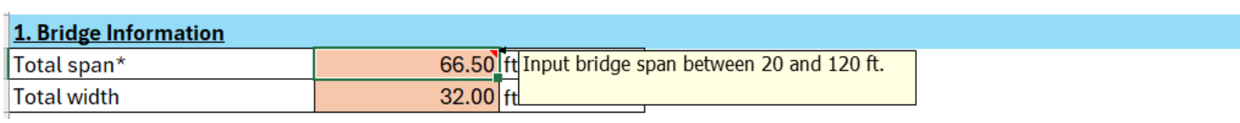


Figure 3-20 Sample image of input cells with notes.

3.3.1.2. Material Properties

This is the second section of the main tab, which is designed for inputting the required material properties. The material properties include compressive strengths of concrete, unit weight of concrete, strengths of reinforcing bars, properties of prestressing strands, unit weights of surfacing materials, and barriers of the bridge. The sample image of Section 2 of the main tab is presented in Figure 3-21.

2. Material Properties

a. Concrete

Required concrete compressive strength at transfer*	f'_{ci}	5.00	ksi
Specified concrete compressive strength for use in design*	f'_c	7.00	ksi
Deck concrete compressive strength *	f'_{c_deck}	4.50	ksi
Concrete unit weight*	w_c	0.15	kcf

Correction factor for source of concrete*	K_1	1	
Modulus of elasticity of concrete for precast beam at transfer	E_{ci}	4286.83	ksi
Modulus of elasticity of concrete for precast beam at service load	E_{c_beam}	5072.24	ksi
Modulus of elasticity of concrete for deck slab	E_{c_slab}	4066.84	ksi

b. Reinforcing Bars

Yield Strength*	f_y	60.00	ksi
Modulus of elasticity*	E_s	29000	ksi

c. Prestressing Strands

Type*	Seven-wire strand	Low-relaxation strand

Diameter	D_p	1/2	in.
Area*	A_p	0.167	in^2
Tensile strength*	f_{pu}	270	ksi
Modulus of elasticity*	E_p	28500	ksi
Yield strength	f_{py}	243	ksi
	K	0.28	

d. Surfacing Material

Type	Asphalt surface	
Unit weight	0.145	kcf

e. Barrier

Type	Steel tube railing	
Unit weight	0.080	kips/ft/side

About | MAIN | Calculation Summary | Envelopes

Figure 3-21 AD-BOX main tab, Section 2 material properties.

3.3.1.3. Box Beam Section Properties

The third section of the main tab is designed for inputting detailed data on the box beam section used in the evaluated bridges. Here, users can specify the box beam section, along with details of prestressing strands, longitudinal reinforcement bars, and shear reinforcement. A sample image of Section 3 in the Main Tab is provided in Figure 3-22.

3. Box Beam Section Properties

Box beam section used	**B21-48**		
Width of each box beam	b	48	in.
Height of each box beam	h	21	in.
No of box beams		8	nos

Section Geometry

No of webs in beam		2	nos
Depth of top flange	h_f	5.5	in.
Depth of bottom flange	h_c	5.5	in.
Width of end web	b_w	5.5	in.
Width of chamfer	w_h	3.0	in.

Section properties		Precast beam	
Area	A	647.80	in^2
Moment of inertia	I	33884.00	in^4
Distance from centroid to extreme bottom fiber	Y_b	10.42	in.
Distance from centroid to extreme top fiber	Y_t	10.58	in.
Section modulus for extreme bottom fiber	S_b	3253.00	in^3
Section modulus for extreme top fiber	S_t	3202.00	in^3

Layers of Prestressing Strands Provided 2

Layer *	Number	Position from extreme tensile face		Remark
Layer 1	18	2	in.	Bottom flange
Layer 2	12	4	in.	Bottom flange
Layer 3	0	0	in.	Top flange
Layer 4	0	0	in.	Top flange
Debonded strands	2	2	in.	Bottom flange

*Note: Input layers from bottom to top of the beam

Longitudinal Reinforcement Bars

Layer	Bar no.	Area	Number	Position from extreme tensile face		Remark
Layer 1	#5	0.31	2	2	in.	Bottom flange

Shear Reinforcement

Zone	Distance to end of region from the support (ft)	Bar no.	Spacing (in.)	Area (in^2)
Region 1	1.50	#4	3	0.40
Region 2	2.00	#4	6	0.40

About | MAIN | Calculation Summary | Envelopes

Figure 3-22 AD-BOX main tab, Section 3 box beam section properties.

Users can select the box beam section used from the drop-down list, as shown in Figure 3-23, which includes all sections from Ohio Standards PSBD 02-07. The properties of the box beam are automatically extracted from the standard table, according to the selected section from the drop-down menu.

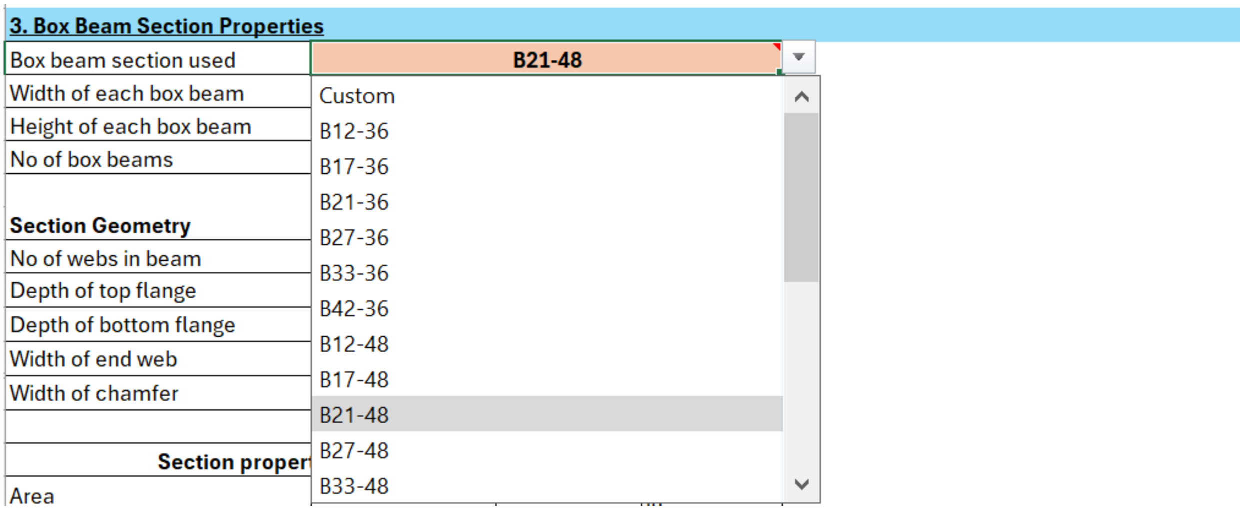


Figure 3-23 Dropdown list to select the box beam section used.

For sections other than those included in PSBD 02-07, users can select 'Custom' from the drop-down list, as shown in Figure 3-24 and manually input its properties, which are highlighted in light orange cells.

3. Box Beam Section Properties			
Box beam section used	**Custom**		
Width of each box beam	b	36	in.
Height of each box beam	h	33	in.
No of box beams		10	nos
Section Geometry			
No of webs in beam		2	nos
Depth of top flange	h_f	5.0	in.
Depth of bottom flange	h_c	5.0	in.
Width of end web	b_w	5.0	in.
Width of chamfer	w_h	3.0	in.
Section properties		**Precast beam**	
Area	A	594.50	in^2
Moment of inertia	I	82048.00	in^4
Distance from centroid to extreme bottom fiber	Y_b	16.28	in.
Distance from centroid to extreme top fiber	Y_t	16.72	in.
Section modulus for extreme bottom fiber	S_b	5039.80	in^3
Section modulus for extreme top fiber	S_t	4907.18	in^3

Figure 3-24 Example of input for custom box beam section in AD-BOX.

The ODOT standard box beams earlier than PSBD 02-07 include multicell box beams. AD-BOX is capable of load rating bridges with box beams that have multiple cells. Users can input the properties of box beams with up to three webs by selecting 'Custom.' The input cell for specifying the number of webs in the beam is activated, allowing users to select between 2 or 3 webs from the drop-down list, as shown in Figure 3-25. Users can manually input the properties, which are highlighted in light orange cells.

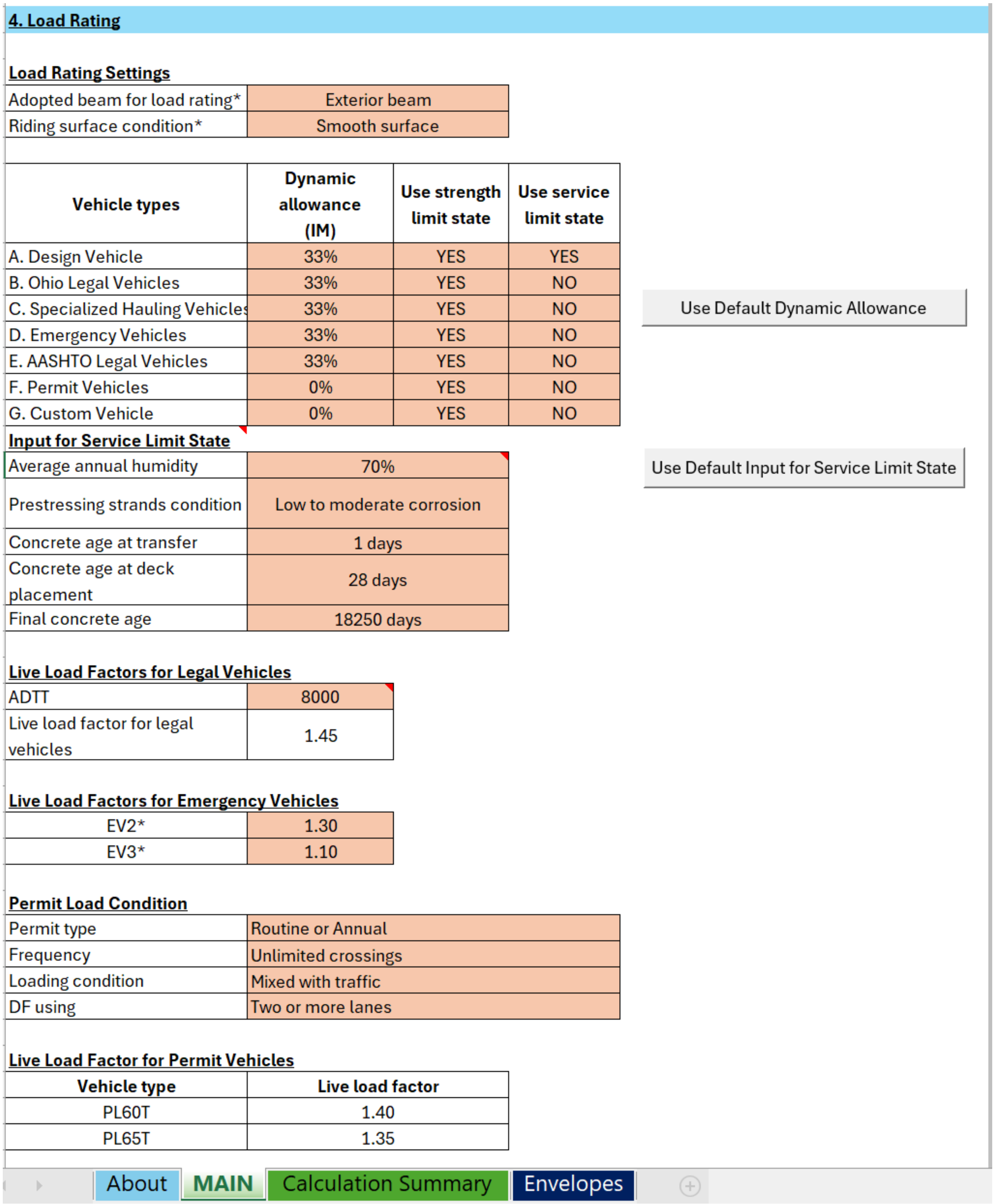
3. Box Beam Section Properties			
Box beam section used	Custom		
Width of each box beam	b	36	in.
Height of each box beam	h	33	in.
No of box beams		10	nos
Section Geometry			
No of webs in beam		3	s
Depth of top flange	h_f	2	in.
Depth of bottom flange	h_c	3	in.
Width of end web	b_w	5.0	in.
Width of middle web	bw_m	3.0	in.
Width of chamfer	w_h	3.0	in.
Section properties		**Precast beam**	
Area	A	594.50	in^2
Moment of inertia	I	82048.00	in^4
Distance from centroid to extreme bottom fiber	Y_b	16.28	in.
Distance from centroid to extreme top fiber	Y_t	16.72	in.
Section modulus for extreme bottom fiber	S_b	5039.80	in^3
Section modulus for extreme top fiber	S_t	4907.18	in^3

Figure 3-25 Example of input for custom box beam section with three webs in AD-BOX.

3.3.1.4. Load Rating

The fourth section of the main tab is for inputting the load rating settings and obtaining the load rating results. A sample image of the load rating setting part of this section is presented in Figure 3-26. Users can set the beam to be rated as an exterior or interior beam. Users can use the default dynamic allowance (IM) for each vehicle type as specified in Section 3.1.3.6 by clicking the provided button. IM can also be manually overwritten as required. Users can input average daily truck traffic (ADTT) in this section. ADTT is used to calculate the live load factors for legal vehicles as specified in Section 3.1.3.6.2. The live load factors for emergency vehicles can be input in this section. Users can input the average annual humidity of the bridge location, prestressing strands condition, and age of concrete required for calculations using service limit states in this section.

Permit load conditions can be selected using the drop-down provided to switch between conditions as presented in Table 3-12. The load factors for permit loads will be automatically calculated based on the selected conditions.



4. Load Rating

Load Rating Settings

Adopted beam for load rating*	Exterior beam
Riding surface condition*	Smooth surface

Vehicle types	Dynamic allowance (IM)	Use strength limit state	Use service limit state
A. Design Vehicle	33%	YES	YES
B. Ohio Legal Vehicles	33%	YES	NO
C. Specialized Hauling Vehicles	33%	YES	NO
D. Emergency Vehicles	33%	YES	NO
E. AASHTO Legal Vehicles	33%	YES	NO
F. Permit Vehicles	0%	YES	NO
G. Custom Vehicle	0%	YES	NO

Use Default Dynamic Allowance

Input for Service Limit State

Average annual humidity	70%
Prestressing strands condition	Low to moderate corrosion
Concrete age at transfer	1 days
Concrete age at deck placement	28 days
Final concrete age	18250 days

Use Default Input for Service Limit State

Live Load Factors for Legal Vehicles

ADTT	8000
Live load factor for legal vehicles	1.45

Live Load Factors for Emergency Vehicles

EV2*	1.30
EV3*	1.10

Permit Load Condition

Permit type	Routine or Annual
Frequency	Unlimited crossings
Loading condition	Mixed with traffic
DF using	Two or more lanes

Live Load Factor for Permit Vehicles

Vehicle type	Live load factor
PL60T	1.40
PL65T	1.35

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Figure 3-26 AD-BOX main tab, Section 4 load rating.

In this section, a custom vehicle with up to 35 axles can be added by selecting ‘YES’ from the drop-down menu. An example of a custom vehicle with 19 axles is shown in Figure 3-27. The custom vehicle is treated as a permit load, and the live load factor will be automatically calculated based on the selected custom vehicle load conditions.

Add custom vehicle*	YES
No of axles	19

Axle No	**Load (kips)**	**Distance from first axle (ft)**
a	20.00	0.00
b	20.00	13.50
c	20.00	18.50
d	20.00	23.50
e	19.00	38.50
f	19.00	43.50
g	19.00	48.50
h	19.00	63.17
i	19.00	68.17
j	19.00	73.17
k	19.00	77.67
l	19.00	82.67
m	19.00	87.67
n	19.00	92.17
o	19.00	97.17
p	19.00	102.17
q	19.00	116.25
r	19.00	121.25
s	19.00	126.25

Custom Vehicle Load Condition

Permit type	Special or Limited crossing
Frequency	Single trip
Loading condition	Escorted with no other vehicle on the bridge
DF using	One lane

Live Load Factor for Custom Vehicle

Vehicle type	**Live load factor**
Custom vehicle	1.10

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Figure 3-27 Inputting custom vehicle in AD-BOX.

After inputting all values and selecting the load rating setting, the load rating for all vehicle types is computed by a click of the 'Compute Load Rating' button as shown in Figure 3-28. The load rating values for each vehicle type will also be displayed in the load rating results of this section. A sample image of the load rating results is presented in Figure 3-28.

LOAD RATING RESULTS

Compute Load Rating

Load Rating Results

Loading Type	GVW Tons	Rating Factor
Ohio Legal Vehicles		
2F1	15	3.234
3F1	23	2.165
5C1	40	2.206
Specialized Hauling Vehicles		
SU4	27	1.902
SU5	31	1.728
SU6	34.5	1.550
SU7	38.75	1.422
Emergency Vehicles		
EV2	28.75	2.085
EV3	43	1.613
AASHTO Legal Vehicles		
Type3	25	2.146
Type3S2	36	2.018
Type3_3	40	2.170
Permit Vehicles		
PL60T	60	2.278
PL65T	65	1.762
Custom Vehicle		
Custom Vehicle 1	183	2.239

Design Vehicles		
Loading Type	Rating Factor	
	Inventory	Operating
HL93	1.004	1.325

Figure 3-28 Load rating results in AD-BOX.

To prevent errors in results due to updates in any input, a warning will be displayed, as shown in the Figure 3-29, whenever a change in input is detected. This prompts the user with the warning that some input values have changed, and re-computation is required.

Click on the 'Compute Load Rating' button.
Some input values have been changed.

Compute Load Rating

Figure 3-29 Message to users to indicate some input values have been changed.

3.3.2. Calculation Summary Tab

The calculation summary tab provides a summary of the detailed calculations involved in the bridge's load rating. Detailed explanations of the calculations involved in the load rating are discussed in Section 3.1.3 of this report. This tab consists of a summary of calculations such as unfactored moment for interior and exterior beams due to dead load and live loads, live load distribution factors, unfactored shear for interior and exterior beams due to dead loads and live loads, moment and shear capacities, and load rating factors. Buttons are provided along with the summary to navigate through the on-demand tabs containing the detailed calculations involved in the summarized values.

A sample image of the summary of unfactored moments for interior and exterior beams due to dead loads is presented in Figure 3-30. The summary of unfactored moments consists of results due to all dead loads at the center, at the shear critical point, and at the moment critical point for all vehicle types. The details of the calculation can be viewed or hidden by clicking the 'Show Moment and Shear Calculations' button provided along with the summary.

Calculation Summary

Dead Loads

a. Beam self weight	0.675	kips/ft/beam
b. Barrier weight	0.020	kips/ft/beam
c. Diaphragm weight	0.550	kips/diaphragm
d. Wearing surface	0.419	kips/ft/beam

Unfactored Moment for Interior and Exterior Beam due to Dead Loads

Location	Vehicle types	Position from left support (ft)	Beam weight (kips-ft) (a)	Barrier weight (kips-ft) (b)	Diaphragm weight (kips-ft) (c)	Dc (kips-ft) (a+b+c)	Wearing surface (kips-ft) (d)	Dw (kips-ft) (d)
At center	All type	32.75	361.88	10.73	23.10	**395.70**	224.73	**224.73**
At shear critical point	All type	1.61	34.72	1.03	2.60	**38.35**	21.56	**21.56**
At Region 2	All type	1.50	32.39	0.96	2.48	**35.83**	20.11	**20.11**
At moment critical point	**A. Design Vehicle**							
	HL93	30.42	360.04	10.67	23.10	**393.81**	223.59	**223.59**
	HL93_Tande	33.75	361.54	10.72	23.10	**395.36**	224.52	**224.52**
	B. Ohio Legal Vehicles							
	2F1	34.42	360.94	10.70	23.10	**394.74**	224.15	**224.15**
	3F1	33.32	361.77	10.72	23.10	**395.59**	224.66	**224.66**
	5C1	27.36	352.09	10.44	23.10	**385.62**	218.65	**218.65**
	C. Specialized Hauling Vehicles							
	SU4	33.97	361.37	10.71	23.10	**395.18**	224.42	**224.42**
	SU5	34.72	360.57	10.69	23.10	**394.36**	223.92	**223.92**
	SU6	33.98	361.37	10.71	23.10	**395.18**	224.41	**224.41**
	SU7	33.23	361.80	10.72	23.10	**395.62**	224.68	**224.68**
	D. Emergency Vehicles							
	EV2	35.88	358.57	10.63	23.10	**392.30**	222.68	**222.68**
	EV3	34.12	361.24	10.71	23.10	**395.05**	224.33	**224.33**
	E. AASHTO Legal Vehicles							
	Type3	34.47	360.88	10.70	23.10	**394.68**	224.11	**224.11**
	Type3S2	29.06	357.27	10.59	23.10	**390.96**	221.87	**221.87**
	Type3_3	32.04	361.71	10.72	23.10	**395.53**	224.62	**224.62**
	F. Permit Vehicles							
	PL60T	32.77	361.88	10.73	23.10	**395.70**	224.73	**224.73**
	PL65T	28.37	355.39	10.53	23.10	**389.03**	220.70	**220.70**
	G. Custom Vehicle							
	Custom_Vehicle_1	34.46	360.89	10.70	23.10	**394.69**	224.12	**224.12**

Show Moment and Shear Calculations

Hide Moment and Shear Calculations

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Figure 3-30 AD-BOX summary tab, example of summary of unfactored moment for interior and exterior beam due to dead loads.

The list of buttons included in the Summary tab is presented in Figure 3-31. Buttons labeled as 'Show' can be used to display the on-demand tabs as mentioned with the button itself. Similarly, the button labeled as 'Hide' can be used to hide the on-demand tabs displayed using the show buttons. This design keeps the interface clear and simple by displaying detailed information only when requested by the user.

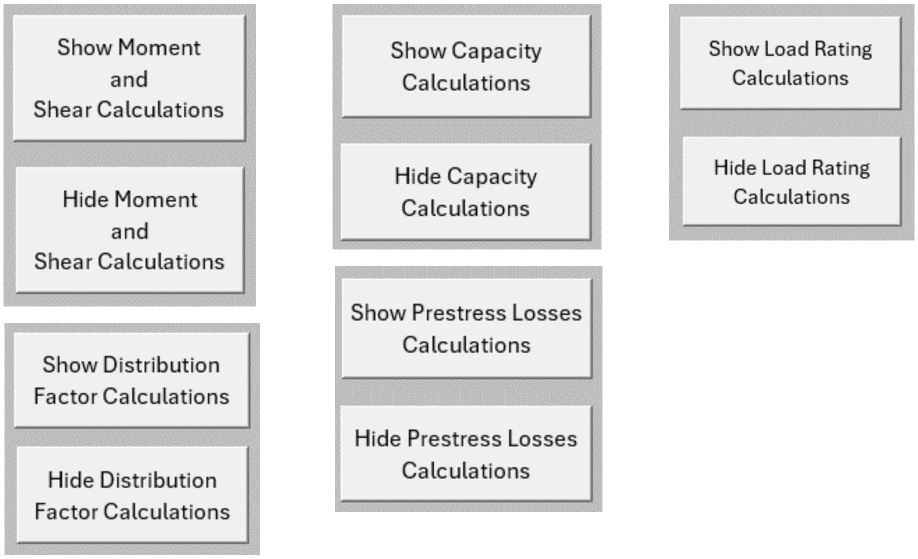
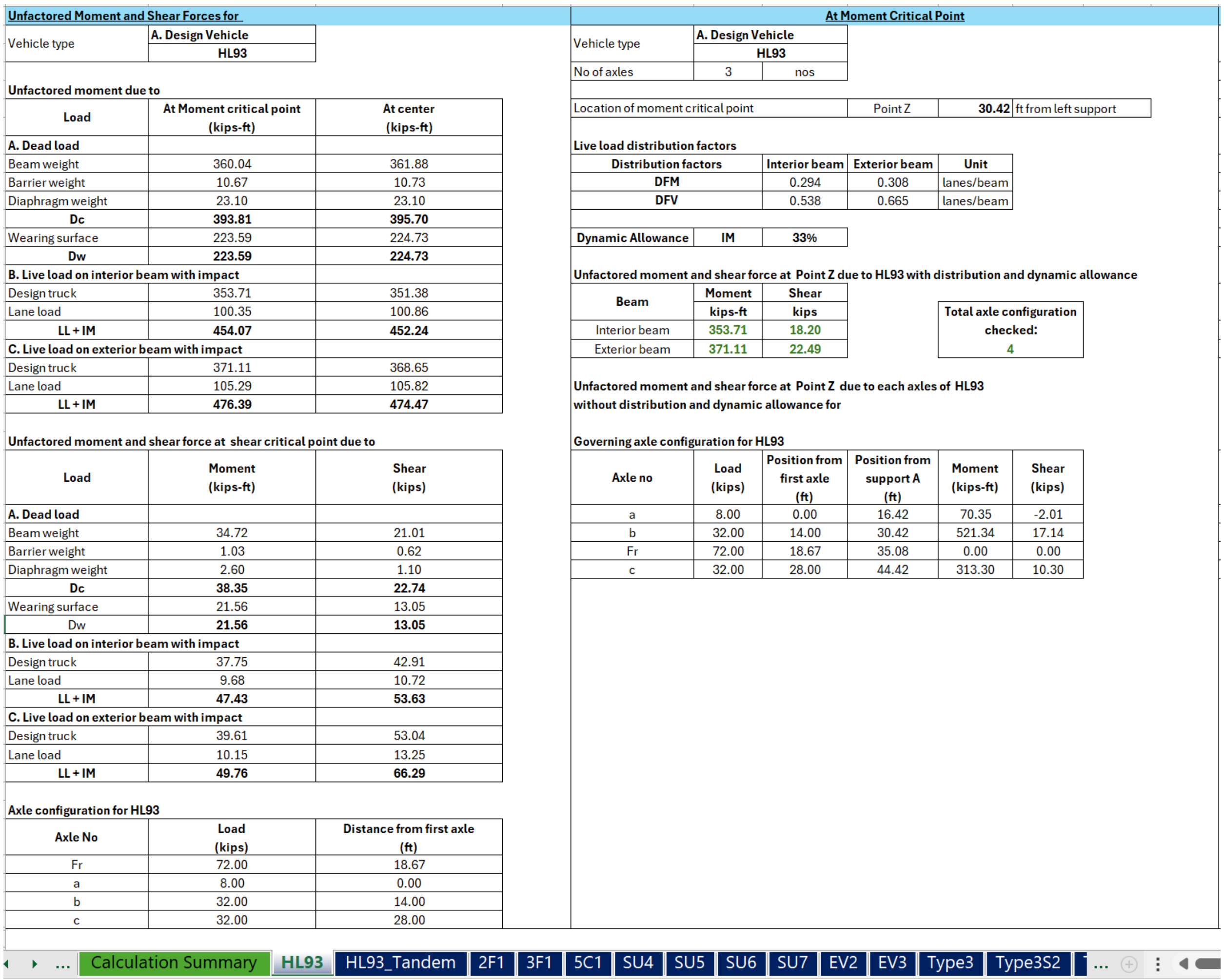


Figure 3-31 List of buttons in the summary tab in AD-BOX.

A sample of the on-demand tab containing the detailed calculations displayed upon clicking the 'Show Moment and Shear Calculations' button is presented in Figure 3-32. This figure provides a sample image of the detailed calculations specifically for the HL-93 vehicle type. The unfactored moment and shear force calculations at the critical moment point are visible in this figure. Each vehicle type has a separate tab, shown in dark blue in Figure 3-32 to ensure a clean and user-friendly interface within AD-BOX. Similarly, calculations for distribution factors, capacity, and load rating each have their own dedicated tabs.



Unfactored Moment and Shear Forces for

Vehicle type	A. Design Vehicle	
	HL93	

Unfactored moment due to

Load	At Moment critical point (kips-ft)	At center (kips-ft)
A. Dead load		
Beam weight	360.04	361.88
Barrier weight	10.67	10.73
Diaphragm weight	23.10	23.10
Dc	**393.81**	**395.70**
Wearing surface	223.59	224.73
Dw	**223.59**	**224.73**
B. Live load on interior beam with impact		
Design truck	353.71	351.38
Lane load	100.35	100.86
LL + IM	**454.07**	**452.24**
C. Live load on exterior beam with impact		
Design truck	371.11	368.65
Lane load	105.29	105.82
LL + IM	**476.39**	**474.47**

Unfactored moment and shear force at shear critical point due to

Load	Moment (kips-ft)	Shear (kips)
A. Dead load		
Beam weight	34.72	21.01
Barrier weight	1.03	0.62
Diaphragm weight	2.60	1.10
Dc	**38.35**	**22.74**
Wearing surface	21.56	13.05
Dw	**21.56**	**13.05**
B. Live load on interior beam with impact		
Design truck	37.75	42.91
Lane load	9.68	10.72
LL + IM	**47.43**	**53.63**
C. Live load on exterior beam with impact		
Design truck	39.61	53.04
Lane load	10.15	13.25
LL + IM	**49.76**	**66.29**

Axle configuration for HL93

Axle No	Load (kips)	Distance from first axle (ft)
Fr	72.00	18.67
a	8.00	0.00
b	32.00	14.00
c	32.00	28.00

At Moment Critical Point

Vehicle type	A. Design Vehicle	
	HL93	
No of axles	3	nos

Location of moment critical point	Point Z	**30.42**	ft from left support

Live load distribution factors

Distribution factors	Interior beam	Exterior beam	Unit
DFM	0.294	0.308	lanes/beam
DFV	0.538	0.665	lanes/beam

Dynamic Allowance	**IM**	**33%**

Unfactored moment and shear force at Point Z due to HL93 with distribution and dynamic allowance

Beam	Moment	Shear
	kips-ft	kips
Interior beam	353.71	18.20
Exterior beam	371.11	22.49

Total axle configuration checked: 4

Unfactored moment and shear force at Point Z due to each axles of HL93 without distribution and dynamic allowance for

Governing axle configuration for HL93

Axle no	Load (kips)	Position from first axle (ft)	Position from support A (ft)	Moment (kips-ft)	Shear (kips)
a	8.00	0.00	16.42	70.35	-2.01
b	32.00	14.00	30.42	521.34	17.14
Fr	72.00	18.67	35.08	0.00	0.00
c	32.00	28.00	44.42	313.30	10.30

Figure 3-32 Sample image of the detailed calculations displayed using a button in the summary tab.

3.3.3. Envelopes Tab

An optional tab (Envelopes) is developed for the presentation of envelopes for bending moment and shear force due to a selected vehicle type on any single span, simply supported bridge, including box beam bridges. This tab is independent of other tabs in AD-BOX.

In this tab, users can input bridge span and vehicle type in the light orange input cell as presented in Figure 3-33. A drop-down menu with a list of 15 vehicle types is provided to reduce user effort in adding the vehicle type. The axle configuration for the selected vehicle type is generated automatically. As the 16th vehicle type, a custom vehicle can be selected from the drop-down menu. For a custom vehicle, input is required for the number of axles and axle configuration. The moment and shear envelopes are calculated with the click of the 'Compute Envelopes' button. The moment and shear envelopes are generated in both tabular and chart formats as presented in Figure 3-33 and Figure 3-34. The calculated moment and shear force do not contain any distribution and impact factors. Appropriate factors should be applied. The values in tabular format allow the engineering community to copy and utilize them for independent analysis, while the chart format provides a visual presentation of the variation of moment and shear values along the bridge span.

Envelopes

This is a standalone tab, which generates moment and shear envelopes for the selected vehicle type on a single span simply supported bridge.

Bridge span	65.50 ft
Vehicle type	Type3_3
Number of axles	6

Compute Envelopes

Vehicle Configuration for Type3_3

Axle	Load (kips)	Distance from first axle (ft)
a	12	0
b	12	15
c	12	19
d	16	34
e	14	50
f	14	54

Envelopes

Distance (ft)	Moment Envelope (kips-ft)	Shear Envelope (kips)
0.00	0.00	50.81
6.55	280.40	42.81
13.10	464.00	35.10
19.65	581.74	28.30
26.20	628.80	21.50
32.04	658.02	16.83
32.75	657.50	16.26
39.30	628.80	11.86
45.85	581.74	7.55
52.40	464.00	4.75
58.95	280.40	1.95
65.50	0.00	0.00

Note: The presented moment and shear values are for the selected vehicle type. These values do not include any distribution factors or impact factors. Appropriate distribution and impact factors should be applied.

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Figure 3-33 Sample image of the envelopes tab.

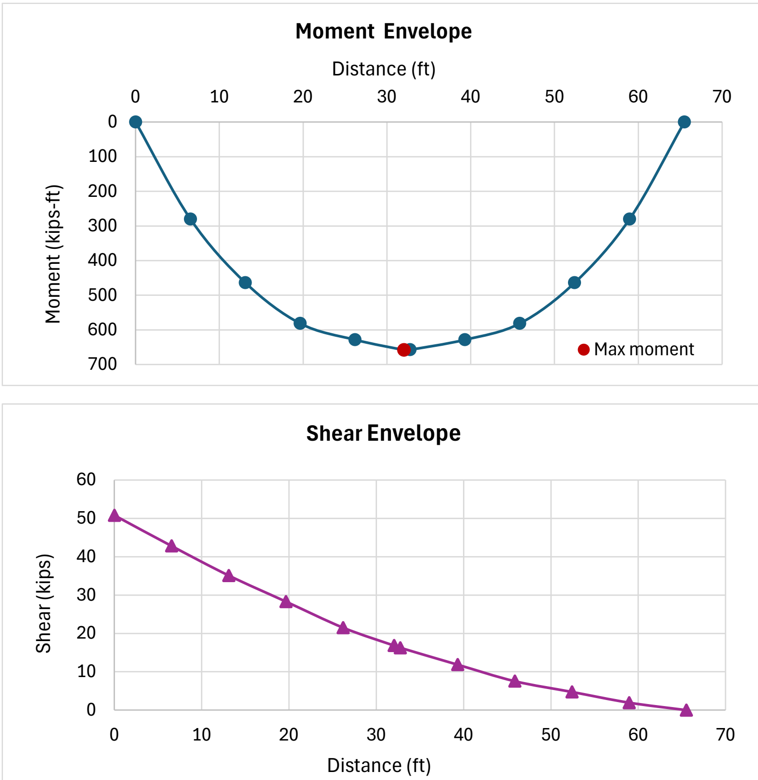

Figure 3-34 Sample of moment and shear envelopes chart in AD-BOX.

3.4. Limitations of AD-BOX

Recognizing a computer tool's boundaries is essential for the proper use of it. Understanding these limitations fosters a more effective and accurate application of AD-BOX in various bridge load rating scenarios.

These limitations are categorized into three groups as follows:

3.4.1. Code Limitations

AD-BOX is designed in accordance with AASHTO MBE (2018) and AASHTO LRFD specifications (2024), with specific elements drawn from the ODOT BDM (2020). While it incorporates equations and methodologies from these standards, certain limitations remain, as outlined below:

a. Range of bridge span

The live load distribution factors used in AD-BOX calculations follow AASHTO LRFD Article 4.6.2.2, applicable only to bridge spans between 20 and 120 ft. AD-BOX cannot perform load ratings for bridges with spans outside this range. To guide the user, a note has been added in the input cell, and AD-BOX will display a warning if a span outside this limit is entered.

b. Skew angle

AASHTO LRFD provides equations to adjust live load distribution factors for skewed bridges with angles up to 60 degrees, but the ODOT BDM restricts skew angles to a maximum of 30 degrees. Since AD-BOX prioritizes ODOT BDM guidelines, a 30-degree upper limit is adopted for the skew angles. Additionally, to apply the skew correction factors, the angle between skewed supports must be less than 10 degrees.

c. Strength of concrete

The equations used for calculations of the moment capacity of the beam are valid for normal-weight concrete strength up to 15.0 ksi.

d. Weight of concrete

AD-BOX can load rate bridges designed with normal-weight concrete, having a unit weight greater than 0.135 kcf and not exceeding 0.155 kcf.

3.4.2. Geometric Limitations

To reduce complexities in the calculations, AD-BOX is developed considering the specific geometry of the bridge section. Users should be aware of the following limitations.

a. Multi-span bridges

AD-BOX is specifically designed for the load rating of single span, simply supported adjacent box beam bridges. It effectively handles load rating for individual spans of these bridge types but does not support continuous beam bridges. For multi-span, simply supported bridges, users should use multiple instances of AD-BOX and load rate each span individually. The capability to handle multiple spans is omitted to maintain a more straightforward user interface in AD-BOX.

b. Multicell box beams

The box beam sections included in AD-BOX are based on the Ohio Standards PSBD 02-07, featuring rectangular box beams with two webs. For other sections not included in PSBD 02-07, AD-BOX offers an additional function for adding custom sections. AD-BOX can load rate beams with up to three webs i.e., multicell beams. However, AD-BOX is only capable of load rating the multicell box beams, which have both cells with identical dimensions.

3.4.3. Calculation Limitations

AD-BOX is designed with a simple, user-friendly interface. To maintain the ease of use, certain capabilities have been intentionally limited, as explained below:

a. Beam capacity calculations

For strength limit state beam capacity calculations, AD-BOX uses approximate flexural resistance equations as outlined in AASHTO LRFD Article 5.6.3. While the strain compatibility method, specified in AASHTO LRFD Article 5.6.3.2.5, may also be used, it requires complex, iterative calculations that would significantly increase complexity. For load rating purposes, the approximate method has been found to provide acceptable estimates of beam capacities as discussed in Section 3.2.2.1 of this report; therefore, the strain compatibility method has not been incorporated into AD-BOX.

b. Bridges designed with multiple box beam sections

AD-BOX can load rate simply supported adjacent box beam bridges with only one type of box beam in the cross-section of the bridge. Exceptional cases with multiple box beams within a single bridge cross-section are not included with AD-BOX.

4. Research Findings and Conclusions

This research developed an innovative computer tool, AD-BOX, which stands for **Ad**jacent **Box** Beam Bridge Analysis and Rating, to address the need for a simple, reliable, and user-friendly tool specialized in the load rating of simply supported adjacent box beam bridges. AD-BOX is developed using the Visual Basic for Applications (VBA) programming language and is included in a user-friendly Microsoft Excel spreadsheet to eliminate the need to install and learn new software. AD-BOX is developed according to the load rating criteria from the AASHTO Manual for Bridge Evaluation (2018), with standards from the AASHTO LRFD Bridge Design Specifications (2024), and specific guidelines from the ODOT Bridge Design Manual (BDM 2020).

AD-BOX is verified with independent hand calculations and compared with an established general-purpose bridge rating software. 18 sample bridges are load rated for 15 vehicle types required by ODOT BDM (2020) and custom vehicles with up to 35 axles, using AD-BOX, independent hand calculations, and the general-purpose bridge rating software. The 15 vehicle types include the Design Vehicle (HL-93), Ohio legal loads (2F1, 3F1, 5C1), AASHTO legal loads (Type 3, Type 3S2, Type 3-3), special hauling vehicles (SU4, SU5, SU6, SU7), emergency vehicles (EV2, EV3), permit loads (PL 60T, PL 65T). The bridge samples consist of seven non-skewed bridges and eleven skewed bridges. All non-skewed bridges consist of single-cell box beams, while nine skewed bridges consist of single-cell box beams, and the remaining two skewed bridges consist of multicell box beams. Eight have non-composite sections while the remaining ten have composite sections.

The verification results with independent hand calculations provide a mean of approximately 1.0 with a coefficient of variation (CV) nearly equal to 0% for the rating factor (RF) ratios of AD-BOX divided by hand calculations. The comparison results with the bridge rating software provide a mean of approximately 1.0 with a CV with up to 3.72% for the RF ratios of AD-BOX divided by the bridge rating software.

AD-BOX uses the maximum moment capacity calculations due to vehicular loadings at the exact maximum moment location instead of the conventional one-tenth-of-the-span method. The research results indicate that this approach provides approximately 3% more accurate maximum moments. In addition, it dramatically reduces the output produced and the associated burden on the users to process the output.

AD-BOX performs shear load rating for all potential shear critical locations, including the point at a distance equal to the effective shear depth (d_v) away from the internal face of the support and other points where shear reinforcement details change. In addition, AD-BOX has the capability to load rate the older box beam sections with multicell configurations.

To consider the future needs for vehicles beyond the 15 vehicle types listed in the ODOT BDM (2020), AD-BOX has been developed with the capability to include custom vehicles with up to 35 axles. A high axle count is selected to consider vehicles that may emerge in the future.

To allow engineers to use the developed tool for any type of simply supported bridge, a capability is developed to calculate moment and shear envelopes due to one of the 15 vehicle types and a custom vehicle. AD-BOX presents the envelope values in both tabular and chart formats. The tabular format allows engineers to copy and use the values in other analysis software or hand calculations, while the chart format offers a visual representation of the variation of the envelopes along with their peak values.

The result of this study demonstrates the accuracy and reliability of AD-BOX for load rating simply supported precast prestressed adjacent box beam bridges for the vehicle types noted above. It is expected that AD-BOX will reduce the time and effort required for load rating adjacent box beam bridges.

5. Recommendations for Implementation

The computer tool, AD-BOX, has been developed for use by practicing engineers and researchers, ensuring readiness for implementation. The following features have been incorporated to facilitate implementation into bridge load rating practice.

- Familiar Microsoft Excel spreadsheet environment,
- Color coded input cells, supported by floating notes that appear when the cursor is hovered,
- Warning and error messages included to minimize input errors,
- Section 3.3 of this report developed as a practical user guide,
- Tutorial videos prepared for dissemination through YouTube,
- A dedicated web page for hosting related documents, user guides, and videos,
- An article in the ODOT's Research Newsletter if requested by ODOT,
- A journal paper to reach a broader audience and facilitate further research in this area, and
- Transportation Research Board (TRB) committee presentations to reach state bridge engineering officials and decision makers.

The following actions are recommended for the users of AD-BOX.

- Review the appropriate resources noted above for the proper use of AD-BOX,
- Load rate a few bridges with known results (e.g., bridges load rated previously using another tool, or sample bridges included in this report) to establish proficiency with AD-BOX,
- Do not proceed in the presence of warning or error messages,
- In the case of unusual results, use another tool or hand calculations to verify, and
- Be wary of the limitations and intended applications of AD-BOX.

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Appendix A: Comprehensive Shear Check

Appendix A contains the detailed shear check at different locations along the bridge span. It explains the process of determining the shear critical location for load rating, including the typical shear check location (distance d_v, from the internal face of the bearing at the support) and other points where the shear reinforcement and its spacing change.

Appendix A: Comprehensive Shear Check

A1. Objective

The objective of this Appendix is to check if the load rating in shear is required at any other location than the typical shear check point, which is at a distance equal to the effective shear depth (d_v) away from the internal face of the bearing at the support.

A2. Methodology

This Appendix investigates the shear load rating of simply supported precast prestressed adjacent box beam bridges at different locations along the bridge span due to the design vehicle HL-93 in the Strength-I limit state at the operating condition. Four cases are studied, considering four bridge samples 2, 7, 11, and 16, among those listed in Table 3-16 of the report, provided by the Ohio Department of Transportation (ODOT), each for the following cases: non-composite non-skew, non-composite skew, composite non-skew, and composite skew. Shear forces, nominal shear capacities, and rating factors are calculated at the typical shear check point and at other locations as the vehicle moves across the bridge span. This Appendix compares shear load rating factors from these different locations, particularly when the provided shear reinforcement details change.

A3. Shear Load Rating

The typical shear critical point on the simply supported bridge is located at a point at a distance equal to the effective shear depth d_v away from the face of bearings at the supports. Apart from the distance *dv* away from the face of the bearing at the support, shear on the beam could be critical at other locations when the shear reinforcement details change as discussed in Section 3.1.3.3.2 of the report.

The nominal shear capacity of the beam is calculated according to the AASHTO LRFD Article 5.7.3.3, as discussed in Section 3.1.3.5.2 of the report. The nominal shear capacity of a beam is governed by factors such as the concrete's strength, and the type and quantity of shear reinforcement, as well as the shear resistance parameters, theta (θ) and beta (β). The values of θ and β are determined by the net longitudinal tensile strain in the section at the centroid of the tensile reinforcement, denoted as ε_s. In the bridge samples provided by ODOT, the ε_s value tends to be minimal, approaching zero, while the β and θ values consistently remain at 4.8 and 29 degrees, respectively. Therefore, the critical factor in determining the nominal shear capacity is the amount of transverse shear reinforcement provided.

According to ODOT standards PSBD 02-07, the shear reinforcements are closely spaced near the supports, as shown in Region 1, and the spacing is increased towards the center, as shown in Region 2 of the typical beam elevation shown in Figure A3-1. Region 1 has complete set of U bars with sufficient development to act as shear reinforcement. Region 2 has a complete set of U bars and only alternative top U bars. The alternate top U bar in Region 2 alone does not act as a shear reinforcement due to insufficient leg length after development. This reduces shear capacity due to increased reinforcement spacing.

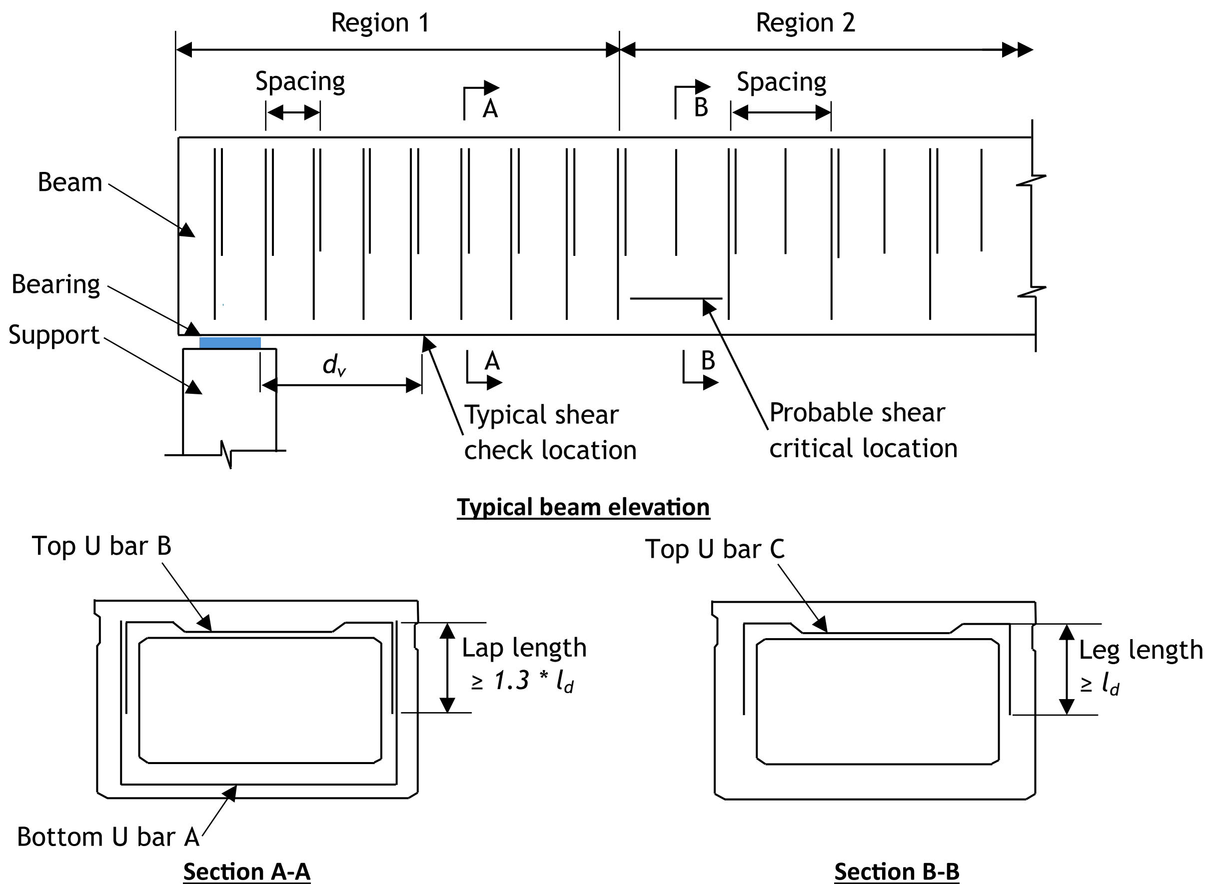

Figure A3-1 Typical beam section and elevation showing typical shear check location and probable critical point.

Development length is the minimum length of a reinforcing bar required to safely transfer stress between the bar and surrounding concrete without slipping. Two types of development length are typically considered: tension development length and compression development length. As the stirrup resists shear, it experiences tensile stresses along its legs. Therefore, the tensile development length is considered while checking shear. AASHTO LRFD Bridge Design Specifications (2024) Article 5.10.8.2 provides guidelines for calculating the tension development length. The development length shall be greater of (a) and (b):

(a) $l_d = l_{bd} * \dfrac{\lambda_{rl}\lambda_{cf}\lambda_{rc}\lambda_{er}}{\lambda}$

in which,

$$l_{bd} = 2.4 d_b \frac{f_y}{\sqrt{f_c'}}$$

(b) 12 in

where:

l_d = Development length, in

f_y = Specified yield strength of reinforcement, ksi

f_c' = Specified compressive strength of concrete, ksi

d_b = Nominal diameter of bar, in

λ_{rl} = Reinforcement location factor, 1

λ_{cf} = Coating factor, 1

λ_{rc} = Reinforcement confinement factor, 1

λ_{er} = Excess reinforcement factor, λ_{er} = (Requires As/Provided As)

λ = Concrete density modification factor

The detailed calculations for the load rating for the four cases at different locations are presented in subsequent sections.

Case-1: Non-Composite Non-Skew (Box Beam Section: B21-48)

The non-composite, non-skew adjacent box beam bridge, with a design span length of 50 ft and beam section B21-48, is analyzed for shear load rating at different locations from the left end to the center of the bridge. The box beam section has a height of 21 in and a width of 48 in. The detailed section and elevation of the B21-48 box beam are presented in Figure A3-2. The detailed calculations are presented below:

Design bridge length (l) = 50 ft
Diameter of the #4 U bars (d_b)= 0.5 in.
Specified yield strength of #4 bar (f_y) = 60 ksi
Specified compressive strength of concrete (f'_c) = 7 ksi
Required area of transverse reinforcement (A_s) = 0.092 in^2
Provided area of transverse reinforcement (A_s) = 0.4 in^2

Development length (l_d) = $2.4 * 0.5 \times \frac{60}{\sqrt{7}} \times \frac{1 \times 1 \times 1 \times \frac{0.092}{0.4}}{1}$ = 6.259 in < 12 in. $\therefore l_d$ = 12 in.

From standard drawings,
Vertical leg length of U bar A = 17 in.
Vertical leg length of U bar B = 17 in.
Vertical leg length of U bar C = 17 in.

1.3* l_d . = 15.6 in. < 17 in.

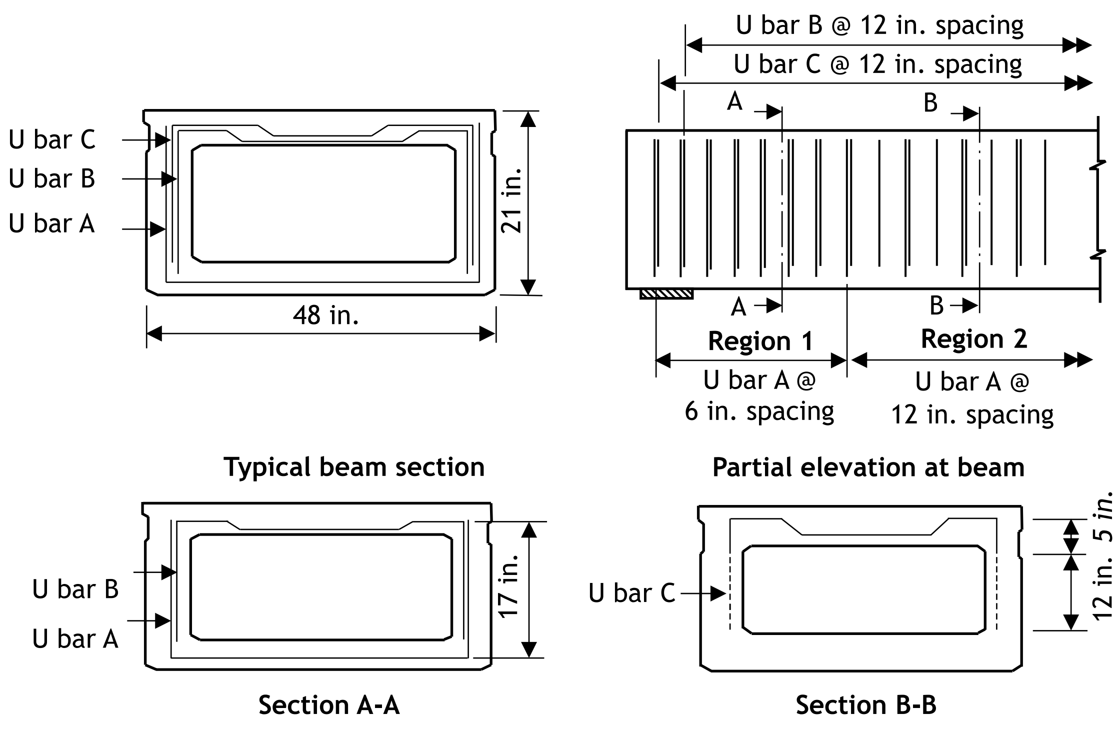

Figure A3-2 Typical beam section and elevation of B21-48 beam.

In Region 1, U bars A-B and U bars A-C overlap to form a complete stirrup, as shown in Figure A3-2. In Region 2, as shown in Section B-B, single U bar C has 17 inches of vertical leg, of which 12 inches are required to fully develop the bar. This leaves only 5 inches available to contribute to the shear resistance, which is insufficient to transfer the shear stress across the section. Therefore, there is no contribution of U bar C to the shear resistance in Region 2, which results in increased spacing of the shear reinforcement compared to Region 1.

The nominal shear capacity and the shear load rating factors for this non-composite, non-skew bridge due to the design vehicle HL-93 in Strength-I limit state at the operating condition, with the vehicle positioned at different locations on the bridge, are presented in Table A3-1.

Table A3-1 Nominal shear capacity and shear load rating factors at different vehicle positions for the non-composite non-skew bridge.

	Distance from the left support (ft)	Nominal shear capacity (kips)	Rating factors	
Region 1	1	200.74	2.426	
	1.8	200.74	2.492	Typical shear check point
	2	200.74	2.512	
	3	200.74	2.603	
	4	200.74	2.700	
Region 2	5	138.46	1.819	Shear critical point
	6	138.46	1.896	
	7	138.46	1.978	
	8	138.46	2.067	
	16	138.46	3.080	
	31	138.46	5.869	Midspan

The nominal shear capacity is higher in Region 1 due to the closer spacing of the shear reinforcement, while the nominal shear capacity in Region 2 decreases significantly because the shear reinforcement spacing is increased compared to Region 1. As a result, the shear load rating factor is minimum at the starting point of Region 2 rather than at the typical shear check point. This demonstrates that shear load rating is required at locations where shear reinforcement details change.

Case-2: Composite Non-Skew (Box Beam Section: CB27-48)

The composite, non-skew adjacent box beam bridge section, with a design span length of 80 ft and beam section CB27-48, is analyzed for shear load rating at different locations from the left extreme end to the center of the bridge. The box beam section has a height of 27 in. and a width of 48 in. The detailed section and elevation of the CB27-48 box beam are presented in Figure A3-3. The detailed calculations are presented below:

Design bridge length (l) = 80 ft
Diameter of the #4 U bars (d_b)= 0.5 in.
Specified yield strength of #4 bar (f_y) = 60 ksi
Specified compressive strength of beam concrete (f'_c) = 7 ksi
Required area of transverse reinforcement (A_s) = 0.092 in^2
Provided area of transverse reinforcement (A_s) = 0.4 in^2

Development length (l_d) = $2.4 \times 0.5 \times \frac{60}{\sqrt{7}} \times \frac{1 \times 1 \times 1 \times \frac{0.092}{0.4}}{1}$ = 6.259 in < 12 in. $\therefore$ l_d = 12 in.

From standard drawings,
Vertical leg length of U bar A = 23 in.
Vertical leg length of U bar B = 17 in.
Vertical leg length of U bar C = 21 in.

1.3* l_d = 15.6 in. < 17 in.

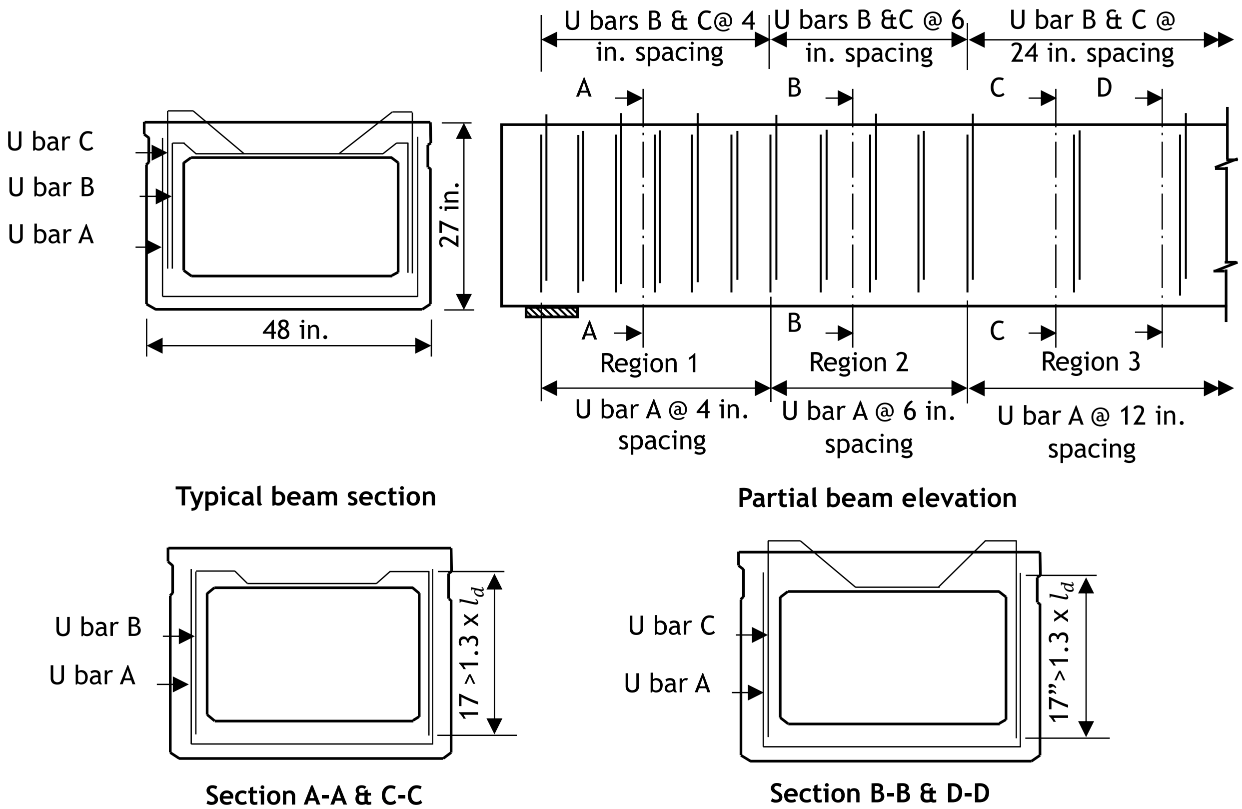

Figure A3-3 Typical beam section and elevation of CB27-48 beam.

In Regions 1, 2, and 3, U bars A and B, as well as U bars A and C, overlap to form a complete stirrup, as shown in Figure A3-3. The lap length exceeds 1.3 times the development length (l_d), ensuring sufficient force transfer between the overlapping sections, as shown in Section A-A and Section B-B in Figure A3-3.

The nominal shear capacity and shear load rating factors for the composite, non-skew bridge due to the design vehicle HL-93 in Strength-I limit State at operating condition, with the vehicle positioned at different locations on the bridge, are presented in Table A3-2.

Table A3-2 Nominal shear capacity and shear load rating factors at different vehicle positions for the composite non-skew bridge.

	Distance from the left support (ft)	**Nominal shear capacity (kips)**	**Rating factors**	
Region 1	1	333.47	3.418	
	2	333.47	3.494	
Region 2	2.45	289.83	2.978	Typical shear check point
	3	289.83	3.016	
	4	289.83	3.088	
Region 3	5	192.60	1.876	Shear critical point
	6	192.60	1.929	
	7	192.60	1.984	
	8	192.60	2.042	
	16	192.60	2.594	
	20	192.60	2.954	
	40	192.60	6.909	Midspan

The nominal shear capacity is higher in Region 1 due to the closer spacing of the shear reinforcement, while the nominal shear capacity in Region 2 decreases significantly because the shear reinforcement spacing is increased compared to Region 1. As a result, the shear load rating factor is minimum at the starting point of Region 2 rather than at the typical shear check point. This demonstrates that shear load rating is required at locations where shear reinforcement details change.

Case-3: Non-Composite Skew (Box Beam Section: B33-36)

The non-composite, skew adjacent box beam bridge, with a design span length of 74.85 ft and beam section B33-36, is analyzed for shear load rating at different locations from the left end to the center of the bridge. The box beam section has a height of 33 in. and a width of 36 in. The detailed section and elevation of the B33-36 box beam are presented in Figure A3-4. The detailed calculations are presented below:

Design bridge length (l) = 74.85 ft
Diameter of the #4 U bars (d_b)= 0.5 in.
Specified yield strength of #4 bar (f_y) = 60 ksi
Specified compressive strength of concrete (f'_c) = 6.5 ksi
Required area of transverse reinforcement (A_s) = 0.081 in^2
Provided area of transverse reinforcement (A_s) = 0.4 in^2

Development length (l_d) $= 2.4 \times 0.5 \times \dfrac{60}{\sqrt{6.5}} \times \dfrac{1 \times 1 \times 1 \times \frac{0.081}{0.4}}{1} = 5.51$ in. < 12 in. $\quad \therefore\ l_d = 12$ in.

From standard drawings,
Vertical leg length of U bar A = 23 in.
Vertical leg length of U bar B = 14 in.
Vertical leg length of U bar C = 14 in.

$1.3 * l_d$ = 15.6 in. > 14 in.

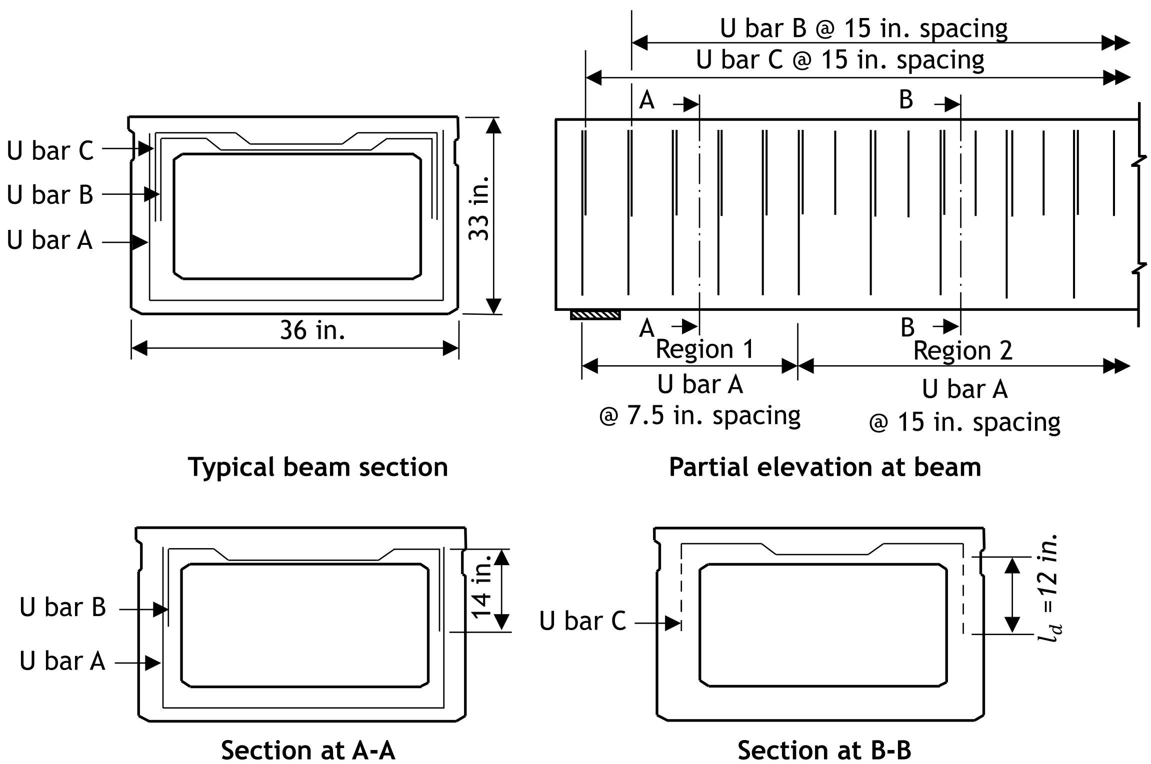

Figure A3-4 Typical beam section and elevation of B21-48 beam.

In Region 1, U bars A and B, as well as U bars A and C, overlap to form a complete stirrup, as shown in Figure A3-4. In Region 2, as shown in Section B-B, U bar C has insufficient development length to transfer the shear stress across the section. Therefore, there is no contribution of U bar C to the shear resistance in Region 2, which results in increased spacing of the shear reinforcement compared to Region 1.

The nominal shear capacity and shear load rating factors for the non-composite, skew bridge due to the design vehicle HL-93 in Strength-I limit state at operating condition, with the vehicle positioned at various locations on the bridge, are illustrated in Table A3-3.

Table A3-3 Nominal shear capacity and shear load rating factors at different vehicle positions for a non-composite skew bridge.

	Distance from the left support (ft)	Nominal shear capacity (kips)	Rating factors	
Region 1	1	284.11	3.335	
	2	284.11	3.409	
	2.7	284.11	3.406	Typical shear check point
	3	284.11	3.486	
Region 2	4	199.04	2.354	Shear critical point
	5	199.04	2.414	
	6	199.04	2.476	
	7	199.04	2.540	
	8	199.04	2.608	
	16	199.04	3.265	
	20	199.04	3.703	
	37.425	199.04	7.795	Midspan

The nominal shear capacity is higher in Region 1 due to the closer spacing of the shear reinforcement, while the nominal shear capacity in Region 2 decreases significantly because the shear reinforcement spacing is increased compared to Region 1. As a result, the shear load rating factor is minimum at the starting point of Region 2 rather than at the typical shear check point. This demonstrates that shear load rating is required at locations where shear reinforcement details change.

Case-4: Composite Skew (Box Beam Section: CB33-48)

The composite, skew adjacent box beam bridge, with a design span length of 83 ft and beam section B33-48, is analyzed for shear load rating at different locations from the left end to the center of the bridge. The box beam section has a height of 33 in and a width of 48 in. The detailed section and elevation of the CB33-48 box beam are presented in Figure A3-5. The detailed calculations are presented below:

Design bridge length (l) = 83 ft
Diameter of the #4 U bars (d_b)= 0.5 in.
Specified yield strength of #4 bar (f_y) = 60 ksi
Specified compressive strength of beam concrete (f'_c) = 7 ksi
Required area of transverse reinforcement (A_s) = 0.18 in^2
Provided area of transverse reinforcement (A_s) = 0.4 in^2

Development length (l_d) = $2.4 \times 0.5 \times \dfrac{60}{\sqrt{7}} \times \dfrac{1 \times 1 \times 1 \times \frac{0.18}{0.4}}{1}$ = 12.25 in. > 12 in. $\therefore\ l_d$ = 12.25 in.

From standard drawings,
Vertical leg length of U bar A = 29 in.
Vertical leg length of U bar B = 17 in.
Vertical leg length of U bar C = 21 in.

1.3* l_d = 15.93 in. > 17 in.

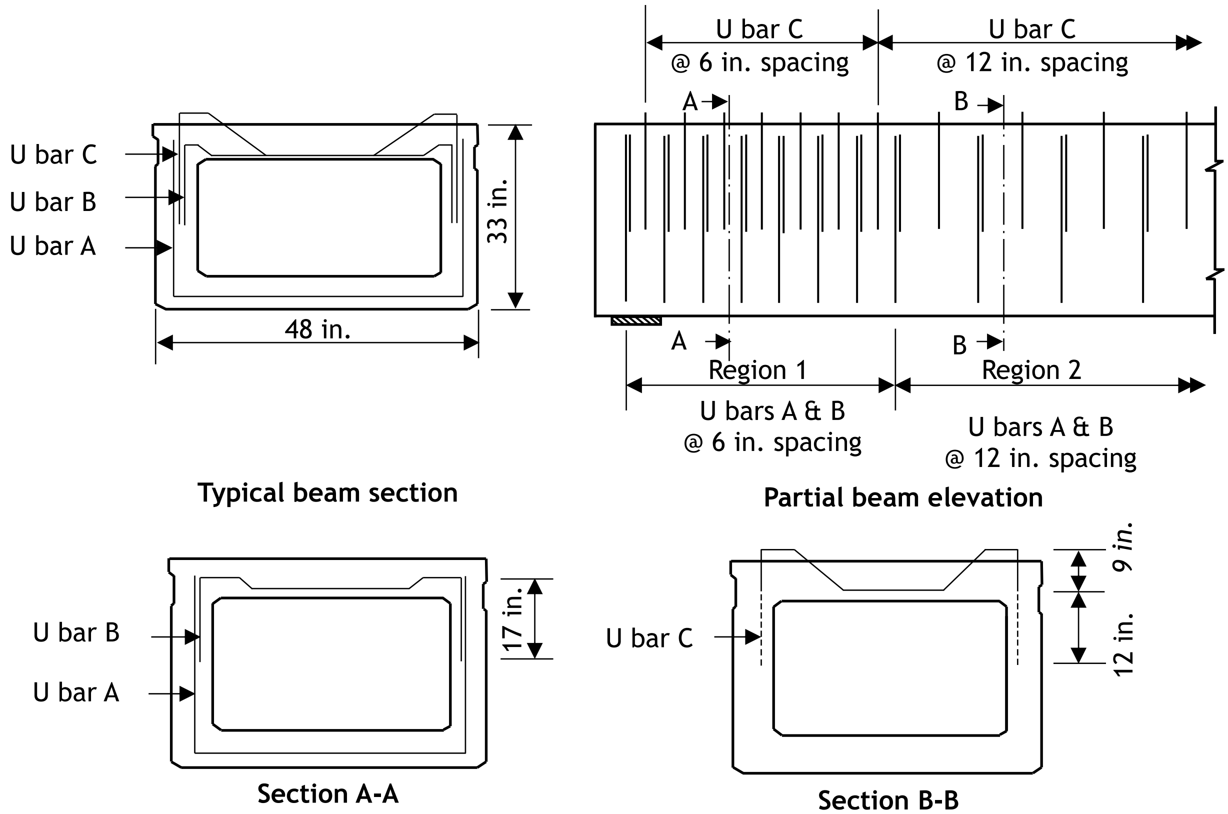

Figure A3-5 Typical beam section and elevation of CB33-36 beam.

In Region 1, U bars A and B overlap to form a complete stirrup, while U bar C has an open end and lacks hoops, as shown in Figure A3-5. In Region 2, as shown in Section B-B, U bar C has insufficient development length to transfer the shear stress across the section. Therefore, there is no contribution of U bar C to the shear resistance in Region 2, which results in increased spacing of the shear reinforcement compared to Region 1.

The nominal shear capacity and shear load rating factors for the composite, skew bridge due to the design vehicle HL-93 in Strength-I limit state at operating condition, with the vehicle positioned at various locations on the bridge, are illustrated in Table A3-4. Table A3-4 Nominal shear capacity and shear load rating factors at different vehicle positions for a composite skew bridge.

	Distance from the left support (ft)	Nominal shear capacity (kips)	Rating factors	
Region 1	1	352.89	2.773	
	2	352.89	2.837	
	2.9	352.89	2.900	Typical shear check point
	3	352.89	2.903	
Region 2	4	234.57	1.714	Shear critical point
	5	234.57	1.763	
	6	234.57	1.814	
	7	234.57	1.867	
	8	234.57	1.921	
	16	234.57	2.444	
	24	234.57	3.185	
	32	234.57	4.320	
	41.5	234.57	6.806	Midspan

The nominal shear capacity is higher in Region 1 due to the closer spacing of the shear reinforcement, while the nominal shear capacity in Region 2 decreases significantly because the shear reinforcement spacing is increased compared to Region 1. As a result, the shear load rating factor is minimum at the starting point of Region 2 rather than at the typical shear check point. This demonstrates that shear load rating is required at locations where shear reinforcement details change.

A4. Conclusion

The load rating values in all four cases for four different bridge configurations in the Strength-I limit state at the operating condition indicate that the rating factor is not always minimum at the typical shear check point. The rating factor value depends on the provided shear reinforcement details. The regions with increased shear reinforcement spacing result in a reduced nominal shear capacity, and thus a lower shear load rating factor at those regions. Consequently, the shear load rating should be performed at every location when the shear reinforcement details change, in addition to the typical shear check point.

AD-BOX is developed with the capability to perform shear load rating at the typical shear check point and other locations, particularly when the shear reinforcement and its spacing details change.

Appendix B: Independent Hand Calculations

Appendix B includes the detailed hand calculations performed for the verification of AD-BOX, which is presented in Section 3.2.1 of the report. Sample bridge 15, among the 18 sample bridges provided by ODOT, as presented in Table 3-16, is adopted as the representative sample for this Appendix. The general data of the sample bridge 15 is provided below:

Bridge Sample no: 15
Year of Construction: 2018
Design Span: 60 ft.
Type of Bridge: Skew
Skew Angle: 24 degrees
Type of Beam: Composite
Box Beam Section: CB27-48

The page count for the detailed hand calculations for each sample bridge is 54 pages. For 18 sample bridges, the total page count is 972 pages. The input data for all 18 sample bridges is consistent with that used for calculations with AD-BOX, as presented in Appendix C. To ensure the conciseness of the report, the representative bridge Sample 15 is presented with detailed calculations, while the results for the remaining 17 sample bridges are presented in a tabular format.

Appendix B: Independent Hand Calculations

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B1. Independent Hand Calculations.

B1.1 Bridge Information

Total Span = 61 ft

Design Span from c/c of bearing = 60 ft.

Skew angle = 24°

Composite box beam cross-section.

Surfacing material = 1" monolithic bituminous surface.

Box Beam Section Properties.

Box beam section used = CB48-27

Required concrete compressive strength at transfer, $f'_{ci} = 5$ ksi

Specified concrete compressive strength for use in design, $f'_c = 7$ ksi.

Concrete unit weight $(w_c) = 0.150$ kcf.

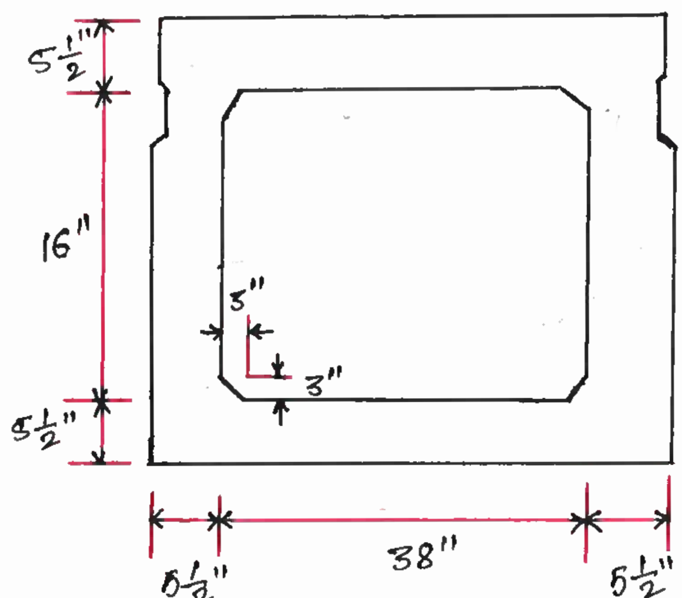


Figure: Box Beam Dimensions

Thickness of concrete slab = 6"

Specified concrete slab compressive strength for use in design $f'_c = 4.5$ ksi

Prestressing strands.

½ inch diameter, low relaxation.
Area of each strand = 0.153 in^2.
Specified tensile strength, f_{pu} = 270 ksi.
Yield strength, $f_{py} = 0.9 f_{pu}$ = 243 ksi.
Modulus of elasticity, E_p = 28500 ksi.

	nos	distance from tensile face.
Layer 1	20	2"
Layer 2	2	4"

Reinforcing bar.

Yield strength, f_y = 60 ksi
Modulus of elasticity, E_s = 29000 ksi.
2 No.5 bar @ 2" from bottom.

- Bituminous surfacing, unit weight = 0.15 kcf
- Unit weight of barrier used = 0.08 kips/ft.

CROSS SECTIONAL PROPERTIES

(i) Non composite beam section.

Area of cross section of precast beam (A_g) = 713.8 in^2

Moment of area about centroid of the non-composite precast beam (I_g) = 66222 in^4.

Distance from centroid to the extreme bottom fiber of the non-composite beam (y_b) = 13.39 in

Distance from centroid to the extreme top fibre of the non-composite precast beam $(y_t) = 13.61$ in

Section modulus from extreme bottom fibre $(S_b) = 4945.63\ in^3$

Section modulus from extreme top fibre $(S_t) = 4865.0\ in^3$.

E_c = modulus of elasticity of concrete, ksi
$= 33{,}000 k_1 (w_c)^{1.5} \sqrt{f_c'}$
where,

k_1 = correction factor for source of aggregate taken as 1.

w_c = unit weight of concrete $= 0.150$ kcf.

f_c' = specified compressive strength of concrete, ksi.

The modulus of elasticity of concrete for cast in place slab, $E_c = 33000(1.0)(1.150)^{1.5}\sqrt{4.5}$
$= 4066.84$ ksi.

Precast beam at transfer, $E_{ci} = 4286.83$ ksi
Precast beam at service load, $E_c = 5072.24$ ksi.

(ii) Composite Section.

Modular ratio between slab and beam concrete.

$$n = \frac{E_c(slab)}{E_c(beam)} = \frac{4066.84}{5072.44} = 0.802.$$

The effective flange width (b) = 48 in.

The effective flange width must be transformed by the modular ratio to provide cross-sectional properties equivalent to the beam concrete.

Transformed flange width = $n \times 48 = 38.49$ in

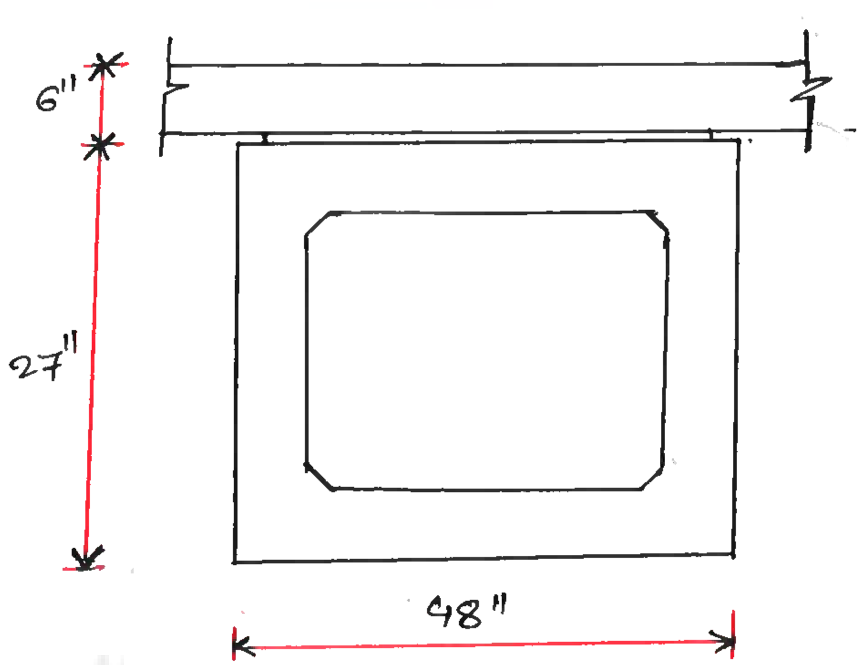
Transformed flange area = $n \times 48 \times 6 = 230.91\ in^2$

Transformed flange moment of inertia = $38.49 \times \frac{6^3}{12}$

$= 692.79\ in^4.$

Given 6" slab thickness.

Properties of composite section.



(iii) Properties of composite Section.

	Area	y_b	$A*y_b$	$A*(y_{bc}-y_b)^2$	I	$I+A*(y_{bc}-y_b)^2$
	in^2	in	in^3	in^4	in^4	in^4
Beam	713.80	13.39	9557.78	11765.62	66222	77987.62
Slab	230.91	30	6927.1	36369.86	692.74	37062.60
Σ	944.71		16485.19			115050.22

Total area of the composite section, $A_c = 944.71\ in^2$

Overall depth $(h_c) = 33$ in

Moment of inertia $(I_c) = 115050.22\ in^4$

Distance from the centroid of the composite section to the extreme bottom fibre of the precast beam.

$$y_{bc} = \frac{16485.19}{944.71} = 17.45 \text{ in.}$$

Distance from the centroid of the composite section to the extreme top fibre of the precast beam,

$y_{tg} = 9.55$ in

Distance from the centroid of the composite section to the extreme top fibre of the deck.

$y_{tc} = 15.55$ in

Composite section modulus for the extreme bottom fiber of the precast beam $(S_{bc}) = 6593.16\ in^3$

Composite Section modulus for the top fibre of the precast beam $(S_{tg}) = 12047.67\ in^3$

Composite section modulus for extreme top fibre of the structural deck slab $(S_{tc}) = 9227.80\ in^3$.

6.1.2 Load Calculations.

(i) Dead loads

(a) Beam self weight, $w_g = \frac{713.80}{12 \times 12} * 0.150 = 0.744$ kips/ft

5% increase in dead load.

$\therefore w_g = 1.05 \times 0.744 = 0.781$ kips/ft/beam

(b) Barrier weight = 2 barriers * 0.08 kips/ft

$= \frac{2 \times 0.08}{8} = 0.02$ kips/ft/beam.

(c) Wearing surface = 0

(d) Diaphragm weight

Diaphragm thickness = 33.375 in

$= \frac{33.375}{12} \left(\frac{48 - 5.5 \times 2}{12} \times \frac{27 - 5.5 \times 2}{12} - 4 \times \frac{1}{2} \times \frac{3}{12} \times \frac{3}{12} \right) \times 0.15$

= 1.663 kips/diaphragm.

(e) Weight of deck slab, 6" thick $= \frac{6 \times 48}{12 \times 12} \times 0.15 = 0.3$ kips/ft

5% increase in dead load

So, $1.05 \times 0.3 = 0.315$ kips/ft.

Permanent loads are uniformly distributed among all beams if the following condition meets.

(i) width of deck is constant (ok!)

(ii) Number of beam not less than 4 (8) (ok!)

(iii) Beams are parallel and have same stiffness. (OK)
(iv) The roadway part of the overhang, $d_e \le 3.0$ ft
$d_e = 0$. (ok!)
(v) Curvature in the plan is less than specified in the LRFD specification (Curvature 0°) (ok!)

Since these criteria are satisfied, the barrier and wearing surface loads are equally distributed among the eight beams.

B1.3 Live load distribution factors for typical interior beam.

(a) For moments (DFM)

For all the limit state except fatigue limit state.
For two or more lanes loaded.

$$DFM = k\left(\frac{b}{305}\right)^{0.6} \cdot \left(\frac{b}{12L}\right)^{0.2}\left(\frac{I_g}{J_g}\right)^{0.06}$$ provided that

$35 \le b \le 60$ (ok!)
$20 \le L \le 120$ (ok!)
$5 \le N_b \le 20$ (ok!)

where, $k = 2.5(N_b)^{-0.2} \geq 1.5$
$= 2.5(8)^{-0.2}$
$\therefore k = 1.649$

$$J_g = \frac{4A_0^2}{\Sigma S/t}$$ where $A_0 = 1041.25\ in^2$.
$S/t = 20.33$
then, $J_g = 213299.37\ in^4$.

$\therefore DFM_{2+} = 0.305$

For one design lane loaded,

$$DFM_1 = k\left(\frac{b}{33.3L}\right)^{0.5}\left(\frac{I_g}{J_g}\right)^{0.25}$$

$\therefore$ DFM$_1$ = 0.219.

For exterior beam.

Two or more design lane loaded.

$g = e \times g_{interior}$

$e = 1.04 + \frac{de}{25}$ where $de = \frac{5.5}{12 \times 12} = 0.23$

$e = 1.049$.

$DFM_{2+} = 1.049 \times 0.305 = 0.320$

One design lane loaded

$g = e \times g_{interior}$

$e = 1.125 + \frac{de}{30} \geq 1$

$= 1.125 + \frac{0.23}{30}$

$\therefore e = 1.133$

$DFM_1 = 1.133 \times 0.219 = 0.248$.

Taking distribution factors for the exterior beam

DFM = max (DFM$_1$, DFM$_{2+}$) = 0.320.

Reduction of live load distribution factors for moments on skewed bridges.

Reduction factor $= 1.05 - 0.25 \tan\theta \leq 1.0$ $\quad 0^\circ \leq \theta \leq 60^\circ$

$= 1.05 - 0.25 \times \tan 24^\circ$

$= 0.939$.

$\therefore$ The required distribution factors $= 0.320 \times 0.939 = 0.300$

For shear force (DFV)

For interior beam

For two or more lane loaded.

$$DFV_{2+} = \left(\frac{b}{156}\right)^{0.4} \left(\frac{b}{12L}\right)^{0.1} \left(\frac{I_g}{J_g}\right)^{0.05} \left(\frac{b}{48}\right)$$

saying that

$b/48 \geq 1$

provided that

$35 \leq b \leq 60$ $\quad b = 48\,in$ ok.

$20 \leq L \leq 120$ $\quad L = 60\,ft$ ok.

$5 \leq N_b \leq 20$ $\quad N_b = 8$ ok.

$25000 \leq J_g \leq 610000$ $\quad J_g = 213299.37$ ok.

$40000 \leq I_g \leq 610000$ $\quad I_g = 115050.22$ ok.

$DFV_{2+} = 0.462$

For one lane loaded

$$DFV_1 = \left(\frac{b}{130L}\right)^{0.15} \left(\frac{I_g}{J_g}\right)^{0.05}$$

$\therefore DFV_1 = 0.452$

$\therefore DFV = \max(0.462, 0.452) = 0.462$

For exterior beam.

Two or more design lane loaded

$g = e \times g_{interior} (48/b) \quad (48/b \leq 1)$

$$e = 1 + \left(\frac{d_e + b/12 - 2}{40}\right)^{0.5} \geq 1$$

where $d_e = 5.5/2\times12 = 0.23\,ft$

$b = 48\,in$

$\boxed{e = 1.24}$

$g = e \times g_{interior} = 1.24 \times 462 = 0.573$

one design lane loaded.

$g = e\, g_{interior}$

$e = 1.25 + \frac{de}{20} \geq 1.0$

$\therefore e = 1.26$

$g = 1.26 \times 0.452 = 0.569.$

DFV for exterior beam = max (0.573, 0.569) = 0.573

Correction factor for shear on skewed bridges.

Correction factor $= 1 + \frac{12L}{90d}\sqrt{\tan\theta}$ where

$L = 60$ ft

$d = 27$ in

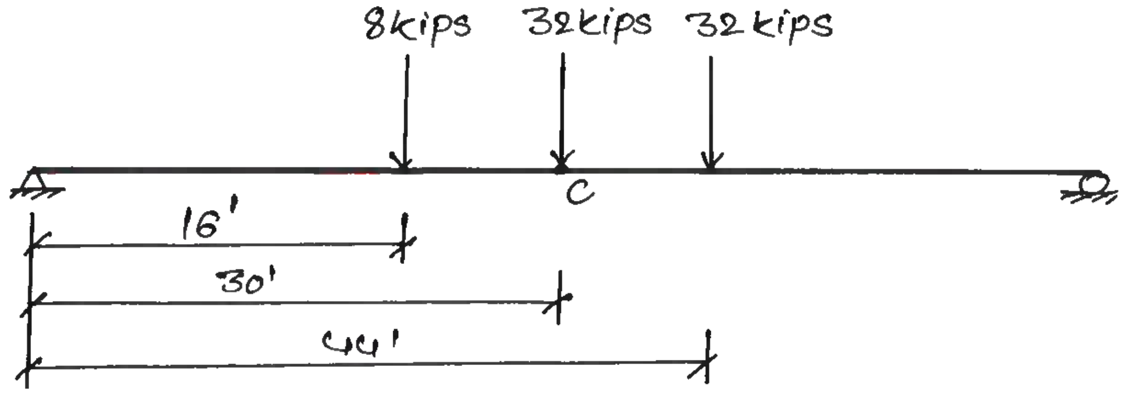
$= 1.198$ $\theta = 24°$

$\therefore$ The required distribution factor $= 0.573 \times 1.198$

$\therefore$ DFV = 0.683.

Now, calculating moments due to live load by positioning HL-93 loading at center and the moment critical location. Also, moments due to dead loads are also calculated.

B1.4 At Center.



ⓐ Moment due to HL-93 without impact

$$M_C = 8\left[\left(1-\frac{16}{60}\right)\times 30 - (30-16)\right] + 32\left[\left(1-\frac{30}{60}\right)\times 30\right] + 32\left[\left(1-\frac{44}{60}\right)\times 30\right]$$

$$= 800 \times 0.300 \text{ (DFM)}$$

$$= 240.24 \text{ kips-ft/beam.}$$

ⓑ Moment due to beam self weight

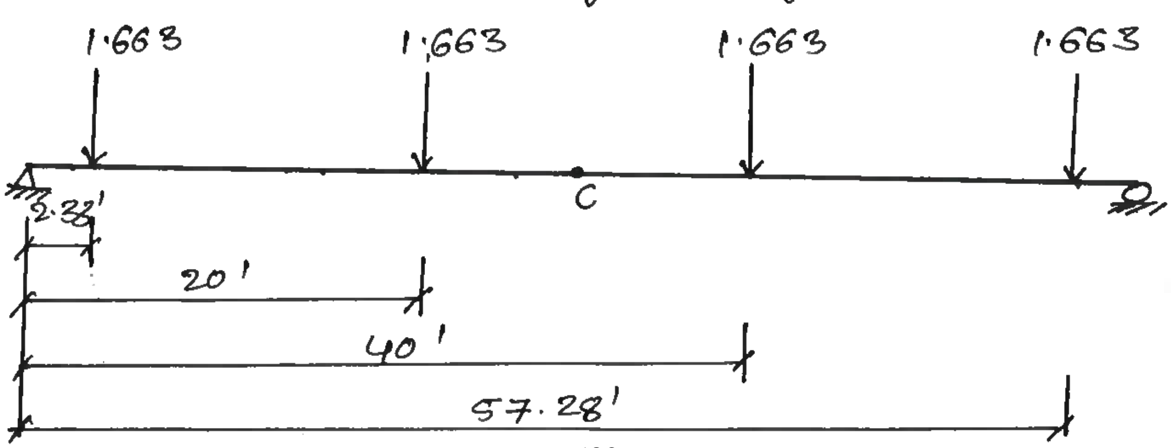
$$M_C = 0.781 \times \frac{30}{2}(60-30)$$

$$\therefore M_C = 351.32 \text{ kips-ft.}$$

ⓒ Moment due to wearing surface.

$$M_C = 0$$

ⓓ Moment due to diaphragm weight.



$$M_C = 1.663\times\left[\left(1-\frac{2.33}{60}\right)\times 30-(30-2.33)\right]+1.663\times\left[\left(1-20/60\right)\times 30-(30-20)\right]+1.663\times\left[\left(1-40/60\right)\times 30\right]+1.663\times\left[\left(1-\frac{57.28}{60}\right)\times 30\right]$$

$$= 37.458 \text{ kips-ft/beam.}$$

ⓔ Moment due to barrier weight.

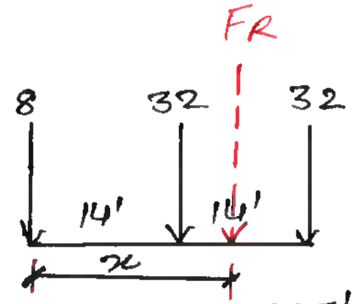
$$M_C = 0.020\times 80/2\times(60-30)$$

$$= 9 \text{ kips-ft.}$$

ⓕ Moment due to lane load.

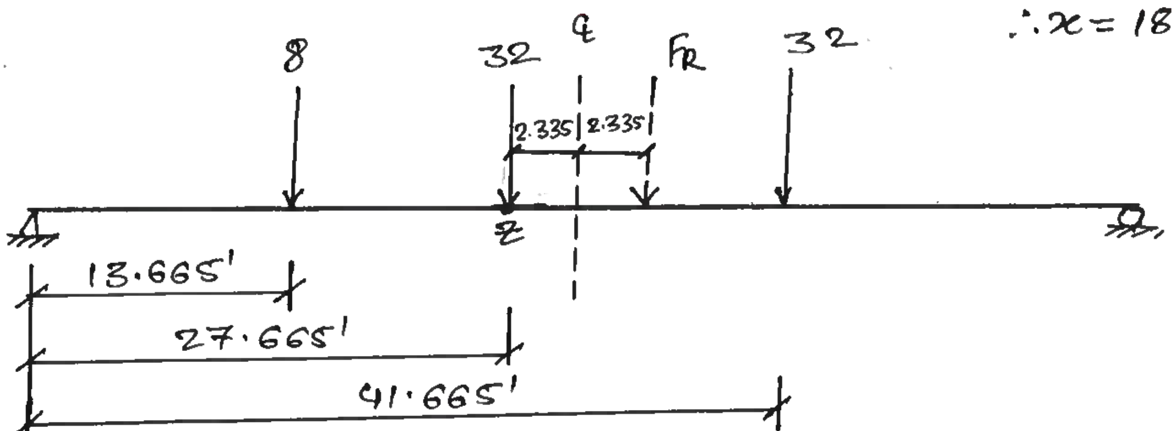
$$M_C = 0.64\times\frac{30}{2}\times(60-30)\times DFM$$

$$= 86.484 \text{ kips-ft/beam.}$$



$\therefore x = 18.667'$

61.5 At moment critical point.



ⓖ Moment due to HL-93 without impact.

$$M_2 = 8\times\left[\left(1-\frac{13.665}{60}\right)\times 27.665-(27.665-13.665)\right]\times 32\times\left[\left(1-\frac{27.665}{60}\right)\times 27.665\right]+32\left[\left(1-\frac{41.665}{60}\right)\times 27.665\right]$$

$$= 806.68\times 0.300 = 242.20 \text{ kips-ft/beam.}$$

ⓑ Moment due to beam self weight.

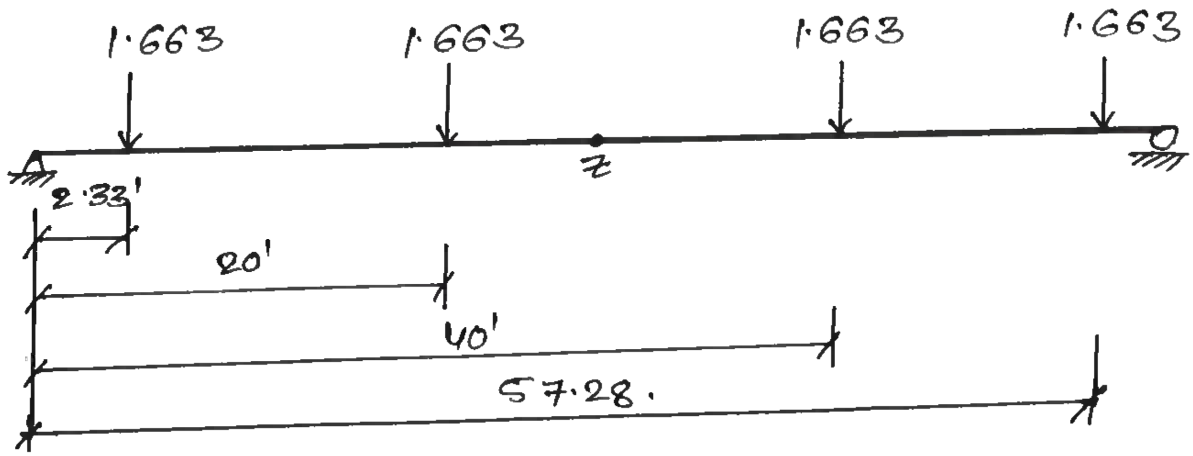
$$M_z = 0.781 \times \frac{27.665}{2} \times (60 - 27.665)$$

$$= 349.2 \text{ kips-ft.}$$

ⓒ Moment due to wearing surface

$M_z = 0$

ⓓ Moment due to diaphragm weight.



$$M_z = 1.663 \times \left[\left(1 - \frac{2.33}{60}\right) \times 27.665 - (27.665 - 2.33)\right] +$$

$$1.663 \times \left[\left(1 - \frac{20}{60}\right) \times 27.665 - (27.665 - 20)\right] + 1.663 \times \left[\left(1 - \frac{40}{60}\right) \times 27.665\right] + 1.663 \times \left[\left(1 - \frac{57.28}{60}\right) \times 27.665\right]$$

$\therefore M_z = 37.48$ kips-ft/beam.

ⓔ Moment due to barrier weight

$$M_z = 0.02 \times \frac{27.665}{2} \times (60 - 27.665)$$

$\therefore M_z = 8.95$ kips-ft/beam.

(f) Moment due to lane load.

$M_2 = 0.64 \times \frac{27.665}{2} \times (60 - 27.665) \times 0.300 \text{ (DFM)}$

$= 85.961$ kips-ft/beam

Steel Transformed Section Properties.

At transfer, $n-1 = \frac{28500}{4286.83} = 5.648$.

At final, $n-1 = \frac{28500}{5072.24} = 4.619$

centroid of the prestressing strands from bottom

$(y_{bs}) = \frac{20 \times 2 + 2 \times 4}{22} = 2.182$ in

Properties of non-composite transformed section at transfer.

	Transformed area (A)	Y_b	A^*Y_b	$A^*(Y_{bti}-Y_b)^2$	I	$I+A^*(Y_{bti}-Y_b)^2$
	in^2	in	in^3	in^4	in^4	in^4
beam	713.80	13.39	9557.78	60.86	66222	66282.86
layer 1	17.28	2.00	34.57	2129.23	n/a	2129.23
Layer 2	1.73	4.00	6.91	148.10	n/a	148.10
Σ	732.81		9599.26			68554.68

$y_{bti} = \frac{\Sigma A^*Y_b}{\Sigma A} = \frac{9599.26}{732.81} = 13.10$ in.

Area of transformed section at transfer, $A_{ti} = 732.81 \text{ in}^2$

moment of inertia of transformed section at transfer,

$I_{ti} = 68554.68 \text{ in}^4$.

Eccentricity of strands with respect to transformed section at transfer = 13.10 − 2.182 = 10.92 in.

Distance from the centroid of the transformed section to the extreme bottom fiber at transfer.

y_{bti} = 13.10 in

Section modulus for the extreme bottom fiber of the transformed section at transfer, S_{bti} = 5233.50 in^3

Section modulus for the extreme top fiber of the transformed section at transformed, S_{tti} = 4981.71 in^3

Properties of non-composite transformed section at final.

	Transformed area (A)	Y_b	$A^* Y_b$	$A^*(Y_{btf}-Y_b)^2$	I	$I+A^*(Y_{btf}-Y_b)^2$
	in^2	in	in^3	in^4	in^4	in^4
Beam	713.80	13.39	9557.78	40.74	66222.00	66262.74
Layer 1	14.13	2.00	28.27	1757.46	n/a	1757.46
Layer 2	1.41	4.00	5.65	118.36	n/a	118.36
Σ	729.35		9591.70			68138.57

Area of transformed section at final time, A_{tf} = 729.35 in^2

Moment of inertia of the transformed section at final time, I_{tf} = 68138.57 in^4

Eccentricity of strands with respect to transformed section at final time, e_{tf} = 10.97 in.

Distance from the centroid of the transformed section to the extreme bottom fiber of the beam at final time, $Y_{btf} = 13.15$ in

Section modulus for the extreme bottom fiber of the transformed section at final time, $S_{btf} = 5181.11\ in^3$

Section modulus for the extreme top fiber of the transformed section at final time, $S_{ttf} = 4920.14\ in^3$

Properties of composite transformed section at final.

	Transformed area (A)	Y_b	$A*Y_b$	$A*(Y_{btc}-Y_b)^2$	I	$I+A*(Y_{btc}-Y_b)^2$
	in^2	in	in^3	in^4	in^4	in^4
Slab	230.91	30	6927.41	37816.71	692.74	38509.45
Beam	713.80	13.39	9557.78	10376.50	66222.00	76598.50
Layer 1	14.13	2.00	28.27	3266.60	n/a	3266.60
Layer 2	1.41	4.00	5.65	246.37	n/a	246.37
Σ	960.26		16519.11			118620.92

$$Y_{btc} = \frac{\Sigma A*Y_b}{\Sigma A} = \frac{16519.11}{960.26} = 17.20 \text{ in}$$

Area of transformed composite section at final time $A_{tc} = 960.26\ in^2$

Moment of inertia of the transformed composite section at final time, $I_{tc} = 118620.92\ in^4$

Eccentricity of strands with respect to transformed composite section at final time, $e_{tc} = 17.20 - 2.18 = 15.02$ in

Distance from the centroid of the transformed section to the extreme bottom fibre of the beam at final time

$y_{btc} = 17.20$ in

section modulus for the extreme bottom fibre of the transformed composite section at the final time

$S_{btc} = 6895.47$ in^3

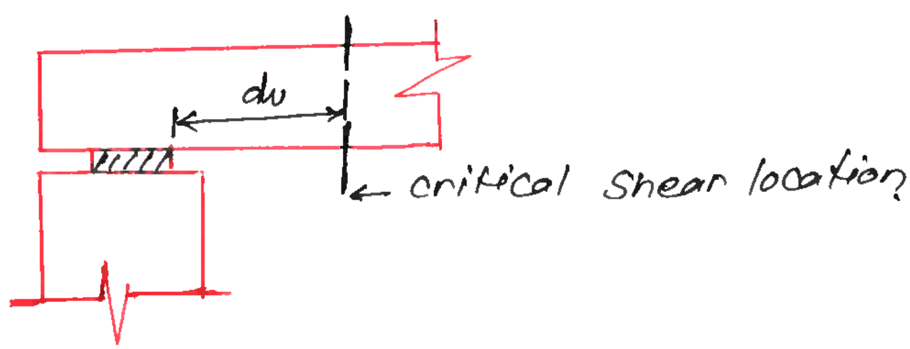
Composite section modulus for the extreme top fiber of the precast beam for transformed composite section at final time, $S_{ttc} = 12107.56$ in^3.

Composite section modulus for the extreme top fiber of the deck slab for transformed composite section at final time, $S_{dtc} = 9365.31$ in^3.

B1.6 Critical Shear Point

critical shear occurs at distance d_v from the internal force of the support.

$d_v = d_e - a/2$ but not less than $0.9d_e$, $0.72h$



y_{bs} = the distance between the centre of gravity of the strands and the bottom concrete fiber of the beam.

$= \frac{20 \times 2 + 2 \times 4}{20 + 2} = 2.18$ in

d_e = effective depth from the extreme compression fibre to the centroid of tensile reinforcement.

$= h - y_{bs}$

$\therefore d_e = 30.82$ in .

We have, $a = \beta_1 c \Rightarrow \beta_1 = 0.85 - 0.05(f'_c - 4)$; $f'_c \geq 4$ ksi

$= 0.825$, for $f'_c = 4.5$ ksi

$\boxed{\therefore a = 0.825c}$

Assuming rectangular section behaviour,

c = depth of neutral axis

$$= \frac{A_{ps} f_{pu} + A_s f_y - A_s' f_y'}{0.85 f'_c \beta_1 b + k A_{ps} f_{pu}/d_p}$$

$$= \frac{0.153 \times 22 \times 270}{0.85 \times 4.5 \times 0.825 \times 48 + 0.28 \times 0.153 \times 22 \times 270/d_p}$$

where, $d_p = h - y_{bs} = 30.82$ in

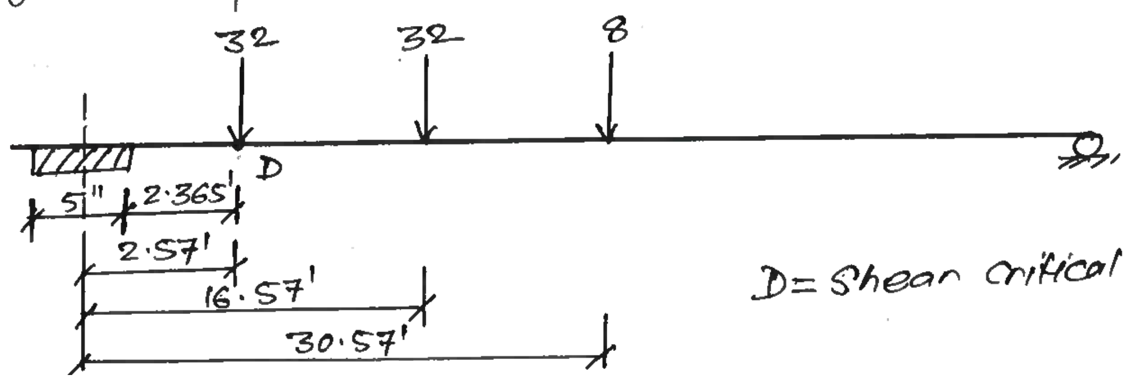
$\therefore c = 5.92$ in

$\therefore a = 0.825 \times 5.92 = 4.89$ in $< (t_f = 11.5'')$ (ok!)

Also, $d_v = d_e - a/2 = 30.82 - 4.89/2 = 28.38$ in $> 0.9 d_e = 27.74$ in

$0.72h = 23.76$ in

Arrangement for maximum shear



D= Shear Critical Point

Shear force at shear critical point D.

(a) Shear due to HL-93

$$V_D = \left[32 \times \left(1 - \frac{2.57}{60}\right) + 32\left(1 - 16.57/60\right) + 8 \times \left(1 - 30.57/60\right)\right] \times DFV$$

$$V_D = (30.63 + 23.16 + 3.92) \times 0.683$$

$\therefore V_D = 39.44$ kips/beam

(b) Shear force due to beam self weight

$$V_D = 0.781 \times (60/2 - 2.57)$$

$= 21.41$ kips/beam

(c) Shear force due to deck slab.

$$V_D = 0.315 \times (60/2 - 2.57)$$

$= 8.64$ kips/beam

(d) Shear force due to barrier weight

$$V_D = 0.02 \times (60/2 - 2.57)$$

$V_D = 0.55$ kips/beam

(e) Shear force due to diaphragm

$$V_D = \left[\left(1 - 2.33/60\right) + \left(1 - 20/60\right) + \left(1 - 40/60\right) + \left(1 - 57.28/60\right)\right] \times 1.663$$

$= 3.34$ kips/beam

(f) Shear force due to wearing surface.

$V_D = 0$

(g) Shear force due to lane load

$V_D = 0.64 \times (60/2 - 2.57) = 11.99$ kips/beam.

Moment at shear critical point D.

(a) Moment due to HL93 load

$$M_D = \left[\left(1-\frac{2.57}{60}\right)\times 2.57\times 32 + 32\times\left(1-\frac{16.57}{60}\right)\times 2.57 + 8\times\left(1-\frac{30.57}{60}\right)\times 2.57\right]\times DFM$$

$M_D = 44.59$ kips-ft/beam

(b) Moment due to beam self weight

$M_D = 0.781\times(2.57/2)\times(60-2.57) = 57.68$ kips-ft/beam

(c) Moment due to deck slab

$M_D = 0.315\times(2.57/2)\times(60-2.57) = 23.27$ kips-ft/beam

(d) Moment due to barrier weight

$M_D = 0.02\times(2.57/2)\times(60-2.57) = 1.48$ kips-ft/beam

(e) moment due to diaphragm

$M_D = 3.34\times 2.57 = 8.59$ kips-ft/beam

(f) Moment due to wearing surface

$M_D = 0$

(g) Moment due to lane load

$M_D = 0.64\times 2.57/2\times(60-2.57) = 47.20$ kips-ft/beam.

B1.7 Nominal Flexural Resistance

Average stress in prestressing strands, $f_{ps} = f_{pu}(1-kc/d_p)$

$\therefore f_{ps} = 270\times\left(1-0.28\times 5.92/30.82\right)$

So $f_{ps} = 255.47$ ksi $\geq 0.5 f_{pu}$ (135 ksi) (ok)

Nominal flexural resistance, M_n

$$M_n = A_{ps} f_{ps} (d_p - a/2) + A_s f_y (d_s - a/2) - A_s' f_s' (d_s' - a/2) + \alpha_1 f_c' (b - b_w) h_f (a/2 - h_f/2)$$

$$= 0.153 \times 22 \times 255.47 \times (30.82 - 4.89/2) + 0 - 0 + 0.85 \times 4.5 (48 - 11) \times 11.5 \times (4.89/2 - 11.5/2)$$

$\therefore M_n = 2121.87$ kips-ft.

for resistance factor,

$$\frac{\varepsilon_t}{0.003} = \frac{d_t - c}{c}$$

or, $\varepsilon_t = 0.003 \times \frac{30.5 - 5.92}{5.92}$

$\therefore \varepsilon_t = 0.0124 \ (> \varepsilon_{tl}, 0.005)$

The section is tension controlled prestressed concrete section.

Factored flexural resistance, $M_r = \phi M_n = 2121.87$ kips-ft.

61.8 Shear Capacity

Nominal shear resistance $(V_n) = \min \begin{pmatrix} V_c + V_s + V_p \\ 0.25 f_c' b_v d_v + V_p \end{pmatrix}$

(i) Nominal shear resistance (V_c)

$V_c = 0.0316 \beta \lambda \sqrt{f_c'} \, b_v d_v$ ($\lambda = 1$, for normal weight concrete)

$= 0.0316 \times \beta \times 1 \times \sqrt{4.5} \times 11 \times 28.38$

$\therefore V_c = 20.93 \beta$ —(i)

$\beta = 4.8 / (1 + 750 \varepsilon_s)$

$$\therefore \varepsilon_s = \frac{\frac{|M_u|}{d_v} + 0.5N_u + |V_u - V_p| - A_{ps}f_{po}}{E_sA_s + E_pA_{ps}}$$

For strength I, inventory,

$M_u = 1.25DC + 1.50DW + 1.75(LL+IM)$

$= 242.4$ kips-ft < check:

Mu shouldn't be less than

$(V_u - V_p)d_v = 366.98$ kips-ft

$\therefore M_u = 366.98$ kips-ft., applied factored bending moments.

$V_u = 1.25DC + 1.50DW + 1.75(LL+IM)$

$= 155.20$ kips, applied factored shear force.

So, $f_{po} = 0.7 f_{pu} = 189$ ksi

$$\varepsilon_s = \frac{\frac{213 \times 12}{28.38} + 0.5 \times 0 + |129.42 - 0| - 0.153 \times 22 \times 189}{0 + 28500 \times 0.153 \times 22}$$

$\therefore \varepsilon_s = -0.00489 < 0$

Adopt $\varepsilon_s = 0$

$\beta = \frac{4.8}{1 + 750\varepsilon_s} = 4.8$

$\theta = 29 + 3500\varepsilon_s = 29°$

$\therefore V_c = 20.93 \times 4.8 = 100.43$ kips

$\therefore V_p = 0$

(ii) Shear resistance provided by transverse reinforcement

$$V_s = \frac{A_v f_y d_v (\cos\theta + \cot\alpha)\sin\alpha}{s}$$

$\therefore \alpha = 90^\circ$

$A_v = 0.4 in^2$, $s = 6 in$

$A_v \geq 0.0316 \, d\sqrt{f'_c} \, b_v s / f_y$

$\geq 0.07 \, in^2/ft.$

$\therefore A_{v,provided} \geq 0.07 \, in^2/ft$

i.e. $0.4 \, in^2$ (ok)

$\therefore V_s = 204.76$ kips.

$\therefore V_n = \min \begin{pmatrix} V_c + V_s + V_p \\ 0.25 f'_c b_v d_v + V_p \end{pmatrix} = \begin{pmatrix} 100.43 + 204.76 + 0 = 305.19 \\ 351.14 \end{pmatrix}$

$\therefore V_n = 305.19$ kips.

* For strength I, operating

$M_u = 1.25 DC + 1.5 DW + 1.35 (LL + IM) = 213$ kips-ft $< (V_u - V_p) d_v$ (358.86)

$= 358.86$ kips-ft

$V_u = 1.25 DC + 1.5 DW + 1.35 (LL + IM)$

$= 129.42$ kips.

$\therefore \varepsilon_s = -0.00516$

$\therefore$ Adops $\varepsilon_s = 0$.

$\beta = 4.8$, $\theta = 29^\circ$.

$\therefore V_c = 100.43$, $V_p = 0$, $V_s = 204.76$ kips

$$V_n = \min\begin{pmatrix} V_c + V_s + V_p \\ 0.25 f'_c b_v d_v + V_p \end{pmatrix} = \begin{pmatrix} 305.19 \\ 351.4 \end{pmatrix} = 305.19 \text{ kips.}$$

$$\therefore V_n = 305.19 \text{ kips}$$

B1.9 Prestress Losses Calculation

(i) Initial prestress prior to transfer, $f_{pi} = 0.75 f_{pu}$

$= 0.75 \times 270$

$\therefore f_{pi} = 202.5$ ksi

(ii) Initial prestressing force prior to transfer

$P_{pi} = 22 \times 30.98 = 681.62$ ksi

$\therefore P_{pi} = 681.62$ ksi

prestress losses.

(i) Elastic Shortening Losses. (Δf_{pES})

$$\Delta f_{pES} = \frac{E_p}{E_{ci}} * f_{cgp}$$

where,

f_{cgp} = Sum of concrete stresses at the center of gravity of prestressig strands due to prestressing force at transfer and the self weight of member at sections of maximum moment.

$$f_{cgp} = \frac{P_{pi}}{A_{ti}} + \frac{P_{pi}\, e_{ti}^2}{I_{ti}} + \frac{(M_g + M_d)\, e_{ti}}{I_{ti}}$$

where, P_{pi} = 681.62 ksi.

A_{ti} = 732.81 in^2.

e_{ti} = 10.92 in.

I_{ti} = 68554.68 in^4.

M_g = 351.32 kips-ft

M_d = 37.46 kips-ft

$\therefore$ f_{cgp} = 1.37 ksi.

$$\therefore \Delta f_{pES} = \frac{28500}{4286.83} \times 1.37 = 9.12 \text{ ksi}$$

$\therefore \Delta f_{pES} = 9.12$ ksi

2) Time Dependent Losses Between Transfer and Deck Placement.

Construction Schedule.

Concrete age at transfer (t_i) = 1 day
Concrete age at deck placement (t_d) = 28 days
Concrete age at final stage (t_f) = 18250 days

(a) Shrinkage of concrete. (Δf_{pSR})

$$\Delta f_{pSR} = \varepsilon_{bid} \cdot E_p \cdot K_{id}$$

ε_{bid} = concrete shrinkage strain of girder for time period between transfer and deck placement.

$$= K_{vs} K_{hs} K_f K_{td} \, 0.48 \times 10^{-3}$$

where,

The factor for the effect of volume to surface ratio of the beam (K_{vs})

$K_{vs} = 1.45 - 0.13 (V/S)$ where, $V/S = \dfrac{713.80}{(48+27)\times 2 + (48-5.5\times 2) + (27-5.5\times 2) + 2\sqrt{2\times 3^2} - 2\times 3}$

$$\boxed{V/S = 3.578.}$$

$\therefore K_{vs} = 1.45 - 0.13 \times 3.578 = 0.985 \ngeq 1$ (should be ≥ 1)

So Adopt $K_{vs} = 1$

The humidity factor for shrinkage $(k_{hs}) = 2.00 - 0.014H$

where H = average annual mean relative humidity.

$\therefore H = 70\%$

$\therefore K_{hs} = 2.00 - 0.014 \times 70 = 1.020$

The factor for the effect of the concrete strength,

$$k_f = \frac{5}{1+f'_{ci}} = \frac{5}{1+5} = 0.833.$$

The time development factor at deck placement,

$$k_{td(d,i)} = \frac{t}{12*\left(\frac{100-4*f_{ci}'}{20+f_{ci}'}\right)+t} = \frac{28-1}{12*\left(\frac{100-4*5}{20+5}\right)+(28-1)} = 0.413.$$

$\therefore \varepsilon_{bid} = 1 * 1.020 * 0.833 * 0.413 * 0.48 \times 10^{-3}$

$= 0.000168$ in/in

K_{id} = transformed section coefficient that accounts for time dependent interaction between concrete and bonded steel in the section being considered for the time period between transfer and deck placement.

$$K_{id} = \frac{1}{1 + \frac{E_p}{E_{ci}} \frac{A_{ps}}{A_g}\left(1 + \frac{A_g (e_{pg})^2}{I_g}\right)[1 + 0.7\,\psi_b(t_f, t_i)]}$$

e_{pg} = eccentricity of prestressing strand with respect to centroid of girder.

$e_{pg} = y_b - y_{bs} = 13.39 - 2.182 = 11.208$ in.

$\psi_b(t_f, t_i)$ = girder creep coefficient at final time due to loading introduced at transfer.

$$\psi_b(t_f, t_i) = 1.9\, k_{vs}\, k_{hs}\, k_f\, k_{td}\, t_i^{-0.118}$$

where,

Humidity factor for creep (k_{hc}) $= 1.56 - 0.008H$

$\therefore k_{hc} = 1.56 - 0.008 \times 90 = 1.000$

Also, $k_{td(f,i)} = (18250-1) \Big/ \left[12 \times \left(\frac{100 - 4 \times 5}{20+5}\right) + (18250-1)\right] = 0.998$

$\therefore \psi_b(t_f, t_i) = 1.9 \times 1.000 \times 1.020 \times 0.833 \times 0.998 \times (1)^{-0.118}$
$= 1.580$

$$\therefore K_{id} = \frac{1}{1 + \frac{28500}{4286.83} \times \left(1 + \frac{713.80 \times 11.208^2}{66222}\right) \times \frac{0.158 \times 22}{713.80} \times [1 + 0.7 \times 1.580]}$$

$\therefore K_{id} = 0.865$ ksi

The prestress loss due to shrinkage $\Delta f_{pSR} = 0.000168 \times 28500 \times 0.865$

$\therefore \Delta f_{pSR} = 4.155$ ksi

(b) Creep of girder concrete. (Δf_{pCR})

$$\Delta f_{pCR} = \frac{E_p}{E_{ci}} f_{cgp}\, \psi_b(t_d, t_i)\, K_{id}$$

where, $\psi_b(t_d, t_i)$ = girder creep coefficient at time of deck placement due to loading introduce at transfer.

$$= 1.9 k_{vs} k_{hc} k_f k_{td} \cdot t_i^{-0.118}$$

$$= 1.9 \times 1.000 \times 1.000 \times 0.833 \times 0.418 \times 1^{-0.118}$$

$$= 0.654$$

$$\therefore \Delta f_{pCR} = \frac{28500}{4286.83} \times 1.37 \times 0.654 \times 0.865$$

$$\boxed{\therefore \Delta f_{pCR} = 5.161 \text{ ksi}}$$

© Relaxation of prestressing strands (Δf_{pR1})

$$\Delta f_{pR1} = \frac{f_{pt}}{K_L}\left(\frac{f_{pt}}{f_{py}} - 0.55\right)$$

where,

f_{pt} = stress in prestressing strand immediately after transfer, taken not less than $0.55 f_y$.

$= (202.5 - 9.12)$ ksi i.e. $f_{pi} - \Delta f_{pES}$

$= 193.38$ kis $> 0.55 \times 60 = 33$ ksi

$\therefore f_{pt} = 193.38$ ksi

K_L = factor accounting for type of steel

= 30 for low relaxation strands.

The beam concrete transformed section coefficient between deck placement and final time, k_{df}

$$K_{df} = \frac{1}{1 + \frac{E_p}{E_{ci}} \times \frac{A_{ps}}{A_c} \times \left(1 + \frac{A_c (e_{pc})^2}{I_c}\right) [1 + 0.7\, \psi_b (t_f, t_i)]}$$

where,

A_c = area of composite section = 944.71 in^2

I_c = 115050.22 in^4

e_{pc} = 15.27 in.

E_p = 28500 ksi

E_{ci} = 4286.88 ksi

$\psi_b(t_f, t_i)$ = 1.580

$\therefore K_{df} = 0.873.$

$\therefore \Delta f_{pSD} = 0.000239 \times 28500 \times 0.873 = 5.940$ ksi.

$\therefore \Delta f_{pSD} = 5.940$ ksi

⑥ Creep of Concrete. (Δf_{pCD})

$$\Delta f_{pCD} = \frac{E_p}{E_{ci}} f_{cpg} [\psi_b(t_f, t_i) - \psi_b(t_d, t_i)] K_{df} + \frac{E_p}{E_c} \Delta f_{cd}\, \psi_b(t_f, t_d) \cdot K_{df}$$

where,

Δf_{cd} = change in concrete stress at centroid of prestressing strands due to long term losses between transfer and deck placement, combined with deck weight & superimposed load.

$$\Delta f_{cd} = -(\Delta f_{pSR} + \Delta f_{pCR} + \Delta f_{pR1}) \frac{A_{ps}}{A_g}\left(1 + \frac{A_g (e_{pg})^2}{I_g}\right) - \left(\frac{M_s e_{tf}}{I_{tf}} + \frac{(M_b + M_{ws}) e_{tc}}{I_{tc}}\right)$$

$$= -(10.90) \times \frac{0.153 \times 22}{713.80}\left(1 + \frac{713.80 \times 11.208^2}{66222.0}\right) - \left(\frac{141.75 \times 10.97}{68138.57} + \left(\frac{(9+0) \times 15.02}{118620.92}\right)\right)$$

$$= -0.409 \text{ ksi.}$$

Time development factor $(k_{tdf}) = \dfrac{t}{12 \times \left(\dfrac{100 - 4f'_{ci}}{20 + f'_{ci}}\right) + t}$

$$\therefore k_{tdf} = \frac{18250 - 28}{12 \times \left(\frac{100 - 4 \times 5}{20 + 5}\right) + (18250 - 28)} = 0.998.$$

Beam creep coefficient at final time due to loading at deck placement, $\Psi_b(t_f, t_d)$

$$\Psi_b(t_f, t_d) = 1.9 \times k_{vs} k_{hc} k_f k_{tdf} t_d^{-0.118}$$

$$= 1.9 \times 1 \times 1.02 \times 0.833 \times (28)^{-0.118}$$

$$\therefore \Psi_b(t_f, t_d) = 1.066$$

$$\Delta f_{pCD} = \frac{28500}{4286.83} \times [1.37] \times [1.58 - 0.654] \times 0.873 + \frac{28500}{5072.24} \times -0.409 \times 1.066 \times 0.873$$

$$\boxed{\therefore \Delta f_{pCD} = 5.241 \text{ ksi}}$$

$\therefore \Delta f_{pR1} = \frac{193.38}{30} \times \left(\frac{193.38}{243} - 0.55 \right)$.

$\therefore \Delta f_{pR1} = 1.584 \text{ ksi}$

$\therefore$ Prestress losses between transfer and deck placement $= \Delta f_{pSR} + \Delta f_{pCR} + \Delta f_{pR1} = 10.90$ ksi.

3) Time Dependent Losses Between Deck Placement and Final Time.

ⓐ Shrinkage of concrete. (Δf_{pSD})

$$\Delta f_{pSD} = \varepsilon_{bdf} E_p K_{df}$$

where, ε_{bdf} = concrete shrinkage strain of girder for the time period between deck placement and final time.

The total girder concrete shrinkage strain between transfer and final time is taken as.

$$\varepsilon_{bif} = k_{vs} k_{hs} k_f k_{tdf} \, 0.48 \times 10^{-3}$$

$$= 1 \times 1.02 \times 0.838 \times 0.998 \times 0.48 \times 10^{-3}$$

$$= 0.000407 \text{ in/in.}$$

$$\varepsilon_{bdf} = \varepsilon_{bif} - \varepsilon_{bid} = 0.000407 - 0.000168 = 0.000239 \text{ in/in.}$$

(c) Relaxation of prestressing strands. (Δf_{pR2})

$\therefore \Delta f_{pR2} = \Delta f_{pR1} = 1.584$ ksi.

$\therefore \Delta f_{pR2} = 1.584$ ksi

(d) Shrinkage of deck concrete.

The prestress gain due to shrinkage of deck concrete (Δf_{pSS})

$$\Delta f_{pSS} = \frac{E_p}{E_c} \Delta f_{cdf} K_{df} [1 + 0.7 \psi_b(t_f, t_d)]$$

where,

Δf_{cdf} = change in concrete stresses at centroid of prestressing strands due to shrinkage of deck concrete.

$$= \frac{\varepsilon_{ddf} A_d E_{cd}}{1 + 0.7 \psi_d(t_f, t_d)} \left(\frac{1}{A_c} - \frac{e_{pc} e_d}{I_c}\right)$$

where,

ε_{ddf} = shrinkage strain of deck concrete between placement and final time.

A_d = area of deck concrete.

E_{cd} = modulus of elasticity of deck concrete.

$\psi_d(t_f, t_d)$ = deck concrete creep coefficient at final time due to loading introduced shortly after deck placement.

e_d = eccentricity of deck with respect to the gross composite section.

Volume to surface ratio for deck (V/S) $= \frac{6\times48}{6+48} = 5.333$

$k_{vs} = 1.45 - 0.13(V/S) = 1.45 - 0.13\times5.333 = 0.757 < 1$, use $k_{vs} = 1$

Assume the initial strength of concrete at deck placement is $0.8\times4.5 = 3.6$ ksi.

$$k_f = \frac{5}{1+f'_{ci}} = \frac{5}{1+0.8\times4.5} = 1.087$$

$$k_{td} = \frac{t}{12\left(\frac{100-4f'_{ci}}{20+f'_{ci}}\right)+t} = \frac{18250-28}{12\left(\frac{100-4\times0.8\times4.5}{20+0.8\times4.5}\right)+(18250-28)}$$

$\therefore k_{td} = 0.998$

$$\varepsilon_{ddf} = k_{vs}k_{hs}k_f k_{td}\, 0.48\times10^{-3}$$

$$= 1\times1.02\times1.087\times0.998\times0.48\times10^{-3}$$

$\therefore \varepsilon_{ddf} = 0.000531.$

$$\psi_d(t_f,t_d) = 1.9\,k_{vs}k_{hc}k_f k_{td}\, t_i^{-0.118}$$

$$= 1.9\times1\times1\times1.087\times0.998\times1^{-0.118}$$

$\therefore \psi_d(t_f,t_d) = 2.06.$

$$\Delta f_{cdf} = \frac{0.000531\times48\times6\times4066.84\times}{1+0.7\times2.06}\left(\frac{1}{944.71} - \frac{15.27\times\left[(27+6-6/2)-\frac{17.[illegible]}{45}\right]}{115050.22}\right)$$

$\therefore \Delta f_{cdf} = -0.155$ ksi.

$$\Delta f_{pSS} = \frac{28500}{5072.24} \times -0.165 \times 0.873 \times [1 + 0.7 \times 1.066]$$

$\therefore \Delta f_{pSS} = -1.324 \text{ ksi}$

Prestress losses between deck placement and final time = $\Delta f_{pSD} + \Delta f_{pCD} + \Delta f_{pR2} + \Delta f_{pSS} = 11.44 \text{ ksi}$

The total time dependent losses. (Δf_{pLT})

$$\Delta f_{pLT} = \Delta f_{pSR} + \Delta f_{pCR} + \Delta f_{pR1} + (\Delta f_{pSD} + \Delta f_{pCD} + \Delta f_{pR2} + \Delta f_{pSS})$$

$$= 10.90 + 11.44$$

$\Delta f_{pLT} = 22.34 \text{ ksi}$

Total prestress losses (f_{pt}) = $\Delta f_{pLT} + \Delta f_{pES}$

$= 22.34 + 9.12$

$\therefore f_{pt} = 31.46 \text{ ksi}$

Force per strand with only total time dependent losses = $(f_{pi} - \Delta f_{pLT}) \times$ area of each strands.

$= (202.5 - 22.34) \times 0.153$

$= 27.56 \text{ ksi}.$

Total prestressing force (P_{pe}) = $27.36 \times$ (no of strands)

$= 27.36 \times 22$

$= 606.41 \text{ ksi}.$

Compressive stress due to effective prestress, f_{pb}

$$f_{pb} = \frac{P_{pe}}{A_{tf}} + \frac{P_{pe} e_{tf}}{S_{btf}}$$

$$= \frac{606.41}{729.35} + \frac{606.41 \times 10.97}{5181.21}$$

$\therefore f_{pb} = 2.115$ ksi

prestressing strand condition = Low to moderate corrosion

Allowable tensile stress = $0.19 \times \sqrt{f'_c} = 0.19 \times \sqrt{7} = 0.503$

$\therefore$ Flexural resistance (f_R) = f_{pb} + allowable tensile stress

$= 2.115 + 0.503$

$\therefore f_R = 2.618$

B1.10 Load Rating

For Strength I limit state.

(a) with flexure.

$C = \phi_c \cdot \phi_s \cdot \phi \cdot R_n$

$\phi_c = 1$

$\phi_s = 1$

$\phi_c \cdot \phi_s \geq 0.85$

$\therefore \phi_c \cdot \phi_s = 1$

(i) At center.

$\gamma_{DC} = 1.25$, $\gamma_{DW} = 1.50$, $\gamma_{LL} =$ inventory $= 1.75$
operating $= 1.35$

IM = 33 %

$DC = 351.32 + 9 + 141.75 + 37.46 = 539.53$ kips-ft

$DW = 0$ kips-ft

$LL+IM = 240.24 \times 1.33 + 86.485 = 406.00$

$C = 1 \times 1 \times 2121.87 = 2121.87$ kips-ft.

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

$$= \frac{1 \times 1 \times 2121.87 - 1.25 \times 539.53 - 1.5 \times 0 \pm 0}{1.75 \times 406}$$

$= 2.037$

$\therefore RF = 2.037$ (inventory)

$\therefore RF = 2.641$ (operating)

(ii) At moment critical location

$DC = 349.20 + 8.95 + 140.89 + 37.43 = 536.46$ kips-ft

$DW = 0$ kips-ft

$LL + IM = 242.2 \times 1.33 + 85.96 = 408.09$ kips-ft

$\therefore RF = 2.032$ (inventory)

$\therefore RF = 2.684$ (operating)

(b) with shear

$C = \phi_c \cdot \phi_s \cdot \phi \cdot R_n$

$C = 1 \times 1 \times 1 \times 305.19 = 305.19$ kips

$DC = 21.41 + 0.55 + 8.64 + 3.34 = 33.94$ kips

$DW = 0$

$LL + IM = 39.44 \times 1.5 + 11.99 = 64.44$ kips

$\therefore RF = 2.330$ (inventory)

$\therefore RF = 3.020$ (operating)

Governing load rating factor for strength I.

Inventory	2.032
Operating	2.634

Inventory rating factors are also checked for Service - III limit state

For Service III limit state.

For moments at center, $f_R = 2.366$ ksi.

Dead load stresses $(f_{DC}) = \dfrac{M_g + M_s + M_d}{S_b} + \dfrac{M_b}{S_{bc}}$

$$= \frac{(357.33 + 141.75 + 37.46) \times 12}{4945.63} + \frac{9}{6593.16}$$

$$= 1.304$$

f_{DW} = wearing surface stress = $\frac{M_{WS}}{S_{bc}} = 0$

Live load stresses = $\frac{M_{LL}}{S_{bc}}$

or $f_{LL+IM} = \frac{240.22 \times (1+0.33) + 86.49}{6593.16}$

$\therefore f_{LL+IM} = 0.739$

For HL-93, inventory loading.

$$\text{Rating Factor (RF)} = \frac{f_R - \gamma_{DC} \cdot f_{DC} - \gamma_{DW} \cdot f_{DW}}{f_{LL+IM} \times \gamma_{LL}}$$

$$= \frac{2.618 - 1 \times 1.304 - 1 \times 0}{0.8 \times 0.739}$$

$\therefore RF = 2.223$

For inventory loading, RF = min (strength I, service III)

= min (2.032, 2.223)

$\therefore RF = 2.032$ Strength I controls

B1.11 Legal Load Rating

Load factors, $\gamma_{LL} = 1.45$ (Considering ADTT Unknown)

All other values are similar to design load rating. Using similar expression used in design load rating, we get,

RF(2F1) = 8.235
RF(3F1) = 4.193
RF(5C1) = 4.277
] – Ohio legal loads

RF(Type 3) = 4.182
RF(Type 3S2) = 4.069
RF(Type 3-3) = 4.428
] – AASHTO legal loads.

B1.12 Permit Load Rating (Strength II Limit State)

Permit type: Routine or Annual

Riding surface condition = Minor surface depressions

Permit vehicle: PL60T

GVW = 120 kips (Gross Vehicle Weight)

AL = 65.08ft (Front axle to rear axle length)

$$\frac{GVW}{AL} = 1.84 \text{ kips/ft}$$

For strength II limit state.

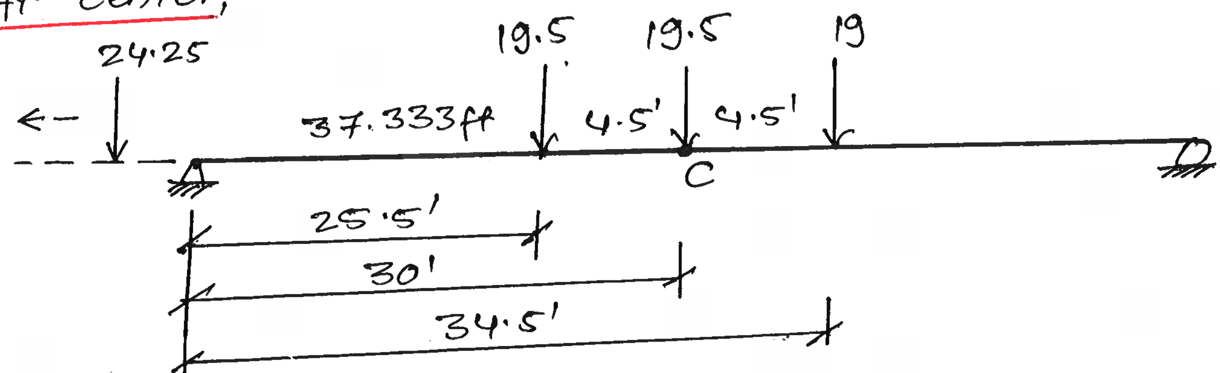
$$\frac{GVW}{AL} = 1.84 < 2 \text{ kips-ft}$$, two or more lane loaded

and unknown AADT.

$$\gamma_L = 1.4$$

IM = 20% [for minor surface depression]

At center,



(a) moment due to PL60T at center

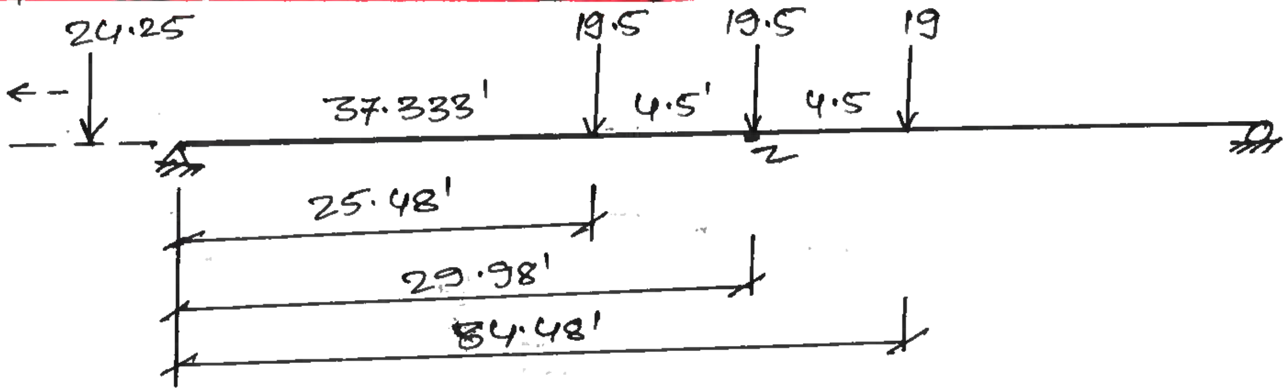
$$M_C = 19.5 \times \left[\left(1 - 25.5/60\right) \times 30 - (30 - 25.5)\right] + 19.5 \times \left[\left(1 - \frac{30}{60}\right) \times 30\right]$$

$$+ 19 \times \left[\left(1 - \frac{34.5}{60}\right) \times 30\right]$$

$$= 783.38 \times DFM\ (0.3)$$

$$\therefore M_C = 235.24 \text{ kips-ft.}$$

At moment critical location.



Resultant position of vehicle axles lies on the bridge.

$$= \frac{19.5 \times 4.5 + 19 \times 9}{19.5 + 19.5 + 19} \quad \text{(from leftmost axle)}$$

$$= 4.46 \text{ ft.}$$

Critical moment location $= \frac{60}{2} - 0.02 = 29.98$ ft

(b) moment due to PL 60T at moment critical location

$$M_z = 19.5\left[\left(1 - 25.48/60\right) \times 29.98 - (29.98 - 25.48)\right] +$$

$$19.5\left[\left(1 - 29.98/60\right) \times 29.98\right] + 19 \times \left[\left(1 - 34.48/60\right) \times 29.98\right]$$

$$= 783.38 \times DFM(0.3)$$

$$\therefore M_z = 235.24 \text{ kips-ft.}$$

Load Rating

At center,

Moment capacity = 2121.87 kips-ft

DC = 539.53 kips-ft

DW = 0 kips-ft

LL+IM = 235.24 × 1.33 = 282.29 kips-ft

$$RF = \frac{1 \times 1 \times 2121.87 - 1.25 \times 539.53 - 0}{1.4 \times 282.29} = 3.662$$

$\therefore RF = 3.662$

At moment critical location

Moment capacity = 2121.87 kips-ft

DC = 539.53 kips-ft

DW = 0

LL+IM = 282.29 kips-ft

$$RF = \frac{1 \times 1 \times 2121.87 - 1.25 \times 539.53 - 1.5 \times 0}{1.4 \times 282.29} = 3.662$$

∴ RF = 3.662 For strength II PL60T loading.

Check for service I limit state for permit loads

$$\text{Cracking moment } (M_{cr}) = \gamma_3 \left[(\gamma_1 f_r + \gamma_2 f_{cpe}) S_{btc} - M_{dnc} \left(\frac{S_{btc}}{S_{btf}} - 1 \right) \right]$$

where,

$\gamma_1 = 1.6$, $\gamma_2 = 1.10$, $\gamma_3 = 1.00$

$S_{btc} = 6895.47 \text{ in}^3$

$S_{btf} = 5781.21 \text{ in}^3$

Modulus of rupture, $f_r = 0.24\sqrt{f'_c} = 0.24 \times \sqrt{7}$

$= 0.635$ ksi

$f_{cpe} = 2.115$ ksi

$M_{dnc} = 530.53$ kips-ft.

∴ $M_{cr} = 1745.31$ kips-ft.

Effective prestress $f_{pe} = 171.04 ksi$

$M_{DC} + M_{DW} + M_{LL+IM} - M_{cr} = -923.49$ kips-ft

(moment above cracking moment)

(i) Simplified check using $0.75M_n$

$0.75M_n = 0.75 \times 2121.87 = 1591.4$ kips-ft

$M_{DC} + M_{DW} + M_{LL+IM} = 539.53 + 0 + 282.29 = 821.82$ kips-ft

moment ratio : $\frac{0.75M_n}{M_{DC} + M_{DW} + M_{LL+IM}} = \frac{1591.4}{821.82} = 1.936 > 1$ (Good)

(ii) Refined check using $0.9f_y$

$f_R = 0.9 f_y = 0.9 \times 243 = 218.70 ksi$

Assuming neutral axis in the top of slab.

$A_{ps} = 3.37 in^2$

$f'_c = 7 ksi$

Effective modular ratio of 2n is applicable

$n = \frac{E_p}{E_c} = \frac{28500}{5072.24} = 5.62 \simeq 6.$

$A_{trans} = A_{ps} \times 2n = 40.39 in^2$

then,

Depth of neutral axis $\Rightarrow C = \frac{C/2 \times b_{trans} \times C + d_e \times A_{trans}}{b_{trans} \times C + A_{trans}}.$

$b_{trans} = 38.49 in$

$d_e = 80.82$ in.

$A_{trans} = 40.39\ in^2$

on substituting and solving,

$c = 7.062$ in.

$$I_{cr} = \frac{1}{12} \times b_{trans} \times c^3 + b_{trans} \times c \times (c/2)^2 + A_{trans} \times (h + t_s - \bar{y}_{bs} - c)^2$$

$$= 1/12 \times 38.49 \times 7.062^3 + 38.49 \times 7.062 \times \left(\frac{7.062}{2}\right)^2 + 40.39 \times (27 + 6 - 2.18 - 7.062)^2$$

$\therefore I_{cr} = 27313.62\ in^4$

Stress beyond the effective prestress, $f = n\frac{My}{I}$

$$\therefore f = \frac{6 \times -923.49 \times 12 \times (27 + 6 - 2 - 7.062)}{27313.62}$$

$\therefore f = -58.27$ ksi

Stress in reinforcement at permit crossing Service I:

$f_s = f_{pe} - f = 171.04 - 58.27 = 112.76$ ksi

$$\therefore \text{stress ratio} = \frac{0.9 f_y}{f_s} = \frac{218.7}{112.76} = 1.939 > 1$$

(Good) (OK)

For this bridge, the simplified check and the more detailed check indicates that the condition for service I is acceptable.

The load factors for other remaining vehicle types were taken from Chapter 3 of this report and rating factors were computed for the remaining vehicles: Ohio legal vehicles (2F1, 3F1, 5C1), AASHTO legal vehicles (Type 3, Type 3S2, Type3-3), specialized hauling vehicles (SU4, SU5, SU6, SU7), and the remaining permit vehicles (PL65T).

The load rating factors for all 18 sample bridges provided by Ohio DOT were calculated using the same formulations as above. The results from the independent hand calculations are presented below for all 18 sample bridges for all the load cases specified in the ODOT BDM 2020.

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B2. Rating Factor Results

B2.1 Non-Skewed Bridges

Sample 1

Vehicle types	Load factors			Dc	Dw	LL+IM	RF	Governing force
	γ_{Dc}	γ_{Dw}	γ_{LL}	kips-ft	kips-ft	kips-ft		
A. Design Vehicles (HL93)								
Inventory	1.25	1.50	1.75	74.59	43.31	179.56	1.703	Flexure
Operating	1.25	1.50	1.35	74.59	43.31	179.56	2.207	Flexure
B. Ohio Legal Vehicles								
2F1	1.25	1.50	1.45	73.91	42.96	83.88	4.411	Flexure
3F1	1.25	1.50	1.45	74.88	43.44	118.66	3.107	Flexure
5C1	1.25	1.50	1.45	74.72	43.37	113.26	3.257	Flexure
C. Specialized Hauling Vehicles								
SU4	1.25	1.50	1.45	74.40	43.21	129.13	2.860	Flexure
SU5	1.25	1.50	1.45	75.01	43.48	138.31	2.664	Flexure
SU6	1.25	1.50	1.45	75.00	43.48	151.54	2.432	Flexure
SU7	1.25	1.50	1.45	74.59	43.31	158.16	2.333	Flexure
D. Emergency Vehicles								
EV2	1.25	1.50	1.45	71.41	41.61	127.41	2.932	Flexure
EV3	1.25	1.50	1.35	74.25	43.14	192.69	2.060	Flexure
E. AASHTO Legal Vehicles								
Type3	1.25	1.50	1.45	73.85	42.93	106.60	3.472	Flexure
Type3S2	1.25	1.50	1.45	74.87	43.43	104.73	3.52	Flexure
Type3-3	1.25	1.50	1.45	74.59	43.31	86.31	4.276	Flexure
E. Permit Vehicles								
PL60T	1.25	1.50	1.40	75.07	43.50	148.31	2.573	Flexure
PL65T	1.25	1.50	1.35	74.59	43.31	160.63	2.468	Flexure

Sample 2

Vehicle types	Load factors			Dc	Dw	LL+IM	RF	Governing force
	γ_{Dc}	γ_{Dw}	γ_{LL}	kips-ft	kips-ft	kips-ft		
A. Design Vehicles (HL93)								
Inventory	1.25	1.50	1.75	221.98	50.53	337.32	1.546	Flexure
Operating	1.25	1.50	1.35	221.98	50.53	337.32	2.004	Flexure
B. Ohio Legal Vehicles								
2F1	1.25	1.50	1.45	223.09	50.75	141.83	4.429	Flexure
3F1	1.25	1.50	1.45	224.25	50.95	208.97	3.001	Flexure
5C1	1.25	1.50	1.45	224.05	50.92	203.91	3.075	Flexure
C. Specialized Hauling Vehicles								
SU4	1.25	1.50	1.45	223.66	50.85	235.60	2.664	Flexure
SU5	1.25	1.50	1.45	222.63	50.66	256.08	2.456	Flexure
SU6	1.25	1.50	1.45	223.65	50.85	283.68	2.212	Flexure
SU7	1.25	1.50	1.45	224.30	50.96	305.50	2.052	Flexure
D. Emergency Vehicles								
EV2	1.25	1.50	1.45	220.24	50.18	238.81	2.643	Flexure
EV3	1.25	1.50	1.45	223.48	50.82	363.08	1.729	Flexure
E. AASHTO Legal Vehicles								
Type3	1.25	1.50	1.45	223.01	50.74	205.79	3.053	Flexure
Type3S2	1.25	1.5	1.45	218.75	49.86	191.76	3.300	Flexure
Type3-3	1.25	1.50	1.45	222.09	50.56	173.04	3.636	Flexure
F. Permit Vehicles								
PL60T	1.25	1.50	1.40	224.51	50.98	250.08	2.595	Flexure
PL65T	1.25	1.50	1.35	223.89	50.90	284.57	2.368	Flexure

Sample 3

Vehicle types	Load factors			Dc	Dw	LL+IM	RF	Governing force
	γ_{Dc}	γ_{Dw}	γ_{LL}	kips-ft	kips-ft	kips-ft		
A. Design Vehicles (HL93)								
Inventory	1.25	1.50	1.75	428.48	76.90	464.24	1.036	Flexure
Operating	1.25	1.50	1.35	428.48	76.90	464.24	1.343	Flexure
B. Ohio Legal Vehicles								
2F1	1.25	1.50	1.45	429.38	77.11	180.26	3.214	Flexure
3F1	1.25	1.50	1.45	430.41	77.31	268.11	2.157	Flexure
5C1	1.25	1.50	1.45	430.26	77.28	263.03	2.199	Flexure
C. Specialized Hauling Vehicles								
SU4	1.25	1.50	1.45	429.92	77.22	304.94	1.898	Flexure
SU5	1.25	1.50	1.45	428.93	77.02	335.50	1.728	Flexure
SU6	1.25	1.50	1.45	429.91	77.21	372.98	1.552	Flexure
SU7	1.25	1.50	1.45	430.45	77.32	405.28	1.427	Flexure
D. Emergency Vehicles								
EV2	1.25	1.50	1.30	426.51	76.55	311.88	2.083	Flexure
EV3	1.25	1.50	1.10	429.75	77.18	473.50	1.612	Flexure
E. AASHTO Legal Vehicles								
Type3	1.25	1.50	1.45	429.31	77.10	269.91	2.147	Flexure
Type3S2	1.25	1.50	1.45	425.26	76.24	283.10	2.062	Flexure
Type3-3	1.25	1.50	1.45	430.40	77.3	259.15	2.232	Flexure
F. Permit Vehicles								
PL60T	1.25	1.50	1.40	430.56	77.34	317.35	1.887	Flexure
PL65T	1.25	1.50	1.35	423.05	75.79	416.16	1.513	Flexure

Sample 4

Vehicle types	Load factors			Dc	Dw	LL+IM	RF	Governing force
	γ_{Dc}	γ_{Dw}	γ_{LL}	kips-ft	kips-ft	kips-ft		
A. Design Vehicles (HL93)								
Inventory	1.25	1.50	1.75	58.44	0.00	125.58	2.258	Flexure
Operating	1.25	1.50	1.35	58.44	0.00	125.58	2.928	Flexure
B. Ohio Legal Vehicles								
2F1	1.25	1.50	1.45	57.72	0.00	58.59	5.853	Flexure
3F1	1.25	1.50	1.45	58.66	0.00	80.75	4.237	Flexure
5C1	1.25	1.50	1.45	58.52	0.00	76.03	4.501	Flexure
C. Specialized Hauling Vehicles								
SU4	1.25	1.50	1..45	58.73	0.00	88.53	3.863	Flexure
SU5	1.25	1.50	1.45	58.76	0.00	95.96	3.563	Flexure
SU6	1.25	1.50	1.45	58.76	0.00	103.48	3.305	Flexure
SU7	1.25	1.50	1.45	58.44	0.00	105.31	3.250	Flexure
D. Emergency Vehicles								
EV2	1.25	1.50	1.45	58.79	0.00	87.11	3.925	Flexure
EV3	1.25	1.50	1.00	58.44	0.00	136.45	3.637	Flexure
E. AASHTO Legal Vehicles								
Type3	1.25	1.50	1.45	58.44	0.00	74.83	4.575	Flexure
Type3S2	1.25	1.50	1.45	58.65	0.00	71.06	4.814	Flexure
Type3_3	1.25	1.50	1.45	58.44	0.00	61.62	5.555	Flexure
F. Permit Vehicles								
PL60T	1.25	1.50	1.40	58.79	0.00	79.10	4.478	Flexure
PL65T	1.25	1.50	1.40	58.79	0.00	84.59	4.187	Flexure

Sample 5

Vehicle types	Load factors			Dc	Dw	LL+IM	RF	Governing force
	γ_{Dc}	γ_{Dw}	γ_{LL}	kips-ft	kips-ft	kips-ft		
A. Design Vehicles (HL93)								
Inventory	1	1.00	0.8	1.41	0.15	0.89	1.495	Flexure
Operating	1.25	1.50	1.35	274.76	43.05	267.55	2.007	Flexure
B. Ohio Legal Vehicles								
2F1	1.25	1.50	1.45	276.31	43.28	117.44	4.243	Flexure
3F1	1.25	1.50	1.45	277.81	43.49	172.02	2.888	Flexure
5C1	1.25	1.50	1.45	277.57	43.46	167.30	2.971	Flexure
C. Specialized Hauling Vehicles								
SU4	1.25	1.50	1.45	277.07	43.39	192.91	2.579	Flexure
SU5	1.25	1.50	1.45	275.67	43.19	208.14	2.397	Flexure
SU6	1.25	1.50	1.45	277.06	43.39	230.01	2.163	Flexure
SU7	1.25	1.50	1.45	277.87	43.50	246.27	2.017	Flexure
D. Emergency Vehicles								
EV2	1.25	1.50	1.45	272.27	42.68	194.57	2.582	Flexure
EV3	1.25	1.50	1.45	276.84	43.36	295.92	1.682	Flexure
E. AASHTO Legal Vehicles								
Type3	1.25	1.50	1.45	276.2	43.27	167.13	2.982	Flexure
Type3S2	1.25	1.50	1.45	277.8	43.49	152.43	3.513	Flexure
Type3-3	1.25	1.50	1.45	274.92	43.08	139.64	3.579	Flexure
F. Permit Vehicles								
PL60T	1.25	1.50	1.40	278.07	43.51	189.95	2.707	Flexure
PL65T	1.25	1.50	1.35	277.37	277.37	43.42	2.490	Flexure

Sample 6

Vehicle types	Load factors			Dc	Dw	LL+IM	RF	Governing force
	γ_{Dc}	γ_{Dw}	γ_{LL}	kips-ft	kips-ft	kips-ft		
A. Design Vehicles (HL93)								
Inventory	1	1.00	0.8	2.03	0.00	1.32	1.183	Flexure
Operating	1.25	1.50	1.35	376.94	0.00	395.32	1.876	Flexure
B. Ohio Legal Vehicles								
2F1	1.25	1.50	1.30	378.84	0.00	160.29	4.794	Flexure
3F1	1.25	1.50	1.30	380.15	0.00	237.24	3.234	Flexure
5C1	1.25	1.50	1.30	380.04	0.00	232.09	3.306	Flexure
C. Specialized Hauling Vehicles								
SU4	1.25	1.50	1.30	379.62	0.00	268.59	2.858	Flexure
SU5	1.25	1.50	1.30	378.20	0.00	293.65	2.619	Flexure
SU6	1.25	1.50	1.30	379.60	0.00	325.87	2.356	Flexure
SU7	1.25	1.50	1.30	380.17	0.00	352.47	2.176	Flexure
D. Emergency Vehicles								
EV2	1.25	1.50	1.30	374.93	0.00	273.39	2.824	Flexure
EV3	1.25	1.50	1.20	379.37	0.00	415.43	2.002	Flexure
E. AASHTO Legal Vehicles								
Type3	1.25	1.50	1.30	378.73	0.00	236.10	3.255	Flexure
Type3S2	1.25	1.50	1.30	372.67	0.00	233.32	3.319	Flexure
Type3-3	1.25	1.50	1.30	379.73	0.00	211.19	3.634	Flexure
F. Permit Vehicles								
PL60T	1.25	1.50	1.40	380.16	0.00	181.67	3.921	Flexure
PL65T	1.25	1.50	1.40	369.82	0.00	215.43	3.350	Flexure

Sample7

Vehicle types	Load factors			Dc	Dw	LL+IM	RF	Governing force
	γ_{Dc}	γ_{Dw}	γ_{LL}	kips-ft	kips-ft	kips-ft		
A. Design Vehicles(HL93)								
Inventory	1	1.00	0.8	2.21	0.00	1.16	1.395	Flexure
Operating	1.25	1.50	1.35	910.00	0.00	638.87	2.293	Flexure
B. Ohio Legal Vehicles								
2F1	1.25	1.50	1.45	911.77	0.00	227.34	5.994	Flexure
3F1	1.25	1.50	1.45	913.61	0.00	340.85	3.993	Flexure
5C1	1.25	1.50	1.45	895.69	0.00	386.99	3.557	Flexure
C. Specialized Hauling Vehicles								
SU4	1.25	1.50	1.45	912.67	0.00	390.70	3.486	Flexure
SU5	1.25	1.50	1.45	911.03	0.00	434.43	3.138	Flexure
SU6	1.25	1.50	1.45	912.66	0.00	484.27	2.812	Flexure
SU7	1.25	1.50	1.45	913.69	0.00	530.03	2.568	Flexure
D. Emergency Vehicles								
EV2	1.25	1.50	1.10	907.26	0.00	403.09	4.469	Flexure
EV3	1.25	1.50	1.10	912.39	0.00	610.60	2.940	Flexure
E. AASHTO Legal Vehicles								
Type3	1.25	1.50	1.45	911.64	0.00	349.79	3.896	Flexure
Type3S2	1.25	1.50	1.45	904.89	0.00	401.95	3.405	Flexure
Type3-3	1.25	1.50	1.45	911.08	0.00	389.38	3.501	Flexure
F. Permit Vehicles								
PL60T	1.25	1.50	1.40	877.40	0.00	383.57	3.759	Flexure
PL65T	1.25	1.50	1.35	901.52	0.00	560.02	2.630	Flexure

B2.2 Skewed Bridges

Sample 8

Vehicle types	Load factors			Dc	Dw	LL+IM	RF	Governing force
	γ_{Dc}	γ_{Dw}	γ_{LL}	kips-ft	kips-ft	kips-ft		
A. Design Vehicles(HL93)								
Inventory	1.25	1.50	1.75	159.09	36.84	243.32	1.639	Flexure
Operating	1.25	1.50	1.35	159.09	36.84	243.32	2.124	Flexure
B. Ohio Legal Vehicles								
2F1	1.25	1.50	1.45	160.34	37.07	110.08	4.359	Flexure
3F1	1.25	1.50	1.45	161.42	37.27	160.53	2.982	Flexure
5C1	1.25	1.50	1.45	161.25	37.24	155.75	3.075	Flexure
C. Specialized Hauling Vehicles								
SU4	1.25	1.50	1.45	160.88	37.17	179.32	2.673	Flexure
SU5	1.25	1.50	1.45	159.90	36.97	192.43	2.496	Flexure
SU6	1.25	1.50	1.45	160.87	37.17	212.24	2.258	Flexure
SU7	1.25	1.50	1.45	161.44	37.28	226.23	2.116	Flexure
D. Emergency Vehicles								
EV2	1.25	1.50	1.45	157.58	36.47	180.25	2.679	Flexure
EV3	1.25	1.50	1.10	160.72	37.14	274.13	2.306	Flexure
E. AASHTO Legal Vehicles								
Type3	1.25	1.50	1.45	160.27	37.05	154.42	3.108	Flexure
Type3S2	1.25	1.50	1.45	161.41	37.27	142.18	3.367	Flexure
Type3-3	1.25	1.50	1.45	159.39	36.86	128.4	3.745	Flexure
F. Permit Vehicles								
PL60T	1.25	1.50	1.40	161.44	37.30	194.33	2.551	Flexure
PL65T	1.25	1.50	1.40	161.10	37.22	218.25	2.358	Flexure

Sample 9

Vehicle types	Load factors			Dc	Dw	LL+IM	RF	Governing force
	γ_{Dc}	γ_{Dw}	γ_{LL}	kips-ft	kips-ft	kips-ft		
A. Design Vehicles (HL93)								
Inventory	1.25	1.50	1.75	411.88	177.76	489.25	1.004	Flexure
Operating	1.25	1.50	1.35	411.88	177.76	489.25	1.301	Flexure
B. Ohio Legal Vehicles								
2F1	1.25	1.50	1.45	412.86	178.21	186.86	3.166	Flexure
3F1	1.25	1.50	1.45	413.77	178.63	278.39	2.120	Flexure
5C1	1.25	1.50	1.45	403.18	173.77	274.56	2.160	Flexure
C. Specialized Hauling Vehicles								
SU4	1.25	1.50	1.45	413.33	178.43	317.15	1.863	Flexure
SU5	1.25	1.50	1.45	412.46	178.03	349.71	1.693	Flexure
SU6	1.25	1.50	1.45	413.33	178.43	389.02	1.519	Flexure
SU7	1.25	1.50	1.45	413.80	178.64	423.37	1.394	Flexure
D. Emergency Vehicles								
EV2	1.25	1.50	1.45	410.27	177.02	324.95	1.830	Flexure
EV3	1.25	1.50	1.45	413.19	178.36	493.14	1.198	Flexure
E. AASHTO Legal Vehicles								
Type3	1.25	1.5	1.45	412.79	178.18	281.4	2.102	Flexure
Type3S2	1.25	1.5	1.45	408.85	176.37	301.13	1.982	Flexure
Type3-3	1.25	1.5	1.45	413.7	178.6	276.6	2.134	Flexure
F. Permit Vehicles								
PL60T	1.25	1.5	1.4	413.86	178.68	328.85	1.859	Flexure
PL65T	1.25	1.5	1.35	406.77	175.43	446.07	1.444	Flexure

Sample 10

Vehicle types	Load factors			Dc	Dw	LL+IM	RF	Governing force
	γ_{Dc}	γ_{Dw}	γ_{LL}	kips-ft	kips-ft	kips-ft		
A. Design Vehicles (HL93)								
Inventory	1	1.00	0.8	1.46	0.83	1.75	1.003	Flexure
Operating	1.25	1.50	1.35	393.81	223.59	476.39	1.325	Flexure
B. Ohio Legal Vehicles								
2F1	1.25	1.50	1.45	394.74	224.15	181.46	3.234	Flexure
3F1	1.25	1.50	1.45	395.59	224.66	270.43	2.165	Flexure
5C1	1.25	1.50	1.45	385.62	218.65	268.37	2.206	Flexure
C. Specialized Hauling Vehicles								
SU4	1.25	1.50	1.45	395.18	224.42	308.16	1.902	Flexure
SU5	1.25	1.50	1.45	394.36	223.92	339.91	1.728	Flexure
SU6	1.25	1.50	1.45	395.18	224.41	378.15	1.550	Flexure
SU7	1.25	1.50	1.45	395.62	224.68	411.64	1.422	Flexure
D. Emergency Vehicles								
EV2	1.25	1.50	1.30	392.30	222.68	315.82	2.085	Flexure
EV3	1.25	1.50	1.10	395.05	224.33	479.26	1.613	Flexure
E. AASHTO Legal Vehicles								
Type3	1.25	1.50	1.45	394.68	224.11	273.52	2.146	Flexure
Type3S2	1.25	1.50	1.45	390.96	221.87	293.61	2.018	Flexure
Type3-3	1.25	1.50	1.45	395.53	224.62	269.83	2.17	Flexure
F. Permit Vehicles								
PL60T	1.25	1.50	1.40	395.70	224.73	292.73	2.071	Flexure
PL65T	1.25	1.50	1.35	395.70	224.73	386.21	1.602	Flexure

Sample 11

Vehicle types	Load factors			Dc	Dw	LL+IM	RF	Governing force
	γ_{Dc}	γ_{Dw}	γ_{LL}	kips-ft	kips-ft	kips-ft		
A. Design Vehicles (HL93)								
Inventory	1	1.00	0.8	1.12	0.15	0.90	0.341	Flexure
Operating	1.25	1.50	1.35	471.17	63.22	379.92	0.941	Flexure
B. Ohio Legal Vehicles								
2F1	1.25	1.50	1.45	472.03	63.34	138.26	2.406	Flexure
3F1	1.25	1.50	1.45	472.81	63.45	206.92	1.605	Flexure
5C1	1.25	1.50	1.45	463.65	62.15	225.82	1.512	Flexure
C. Specialized Hauling Vehicles								
SU4	1.25	1.50	1.45	472.43	63.40	236.75	1.404	Flexure
SU5	1.25	1.50	1.45	471.68	63.29	262.60	1.268	Flexure
SU6	1.25	1.50	1.45	472.43	63.40	292.56	1.136	Flexure
SU7	1.25	1.50	1.45	472.84	63.46	319.69	1.039	Flexure
D. Emergency Vehicles								
EV2	1.25	1.50	1.30	469.79	63.02	243.75	1.532	Flexure
EV3	1.25	1.50	1.10	472.31	63.38	369.45	1.186	Flexure
E. AASHTO Legal Vehicles								
Type3	1.25	1.50	1.45	471.97	63.33	211.40	1.574	Flexure
Type3S2	1.25	1.50	1.45	468.56	62.85	238.07	1.413	Flexure
Type3-3	1.25	1.50	1.45	471.70	63.29	226.91	1.469	Flexure
F. Permit Vehicles								
PL60T	1.25	1.50	1.40	472.91	63.47	244.64	1.406	Flexure
PL65T	1.25	1.50	1.35	472.91	63.47	351.16	1.011	Flexure

Sample 12

Vehicle types	Load factors			Dc	Dw	LL+IM	RF	Governing force
	γ_{Dc}	γ_{Dw}	γ_{LL}	kips-ft	kips-ft	kips-ft		
A. Design Vehicles (HL93)								
Inventory	1	1.00	0.8	1.17	0.22	0.98	1.503	Flexure
Operating	1.25	1.50	1.35	512.59	96.10	432.97	2.228	Flexure
B. Ohio Legal Vehicles								
2F1	1.25	1.50	1.45	513.39	96.28	157.46	5.697	Flexure
3F1	1.25	1.50	1.45	514.27	96.45	235.67	3.803	Flexure
5C1	1.25	1.50	1.45	504.56	94.48	257.51	3.520	Flexure
C. Specialized Hauling Vehicles								
SU4	1.25	1.50	1.45	513.84	96.37	269.66	3.325	Flexure
SU5	1.25	1.50	1.45	513.00	96.21	299.13	3.000	Flexure
SU6	1.25	1.50	1.45	513.83	96.37	333.26	2.691	Flexure
SU7	1.25	1.50	1.45	514.30	96.46	364.17	2.460	Flexure
D. Emergency Vehicles								
EV2	1.25	1.50	1.45	510.92	95.80	277.65	3.240	Flexure
EV3	1.25	1.50	1.45	513.70	96.34	420.83	2.131	Flexure
E. AASHTO Legal Vehicles								
Type3	1.25	1.50	1.45	513.32	96.27	240.81	3.724	Flexure
Type3S2	1.25	1.50	1.45	509.81	95.54	271.35	3.319	Flexure
Type3-3	1.25	1.50	1.45	513.03	96.21	258.77	3.468	Flexure
F. Permit Vehicles								
PL60T	1.25	1.50	1.40	514.21	96.44	232.29	3.996	Flexure
PL65T	1.25	1.50	1.40	507.91	95.15	341.35	2.740	Flexure

Sample 13

Vehicle types	Load factors			Dc	Dw	LL+IM	RF	Governing force
	γ_{Dc}	γ_{Dw}	γ_{LL}	kips-ft	kips-ft	kips-ft		
A. Design Vehicles (HL93)								
Inventory	1.25	1.50	1.75	80.63	2.52	134.31	3.473	Flexure
Operating	1.25	1.50	1.35	80.63	2.52	134.31	4.502	Flexure
B. Ohio Legal Vehicles								
2F1	1.25	1.50	1.45	79.72	2.49	62.72	8.987	Flexure
3F1	1.25	1.50	1.45	81.00	2.53	87.00	6.466	Flexure
5C1	1.25	1.50	1.45	80.80	2.52	82.19	6.847	Flexure
C. Specialized Hauling Vehicles								
SU4	1.25	1.50	1.45	80.97	2.53	94.50	5.953	Flexure
SU5	1.25	1.50	1.45	81.09	2.53	102.91	5.466	Flexure
SU6	1.25	1.50	1.45	81.02	2.53	111.40	5.050	Flexure
SU7	1.25	1.50	1.45	80.63	2.52	114.08	4.935	Flexure
D. Emergency Vehicles								
EV2	1.25	1.50	1.30	81.10	2.54	92.16	6.808	Flexure
EV3	1.25	1.50	1.10	80.63	2.52	145.33	5.106	Flexure
E. AASHTO Legal Vehicles								
Type3	1.25	1.50	1.45	80.63	2.52	79.70	7.063	Flexure
Type3S2	1.25	1.50	1.45	80.99	2.53	76.62	7.343	Flexure
Type3-3	1.25	1.50	1.45	80.63	2.52	65.63	8.577	Flexure
F. Permit Vehicles								
PL60T	1.25	1.50	1.40	81.10	2.53	84.70	6.878	Flexure
PL65T	1.25	1.50	1.40	81.10	2.54	90.43	6.443	Flexure

Sample 14

Vehicle types	Load factors			Dc	Dw	LL+IM	RF	Governing force
	γ_{Dc}	γ_{Dw}	γ_{LL}	kips-ft	kips-ft	kips-ft		
A. Design Vehicles (HL93)								
Inventory	1.25	1.50	1.75	293.04	0.00	285.04	3.313	Flexure
Operating	1.25	1.50	1.35	293.04	0.00	285.04	4.295	Flexure
B. Ohio Legal Vehicles								
2F1	1.25	1.50	1.45	291.85	0.00	128.99	8.846	Flexure
3F1	1.25	1.50	1.45	293.58	0.00	189.57	6.011	Flexure
5C1	1.25	1.50	1.45	293.28	0.00	184.72	6.170	Flexure
C. Specialized Hauling Vehicles								
SU4	1.25	1.50	1.45	292.69	0.00	213.24	5.348	Flexure
SU5	1.25	1.50	1.45	291.17	0.00	231.06	4.941	Flexure
SU6	1.25	1.50	1.45	292.68	0.00	255.69	4.461	Flexure
SU7	1.25	1.50	1.45	293.63	0.00	274.69	4.149	Flexure
D. Emergency Vehicles								
EV2	1.25	1.50	1.45	287.69	0.00	215.68	5.307	Flexure
EV3	1.25	1.50	1.45	292.43	0.00	327.98	3.468	Flexure
E. AASHTO Legal Vehicles								
Type3	1.25	1.50	1.45	291.74	0.00	185.61	6.148	Flexure
Type3S2	1.25	1.50	1.45	293.56	0.00	168.05	6.781	Flexure
Type3-3	1.25	1.50	1.45	290.39	0.00	155.65	7.339	Flexure
F. Permit Vehicles								
PL60T	1.25	1.50	1.40	293.56	0.00	173.79	6.792	Flexure
PL65T	1.25	1.50	1.40	293.04	0.00	197.11	5.990	Flexure

Sample 15

Vehicle types	Load factors			Dc	Dw	LL+IM	RF	Governing force
	γ_{Dc}	γ_{Dw}	γ_{LL}	kips-ft	kips-ft	kips-ft		
A. Design Vehicles (HL93)								
Inventory	1.25	1.50	1.75	536.47	0.00	408.09	2.032	Flexure
Operating	1.25	1.50	1.35	536.47	0.00	408.09	2.634	Flexure
B. Ohio Legal Vehicles								
2F1	1.25	1.50	1.45	538.00	0.00	160.31	6.235	Flexure
3F1	1.25	1.50	1.45	539.36	0.00	238.14	4.193	Flexure
5C1	1.25	1.50	1.45	539.16	0.00	233.46	4.277	Flexure
C. Specialized Hauling Vehicles								
SU4	1.25	1.50	1.45	538.71	0.00	270.53	3.693	Flexure
SU5	1.25	1.50	1.45	537.39	0.00	297.15	3.366	Flexure
SU6	1.25	1.50	1.45	538.70	0.00	330.20	3.025	Flexure
SU7	1.25	1.50	1.45	539.41	0.00	358.38	2.786	Flexure
D. Emergency Vehicles								
EV2	1.25	1.50	1.30	534.10	0.00	276.34	4.048	Flexure
EV3	1.25	1.50	1.10	538.50	0.00	419.64	3.138	Flexure
E. AASHTO Legal Vehicles								
Type3	1.25	1.50	1.45	537.90	0.00	239.02	4.182	Flexure
Type3S2	1.25	1.50	1.45	531.88	0.00	246.98	4.069	Flexure
Type3-3	1.25	1.50	1.45	539.25	0.00	225.48	4.428	Flexure
F. Permit Vehicles								
PL60T	1.25	1.50	1.40	539.53	0.00	282.29	3.662	Flexure
PL65T	1.25	1.50	1.35	528.76	0.00	360.95	2.998	Flexure

Sample 16

Vehicle types	Load factors			Dc	Dw	LL+IM	RF	Governing force
	γ_{Dc}	γ_{Dw}	γ_{LL}	kips-ft	kips-ft	kips-ft		
A. Design Vehicles (HL93)								
Inventory	1	1.00	0.8	1.85	0.29	0.89	1.001	Flexure
Operating	1.25	1.50	1.35	1055.86	206.02	645.36	1.966	Flexure
B. Ohio Legal Vehicles								
2F1	1.25	1.50	1.45	1054.25	206.34	226.82	5.209	Flexure
3F1	1.25	1.50	1.45	1056.50	206.63	340.39	3.466	Flexure
5C1	1.25	1.50	1.45	1040.87	203.19	394.30	3.036	Flexure
C. Specialized Hauling Vehicles								
SU4	1.25	1.50	1.45	1055.32	206.49	390.54	3.023	Flexure
SU5	1.25	1.50	1.45	1053.40	206.21	434.80	2.720	Flexure
SU6	1.25	1.50	1.45	1055.30	206.49	484.83	2.435	Flexure
SU7	1.25	1.50	1.45	1056.61	206.64	531.09	2.221	Flexure
D. Emergency Vehicles								
EV2	1.25	1.50	1.45	1049.14	205.49	403.37	2.944	Flexure
EV3	1.25	1.50	1.45	1054.99	206.44	610.82	1.933	Flexure
E. AASHTO Legal Vehicles								
Type3	1.25	1.50	1.45	1054.11	206.31	350.12	3.375	Flexure
Type3S2	1.25	1.50	1.45	1051.74	205.03	406.51	2.917	Flexure
Type3-3	1.25	1.50	1.45	1053.45	206.21	396.94	2.98	Flexure
F. Permit Vehicles								
PL60T	1.25	1.50	1.40	1010.32	197.61	429.26	2.966	Flexure
PL65T	1.25	1.50	1.35	1047.70	204.36	620.04	2.061	Flexure

B2.3 Multicell Box Beam Bridges

Sample 17

Vehicle types	Load factors			Dc	Dw	LL+IM	RF	Governing force
	γ_{Dc}	γ_{Dw}	γ_{LL}	kips-ft	kips-ft	kips-ft		
A. Design Vehicles (HL93)								
Inventory	1.00	1.00	0.8	0.78	0.00	0.61	1.158	Flexure
Operating	1.25	1.50	1.35	143.01	0.00	183.97	1.946	Flexure
B. Ohio Legal Vehicles								
2F1	1.25	1.50	1.43	141.96	0.00	85.50	3.961	Flexure
3F1	1.25	1.50	1.43	143.48	0.00	122.92	2.744	Flexure
5C1	1.25	1.50	1.43	143.22	0.00	118.33	2.853	Flexure
C. Specialized Hauling Vehicles								
SU4	1.25	1.50	1.43	142.70	0.00	135.60	2.494	Flexure
SU5	1.25	1.50	1.43	141.36	0.00	142.99	2.372	Flexure
SU6	1.25	1.50	1.43	143.68	0.00	156.63	2.152	Flexure
SU7	1.25	1.50	1.43	143.01	0.00	166.07	2.033	Flexure
D. Emergency Vehicles								
EV2	1.25	1.50	1.30	138.27	0.00	134.97	2.790	Flexure
EV3	1.25	1.50	1.10	142.47	0.00	204.96	2.149	Flexure
E. AASHTO Legal Vehicles								
Type3	1.25	1.50	1.43	141.86	0.00	114.48	2.960	Flexure
Type3S2	1.25	1.50	1.43	143.47	0.00	108.68	3.103	Flexure
Type3-3	1.25	1.50	1.43	140.66	0.00	93.70	3.628	Flexure
F. Permit Vehicles								
PL60T	1.25	1.50	1.40	143.84	0.00	101.57	3.393	Flexure
PL65T	1.25	1.50	1.40	143.01	0.00	112.10	3.081	Flexure

Sample 18

Vehicle types	Load factors			Dc	Dw	LL+IM	RF	Governing force
	γ_{Dc}	γ_{Dw}	γ_{LL}	kips-ft	kips-ft	kips-ft		
A. Design Vehicles (HL93)								
Inventory	1	1.00	0.8	0.95	0.00	0.76	1.428	Flexure
Operating	1.25	1.50	1.35	235.73	0.00	281.22	2.090	Flexure
B. Ohio Legal Vehicles								
2F1	1.25	1.50	1.30	236.92	0.00	123.44	4.936	Flexure
3F1	1.25	1.50	1.30	238.02	0.00	180.81	3.364	Flexure
5C1	1.25	1.50	1.30	237.86	0.00	175.85	3.460	Flexure
C. Specialized Hauling Vehicles								
SU4	1.25	1.50	1.30	237.50	0.00	202.76	3.002	Flexure
SU5	1.25	1.50	1.30	236.44	0.00	218.78	2.787	Flexure
SU6	1.25	1.50	1.30	237.49	0.00	241.76	2.519	Flexure
SU7	1.25	1.50	1.30	238.06	0.00	258.85	2.349	Flexure
D. Emergency Vehicles								
EV2	1.25	1.50	1.30	233.79	0.00	204.51	2.994	Flexure
EV3	1.25	1.50	1.30	237.32	0.00	311.04	1.958	Flexure
E. AASHTO Legal Vehicles								
Type3	1.25	1.50	1.30	236.84	0.00	175.67	3.468	Flexure
Type3S2	1.25	1.50	1.30	238.01	0.00	160.22	3.795	Flexure
Type3-3	1.25	1.50	1.30	235.86	0.00	146.77	4.157	Flexure
F. Permit Vehicles								
PL60T	1.25	1.50	1.40	238.16	0.00	136.56	4.135	Flexure
PL65T	1.25	1.50	1.40	237.72	0.00	154.22	3.664	Flexure

Appendix C: AD-BOX Solved Examples

Appendix C includes the pages from the main tab of AD-BOX, which includes the input data and load rating results for the 18 sample bridges summarized in Table 3-16. The results from these files are used in the verification study discussed in Section 3.2. Each bridge sample has 6 pages, resulting in a total of 108 pages of appendices for 18 sample bridges.

Appendix C: AD-BOX Solved Examples

Table of Contents

C1: Non-Skewed Bridges

EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample bridge 1	Load rated by	SD	Date	5/13/2025
Construction year	2024	Checked by	YM	Date	5/13/2025

1. Bridge Information

Total span*	30.00	ft
Total width	20.00	ft

Single lane width	18.00	ft
End offset	0.00	in.
Width of bearing	5.00	in.
Barrier type	Steel guard rail	
Width of barrier	0.00	ft each side

Design span	30.00	ft
Road way width	20.00	ft

Composite /Non composite*	Non composite	
Thickness of deck slab*	0	in.

Skew/Non skew*	Non skew	
Skew angle*	0	Degrees

Surfacing material	Asphalt surface	
Thickness	8	in.

Total number of diaphragm*	3	nos

Diaphragm number	Position from left support		Thickness	
1	0.00	ft	18.00	in.
2	15.00	ft	18.00	in.
3	30.00	ft	18.00	in.

Bridge appraisal rating	9
Condition factor	1.00

Additional beam weight	0%
Additional barrier weight	0%

2. Material Properties

a. Concrete

Required concrete compressive strength at transfer*	f'_{ci}	5.00	ksi
Specified concrete compressive strength for use in design*	f'_c	7.00	ksi
Deck concrete compressive strength *	f'_{c_deck}	4.50	ksi
Concrete unit weight*	w_c	0.15	kcf

Correction factor for source of concrete*	K_1	1	
Modulus of elasticity of concrete for precast beam at transfer	E_{ci}	4286.83	ksi
Modulus of elasticity of concrete for precast beam at service load	E_{c_beam}	5072.24	ksi
Modulus of elasticity of concrete for deck slab	E_{c_slab}	4066.84	ksi

b. Reinforcing Bars

Yield Strength*	f_y	60.00	ksi
Modulus of elasticity*	E_s	29000	ksi

c. Prestressing Strands

Type*	Seven-wire strand	Low-relaxation strand

Diameter	D_p	1/2	in.
Area*	A_p	0.167	in^2
Tensile strength*	f_{pu}	270	ksi
Modulus of elasticity*	E_p	28500	ksi
Yield strength	f_{py}	243	ksi
	K	0.28	

d. Surfacing Material

Type	Asphalt surface	
Unit weight	0.145	kcf

e. Barrier

Type	Steel guard rail	
Unit weight	0.078	kips/ft/side

3. Box Beam Section Properties

Box beam section used	**B17-48**		
Width of each box beam	b	48	in.
Height of each box beam	h	17	in.
No of box beams		5	nos

Section Geometry

No of webs in beam		2	nos
Depth of top flange	h_f	5.5	in.
Depth of bottom flange	h_c	5.5	in.
Width of end web	b_w	5.5	in.
Width of chamfer	w_h	3.0	in.

Section properties		**Precast beam**	
Area	A	590.30	in^2
Moment of inertia	I	18819.00	in^4
Distance from centroid to extreme bottom fiber	Y_b	8.44	in.
Distance from centroid to extreme top fiber	Y_t	8.56	in.
Section modulus for extreme bottom fiber	S_b	2230.00	in^3
Section modulus for extreme top fiber	S_t	2198.00	in^3

Layers of Prestressing Strands Provided: 1

Layer *	Number	Position from extreme tensile face		Remark
Layer 1	14	2	in.	Bottom flange
Layer 2	0	0	in.	Top flange
Layer 3	0	0	in.	Top flange
Layer 4	0	0	in.	Top flange
Debonded strands	0	0	in.	Top flange

*Note: Input layers from bottom to top of the beam

Longitudinal Reinforcement Bars

Layer	Bar no.	Area	Number	Position from extreme tensile face		Remark
Layer 1		0.00			in.	Bottom flange

Shear Reinforcement

Zone	Distance to end of region from the support (ft)	Bar no.	Spacing (in.)	Area (in^2)
Region 1	4.50	#4	3	0.40
Region 2	9.50	#4	6	0.40

4. Load Rating

Load Rating Settings

Adopted beam for load rating*	Exterior beam
Riding surface condition*	Smooth surface

Vehicle types	Dynamic allowance (IM)	Use strength limit state	Use service limit state
A. Design Vehicle	33%	YES	YES
B. Ohio Legal Vehicles	33%	YES	NO
C. Specialized Hauling Vehicles	33%	YES	NO
D. Emergency Vehicles	33%	YES	NO
E. AASHTO Legal Vehicles	33%	YES	NO
F. Permit Vehicles	20%	YES	NO
G. Custom Vehicle	33%	YES	NO

Input for Service Limit State

Average annual humidity	70%
Prestressing strands condition	Severe corrosion
Concrete age at transfer	1 days
Concrete age at deck placement	28 days
Final concrete age	18250 days

Live Load Factors for Legal Vehicles

ADTT	8000
Live load factor for legal vehicles	1.45

Live Load Factors for Emergency Vehicles

EV2*	1.45
EV3*	1.35

Permit Load Condition

Permit type	Routine or Annual
Frequency	Unlimited crossings
Loading condition	Mixed with traffic
DF using	Two or more lanes

Live Load Factor for Permit Vehicles

Vehicle type	Live load factor
PL60T	1.40
PL65T	1.35

Add custom vehicle*	YES
No of axles	12

Axle No	Load (kips)	Distance from first axle (ft)
a	16.00	0.00
b	19.00	16.25
c	19.00	20.75
d	19.00	25.25
e	19.00	41.00
f	19.00	46.00
g	19.00	51.00
h	19.00	91.17
i	19.00	96.17
j	19.00	101.17
k	19.00	117.42
l	19.00	122.58

Custom Vehicle Load Condition

Permit type	Special or Limited crossing
Frequency	Multiple trips(<100 crossings)
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Custom Vehicle

Vehicle type	Live load factor
Custom vehicle	1.40

LOAD RATING RESULTS

Load Rating Results

Ohio Legal Vehicles		
Loading Type	GVW	Rating Factor
	Tons	
2F1	15	4.213
3F1	23	2.990
5C1	40	3.257

Specialized Hauling Vehicles		
SU4	27	2.723
SU5	31	2.573
SU6	34.5	2.432
SU7	38.75	2.333

Emergency Vehicles		
EV2	28.75	2.533
EV3	43	1.866

AASHTO Legal Vehicles		
Type3	25	3.103
Type3S2	36	3.520
Type3_3	40	3.755

Permit Vehicles		
PL60T	60	2.573
PL65T	65	2.468

Custom Vehicle		
Custom Vehicle 1	113	2.840

Design Vehicles		
Loading Type	Rating Factor	
	Inventory	Operating
HL93	1.703	2.207

EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample bridge 2		Load rated by	SD	Date	5/13/2025
Construction year	2018		Checked by	YM	Date	5/13/2025

1. Bridge Information

Total span*	51.00	ft
Total width	32.00	ft

Single lane width	12.00	ft
End offset	6.00	in.
Width of bearing	8.00	in.
Barrier type	Steel guard rail	
Width of barrier	0.00	ft each side

Design span	50.00	ft
Road way width	32.00	ft

Composite /Non composite*	Non composite	
Thickness of deck slab*	0	in.

Skew/Non skew*	Non skew	
Skew angle*	0	Degrees

Surfacing material	Asphalt surface	
Thickness	3.375	in.

Total number of diaphragm*	3	nos

Diaphragm number	Position from left support		Thickness	
1	0.00	ft	18.00	in.
2	25.00	ft	18.00	in.
3	50.00	ft	18.00	in.

Bridge appraisal rating	9
Condition factor	1.00

Additional beam weight	2%
Additional barrier weight	2%

2. Material Properties

a. Concrete

Required concrete compressive strength at transfer*	f'_{ci}	5.00	ksi
Specified concrete compressive strength for use in design*	f'_c	7.00	ksi
Deck concrete compressive strength *	f'_{c_deck}	4.50	ksi
Concrete unit weight*	w_c	0.15	kcf

Correction factor for source of concrete*	K_1	1	
Modulus of elasticity of concrete for precast beam at transfer	E_{ci}	4286.83	ksi
Modulus of elasticity of concrete for precast beam at service load	E_{c_beam}	5072.24	ksi
Modulus of elasticity of concrete for deck slab	E_{c_slab}	4066.84	ksi

b. Reinforcing Bars

Yield Strength*	f_y	60.00	ksi
Modulus of elasticity*	E_s	29000	ksi

c. Prestressing Strands

Type*	Seven-wire strand	Low-relaxation strand

Diameter	D_p	1/2	in.
Area*	A_p	0.167	in^2
Tensile strength*	f_{pu}	270	ksi
Modulus of elasticity*	E_p	28500	ksi
Yield strength	f_{py}	243	ksi
	K	0.28	

d. Surfacing Material

Type	Asphalt surface	
Unit weight	0.145	kcf

e. Barrier

Type	Steel guard rail	
Unit weight	0.032	kips/ft/side

3. Box Beam Section Properties

Box beam section used	B21-48		
Width of each box beam	b	48	in.
Height of each box beam	h	21	in.
No of box beams		8	nos

Section Geometry

No of webs in beam		2	nos
Depth of top flange	h_f	5.5	in.
Depth of bottom flange	h_c	5.5	in.
Width of end web	b_w	5.5	in.
Width of chamfer	w_h	3.0	in.

Section properties		Precast beam	
Area	A	647.80	in^2
Moment of inertia	I	33884.00	in^4
Distance from centroid to extreme bottom fiber	Y_b	10.42	in.
Distance from centroid to extreme top fiber	Y_t	10.58	in.
Section modulus for extreme bottom fiber	S_b	3253.00	in^3
Section modulus for extreme top fiber	S_t	3202.00	in^3

Layers of Prestressing Strands Provided: 2

Layer *	Number	Position from extreme tensile face		Remark
Layer 1	18	2	in.	Bottom flange
Layer 2	2	4	in.	Bottom flange
Layer 3	0	0	in.	Top flange
Layer 4	0	0	in.	Top flange
Debonded strands	0	0	in.	Top flange

*Note: Input layers from bottom to top of the beam

Longitudinal Reinforcement Bars

Layer	Bar no.	Area	Number	Position from extreme tensile face		Remark
Layer 1	#5	0.31	2	2	in.	Bottom flange

Shear Reinforcement

Zone	Distance to end of region from the support (ft)	Bar no.	Spacing (in.)	Area (in^2)
Region 1	4.00	#4	6	0.40
Region 2	25.00	#4	6	0.40

4. Load Rating

Load Rating Settings

Adopted beam for load rating*	Exterior beam
Riding surface condition*	Minor depression

Vehicle types	Dynamic allowance (IM)	Use strength limit state	Use service limit state
A. Design Vehicle	33%	YES	YES
B. Ohio Legal Vehicles	33%	YES	NO
C. Specialized Hauling Vehicles	33%	YES	NO
D. Emergency Vehicles	33%	YES	NO
E. AASHTO Legal Vehicles	33%	YES	NO
F. Permit Vehicles	20%	YES	NO
G. Custom Vehicle	33%	YES	NO

Input for Service Limit State

Average annual humidity	70%
Prestressing strands condition	Low to moderate corrosion
Concrete age at transfer	1 days
Concrete age at deck placement	28 days
Final concrete age	18250 days

Live Load Factors for Legal Vehicles

ADTT	Unknown
Live load factor for legal vehicles	1.45

Live Load Factors for Emergency Vehicles

EV2*	1.45
EV3*	1.45

Permit Load Condition

Permit type	Routine or Annual
Frequency	Unlimited crossings
Loading condition	Mixed with traffic
DF using	Two or more lanes

Live Load Factor for Permit Vehicles

Vehicle type	Live load factor
PL60T	1.40
PL65T	1.35

Add custom vehicle*	YES
No of axles	12

Axle No	Load (kips)	Distance from first axle (ft)
a	16.00	0.00
b	19.00	16.25
c	19.00	20.75
d	19.00	25.25
e	19.00	41.00
f	19.00	46.00
g	19.00	51.00
h	19.00	91.17
i	19.00	96.17
j	19.00	101.17
k	19.00	117.42
l	19.00	122.58

Custom Vehicle Load Condition

Permit type	Special or Limited crossing
Frequency	Multiple trips(<100 crossings)
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Custom Vehicle

Vehicle type	Live load factor
Custom vehicle	1.40

LOAD RATING RESULTS

Load Rating Results

Ohio Legal Vehicles		
Loading Type	GVW	Rating Factor
	Tons	
2F1	15	4.430
3F1	23	3.001
5C1	40	3.077

Specialized Hauling Vehicles		
SU4	27	2.665
SU5	31	2.456
SU6	34.5	2.213
SU7	38.75	2.053

Emergency Vehicles		
EV2	28.75	2.644
EV3	43	1.730

AASHTO Legal Vehicles		
Type3	25	3.054
Type3S2	36	3.301
Type3_3	40	3.638

Permit Vehicles		
PL60T	60	2.596
PL65T	65	2.369

Custom Vehicle		
Custom Vehicle 1	113	3.088

Design Vehicles		
Loading Type	Rating Factor	
	Inventory	Operating
HL93	1.546	2.005

EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample Bridge 3	Load rated by	SD	Date	5/13/2025
Construction year	1982	Checked by	YM	Date	5/13/2025

1. Bridge Information

Total span*	64.00	ft
Total width	28.00	ft

Single lane width	12.00	ft
End offset	12.00	in.
Width of bearing	5.00	in.
Barrier type	Steel guard rail	
Width of barrier	0.00	ft each side

Design span	62.00	ft
Road way width	28.00	ft

Composite /Non composite*	Non composite	
Thickness of deck slab*	0	in.

Skew/Non skew*	Non skew	
Skew angle*	0	Degrees

Surfacing material	Asphalt surface	
Thickness	3.33	in.

Total number of diaphragm*	4	nos

Diaphragm number	Position from left support		Thickness	
1	1.00	ft	36.00	in.
2	17.00	ft	36.00	in.
3	45.00	ft	36.00	in.
4	62.00	ft	36.00	in.

Bridge appraisal rating	5
Condition factor	0.95

Additional beam weight	3%
Additional barrier weight	3%

2. Material Properties

a. Concrete

Required concrete compressive strength at transfer*	f'_{ci}	4.00	ksi
Specified concrete compressive strength for use in design*	f'_c	5.50	ksi
Deck concrete compressive strength *	f'_{c_deck}	4.00	ksi
Concrete unit weight*	w_c	0.15	kcf

Correction factor for source of concrete*	K_1	1	
Modulus of elasticity of concrete for precast beam at transfer	E_{ci}	3834.25	ksi
Modulus of elasticity of concrete for precast beam at service load	E_{c_beam}	4496.06	ksi
Modulus of elasticity of concrete for deck slab	E_{c_slab}	3834.25	ksi

b. Reinforcing Bars

Yield Strength*	f_y	60.00	ksi
Modulus of elasticity*	E_s	29000	ksi

c. Prestressing Strands

Type*	Seven-wire strand	Stress-relieved strand

Diameter	D_p	1/2	in.
Area*	A_p	0.153	in^2
Tensile strength*	f_{pu}	270	ksi
Modulus of elasticity*	E_p	28500	ksi
Yield strength	f_{py}	229.5	ksi
	K	0.38	

d. Surfacing Material

Type	Asphalt surface	
Unit weight	0.145	kcf

e. Barrier

Type	Steel guard rail	
Unit weight	0.047	kips/ft/side

3. Box Beam Section Properties

Box beam section used	Custom		
Width of each box beam	b	48	in.
Height of each box beam	h	33	in.
No of box beams		7	nos

Section Geometry

No of webs in beam		2	nos
Depth of top flange	h_f	5.5	in.
Depth of bottom flange	h_c	5.0	in.
Width of end web	b_w	5.0	in.
Width of chamfer	w_h	3.0	in.

Section properties		Precast beam	
Area	A	733.50	in^2
Moment of inertia	I	108150.00	in^4
Distance from centroid to extreme bottom fiber	Y_b	16.63	in.
Distance from centroid to extreme top fiber	Y_t	16.37	in.
Section modulus for extreme bottom fiber	S_b	6503.31	in^3
Section modulus for extreme top fiber	S_t	6606.60	in^3

Layers of Prestressing Strands Provided: 1

Layer *	Number	Position from extreme tensile face		Remark
Layer 1	16	1.75	in.	Bottom flange
Layer 2	0	0	in.	Top flange
Layer 3	0	0	in.	Top flange
Layer 4	0	0	in.	Top flange
Debonded strands	0	0	in.	Top flange

*Note: Input layers from bottom to top of the beam

Longitudinal Reinforcement Bars

Layer	Bar no.	Area	Number	Position from extreme tensile face		Remark
Layer 1		0.00			in.	Bottom flange

Shear Reinforcement

Zone	Distance to end of region from the support (ft)	Bar no.	Spacing (in.)	Area (in^2)
Region 1	4.00	#4	6	0.40
Region 2	31.00	#4	6	0.40

4. Load Rating

Load Rating Settings

Adopted beam for load rating*	Exterior beam
Riding surface condition*	Minor depression

Vehicle types	Dynamic allowance (IM)	Use strength limit state	Use service limit state
A. Design Vehicle	33%	YES	YES
B. Ohio Legal Vehicles	33%	YES	NO
C. Specialized Hauling Vehicles	33%	YES	NO
D. Emergency Vehicles	33%	YES	NO
E. AASHTO Legal Vehicles	33%	YES	NO
F. Permit Vehicles	20%	YES	NO
G. Custom Vehicle	33%	YES	NO

Input for Service Limit State

Average annual humidity	70%
Prestressing strands condition	Low to moderate corrosion
Concrete age at transfer	1 days
Concrete age at deck placement	28 days
Final concrete age	18250 days

Live Load Factors for Legal Vehicles

ADTT	8156
Live load factor for legal vehicles	1.45

Live Load Factors for Emergency Vehicles

EV2*	1.30
EV3*	1.10

Permit Load Condition

Permit type	Routine or Annual
Frequency	Unlimited crossings
Loading condition	Mixed with traffic
DF using	Two or more lanes

Live Load Factor for Permit Vehicles

Vehicle type	Live load factor
PL60T	1.40
PL65T	1.35

Add custom vehicle*	YES
No of axles	12

Axle No	**Load (kips)**	**Distance from first axle (ft)**
a	16.00	0.00
b	19.00	16.25
c	19.00	20.75
d	19.00	25.25
e	19.00	41.00
f	19.00	46.00
g	19.00	51.00
h	19.00	91.17
i	19.00	96.17
j	19.00	101.17
k	19.00	117.42
l	19.00	122.58

Custom Vehicle Load Condition

Permit type	Special or Limited crossing
Frequency	Multiple trips(<100 crossings)
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Custom Vehicle

Vehicle type	**Live load factor**
Custom vehicle	1.40

LOAD RATING RESULTS

Load Rating Results

Loading Type	GVW	Rating Factor
	Tons	
Ohio Legal Vehicles		
2F1	15	3.214
3F1	23	2.157
5C1	40	2.199
Specialized Hauling Vehicles		
SU4	27	1.898
SU5	31	1.728
SU6	34.5	1.552
SU7	38.75	1.427
Emergency Vehicles		
EV2	28.75	2.083
EV3	43	1.612
AASHTO Legal Vehicles		
Type3	25	2.147
Type3S2	36	2.062
Type3_3	40	2.232
Permit Vehicles		
PL60T	60	1.887
PL65T	65	1.513
Custom Vehicle		
Custom Vehicle 1	113	1.978

Design Vehicles

Loading Type	Rating Factor	
	Inventory	Operating
HL93	1.036	1.343

EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample Bridge 4	Load rated by	SD	Date	5/13/2025
Construction year	2023	Checked by	YM	Date	5/13/2025

1. Bridge Information

Total span*	26.00	ft
Total width	33.00	ft

Single lane width	12.00	ft
End offset	6.00	in.
Width of bearing	5.00	in.
Barrier type	Steel guard rail	
Width of barrier	0.00	ft each side

Design span	25.00	ft
Road way width	33.00	ft

Composite /Non composite*	Composite	
Thickness of deck slab*	6	in.

Skew/Non skew*	Non skew	
Skew angle*	0	Degrees

Surfacing material	Asphalt surface	
Thickness	0	in.

Total number of diaphragm*	3	nos

Diaphragm number	Position from left support		Thickness	
1	1.38	ft	18.00	in.
2	15.00	ft	18.00	in.
3	23.62	ft	18.00	in.

Bridge appraisal rating	9
Condition factor	1.00

Additional beam weight	5%
Additional barrier weight	0%

2. Material Properties

a. Concrete

Required concrete compressive strength at transfer*	f'_{ci}	5.00	ksi
Specified concrete compressive strength for use in design*	f'_c	7.00	ksi
Deck concrete compressive strength *	f'_{c_deck}	4.50	ksi
Concrete unit weight*	w_c	0.15	kcf

Correction factor for source of concrete*	K_1	1	
Modulus of elasticity of concrete for precast beam at transfer	E_{ci}	4286.83	ksi
Modulus of elasticity of concrete for precast beam at service load	E_{c_beam}	5072.24	ksi
Modulus of elasticity of concrete for deck slab	E_{c_slab}	4066.84	ksi

b. Reinforcing Bars

Yield Strength*	f_y	60.00	ksi
Modulus of elasticity*	E_s	29000	ksi

c. Prestressing Strands

Type*	Seven-wire strand	Low-relaxation strand

Diameter	D_p	1/2	in.
Area*	A_p	0.167	in^2
Tensile strength*	f_{pu}	270	ksi
Modulus of elasticity*	E_p	28500	ksi
Yield strength	f_{py}	243	ksi
	K	0.28	

d. Surfacing Material

Type	Asphalt surface	
Unit weight	0	kcf

e. Barrier

Type	Steel guard rail	
Unit weight	0.080	kips/ft/side

3. Box Beam Section Properties

Box beam section used	CB17-36		
Width of each box beam	b	36	in.
Height of each box beam	h	17	in.
No of box beams		11	nos

Section Geometry

No of webs in beam		2	nos
Depth of top flange	h_f	5.5	in.
Depth of bottom flange	h_c	5.5	in.
Width of end web	b_w	5.5	in.
Width of chamfer	w_h	3.0	in.

Section properties		Precast beam		Composite Beam	
Area	A	458.30	in^2	631.49	in^2
Moment of inertia	I	14122.00	in^4	31496.01	in^2
Distance from centroid to extreme bottom fiber	Y_b	8.42	in.	11.60	in^2
Distance from centroid to extreme top fiber	Y_t	8.58	in.	11.40	in^2
Section modulus for extreme bottom fiber	S_b	1677.00	in^3	2716.15	in^2
Section modulus for extreme top fiber	S_t	1646.00	in^3	3444.56	in^2

Layers of Prestressing Strands Provided		1		
Layer *	Number	Position from extreme tensile face		Remark
Layer 1	8	2	in.	Bottom flange
Layer 2	0	0	in.	Top flange
Layer 3	0	0	in.	Top flange
Layer 4	0	0	in.	Top flange
Debonded strands	0	0	in.	Top flange

*Note: Input layers from bottom to top of the beam

Longitudinal Reinforcement Bars

Layer	Bar no.	Area	Number	Position from extreme tensile face		Remark
Layer 1		0.00			in.	Bottom flange

Shear Reinforcement

Zone	Distance to end of region from the support (ft)	Bar no.	Spacing (in.)	Area (in^2)
Region 1	1.50	#4	1.5	0.40
Region 2	4.00	#4	3	0.40

4. Load Rating

Load Rating Settings

Adopted beam for load rating*	Exterior beam
Riding surface condition*	Smooth surface

Vehicle types	Dynamic allowance (IM)	Use strength limit state	Use service limit state
A. Design Vehicle	33%	YES	YES
B. Ohio Legal Vehicles	33%	YES	NO
C. Specialized Hauling Vehicles	33%	YES	NO
D. Emergency Vehicles	33%	YES	NO
E. AASHTO Legal Vehicles	33%	YES	NO
F. Permit Vehicles	10%	YES	NO
G. Custom Vehicle	33%	YES	NO

Input for Service Limit State

Average annual humidity	70%
Prestressing strands condition	Low to moderate corrosion
Concrete age at transfer	1 days
Concrete age at deck placement	28 days
Final concrete age	18250 days

Live Load Factors for Legal Vehicles

ADTT	Unknown
Live load factor for legal vehicles	1.45

Live Load Factors for Emergency Vehicles

EV2*	1.35
EV3*	1.00

Permit Load Condition

Permit type	Routine or Annual
Frequency	Unlimited crossings
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Permit Vehicles

Vehicle type	Live load factor
PL60T	1.40
PL65T	1.40

Add custom vehicle*	YES
No of axles	12

Axle No	Load (kips)	Distance from first axle (ft)
a	16.00	0.00
b	19.00	16.25
c	19.00	20.75
d	19.00	25.25
e	19.00	41.00
f	19.00	46.00
g	19.00	51.00
h	19.00	91.17
i	19.00	96.17
j	19.00	101.17
k	19.00	117.42
l	19.00	122.58

Custom Vehicle Load Condition

Permit type	Special or Limited crossing
Frequency	Multiple trips(<100 crossings)
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Custom Vehicle

Vehicle type	Live load factor
Custom vehicle	1.40

LOAD RATING RESULTS

Load Rating Results

Ohio Legal Vehicles		
Loading Type	**GVW**	**Rating Factor**
	Tons	
2F1	15	5.832
3F1	23	4.223
5C1	40	4.486
Specialized Hauling Vehicles		
SU4	27	3.851
SU5	31	3.552
SU6	34.5	3.295
SU7	38.75	3.241
Emergency Vehicles		
EV2	28.75	4.026
EV3	43	3.627
AASHTO Legal Vehicles		
Type3	25	4.561
Type3S2	36	4.798
Type3_3	40	5.538
Permit Vehicles		
PL60T	60	4.463
PL65T	65	4.174
Custom Vehicle		
Custom Vehicle 1	113	3.764

Design Vehicles		
Loading Type	**Rating Factor**	
	Inventory	**Operating**
HL93	2.252	2.919

EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample Bridge 5	Load rated by	SD	Date	5/13/2025
Construction year	2021	Checked by	YM	Date	5/13/2025

1. Bridge Information

Total span*	46.00	ft
Total width	56.00	ft

Single lane width	12.00	ft
End offset	6.00	in.
Width of bearing	5.00	in.
Barrier type	Steel Guard rail	
Width of barrier	8.08	ft each side

Design span	45.00	ft
Road way width	39.84	ft

Composite /Non composite*	Composite	
Thickness of deck slab*	6	in.

Skew/Non skew*	Non skew	
Skew angle*	0	Degrees

Surfacing material	Asphalt surface	
Thickness	5	in.

Total number of diaphragm*	3	nos

Diaphragm number	Position from left support		Thickness	
1	1.88	ft	18.00	in.
2	22.50	ft	18.00	in.
3	43.13	ft	18.00	in.

Bridge appraisal rating	9
Condition factor	1.00

Additional beam weight	0%
Additional barrier weight	0%

2. Material Properties

a. Concrete

Required concrete compressive strength at transfer*	f'_{ci}	5.00	ksi
Specified concrete compressive strength for use in design*	f'_{c}	7.00	ksi
Deck concrete compressive strength *	f'_{c_deck}	4.50	ksi
Concrete unit weight*	w_c	0.15	kcf

Correction factor for source of concrete*	K_1	1	
Modulus of elasticity of concrete for precast beam at transfer	E_{ci}	4286.83	ksi
Modulus of elasticity of concrete for precast beam at service load	E_{c_beam}	5072.24	ksi
Modulus of elasticity of concrete for deck slab	E_{c_slab}	4066.84	ksi

b. Reinforcing Bars

Yield Strength*	f_y	60.00	ksi
Modulus of elasticity*	E_s	29000	ksi

c. Prestressing Strands

Type*	Seven-wire strand	Low-relaxation strand

Diameter	D_p	1/2	in.
Area*	A_p	0.167	in^2
Tensile strength*	f_{pu}	270	ksi
Modulus of elasticity*	E_p	28500	ksi
Yield strength	f_{py}	243	ksi
	K	0.28	

d. Surfacing Material

Type	Asphalt surface	
Unit weight	0.145	kcf

e. Barrier

Type	Steel Guard rail	
Unit weight	1.170	kips/ft/side

3. Box Beam Section Properties

Box beam section used	**CB17-48**		
Width of each box beam	b	48	in.
Height of each box beam	h	17	in.
No of box beams		14	nos

Section Geometry

No of webs in beam		2	nos
Depth of top flange	h_f	5.5	in.
Depth of bottom flange	h_c	5.5	in.
Width of end web	b_w	5.5	in.
Width of chamfer	w_h	3.0	in.

Section properties		**Precast beam**		**Composite Beam**	
Area	A	590.30	in^2	821.21	in^2
Moment of inertia	I	18819.00	in^4	41692.79	in^2
Distance from centroid to extreme bottom fiber	Y_b	8.44	in.	11.69	in^2
Distance from centroid to extreme top fiber	Y_t	8.56	in.	11.31	in^2
Section modulus for extreme bottom fiber	S_b	2230.00	in^3	3566.38	in^2
Section modulus for extreme top fiber	S_t	2198.00	in^3	4597.91	in^2

Layers of Prestressing Strands Provided		1		
Layer *	**Number**	**Position from extreme tensile face**		**Remark**
Layer 1	16	2	in.	Bottom flange
Layer 2	0	0	in.	Top flange
Layer 3	0	0	in.	Top flange
Layer 4	0	0	in.	Top flange
Debonded strands	0	0	in.	Top flange

*Note: Input layers from bottom to top of the beam

Longitudinal Reinforcement Bars

Layer	**Bar no.**	**Area**	**Number**	**Position from extreme tensile face**		**Remark**
Layer 1	#5	0.31	2	2	in.	Bottom flange

Shear Reinforcement

Zone	**Distance to end of region from the support (ft)**	**Bar no.**	**Spacing (in.)**	**Area (in^2)**
Region 1	4.00	#4	6	0.40
Region 2	22.50	#4	6	0.40

4. Load Rating

Load Rating Settings

Adopted beam for load rating*	Exterior beam
Riding surface condition*	Smooth surface

Vehicle types	Dynamic allowance (IM)	Use strength limit state	Use service limit state
A. Design Vehicle	33%	YES	YES
B. Ohio Legal Vehicles	33%	YES	NO
C. Specialized Hauling Vehicles	33%	YES	NO
D. Emergency Vehicles	33%	YES	NO
E. AASHTO Legal Vehicles	33%	YES	NO
F. Permit Vehicles	10%	YES	NO
G. Custom Vehicle	33%	YES	NO

Input for Service Limit State

Average annual humidity	70%
Prestressing strands condition	Low to moderate corrosion
Concrete age at transfer	1 days
Concrete age at deck placement	28 days
Final concrete age	18250 days

Live Load Factors for Legal Vehicles

ADTT	5600
Live load factor for legal vehicles	1.45

Live Load Factors for Emergency Vehicles

EV2*	1.45
EV3*	1.45

Permit Load Condition

Permit type	Routine or Annual
Frequency	Unlimited crossings
Loading condition	Mixed with traffic
DF using	Two or more lanes

Live Load Factor for Permit Vehicles

Vehicle type	Live load factor
PL60T	1.40
PL65T	1.35

Add custom vehicle*	YES
No of axles	12

Axle No	Load (kips)	Distance from first axle (ft)
a	16.00	0.00
b	19.00	16.25
c	19.00	20.75
d	19.00	25.25
e	19.00	41.00
f	19.00	46.00
g	19.00	51.00
h	19.00	91.17
i	19.00	96.17
j	19.00	101.17
k	19.00	117.42
l	19.00	122.58

Custom Vehicle Load Condition

Permit type	Special or Limited crossing
Frequency	Multiple trips(<100 crossings)
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Custom Vehicle

Vehicle type	Live load factor
Custom vehicle	1.40

LOAD RATING RESULTS

Load Rating Results

Ohio Legal Vehicles		
Loading Type	**GVW**	**Rating Factor**
	Tons	
2F1	15	4.243
3F1	23	2.888
5C1	40	2.971
Specialized Hauling Vehicles		
SU4	27	2.579
SU5	31	2.397
SU6	34.5	2.163
SU7	38.75	2.017
Emergency Vehicles		
EV2	28.75	2.582
EV3	43	1.682
AASHTO Legal Vehicles		
Type3	25	2.982
Type3S2	36	3.259
Type3_3	40	3.579
Permit Vehicles		
PL60T	60	2.707
PL65T	65	2.490
Custom Vehicle		
Custom Vehicle 1	113	3.083

Design Vehicles		
Loading Type	**Rating Factor**	
	Inventory	**Operating**
HL93	1.495	2.007

EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample Bridge 6		Load rated by	SD	Date	5/13/2025
Construction year	2018		Checked by	YM	Date	5/13/2025

1. Bridge Information

Total span*	57.00	ft
Total width	28.00	ft

Single lane width	14.00	ft
End offset	12.00	in.
Width of bearing	5.00	in.
Barrier type	Steel guard rail	
Width of barrier	0.00	ft each side

Design span	55.00	ft
Road way width	28.00	ft

Composite /Non composite*	Composite	
Thickness of deck slab*	6	in.

Skew/Non skew*	Non skew	
Skew angle*	0	Degrees

Surfacing material	None	
Thickness	0	in.

Total number of diaphragm*	5	nos

Diaphragm number	Position from left support		Thickness	
1	2.50	ft	36.00	in.
2	15.50	ft	36.00	in.
3	28.50	ft	36.00	in.
4	41.50	ft	36.00	in.
5	54.50	ft	36.00	in.

Bridge appraisal rating	5
Condition factor	0.95

Additional beam weight	2%
Additional barrier weight	0%

2. Material Properties

a. Concrete

Required concrete compressive strength at transfer*	f'_{ci}	5.50	ksi
Specified concrete compressive strength for use in design*	f'_{c}	7.00	ksi
Deck concrete compressive strength *	f'_{c_deck}	4.50	ksi
Concrete unit weight*	w_c	0.15	kcf

Correction factor for source of concrete*	K_1	1	
Modulus of elasticity of concrete for precast beam at transfer	E_{ci}	4496.06	ksi
Modulus of elasticity of concrete for precast beam at service load	E_{c_beam}	5072.24	ksi
Modulus of elasticity of concrete for deck slab	E_{c_slab}	4066.84	ksi

b. Reinforcing Bars

Yield Strength*	f_y	60.00	ksi
Modulus of elasticity*	E_s	29000	ksi

c. Prestressing Strands

Type*	Seven-wire strand	Low-relaxation strand

Diameter	D_p	1/2	in.
Area*	A_p	0.153	in^2
Tensile strength*	f_{pu}	270	ksi
Modulus of elasticity*	E_p	28500	ksi
Yield strength	f_{py}	243	ksi
	K	0.28	

d. Surfacing Material

Type	None	
Unit weight	0	kcf

e. Barrier

Type	Steel guard rail	
Unit weight	0.080	kips/ft/side

3. Box Beam Section Properties

Box beam section used	**CB17-48**		
Width of each box beam	b	48	in.
Height of each box beam	h	17	in.
No of box beams		7	nos

Section Geometry

No of webs in beam		2	nos
Depth of top flange	h_f	5.5	in.
Depth of bottom flange	h_c	5.5	in.
Width of end web	b_w	5.5	in.
Width of chamfer	w_h	3.0	in.

Section properties		Precast beam		Composite Beam	
Area	A	590.30	in^2	821.21	in^2
Moment of inertia	I	18819.00	in^4	41692.79	in^2
Distance from centroid to extreme bottom fiber	Y_b	8.44	in.	11.69	in^2
Distance from centroid to extreme top fiber	Y_t	8.56	in.	11.31	in^2
Section modulus for extreme bottom fiber	S_b	2230.00	in^3	3566.38	in^2
Section modulus for extreme top fiber	S_t	2198.00	in^3	4597.91	in^2

Layers of Prestressing Strands Provided		2		
Layer *	**Number**	**Position from extreme tensile face**		**Remark**
Layer 1	16	2	in.	Bottom flange
Layer 2	12	4	in.	Bottom flange
Layer 3	0	0	in.	Top flange
Layer 4	0	0	in.	Top flange
Debonded strands	0	0	in.	Top flange

*Note: Input layers from bottom to top of the beam

Longitudinal Reinforcement Bars

Layer	Bar no.	Area	Number	Position from extreme tensile face		Remark
Layer 1	#5	0.31	2	2	in.	Bottom flange

Shear Reinforcement

Zone	Distance to end of region from the support (ft)	Bar no.	Spacing (in.)	Area (in^2)
Region 1	4.00	#4	6	0.40
Region 2	27.50	#4	6	0.40

4. Load Rating

Load Rating Settings

Adopted beam for load rating*	Exterior beam
Riding surface condition*	Minor depression

Vehicle types	Dynamic allowance (IM)	Use strength limit state	Use service limit state
A. Design Vehicle	33%	YES	YES
B. Ohio Legal Vehicles	33%	YES	NO
C. Specialized Hauling Vehicles	33%	YES	NO
D. Emergency Vehicles	33%	YES	NO
E. AASHTO Legal Vehicles	33%	YES	NO
F. Permit Vehicles	20%	YES	NO
G. Custom Vehicle	33%	YES	NO

Input for Service Limit State

Average annual humidity	70%
Prestressing strands condition	Severe corrosion
Concrete age at transfer	1 days
Concrete age at deck placement	28 days
Final concrete age	18250 days

Live Load Factors for Legal Vehicles

ADTT	1000
Live load factor for legal vehicles	1.30

Live Load Factors for Emergency Vehicles

EV2*	1.30
EV3*	1.20

Permit Load Condition

Permit type	Routine or Annual
Frequency	Unlimited crossings
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Permit Vehicles

Vehicle type	Live load factor
PL60T	1.40
PL65T	1.40

Add custom vehicle*	YES
No of axles	12

Axle No	Load (kips)	Distance from first axle (ft)
a	16.00	0.00
b	19.00	16.25
c	19.00	20.75
d	19.00	25.25
e	19.00	41.00
f	19.00	46.00
g	19.00	51.00
h	19.00	91.17
i	19.00	96.17
j	19.00	101.17
k	19.00	117.42
l	19.00	122.58

Custom Vehicle Load Condition

Permit type	Special or Limited crossing
Frequency	Multiple trips(<100 crossings)
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Custom Vehicle

Vehicle type	Live load factor
Custom vehicle	1.40

LOAD RATING RESULTS

Load Rating Results

Loading Type	GVW	Rating Factor
Ohio Legal Vehicles		
	Tons	
2F1	15	4.794
3F1	23	3.234
5C1	40	3.306
Specialized Hauling Vehicles		
SU4	27	2.858
SU5	31	2.619
SU6	34.5	2.356
SU7	38.75	2.176
Emergency Vehicles		
EV2	28.75	2.824
EV3	43	2.002
AASHTO Legal Vehicles		
Type3	25	3.255
Type3S2	36	3.319
Type3_3	40	3.634
Permit Vehicles		
PL60T	60	3.821
PL65T	65	2.807
Custom Vehicle		
Custom Vehicle 1	113	2.883

Design Vehicles		
Loading Type	Rating Factor	
	Inventory	Operating
HL93	1.183	1.876

EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample Bridge 7	Load rated by	SD	Date	5/13/2025
Construction year	2021	Checked by	YM	Date	5/13/2025

1. Bridge Information

Total span*	81.00	ft
Total width	28.00	ft

Single lane width	15.00	ft
End offset	6.00	in.
Width of bearing	5.00	in.
Barrier type	Steel guard rail	
Width of barrier	0.00	ft each side

Design span	80.00	ft
Road way width	28.00	ft

Composite /Non composite*	Composite	
Thickness of deck slab*	6	in.

Skew/Non skew*	Non skew	
Skew angle*	0	Degrees

Surfacing material	Asphalt surface	
Thickness	0	in.

Total number of diaphragm*	5	nos

Diaphragm number	Position from left support		Thickness	
1	0.00	ft	18.00	in.
2	20.00	ft	18.00	in.
3	40.00	ft	18.00	in.
4	60.00	ft	18.00	in.
5	80.00	ft	18.00	in.

Bridge appraisal rating	9
Condition factor	1.00

Additional beam weight	3%
Additional barrier weight	0%

2. Material Properties

a. Concrete

Required concrete compressive strength at transfer*	f'_{ci}	5.00	ksi
Specified concrete compressive strength for use in design*	f'_c	7.00	ksi
Deck concrete compressive strength *	f'_{c_deck}	4.50	ksi
Concrete unit weight*	w_c	0.15	kcf

Correction factor for source of concrete*	K_1	1	
Modulus of elasticity of concrete for precast beam at transfer	E_{ci}	4286.83	ksi
Modulus of elasticity of concrete for precast beam at service load	E_{c_beam}	5072.24	ksi
Modulus of elasticity of concrete for deck slab	E_{c_slab}	4066.84	ksi

b. Reinforcing Bars

Yield Strength*	f_y	60.00	ksi
Modulus of elasticity*	E_s	29000	ksi

c. Prestressing Strands

Type*	Seven-wire strand	Low-relaxation strand

Diameter	D_p	1/2	in.
Area*	A_p	0.167	in^2
Tensile strength*	f_{pu}	270	ksi
Modulus of elasticity*	E_p	28500	ksi
Yield strength	f_{py}	243	ksi
	K	0.28	

d. Surfacing Material

Type	Asphalt surface	
Unit weight	0.145	kcf

e. Barrier

Type	Steel guard rail	
Unit weight	0.080	kips/ft/side

3. Box Beam Section Properties

Box beam section used	**CB27-48**		
Width of each box beam	b	48	in.
Height of each box beam	h	27	in.
No of box beams		7	nos

Section Geometry

No of webs in beam		2	nos
Depth of top flange	h_f	5.5	in.
Depth of bottom flange	h_c	5.5	in.
Width of end web	b_w	5.5	in.
Width of chamfer	w_h	3.0	in.

Section properties		Precast beam		Composite Beam	
Area	A	713.80	in^2	944.71	in^2
Moment of inertia	I	66222.00	in^4	115050.22	in^2
Distance from centroid to extreme bottom fiber	Y_b	13.39	in.	17.45	in^2
Distance from centroid to extreme top fiber	Y_t	13.61	in.	15.55	in^2
Section modulus for extreme bottom fiber	S_b	4945.00	in^3	6593.16	in^2
Section modulus for extreme top fiber	S_t	4866.00	in^3	9227.80	in^2

Layers of Prestressing Strands Provided		2		
Layer *	**Number**	**Position from extreme tensile face**		**Remark**
Layer 1	16	2	in.	Bottom flange
Layer 2	18	4	in.	Bottom flange
Layer 3	0	0	in.	Top flange
Layer 4	0	0	in.	Top flange
Debonded strands	0	0	in.	Top flange

*Note: Input layers from bottom to top of the beam

Longitudinal Reinforcement Bars

Layer	Bar no.	Area	Number	Position from extreme tensile face		Remark
Layer 1	#5	0.31	2	2	in.	Bottom flange

Shear Reinforcement

Zone	Distance to end of region from the support (ft)	Bar no.	Spacing (in.)	Area (in^2)
Region 1	4.00	#4	6	0.40
Region 2	40.00	#4	6	0.40

4. Load Rating

Load Rating Settings

Adopted beam for load rating*	Exterior beam
Riding surface condition*	Smooth surface

Vehicle types	Dynamic allowance (IM)	Use strength limit state	Use service limit state
A. Design Vehicle	33%	YES	YES
B. Ohio Legal Vehicles	33%	YES	NO
C. Specialized Hauling Vehicles	33%	YES	NO
D. Emergency Vehicles	33%	YES	NO
E. AASHTO Legal Vehicles	33%	YES	NO
F. Permit Vehicles	10%	YES	NO
G. Custom Vehicle	33%	YES	NO

Input for Service Limit State

Average annual humidity	70%
Prestressing strands condition	Severe corrosion
Concrete age at transfer	1 days
Concrete age at deck placement	28 days
Final concrete age	18250 days

Live Load Factors for Legal Vehicles

ADTT	Unknown
Live load factor for legal vehicles	1.45

Live Load Factors for Emergency Vehicles

EV2*	1.10
EV3*	1.10

Permit Load Condition

Permit type	Routine or Annual
Frequency	Unlimited crossings
Loading condition	Mixed with traffic
DF using	Two or more lanes

Live Load Factor for Permit Vehicles

Vehicle type	Live load factor
PL60T	1.40
PL65T	1.35

Add custom vehicle*	YES
No of axles	12

Axle No	**Load (kips)**	**Distance from first axle (ft)**
a	16.00	0.00
b	19.00	16.25
c	19.00	20.75
d	19.00	25.25
e	19.00	41.00
f	19.00	46.00
g	19.00	51.00
h	19.00	91.17
i	19.00	96.17
j	19.00	101.17
k	19.00	117.42
l	19.00	122.58

Custom Vehicle Load Condition

Permit type	Special or Limited crossing
Frequency	Multiple trips(<100 crossings)
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Custom Vehicle

Vehicle type	**Live load factor**
Custom vehicle	1.40

LOAD RATING RESULTS

Load Rating Results

Ohio Legal Vehicles		
Loading Type	GVW	Rating Factor
	Tons	
2F1	15	5.994
3F1	23	3.993
5C1	40	3.557
Specialized Hauling Vehicles		
SU4	27	3.486
SU5	31	3.138
SU6	34.5	2.812
SU7	38.75	2.568
Emergency Vehicles		
EV2	28.75	4.469
EV3	43	2.940
AASHTO Legal Vehicles		
Type3	25	3.896
Type3S2	36	3.405
Type3_3	40	3.501
Permit Vehicles		
PL60T	60	3.759
PL65T	65	2.630
Custom Vehicle		
Custom Vehicle 1	113	3.426

Design Vehicles		
Loading Type	Rating Factor	
	Inventory	Operating
HL93	1.395	2.293

C2: Skewed Bridges

EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample Bridge 8	Load rated by	SD	Date	5/13/2025
Construction year	2018	Checked by	YM	Date	5/13/2025

1. Bridge Information

Total span*	43.00	ft
Total width	32.00	ft

Single lane width	12.00	ft
End offset	6.00	in.
Width of bearing	5.00	in.
Barrier type	Steel Guard rail	
Width of barrier	0.00	ft each side

Design span	42.00	ft
Road way width	32.00	ft

Composite /Non composite*	Non composite	
Thickness of deck slab*	0	in.

Skew/Non skew*	Skew	
Skew angle*	28	Degrees

Surfacing material	Asphalt surface	
Thickness	3.5	in.

Total number of diaphragm*	3	nos

Diaphragm number	Position from left support		Thickness	
1	4.13	ft	12.00	in.
2	21.56	ft	12.00	in.
3	37.88	ft	12.00	in.

Bridge appraisal rating	9
Condition factor	1.00

Additional beam weight	2%
Additional barrier weight	0%

2. Material Properties

a. Concrete

Required concrete compressive strength at transfer*	f'_{ci}	5.00	ksi
Specified concrete compressive strength for use in design*	f'_{c}	7.00	ksi
Deck concrete compressive strength *	f'_{c_deck}	4.00	ksi
Concrete unit weight*	w_c	0.15	kcf

Correction factor for source of concrete*	K_1	1	
Modulus of elasticity of concrete for precast beam at transfer	E_{ci}	4286.83	ksi
Modulus of elasticity of concrete for precast beam at service load	E_{c_beam}	5072.24	ksi
Modulus of elasticity of concrete for deck slab	E_{c_slab}	3834.25	ksi

b. Reinforcing Bars

Yield Strength*	f_y	60.00	ksi
Modulus of elasticity*	E_s	29000	ksi

c. Prestressing Strands

Type*	Seven-wire strand	Low-relaxation strand

Diameter	D_p	1/2	in.
Area*	A_p	0.167	in^2
Tensile strength*	f_{pu}	270	ksi
Modulus of elasticity*	E_p	28500	ksi
Yield strength	f_{py}	243	ksi
	K	0.28	

d. Surfacing Material

Type	Asphalt surface	
Unit weight	0.145	kcf

e. Barrier

Type	Steel Guard rail	
Unit weight	0.080	kips/ft/side

3. Box Beam Section Properties

Box beam section used	**B21-48**		
Width of each box beam	b	48	in.
Height of each box beam	h	21	in.
No of box beams		8	nos

Section Geometry

No of webs in beam		2	nos
Depth of top flange	h_f	5.5	in.
Depth of bottom flange	h_c	5.5	in.
Width of end web	b_w	5.5	in.
Width of chamfer	w_h	3.0	in.

Section properties		Precast beam	
Area	A	647.80	in^2
Moment of inertia	I	33884.00	in^4
Distance from centroid to extreme bottom fiber	Y_b	10.42	in.
Distance from centroid to extreme top fiber	Y_t	10.58	in.
Section modulus for extreme bottom fiber	S_b	3253.00	in^3
Section modulus for extreme top fiber	S_t	3202.00	in^3

Layers of Prestressing Strands Provided		1		
Layer *	**Number**	**Position from extreme tensile face**		**Remark**
Layer 1	14	2	in.	Bottom flange
Layer 2	0	0	in.	Top flange
Layer 3	0	0	in.	Top flange
Layer 4	0	0	in.	Top flange
Debonded strands	0	0	in.	Top flange

*Note: Input layers from bottom to top of the beam

Longitudinal Reinforcement Bars

Layer	Bar no.	Area	Number	Position from extreme tensile face		Remark
Layer 1	#5	0.31	2	2	in.	Bottom flange

Shear Reinforcement

Zone	Distance to end of region from the support (ft)	Bar no.	Spacing (in.)	Area (in^2)
Region 1	4.00	#4	3	0.40
Region 2	21.00	#4	6	0.40

4. Load Rating

Load Rating Settings

Adopted beam for load rating*	Exterior beam
Riding surface condition*	Minor depression

Vehicle types	Dynamic allowance (IM)	Use strength limit state	Use service limit state
A. Design Vehicle	33%	YES	YES
B. Ohio Legal Vehicles	33%	YES	NO
C. Specialized Hauling Vehicles	33%	YES	NO
D. Emergency Vehicles	33%	YES	NO
E. AASHTO Legal Vehicles	33%	YES	NO
F. Permit Vehicles	20%	YES	NO
G. Custom Vehicle	33%	YES	NO

Input for Service Limit State

Average annual humidity	70%
Prestressing strands condition	Low to moderate corrosion
Concrete age at transfer	1 days
Concrete age at deck placement	28 days
Final concrete age	18250 days

Live Load Factors for Legal Vehicles

ADTT	Unknown
Live load factor for legal vehicles	1.45

Live Load Factors for Emergency Vehicles

EV2*	1.45
EV3*	1.10

Permit Load Condition

Permit type	Routine or Annual
Frequency	Unlimited crossings
Loading condition	Mixed with traffic
DF using	Two or more lanes

Live Load Factor for Permit Vehicles

Vehicle type	Live load factor
PL60T	1.40
PL65T	1.35

Add custom vehicle*	YES
No of axles	12

Axle No	Load (kips)	Distance from first axle (ft)
a	16.00	0.00
b	19.00	16.25
c	19.00	20.75
d	19.00	25.25
e	19.00	41.00
f	19.00	46.00
g	19.00	51.00
h	19.00	91.17
i	19.00	96.17
j	19.00	101.17
k	19.00	117.42
l	19.00	122.58

Custom Vehicle Load Condition

Permit type	Special or Limited crossing
Frequency	Multiple trips(<100 crossings)
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Custom Vehicle

Vehicle type	Live load factor
Custom vehicle	1.40

LOAD RATING RESULTS

Load Rating Results

Ohio Legal Vehicles		
Loading Type	**GVW**	**Rating Factor**
	Tons	
2F1	15	4.359
3F1	23	2.982
5C1	40	3.075

Specialized Hauling Vehicles		
SU4	27	2.673
SU5	31	2.496
SU6	34.5	2.258
SU7	38.75	2.116

Emergency Vehicles		
EV2	28.75	2.633
EV3	43	2.306

AASHTO Legal Vehicles		
Type3	25	3.108
Type3S2	36	3.367
Type3_3	40	3.607

Permit Vehicles		
PL60T	60	2.551
PL65T	65	2.358

Custom Vehicle		
Custom Vehicle 1	113	3.306

Design Vehicles		
Loading Type	**Rating Factor**	
	Inventory	**Operating**
HL93	1.639	2.124

EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample bridge 9	Load rated by	SD	Date	5/13/2025
Construction year	1984	Checked by	YM	Date	5/13/2025

1. Bridge Information

Total span*	66.00	ft
Total width	28.00	ft

Single lane width	14.00	ft
End offset	6.00	in.
Width of bearing	5.00	in.
Barrier type	Steel guard rail	
Width of barrier	0.00	ft each side

Design span	65.00	ft
Road way width	28.00	ft

Composite /Non composite*	Non composite	
Thickness of deck slab*	0	in.

Skew/Non skew*	Skew	
Skew angle*	5	Degrees

Surfacing material	Asphalt surface	
Thickness	7	in.

Total number of diaphragm*	4	nos

Diaphragm number	Position from left support		Thickness	
1	0.00	ft	21.00	in.
2	22.00	ft	21.00	in.
3	43.00	ft	21.00	in.
4	65.00	ft	21.00	in.

Bridge appraisal rating	6
Condition factor	1.00

Additional beam weight	3%
Additional barrier weight	0%

2. Material Properties

a. Concrete

Required concrete compressive strength at transfer*	f'_{ci}	4.00	ksi
Specified concrete compressive strength for use in design*	f'_c	5.50	ksi
Deck concrete compressive strength *	f'_{c_deck}	4.00	ksi
Concrete unit weight*	w_c	0.15	kcf

Correction factor for source of concrete*	K_1	1	
Modulus of elasticity of concrete for precast beam at transfer	E_{ci}	3834.25	ksi
Modulus of elasticity of concrete for precast beam at service load	E_{c_beam}	4496.06	ksi
Modulus of elasticity of concrete for deck slab	E_{c_slab}	3834.25	ksi

b. Reinforcing Bars

Yield Strength*	f_y	60.00	ksi
Modulus of elasticity*	E_s	29000	ksi

c. Prestressing Strands

Type*	Seven-wire strand	Stress-relieved strand

Diameter	D_p	1/2	in.
Area*	A_p	0.153	in^2
Tensile strength*	f_{pu}	270	ksi
Modulus of elasticity*	E_p	28500	ksi
Yield strength	f_{py}	229.5	ksi
	K	0.38	

d. Surfacing Material

Type	Asphalt surface	
Unit weight	0.145	kcf

e. Barrier

Type	Steel guard rail	
Unit weight	0.032	kips/ft/side

3. Box Beam Section Properties

Box beam section used	**Custom**		
Width of each box beam	b	48	in.
Height of each box beam	h	27	in.
No of box beams		7	nos

Section Geometry

No of webs in beam		2	nos
Depth of top flange	h_f	5.5	in.
Depth of bottom flange	h_c	5.0	in.
Width of end web	b_w	5.0	in.
Width of chamfer	w_h	3.0	in.

Section properties		**Precast beam**	
Area	A	678.80	in^2
Moment of inertia	I	64649.00	in^4
Distance from centroid to extreme bottom fiber	Y_b	13.61	in.
Distance from centroid to extreme top fiber	Y_t	13.39	in.
Section modulus for extreme bottom fiber	S_b	4750.11	in^3
Section modulus for extreme top fiber	S_t	4828.16	in^3

Layers of Prestressing Strands Provided: 1

Layer *	Number	Position from extreme tensile face		Remark
Layer 1	22	1.75	in.	Bottom flange
Layer 2	0	0	in.	Top flange
Layer 3	0	0	in.	Top flange
Layer 4	0	0	in.	Top flange
Debonded strands	0	0	in.	Top flange

*Note: Input layers from bottom to top of the beam

Longitudinal Reinforcement Bars

Layer	Bar no.	Area	Number	Position from extreme tensile face		Remark
Layer 1		0.00			in.	Bottom flange

Shear Reinforcement

Zone	Distance to end of region from the support (ft)	Bar no.	Spacing (in.)	Area (in^2)
Region 1	4.00	#4	6	0.40
Region 2	32.50	#4	6	0.40

4. Load Rating

Load Rating Settings

Adopted beam for load rating*	Exterior beam
Riding surface condition*	Minor depression

Vehicle types	Dynamic allowance (IM)	Use strength limit state	Use service limit state
A. Design Vehicle	33%	YES	NO
B. Ohio Legal Vehicles	33%	YES	NO
C. Specialized Hauling Vehicles	33%	YES	NO
D. Emergency Vehicles	33%	YES	NO
E. AASHTO Legal Vehicles	33%	YES	NO
F. Permit Vehicles	20%	YES	NO
G. Custom Vehicle	33%	YES	NO

Input for Service Limit State

Average annual humidity	70%
Prestressing strands condition	Low to moderate corrosion
Concrete age at transfer	1 days
Concrete age at deck placement	28 days
Final concrete age	18250 days

Live Load Factors for Legal Vehicles

ADTT	8000
Live load factor for legal vehicles	1.45

Live Load Factors for Emergency Vehicles

EV2*	1.45
EV3*	1.45

Permit Load Condition

Permit type	Routine or Annual
Frequency	Unlimited crossings
Loading condition	Mixed with traffic
DF using	Two or more lanes

Live Load Factor for Permit Vehicles

Vehicle type	Live load factor
PL60T	1.40
PL65T	1.35

Add custom vehicle*	YES
No of axles	12

Axle No	Load (kips)	Distance from first axle (ft)
a	16.00	0.00
b	19.00	16.25
c	19.00	20.75
d	19.00	25.25
e	19.00	41.00
f	19.00	46.00
g	19.00	51.00
h	19.00	91.17
i	19.00	96.17
j	19.00	101.17
k	19.00	117.42
l	19.00	122.58

Custom Vehicle Load Condition

Permit type	Special or Limited crossing
Frequency	Multiple trips(<100 crossings)
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Custom Vehicle

Vehicle type	Live load factor
Custom vehicle	1.40

LOAD RATING RESULTS

Load Rating Results

Ohio Legal Vehicles		
Loading Type	GVW	Rating Factor
	Tons	
2F1	15	3.165
3F1	23	2.120
5C1	40	2.160
Specialized Hauling Vehicles		
SU4	27	1.863
SU5	31	1.693
SU6	34.5	1.519
SU7	38.75	1.394
Emergency Vehicles		
EV2	28.75	1.831
EV3	43	1.199
AASHTO Legal Vehicles		
Type3	25	2.102
Type3S2	36	1.982
Type3_3	40	2.134
Permit Vehicles		
PL60T	60	1.859
PL65T	65	1.444
Custom Vehicle		
Custom Vehicle 1	113	1.958

Design Vehicles		
Loading Type	Rating Factor	
	Inventory	Operating
HL93	1.004	1.301

EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample Bridge 10	Load rated by	SD	Date	5/13/2025
Construction year	2009	Checked by	YM	Date	5/13/2025

1. Bridge Information

Total span*	66.50	ft
Total width	32.00	ft

Single lane width	12.00	ft
End offset	6.00	in.
Width of bearing	5.00	in.
Barrier type	Twin steel tube railing	
Width of barrier	0.00	ft each side

Design span	65.50	ft
Road way width	32.00	ft

Composite /Non composite*	Non composite	
Thickness of deck slab*	0	in.

Skew/Non skew*	Skew	
Skew angle*	12	Degrees

Surfacing material	Asphalt surface	
Thickness	8.67	in.

Total number of diaphragm*	6	nos

Diaphragm number	Position from left support		Thickness	
1	1.49	ft	18.00	in.
2	13.99	ft	18.00	in.
3	26.49	ft	18.00	in.
4	38.99	ft	18.00	in.
5	51.49	ft	18.00	in.
6	63.99	ft	18.00	in.

Bridge appraisal rating	9
Condition factor	1.00

Additional beam weight	0%
Additional barrier weight	0%

2. Material Properties

a. Concrete

Required concrete compressive strength at transfer*	f'_{ci}	5.00	ksi
Specified concrete compressive strength for use in design*	f'_c	7.00	ksi
Deck concrete compressive strength *	f'_{c_deck}	4.50	ksi
Concrete unit weight*	w_c	0.15	kcf

Correction factor for source of concrete*	K_1	1	
Modulus of elasticity of concrete for precast beam at transfer	E_{ci}	4286.83	ksi
Modulus of elasticity of concrete for precast beam at service load	E_{c_beam}	5072.24	ksi
Modulus of elasticity of concrete for deck slab	E_{c_slab}	4066.84	ksi

b. Reinforcing Bars

Yield Strength*	f_y	60.00	ksi
Modulus of elasticity*	E_s	29000	ksi

c. Prestressing Strands

Type*	Seven-wire strand	Low-relaxation strand

Diameter	D_p	1/2	in.
Area*	A_p	0.167	in^2
Tensile strength*	f_{pu}	270	ksi
Modulus of elasticity*	E_p	28500	ksi
Yield strength	f_{py}	243	ksi
	K	0.28	

d. Surfacing Material

Type	Asphalt surface	
Unit weight	0.145	kcf

e. Barrier

Type	Twin steel tube railing	
Unit weight	0.080	kips/ft/side

3. Box Beam Section Properties

Box beam section used	B21-48		
Width of each box beam	b	48	in.
Height of each box beam	h	21	in.
No of box beams		8	nos

Section Geometry

No of webs in beam		2	nos
Depth of top flange	h_f	5.5	in.
Depth of bottom flange	h_c	5.5	in.
Width of end web	b_w	5.5	in.
Width of chamfer	w_h	3.0	in.

Section properties		Precast beam	
Area	A	647.80	in^2
Moment of inertia	I	33884.00	in^4
Distance from centroid to extreme bottom fiber	Y_b	10.42	in.
Distance from centroid to extreme top fiber	Y_t	10.58	in.
Section modulus for extreme bottom fiber	S_b	3253.00	in^3
Section modulus for extreme top fiber	S_t	3202.00	in^3

Layers of Prestressing Strands Provided: 1

Layer *	Number	Position from extreme tensile face		Remark
Layer 1	18	2	in.	Bottom flange
Layer 2	12	4	in.	Bottom flange
Layer 3	0	0	in.	Top flange
Layer 4	0	0	in.	Top flange
Debonded strands	0	0	in.	Top flange

*Note: Input layers from bottom to top of the beam

Longitudinal Reinforcement Bars

Layer	Bar no.	Area	Number	Position from extreme tensile face		Remark
Layer 1	#5	0.31	2	2	in.	Bottom flange

Shear Reinforcement

Zone	Distance to end of region from the support (ft)	Bar no.	Spacing (in.)	Area (in^2)
Region 1	4.00	#5	6	0.62
Region 2	32.75	#5	6	0.62

4. Load Rating

Load Rating Settings

Adopted beam for load rating*	Exterior beam
Riding surface condition*	Smooth surface

Vehicle types	Dynamic allowance (IM)	Use strength limit state	Use service limit state
A. Design Vehicle	33%	YES	YES
B. Ohio Legal Vehicles	33%	YES	NO
C. Specialized Hauling Vehicles	33%	YES	NO
D. Emergency Vehicles	33%	YES	NO
E. AASHTO Legal Vehicles	33%	YES	NO
F. Permit Vehicles	10%	YES	NO
G. Custom Vehicle	33%	YES	NO

Input for Service Limit State

Average annual humidity	70%
Prestressing strands condition	Low to moderate corrosion
Concrete age at transfer	1 days
Concrete age at deck placement	28 days
Final concrete age	18250 days

Live Load Factors for Legal Vehicles

ADTT	8000
Live load factor for legal vehicles	1.45

Live Load Factors for Emergency Vehicles

EV2*	1.30
EV3*	1.10

Permit Load Condition

Permit type	Routine or Annual
Frequency	Unlimited crossings
Loading condition	Mixed with traffic
DF using	Two or more lanes

Live Load Factor for Permit Vehicles

Vehicle type	Live load factor
PL60T	1.40
PL65T	1.35

Add custom vehicle*	YES
No of axles	12

Axle No	**Load (kips)**	**Distance from first axle (ft)**
a	16.00	0.00
b	19.00	16.25
c	19.00	20.75
d	19.00	25.25
e	19.00	41.00
f	19.00	46.00
g	19.00	51.00
h	19.00	91.17
i	19.00	96.17
j	19.00	101.17
k	19.00	117.42
l	19.00	122.58

Custom Vehicle Load Condition

Permit type	Special or Limited crossing
Frequency	Multiple trips(<100 crossings)
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Custom Vehicle

Vehicle type	**Live load factor**
Custom vehicle	1.40

LOAD RATING RESULTS

Load Rating Results

Ohio Legal Vehicles		
Loading Type	GVW	Rating Factor
	Tons	
2F1	15	3.234
3F1	23	2.165
5C1	40	2.206

Specialized Hauling Vehicles		
SU4	27	1.902
SU5	31	1.728
SU6	34.5	1.550
SU7	38.75	1.422

Emergency Vehicles		
EV2	28.75	2.085
EV3	43	1.613

AASHTO Legal Vehicles		
Type3	25	2.146
Type3S2	36	2.018
Type3_3	40	2.170

Permit Vehicles		
PL60T	60	2.071
PL65T	65	1.602

Custom Vehicle		
Custom Vehicle 1	113	2.042

Design Vehicles		
Loading Type	Rating Factor	
	Inventory	Operating
HL93	1.004	1.325

EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample bridge 11	Load rated by	SD	Date	5/13/2025
Construction year	1985	Checked by	YM	Date	5/13/2025

1. Bridge Information

Total span*	76.00	ft
Total width	30.00	ft

Single lane width	15.50	ft
End offset	6.90	in.
Width of bearing	5.00	in.
Barrier type	Steel guard rail	
Width of barrier	0.00	ft each side

Design span	74.85	ft
Road way width	30.00	ft

Composite /Non composite*	Non composite	
Thickness of deck slab*	0	in.

Skew/Non skew*	Skew	
Skew angle*	30	Degrees

Surfacing material	Asphalt surface	
Thickness	2.5	in.

Total number of diaphragm*	4	nos

Diaphragm number	Position from left support		Thickness	
1	0.00	ft	20.75	in.
2	24.95	ft	20.75	in.
3	49.90	ft	20.75	in.
4	74.84	ft	20.75	in.

Bridge appraisal rating	7
Condition factor	1.00

Additional beam weight	2%
Additional barrier weight	0%

2. Material Properties

a. Concrete

Required concrete compressive strength at transfer*	f'_{ci}	5.50	ksi
Specified concrete compressive strength for use in design*	f'_c	6.50	ksi
Deck concrete compressive strength *	f'_{c_deck}	4.00	ksi
Concrete unit weight*	w_c	0.15	kcf

Correction factor for source of concrete*	K_1	1	
Modulus of elasticity of concrete for precast beam at transfer	E_{ci}	4496.06	ksi
Modulus of elasticity of concrete for precast beam at service load	E_{c_beam}	4887.73	ksi
Modulus of elasticity of concrete for deck slab	E_{c_slab}	3834.25	ksi

b. Reinforcing Bars

Yield Strength*	f_y	60.00	ksi
Modulus of elasticity*	E_s	29000	ksi

c. Prestressing Strands

Type*	Seven-wire strand	Stress-relieved strand

Diameter	D_p	1/2	in.
Area*	A_p	0.153	in^2
Tensile strength*	f_{pu}	270	ksi
Modulus of elasticity*	E_p	28500	ksi
Yield strength	f_{py}	229.5	ksi
	K	0.38	

d. Surfacing Material

Type	Asphalt surface	
Unit weight	0.145	kcf

e. Barrier

Type	Steel guard rail	
Unit weight	0.032	kips/ft/side

3. Box Beam Section Properties

Box beam section used	Custom		
Width of each box beam	b	36	in.
Height of each box beam	h	33	in.
No of box beams		10	nos

Section Geometry

No of webs in beam		2	nos
Depth of top flange	h_f	5.0	in.
Depth of bottom flange	h_c	5.0	in.
Width of end web	b_w	5.0	in.
Width of chamfer	w_h	3.0	in.

Section properties		Precast beam	
Area	A	594.50	in^2
Moment of inertia	I	82048.00	in^4
Distance from centroid to extreme bottom fiber	Y_b	16.28	in.
Distance from centroid to extreme top fiber	Y_t	16.72	in.
Section modulus for extreme bottom fiber	S_b	5039.80	in^3
Section modulus for extreme top fiber	S_t	4907.18	in^3

Layers of Prestressing Strands Provided: 2

Layer *	Number	Position from extreme tensile face		Remark
Layer 1	10	2	in.	Bottom flange
Layer 2	2	4	in.	Bottom flange
Layer 3	0	0	in.	Top flange
Layer 4	0	0	in.	Top flange
Debonded strands	0	0	in.	Top flange

*Note: Input layers from bottom to top of the beam

Longitudinal Reinforcement Bars

Layer	Bar no.	Area	Number	Position from extreme tensile face		Remark
Layer 1		0.00			in.	Bottom flange

Shear Reinforcement

Zone	Distance to end of region from the support (ft)	Bar no.	Spacing (in.)	Area (in^2)
Region 1	4.00	#4	6	0.40
Region 2	37.43	#4	6	0.40

4. Load Rating

Load Rating Settings

Adopted beam for load rating*	Interior beam
Riding surface condition*	Minor depression

Vehicle types	Dynamic allowance (IM)	Use strength limit state	Use service limit state
A. Design Vehicle	33%	YES	YES
B. Ohio Legal Vehicles	33%	YES	NO
C. Specialized Hauling Vehicles	33%	YES	NO
D. Emergency Vehicles	33%	YES	NO
E. AASHTO Legal Vehicles	33%	YES	NO
F. Permit Vehicles	20%	YES	NO
G. Custom Vehicle	33%	YES	NO

Input for Service Limit State

Average annual humidity	70%
Prestressing strands condition	Severe corrosion
Concrete age at transfer	1 days
Concrete age at deck placement	28 days
Final concrete age	18250 days

Live Load Factors for Legal Vehicles

ADTT	Unknown
Live load factor for legal vehicles	1.45

Live Load Factors for Emergency Vehicles

EV2*	1.30
EV3*	1.10

Permit Load Condition

Permit type	Routine or Annual
Frequency	Unlimited crossings
Loading condition	Mixed with traffic
DF using	Two or more lanes

Live Load Factor for Permit Vehicles

Vehicle type	Live load factor
PL60T	1.40
PL65T	1.35

Add custom vehicle*	YES
No of axles	12

Axle No	Load (kips)	Distance from first axle (ft)
a	16.00	0.00
b	19.00	16.25
c	19.00	20.75
d	19.00	25.25
e	19.00	41.00
f	19.00	46.00
g	19.00	51.00
h	19.00	91.17
i	19.00	96.17
j	19.00	101.17
k	19.00	117.42
l	19.00	122.58

Custom Vehicle Load Condition

Permit type	Special or Limited crossing
Frequency	Multiple trips(<100 crossings)
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Custom Vehicle

Vehicle type	Live load factor
Custom vehicle	1.40

LOAD RATING RESULTS

Load Rating Results

Ohio Legal Vehicles		
Loading Type	GVW	Rating Factor
	Tons	
2F1	15	2.406
3F1	23	1.605
5C1	40	1.512

Specialized Hauling Vehicles		
SU4	27	1.404
SU5	31	1.268
SU6	34.5	1.136
SU7	38.75	1.039

Emergency Vehicles		
EV2	28.75	1.532
EV3	43	1.186

AASHTO Legal Vehicles		
Type3	25	1.574
Type3S2	36	1.413
Type3_3	40	1.469

Permit Vehicles		
PL60T	60	1.406
PL65T	65	1.011

Custom Vehicle		
Custom Vehicle 1	113	1.335

Design Vehicles		
Loading Type	Rating Factor	
	Inventory	Operating
HL93	0.341	0.941

EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample bridge 12	Load rated by	SD	Date	5/13/2025
Construction year	2016	Checked by	YM	Date	5/13/2025

1. Bridge Information

Total span*	76.00	ft
Total width	33.00	ft

Single lane width	16.50	ft
End offset	6.00	in.
Width of bearing	5.00	in.
Barrier type	Deep beam rail	
Width of barrier	0.00	ft each side

Design span	75.00	ft
Road way width	33.00	ft

Composite /Non composite*	Non composite	
Thickness of deck slab*	0	in.

Skew/Non skew*	Skew	
Skew angle*	10	Degrees

Surfacing material	Asphalt surface	
Thickness	3.785	in.

Total number of diaphragm*	4	nos

Diaphragm number	Position from left support		Thickness	
1	2.18	ft	24.60	in.
2	25.50	ft	24.60	in.
3	50.50	ft	24.60	in.
4	73.82	ft	24.60	in.

Bridge appraisal rating	9
Condition factor	1.00

Additional beam weight	2%
Additional barrier weight	0%

2. Material Properties

a. Concrete

Required concrete compressive strength at transfer*	f'_{ci}	5.00	ksi
Specified concrete compressive strength for use in design*	f'_c	7.00	ksi
Deck concrete compressive strength *	f'_{c_deck}	4.50	ksi
Concrete unit weight*	w_c	0.15	kcf

Correction factor for source of concrete*	K_1	1	
Modulus of elasticity of concrete for precast beam at transfer	E_{ci}	4286.83	ksi
Modulus of elasticity of concrete for precast beam at service load	E_{c_beam}	5072.24	ksi
Modulus of elasticity of concrete for deck slab	E_{c_slab}	4066.84	ksi

b. Reinforcing Bars

Yield Strength*	f_y	60.00	ksi
Modulus of elasticity*	E_s	29000	ksi

c. Prestressing Strands

Type*	Seven-wire strand	Low-relaxation strand

Diameter	D_p	1/2	in.
Area*	A_p	0.167	in^2
Tensile strength*	f_{pu}	270	ksi
Modulus of elasticity*	E_p	28500	ksi
Yield strength	f_{py}	243	ksi
	K	0.28	

d. Surfacing Material

Type	Asphalt surface	
Unit weight	0.145	kcf

e. Barrier

Type	Deep beam rail	
Unit weight	0.032	kips/ft/side

3. Box Beam Section Properties

Box beam section used	B33-36		
Width of each box beam	b	36	in.
Height of each box beam	h	33	in.
No of box beams		11	nos

Section Geometry

No of webs in beam		2	nos
Depth of top flange	h_f	5.5	in.
Depth of bottom flange	h_c	5.5	in.
Width of end web	b_w	5.5	in.
Width of chamfer	w_h	3.0	in.

Section properties		Precast beam	
Area	A	642.50	in^2
Moment of inertia	I	86049.00	in^4
Distance from centroid to extreme bottom fiber	Y_b	16.30	in.
Distance from centroid to extreme top fiber	Y_t	16.70	in.
Section modulus for extreme bottom fiber	S_b	5279.00	in^3
Section modulus for extreme top fiber	S_t	5153.00	in^3

Layers of Prestressing Strands Provided: 2

Layer *	Number	Position from extreme tensile face		Remark
Layer 1	12	2	in.	Bottom flange
Layer 2	8	4	in.	Bottom flange
Layer 3	0	0	in.	Top flange
Layer 4	0	0	in.	Top flange
Debonded strands	0	0	in.	Top flange

*Note: Input layers from bottom to top of the beam

Longitudinal Reinforcement Bars

Layer	Bar no.	Area	Number	Position from extreme tensile face		Remark
Layer 1	#5	0.31	2	2	in.	Bottom flange

Shear Reinforcement

Zone	Distance to end of region from the support (ft)	Bar no.	Spacing (in.)	Area (in^2)
Region 1	4.00	#4	6	0.40
Region 2	37.50	#4	6	0.40

4. Load Rating

Load Rating Settings

Adopted beam for load rating*	Exterior beam
Riding surface condition*	Minor depression

Vehicle types	Dynamic allowance (IM)	Use strength limit state	Use service limit state
A. Design Vehicle	33%	YES	YES
B. Ohio Legal Vehicles	33%	YES	NO
C. Specialized Hauling Vehicles	33%	YES	NO
D. Emergency Vehicles	33%	YES	NO
E. AASHTO Legal Vehicles	33%	YES	NO
F. Permit Vehicles	20%	YES	NO
G. Custom Vehicle	33%	YES	NO

Input for Service Limit State

Average annual humidity	70%
Prestressing strands condition	Low to moderate corrosion
Concrete age at transfer	1 days
Concrete age at deck placement	28 days
Final concrete age	18250 days

Live Load Factors for Legal Vehicles

ADTT	Unknown
Live load factor for legal vehicles	1.45

Live Load Factors for Emergency Vehicles

EV2*	1.45
EV3*	1.45

Permit Load Condition

Permit type	Routine or Annual
Frequency	Unlimited crossings
Loading condition	Mixed with traffic
DF using	Two or more lanes

Live Load Factor for Permit Vehicles

Vehicle type	Live load factor
PL60T	1.40
PL65T	1.35

Add custom vehicle*	YES
No of axles	12

Axle No	Load (kips)	Distance from first axle (ft)
a	16.00	0.00
b	19.00	16.25
c	19.00	20.75
d	19.00	25.25
e	19.00	41.00
f	19.00	46.00
g	19.00	51.00
h	19.00	91.17
i	19.00	96.17
j	19.00	101.17
k	19.00	117.42
l	19.00	122.58

Custom Vehicle Load Condition

Permit type	Special or Limited crossing
Frequency	Multiple trips(<100 crossings)
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Custom Vehicle

Vehicle type	Live load factor
Custom vehicle	1.40

LOAD RATING RESULTS

Load Rating Results

Ohio Legal Vehicles		
Loading Type	**GVW**	**Rating Factor**
	Tons	
2F1	15	5.697
3F1	23	3.803
5C1	40	3.520
Specialized Hauling Vehicles		
SU4	27	3.325
SU5	31	3.000
SU6	34.5	2.690
SU7	38.75	2.461
Emergency Vehicles		
EV2	28.75	3.240
EV3	43	2.131
AASHTO Legal Vehicles		
Type3	25	3.726
Type3S2	36	3.320
Type3_3	40	3.468
Permit Vehicles		
PL60T	60	3.330
PL65T	65	2.368
Custom Vehicle		
Custom Vehicle 1	113	2.920

Design Vehicles		
Loading Type	**Rating Factor**	
	Inventory	**Operating**
HL93	1.718	2.228

EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample bridge 13	Load rated by	SD	Date	5/13/2025
Construction year	2021	Checked by	YM	Date	5/13/2025

1. Bridge Information

Total span*	27.00	ft
Total width	44.00	ft

Single lane width	18.00	ft
End offset	6.00	in.
Width of bearing	5.00	in.
Barrier type	Steel guard rail	
Width of barrier	0.00	ft each side

Design span	26.00	ft
Road way width	44.00	ft

Composite /Non composite*	Composite	
Thickness of deck slab*	6	in.

Skew/Non skew*	Skew	
Skew angle*	30	Degrees

Surfacing material	Concrete	
Thickness	0.6	in.

Total number of diaphragm*	3	nos

Diaphragm number	Position from left support		Thickness	
1	2.75	ft	12.00	in.
2	13.57	ft	12.00	in.
3	24.40	ft	12.00	in.

Bridge appraisal rating	9
Condition factor	1.00

Additional beam weight	2%
Additional barrier weight	0%

2. Material Properties

a. Concrete

Required concrete compressive strength at transfer*	f'_{ci}	5.00	ksi
Specified concrete compressive strength for use in design*	f'_c	7.00	ksi
Deck concrete compressive strength *	f'_{c_deck}	4.50	ksi
Concrete unit weight*	w_c	0.15	kcf

Correction factor for source of concrete*	K_1	1	
Modulus of elasticity of concrete for precast beam at transfer	E_{ci}	4286.83	ksi
Modulus of elasticity of concrete for precast beam at service load	E_{c_beam}	5072.24	ksi
Modulus of elasticity of concrete for deck slab	E_{c_slab}	4066.84	ksi

b. Reinforcing Bars

Yield Strength*	f_y	60.00	ksi
Modulus of elasticity*	E_s	29000	ksi

c. Prestressing Strands

Type*	Seven-wire strand	Low-relaxation strand

Diameter	D_p	1/2	in.
Area*	A_p	0.167	in^2
Tensile strength*	f_{pu}	270	ksi
Modulus of elasticity*	E_p	28500	ksi
Yield strength	f_{py}	243	ksi
	K	0.28	

d. Surfacing Material

Type	Concrete	
Unit weight	0.15	kcf

e. Barrier

Type	Steel guard rail	
Unit weight	0.030	kips/ft/side

3. Box Beam Section Properties

Box beam section used	B17-48		
Width of each box beam	b	48	in.
Height of each box beam	h	17	in.
No of box beams		11	nos

Section Geometry

No of webs in beam		2	nos
Depth of top flange	h_f	5.5	in.
Depth of bottom flange	h_c	5.5	in.
Width of end web	b_w	5.5	in.
Width of chamfer	w_h	3.0	in.

Section properties		Precast beam		Composite Beam	
Area	A	590.30	in^2	821.21	in^2
Moment of inertia	I	18819.00	in^4	41692.79	in^2
Distance from centroid to extreme bottom fiber	Y_b	8.44	in.	11.69	in^2
Distance from centroid to extreme top fiber	Y_t	8.56	in.	11.31	in^2
Section modulus for extreme bottom fiber	S_b	2230.00	in^3	3566.38	in^2
Section modulus for extreme top fiber	S_t	2198.00	in^3	4597.91	in^2

Layers of Prestressing Strands Provided		2		
Layer *	Number	Position from extreme tensile face		Remark
Layer 1	8	2	in.	Bottom flange
Layer 2	6	4	in.	Bottom flange
Layer 3	0	0	in.	Top flange
Layer 4	0	0	in.	Top flange
Debonded strands	0	0	in.	Top flange

*Note: Input layers from bottom to top of the beam

Longitudinal Reinforcement Bars

Layer	Bar no.	Area	Number	Position from extreme tensile face		Remark
Layer 1		0.00			in.	Bottom flange

Shear Reinforcement

Zone	Distance to end of region from the support (ft)	Bar no.	Spacing (in.)	Area (in^2)
Region 1	3.00	#4	3	0.40
Region 2	13.00	#4	6	0.40

4. Load Rating

Load Rating Settings

Adopted beam for load rating*	Exterior beam
Riding surface condition*	Minor depression

Vehicle types	Dynamic allowance (IM)	Use strength limit state	Use service limit state
A. Design Vehicle	33%	YES	YES
B. Ohio Legal Vehicles	33%	YES	NO
C. Specialized Hauling Vehicles	33%	YES	NO
D. Emergency Vehicles	33%	YES	NO
E. AASHTO Legal Vehicles	33%	YES	NO
F. Permit Vehicles	20%	YES	NO
G. Custom Vehicle	33%	YES	NO

Input for Service Limit State

Average annual humidity	70%
Prestressing strands condition	Low to moderate corrosion
Concrete age at transfer	1 days
Concrete age at deck placement	28 days
Final concrete age	18250 days

Live Load Factors for Legal Vehicles

ADTT	Unknown
Live load factor for legal vehicles	1.45

Live Load Factors for Emergency Vehicles

EV2*	1.30
EV3*	1.10

Permit Load Condition

Permit type	Routine or Annual
Frequency	Unlimited crossings
Loading condition	Mixed with traffic
DF using	Two or more lanes

Live Load Factor for Permit Vehicles

Vehicle type	Live load factor
PL60T	1.40
PL65T	1.35

Add custom vehicle*	YES
No of axles	12

Axle No	Load (kips)	Distance from first axle (ft)
a	16.00	0.00
b	19.00	16.25
c	19.00	20.75
d	19.00	25.25
e	19.00	41.00
f	19.00	46.00
g	19.00	51.00
h	19.00	91.17
i	19.00	96.17
j	19.00	101.17
k	19.00	117.42
l	19.00	122.58

Custom Vehicle Load Condition

Permit type	Special or Limited crossing
Frequency	Multiple trips(<100 crossings)
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Custom Vehicle

Vehicle type	Live load factor
Custom vehicle	1.40

LOAD RATING RESULTS

Load Rating Results

Ohio Legal Vehicles		
Loading Type	**GVW**	**Rating Factor**
	Tons	
2F1	15	5.639
3F1	23	4.048
5C1	40	4.660

Specialized Hauling Vehicles		
SU4	27	3.722
SU5	31	3.562
SU6	34.5	3.672
SU7	38.75	3.878

Emergency Vehicles		
EV2	28.75	3.856
EV3	43	3.137

AASHTO Legal Vehicles		
Type3	25	4.277
Type3S2	36	5.111
Type3_3	40	5.231

Permit Vehicles		
PL60T	60	4.370
PL65T	65	4.265

Custom Vehicle		
Custom Vehicle 1	113	6.001

Design Vehicles		
Loading Type	**Rating Factor**	
	Inventory	**Operating**
HL93	2.626	3.403

EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample bridge 14	Load rated by	SD	Date	5/13/2025
Construction year	2022	Checked by	YM	Date	5/13/2025

1. Bridge Information

Total span*	49.00	ft
Total width	36.00	ft

Single lane width	18.00	ft
End offset	7.74	in.
Width of bearing	5.00	in.
Barrier type	Twin steel post rail	
Width of barrier	0.00	ft each side

Design span	47.71	ft
Road way width	36.00	ft

Composite /Non composite*	Composite	
Thickness of deck slab*	6	in.

Skew/Non skew*	Skew	
Skew angle*	19	Degrees

Surfacing material	None	
Thickness	0	in.

Total number of diaphragm*	3	nos

Diaphragm number	Position from left support		Thickness	
1	1.67	ft	28.44	in.
2	24.38	ft	28.44	in.
3	47.09	ft	28.44	in.

Bridge appraisal rating	9
Condition factor	1.00

Additional beam weight	0%
Additional barrier weight	0%

2. Material Properties

a. Concrete

Required concrete compressive strength at transfer*	f'_{ci}	5.00	ksi
Specified concrete compressive strength for use in design*	f'_c	7.00	ksi
Deck concrete compressive strength *	f'_{c_deck}	4.50	ksi
Concrete unit weight*	w_c	0.15	kcf

Correction factor for source of concrete*	K_1	1	
Modulus of elasticity of concrete for precast beam at transfer	E_{ci}	4286.83	ksi
Modulus of elasticity of concrete for precast beam at service load	E_{c_beam}	5072.24	ksi
Modulus of elasticity of concrete for deck slab	E_{c_slab}	4066.84	ksi

b. Reinforcing Bars

Yield Strength*	f_y	75.00	ksi
Modulus of elasticity*	E_s	29000	ksi

c. Prestressing Strands

Type*	Seven-wire strand	Low-relaxation strand

Diameter	D_p	1/2	in.
Area*	A_p	0.216	in^2
Tensile strength*	f_{pu}	250	ksi
Modulus of elasticity*	E_p	28500	ksi
Yield strength	f_{py}	225	ksi
	K	0.28	

d. Surfacing Material

Type	None	
Unit weight	0	kcf

e. Barrier

Type	Twin steel post rail	
Unit weight	0.080	kips/ft/side

3. Box Beam Section Properties

Box beam section used	CB21-48		
Width of each box beam	b	48	in.
Height of each box beam	h	21	in.
No of box beams		9	nos

Section Geometry

No of webs in beam		2	nos
Depth of top flange	h_f	5.5	in.
Depth of bottom flange	h_c	5.5	in.
Width of end web	b_w	5.5	in.
Width of chamfer	w_h	3.0	in.

Section properties		Precast beam		Composite Beam	
Area	A	647.80	in^2	878.71	in^2
Moment of inertia	I	33884.00	in^4	65970.46	in^2
Distance from centroid to extreme bottom fiber	Y_b	10.42	in.	13.99	in^2
Distance from centroid to extreme top fiber	Y_t	10.58	in.	13.01	in^2
Section modulus for extreme bottom fiber	S_b	3253.00	in^3	4716.00	in^2
Section modulus for extreme top fiber	S_t	3202.00	in^3	6323.67	in^2

Layers of Prestressing Strands Provided		2		
Layer *	Number	Position from extreme tensile face		Remark
Layer 1	16	2	in.	Bottom flange
Layer 2	6	4	in.	Bottom flange
Layer 3	0	0	in.	Top flange
Layer 4	0	0	in.	Top flange
Debonded strands	0	0	in.	Top flange

*Note: Input layers from bottom to top of the beam

Longitudinal Reinforcement Bars

Layer	Bar no.	Area	Number	Position from extreme tensile face		Remark
Layer 1	#5	0.31	2	2	in.	Bottom flange

Shear Reinforcement

Zone	Distance to end of region from the support (ft)	Bar no.	Spacing (in.)	Area (in^2)
Region 1	4.00	#4	4	0.40
Region 2	23.86	#4	8	0.40

4. Load Rating

Load Rating Settings

Adopted beam for load rating*	Exterior beam
Riding surface condition*	Minor depression

Vehicle types	Dynamic allowance (IM)	Use strength limit state	Use service limit state
A. Design Vehicle	33%	YES	YES
B. Ohio Legal Vehicles	33%	YES	NO
C. Specialized Hauling Vehicles	33%	YES	NO
D. Emergency Vehicles	33%	YES	NO
E. AASHTO Legal Vehicles	33%	YES	NO
F. Permit Vehicles	20%	YES	NO
G. Custom Vehicle	33%	YES	NO

Input for Service Limit State

Average annual humidity	70%
Prestressing strands condition	Severe corrosion
Concrete age at transfer	1 days
Concrete age at deck placement	28 days
Final concrete age	18250 days

Live Load Factors for Legal Vehicles

ADTT	Unknown
Live load factor for legal vehicles	1.45

Live Load Factors for Emergency Vehicles

EV2*	1.45
EV3*	1.45

Permit Load Condition

Permit type	Routine or Annual
Frequency	Unlimited crossings
Loading condition	Mixed with traffic
DF using	Two or more lanes

Live Load Factor for Permit Vehicles

Vehicle type	Live load factor
PL60T	1.40
PL65T	1.35

Add custom vehicle*	YES
No of axles	12

Axle No	Load (kips)	Distance from first axle (ft)
a	16.00	0.00
b	19.00	16.25
c	19.00	20.75
d	19.00	25.25
e	19.00	41.00
f	19.00	46.00
g	19.00	51.00
h	19.00	91.17
i	19.00	96.17
j	19.00	101.17
k	19.00	117.42
l	19.00	122.58

Custom Vehicle Load Condition

Permit type	Special or Limited crossing
Frequency	Multiple trips(<100 crossings)
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Custom Vehicle

Vehicle type	Live load factor
Custom vehicle	1.40

LOAD RATING RESULTS

Load Rating Results

Ohio Legal Vehicles		
Loading Type	**GVW**	**Rating Factor**
	Tons	
2F1	15	6.117
3F1	23	4.175
5C1	40	4.501

Specialized Hauling Vehicles		
SU4	27	3.682
SU5	31	3.341
SU6	34.5	3.207
SU7	38.75	3.110

Emergency Vehicles		
EV2	28.75	3.441
EV3	43	2.331

AASHTO Legal Vehicles		
Type3	25	4.086
Type3S2	36	4.100
Type3_3	40	4.338

Permit Vehicles		
PL60T	60	4.676
PL65T	65	3.716

Custom Vehicle		
Custom Vehicle 1	113	4.605

Design Vehicles		
Loading Type	**Rating Factor**	
	Inventory	**Operating**
HL93	2.481	3.215

EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample bridge 15	Load rated by	SD	Date	5/13/2025
Construction year	2018	Checked by	YM	Date	5/13/2025

1. Bridge Information

Total span*	62.00	ft
Total width	32.00	ft

Single lane width	16.00	ft
End offset	12.00	in.
Width of bearing	5.00	in.
Barrier type	Steel guard rail	
Width of barrier	0.00	ft each side

Design span	60.00	ft
Road way width	32.00	ft

Composite /Non composite*	Composite	
Thickness of deck slab*	6	in.

Skew/Non skew*	Skew	
Skew angle*	24	Degrees

Surfacing material	None	
Thickness	0	in.

Total number of diaphragm*	4	nos

Diaphragm number	Position from left support		Thickness	
1	2.33	ft	33.38	in.
2	20.00	ft	33.38	in.
3	40.00	ft	33.38	in.
4	57.28	ft	33.38	in.

Bridge appraisal rating	9
Condition factor	1.00

Additional beam weight	5%
Additional barrier weight	0%

2. Material Properties

a. Concrete

Required concrete compressive strength at transfer*	f'_{ci}	5.00	ksi
Specified concrete compressive strength for use in design*	f'_c	7.00	ksi
Deck concrete compressive strength *	f'_{c_deck}	4.50	ksi
Concrete unit weight*	w_c	0.15	kcf

Correction factor for source of concrete*	K_1	1	
Modulus of elasticity of concrete for precast beam at transfer	E_{ci}	4286.83	ksi
Modulus of elasticity of concrete for precast beam at service load	E_{c_beam}	5072.24	ksi
Modulus of elasticity of concrete for deck slab	E_{c_slab}	4066.84	ksi

b. Reinforcing Bars

Yield Strength*	f_y	60.00	ksi
Modulus of elasticity*	E_s	29000	ksi

c. Prestressing Strands

Type*	Seven-wire strand	Low-relaxation strand

Diameter	D_p	1/2	in.
Area*	A_p	0.153	in^2
Tensile strength*	f_{pu}	270	ksi
Modulus of elasticity*	E_p	28500	ksi
Yield strength	f_{py}	243	ksi
	K	0.28	

d. Surfacing Material

Type	None	
Unit weight	0	kcf

e. Barrier

Type	Steel guard rail	
Unit weight	0.080	kips/ft/side

3. Box Beam Section Properties

Box beam section used	CB27-48		
Width of each box beam	b	48	in.
Height of each box beam	h	27	in.
No of box beams		8	nos

Section Geometry

No of webs in beam		2	nos
Depth of top flange	h_f	5.5	in.
Depth of bottom flange	h_c	5.5	in.
Width of end web	b_w	5.5	in.
Width of chamfer	w_h	3.0	in.

Section properties		Precast beam		Composite Beam	
Area	A	713.80	in^2	944.71	in^2
Moment of inertia	I	66222.00	in^4	115050.22	in^2
Distance from centroid to extreme bottom fiber	Y_b	13.39	in.	17.45	in^2
Distance from centroid to extreme top fiber	Y_t	13.61	in.	15.55	in^2
Section modulus for extreme bottom fiber	S_b	4945.00	in^3	6593.16	in^2
Section modulus for extreme top fiber	S_t	4866.00	in^3	9227.80	in^2

Layers of Prestressing Strands Provided		2		
Layer *	**Number**	**Position from extreme tensile face**		**Remark**
Layer 1	20	2	in.	Bottom flange
Layer 2	2	4	in.	Bottom flange
Layer 3	0	0	in.	Top flange
Layer 4	0	0	in.	Top flange
Debonded strands	0	0	in.	Top flange

*Note: Input layers from bottom to top of the beam

Longitudinal Reinforcement Bars

Layer	Bar no.	Area	Number	Position from extreme tensile face		Remark
Layer 1	#5	0.31	2	2	in.	Bottom flange

Shear Reinforcement

Zone	Distance to end of region from the support (ft)	Bar no.	Spacing (in.)	Area (in^2)
Region 1	4.00	#4	3	0.40
Region 2	30.00	#4	6	0.40

4. Load Rating

Load Rating Settings

Adopted beam for load rating*	Exterior beam
Riding surface condition*	Minor depression

Vehicle types	Dynamic allowance (IM)	Use strength limit state	Use service limit state
A. Design Vehicle	33%	YES	YES
B. Ohio Legal Vehicles	33%	YES	NO
C. Specialized Hauling Vehicles	33%	YES	NO
D. Emergency Vehicles	33%	YES	NO
E. AASHTO Legal Vehicles	33%	YES	NO
F. Permit Vehicles	20%	YES	NO
G. Custom Vehicle	33%	YES	NO

Input for Service Limit State

Average annual humidity	70%
Prestressing strands condition	Low to moderate corrosion
Concrete age at transfer	1 days
Concrete age at deck placement	28 days
Final concrete age	18250 days

Live Load Factors for Legal Vehicles

ADTT	Unknown
Live load factor for legal vehicles	1.45

Live Load Factors for Emergency Vehicles

EV2*	1.30
EV3*	1.10

Permit Load Condition

Permit type	Routine or Annual
Frequency	Unlimited crossings
Loading condition	Mixed with traffic
DF using	Two or more lanes

Live Load Factor for Permit Vehicles

Vehicle type	Live load factor
PL60T	1.40
PL65T	1.35

Add custom vehicle*	YES
No of axles	12

Axle No	Load (kips)	Distance from first axle (ft)
a	16.00	0.00
b	19.00	16.25
c	19.00	20.75
d	19.00	25.25
e	19.00	41.00
f	19.00	46.00
g	19.00	51.00
h	19.00	91.17
i	19.00	96.17
j	19.00	101.17
k	19.00	117.42
l	19.00	122.58

Custom Vehicle Load Condition

Permit type	Special or Limited crossing
Frequency	Multiple trips(<100 crossings)
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Custom Vehicle

Vehicle type	Live load factor
Custom vehicle	1.40

LOAD RATING RESULTS

Load Rating Results

Loading Type	GVW	Rating Factor
Ohio Legal Vehicles		
	Tons	
2F1	15	6.235
3F1	23	4.193
5C1	40	4.277
Specialized Hauling Vehicles		
SU4	27	3.693
SU5	31	3.366
SU6	34.5	3.025
SU7	38.75	2.786
Emergency Vehicles		
EV2	28.75	4.048
EV3	43	3.138
AASHTO Legal Vehicles		
Type3	25	4.182
Type3S2	36	4.069
Type3_3	40	4.428
Permit Vehicles		
PL60T	60	3.662
PL65T	65	2.998
Custom Vehicle		
Custom Vehicle 1	113	3.869

Design Vehicles

Loading Type	Rating Factor	
	Inventory	Operating
HL93	2.032	2.634

EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample bridge 16	Load rated by	SD	Date	5/13/2025
Construction year	2019	Checked by	YM	Date	5/13/2025

1. Bridge Information

Total span*	84.00	ft
Total width	28.00	ft

Single lane width	12.00	ft
End offset	6.00	in.
Width of bearing	5.00	in.
Barrier type	Steel guard rail	
Width of barrier	0.00	ft each side

Design span	83.00	ft
Road way width	28.00	ft

Composite /Non composite*	Composite	
Thickness of deck slab*	6	in.

Skew/Non skew*	Skew	
Skew angle*	20	Degrees

Surfacing material	Concrete	
Thickness	4.8	in.

Total number of diaphragm*	5	nos

Diaphragm number	Position from left support		Thickness	
1	0.00	ft	30.00	in.
2	18.24	ft	30.00	in.
3	38.07	ft	30.00	in.
4	57.91	ft	30.00	in.
5	83.00	ft	30.00	in.

Bridge appraisal rating	9
Condition factor	1.00

Additional beam weight	0%
Additional barrier weight	0%

2. Material Properties

a. Concrete

Required concrete compressive strength at transfer*	f'_{ci}	5.00	ksi
Specified concrete compressive strength for use in design*	f'_c	7.00	ksi
Deck concrete compressive strength *	f'_{c_deck}	4.50	ksi
Concrete unit weight*	w_c	0.15	kcf

Correction factor for source of concrete*	K_1	1	
Modulus of elasticity of concrete for precast beam at transfer	E_{ci}	4286.83	ksi
Modulus of elasticity of concrete for precast beam at service load	E_{c_beam}	5072.24	ksi
Modulus of elasticity of concrete for deck slab	E_{c_slab}	4066.84	ksi

b. Reinforcing Bars

Yield Strength*	f_y	60.00	ksi
Modulus of elasticity*	E_s	29000	ksi

c. Prestressing Strands

Type*	Seven-wire strand	Low-relaxation strand

Diameter	D_p	1/2	in.
Area*	A_p	0.167	in^2
Tensile strength*	f_{pu}	270	ksi
Modulus of elasticity*	E_p	28500	ksi
Yield strength	f_{py}	243	ksi
	K	0.28	

d. Surfacing Material

Type	Concrete	
Unit weight	0.15	kcf

e. Barrier

Type	Steel guard rail	
Unit weight	0.080	kips/ft/side

3. Box Beam Section Properties

Box beam section used	CB33-48		
Width of each box beam	b	48	in.
Height of each box beam	h	33	in.
No of box beams		7	nos

Section Geometry

No of webs in beam		2	nos
Depth of top flange	h_f	5.5	in.
Depth of bottom flange	h_c	5.5	in.
Width of end web	b_w	5.5	in.
Width of chamfer	w_h	3.0	in.

Section properties		Precast beam		Composite Beam	
Area	A	774.50	in^2	1005.41	in^2
Moment of inertia	I	111342.00	in^4	180857.97	in^2
Distance from centroid to extreme bottom fiber	Y_b	16.33	in.	20.85	in^2
Distance from centroid to extreme top fiber	Y_t	16.67	in.	18.15	in^2
Section modulus for extreme bottom fiber	S_b	6816.00	in^3	8675.24	in^2
Section modulus for extreme top fiber	S_t	6681.00	in^3	12426.44	in^2

Layers of Prestressing Strands Provided		2		
Layer *	**Number**	**Position from extreme tensile face**		**Remark**
Layer 1	16	2	in.	Bottom flange
Layer 2	12	4	in.	Bottom flange
Layer 3	0	0	in.	Top flange
Layer 4	0	0	in.	Top flange
Debonded strands	0	0	in.	Top flange

*Note: Input layers from bottom to top of the beam

Longitudinal Reinforcement Bars

Layer	Bar no.	Area	Number	Position from extreme tensile face		Remark
Layer 1	#5	0.31	2	2	in.	Bottom flange

Shear Reinforcement

Zone	Distance to end of region from the support (ft)	Bar no.	Spacing (in.)	Area (in^2)
Region 1	4.00	#4	6	0.40
Region 2	41.50	#4	6	0.40

4. Load Rating

Load Rating Settings

Adopted beam for load rating*	Exterior beam
Riding surface condition*	Minor depression

Vehicle types	Dynamic allowance (IM)	Use strength limit state	Use service limit state
A. Design Vehicle	33%	YES	YES
B. Ohio Legal Vehicles	33%	YES	NO
C. Specialized Hauling Vehicles	33%	YES	NO
D. Emergency Vehicles	33%	YES	NO
E. AASHTO Legal Vehicles	33%	YES	NO
F. Permit Vehicles	20%	YES	NO
G. Custom Vehicle	33%	YES	NO

Input for Service Limit State

Average annual humidity	70%
Prestressing strands condition	Severe corrosion
Concrete age at transfer	1 days
Concrete age at deck placement	28 days
Final concrete age	18250 days

Live Load Factors for Legal Vehicles

ADTT	Unknown
Live load factor for legal vehicles	1.45

Live Load Factors for Emergency Vehicles

EV2*	1.45
EV3*	1.45

Permit Load Condition

Permit type	Routine or Annual
Frequency	Unlimited crossings
Loading condition	Mixed with traffic
DF using	Two or more lanes

Live Load Factor for Permit Vehicles

Vehicle type	Live load factor
PL60T	1.40
PL65T	1.35

Add custom vehicle*	YES
No of axles	12

Axle No	Load (kips)	Distance from first axle (ft)
a	16.00	0.00
b	19.00	16.25
c	19.00	20.75
d	19.00	25.25
e	19.00	41.00
f	19.00	46.00
g	19.00	51.00
h	19.00	91.17
i	19.00	96.17
j	19.00	101.17
k	19.00	117.42
l	19.00	122.58

Custom Vehicle Load Condition

Permit type	Special or Limited crossing
Frequency	Multiple trips(<100 crossings)
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Custom Vehicle

Vehicle type	Live load factor
Custom vehicle	1.40

LOAD RATING RESULTS

Load Rating Results

Ohio Legal Vehicles		
Loading Type	**GVW**	**Rating Factor**
	Tons	
2F1	15	5.209
3F1	23	3.466
5C1	40	3.036
Specialized Hauling Vehicles		
SU4	27	3.023
SU5	31	2.720
SU6	34.5	2.435
SU7	38.75	2.221
Emergency Vehicles		
EV2	28.75	2.944
EV3	43	1.933
AASHTO Legal Vehicles		
Type3	25	3.375
Type3S2	36	2.917
Type3_3	40	2.980
Permit Vehicles		
PL60T	60	2.966
PL65T	65	2.061
Custom Vehicle		
Custom Vehicle 1	113	2.893

Design Vehicles		
Loading Type	**Rating Factor**	
	Inventory	**Operating**
HL93	1.001	1.966

C3: Multicell Box Beam Bridges

EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample bridge 17	Load rated by	SD	Date	5/13/2025
Construction year	1996	Checked by	YM	Date	5/13/2025

1. Bridge Information

Total span*	36.67	ft
Total width	44.00	ft

Single lane width	12.00	ft
End offset	10.02	in.
Width of bearing	5.00	in.
Barrier type	TSTRR	
Width of barrier	1.00	ft each side

Design span	35.00	ft
Road way width	42.00	ft

Composite /Non composite*	Composite	
Thickness of deck slab*	6	in.

Skew/Non skew*	Skew	
Skew angle*	30	Degrees

Surfacing material	None	
Thickness	0	in.

Total number of diaphragm*	3	nos

Diaphragm number	Position from left support		Thickness	
1	2.00	ft	28.00	in.
2	17.50	ft	28.00	in.
3	33.00	ft	28.00	in.

Bridge appraisal rating	9
Condition factor	1.00

Additional beam weight	0%
Additional barrier weight	0%

2. Material Properties

a. Concrete

Required concrete compressive strength at transfer*	f'_{ci}	4.00	ksi
Specified concrete compressive strength for use in design*	f'_c	5.50	ksi
Deck concrete compressive strength *	f'_{c_deck}	4.50	ksi
Concrete unit weight*	w_c	0.15	kcf

Correction factor for source of concrete*	K_1	1	
Modulus of elasticity of concrete for precast beam at transfer	E_{ci}	3834.25	ksi
Modulus of elasticity of concrete for precast beam at service load	E_{c_beam}	4496.06	ksi
Modulus of elasticity of concrete for deck slab	E_{c_slab}	4066.84	ksi

b. Reinforcing Bars

Yield Strength*	f_y	75.00	ksi
Modulus of elasticity*	E_s	29000	ksi

c. Prestressing Strands

Type*	Seven-wire strand	Stress-relieved strand

Diameter	D_p	1/2	in.
Area*	A_p	0.153	in^2
Tensile strength*	f_{pu}	270	ksi
Modulus of elasticity*	E_p	28500	ksi
Yield strength	f_{py}	229.5	ksi
	K	0.38	

d. Surfacing Material

Type	None	
Unit weight	0	kcf

e. Barrier

Type	TSTRR	
Unit weight	0.549	kips/ft/side

3. Box Beam Section Properties

Box beam section used	Custom		
Width of each box beam	b	48	in.
Height of each box beam	h	17	in.
No of box beams		11	nos

Section Geometry

No of webs in beam		3	nos
Depth of top flange	h_f	3.0	in.
Depth of bottom flange	h_c	4.5	in.
Width of end web	b_w	5.0	in.
Width of middle web	bw_m	3.0	in.
Width of chamfer	w_h	1.5	in.

Section properties		Precast beam		Composite Beam	
Area	A	464.30	in^2	724.81	in^2
Moment of inertia	I	16778.00	in^4	41911.16	in^2
Distance from centroid to extreme bottom fiber	Y_b	7.92	in.	12.26	in^2
Distance from centroid to extreme top fiber	Y_t	9.08	in.	10.74	in^2
Section modulus for extreme bottom fiber	S_b	2118.43	in^3	3418.05	in^2
Section modulus for extreme top fiber	S_t	1847.80	in^3	4314.90	in^2

Layers of Prestressing Strands Provided		1		
Layer *	**Number**	**Position from extreme tensile face**		**Remark**
Layer 1	10	1.75	in.	Bottom flange
Layer 2	0	0	in.	Top flange
Layer 3	0	0	in.	Top flange
Layer 4	0	0	in.	Top flange
Debonded strands	0	0	in.	Top flange

*Note: Input layers from bottom to top of the beam

Longitudinal Reinforcement Bars

Layer	Bar no.	Area	Number	Position from extreme tensile face		Remark
Layer 1		0.00			in.	Bottom flange

Shear Reinforcement

Zone	Distance to end of region from the support (ft)	Bar no.	Spacing (in.)	Area (in^2)
Region 1	1.50	#4	6	0.60
Region 2	17.50	#4	6	0.60

4. Load Rating

Load Rating Settings

Adopted beam for load rating*	Exterior beam
Riding surface condition*	Smooth surface

Vehicle types	Dynamic allowance (IM)	Use strength limit state	Use service limit state
A. Design Vehicle	33%	YES	YES
B. Ohio Legal Vehicles	33%	YES	NO
C. Specialized Hauling Vehicles	33%	YES	NO
D. Emergency Vehicles	33%	YES	NO
E. AASHTO Legal Vehicles	33%	YES	NO
F. Permit Vehicles	10%	YES	NO
G. Custom Vehicle	33%	YES	NO

Input for Service Limit State

Average annual humidity	70%
Prestressing strands condition	Severe corrosion
Concrete age at transfer	1 days
Concrete age at deck placement	28 days
Final concrete age	18250 days

Live Load Factors for Legal Vehicles

ADTT	4506
Live load factor for legal vehicles	1.43

Live Load Factors for Emergency Vehicles

EV2*	1.30
EV3*	1.10

Permit Load Condition

Permit type	Routine or Annual
Frequency	Unlimited crossings
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Permit Vehicles

Vehicle type	Live load factor
PL60T	1.40
PL65T	1.40

Add custom vehicle*	YES
No of axles	15

Axle No	Load (kips)	Distance from first axle (ft)
a	14.00	0.00
b	18.00	12.17
c	18.00	16.67
d	18.00	21.17
e	18.00	36.83
f	18.00	41.83
g	18.00	46.83
h	20.00	123.75
i	20.00	128.75
j	18.00	141.25
k	18.00	146.25
l	18.00	151.25
m	18.00	165.25
n	18.00	170.25
o	18.00	175.25

Custom Vehicle Load Condition

Permit type	Special or Limited crossing
Frequency	Multiple trips(<100 crossings)
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Custom Vehicle

Vehicle type	Live load factor
Custom vehicle	1.40

LOAD RATING RESULTS

Load Rating Results

Ohio Legal Vehicles		
Loading Type	GVW	Rating Factor
	Tons	
2F1	15	3.962
3F1	23	2.745
5C1	40	2.853

Specialized Hauling Vehicles		
SU4	27	2.493
SU5	31	2.373
SU6	34.5	2.153
SU7	38.75	2.034

Emergency Vehicles		
EV2	28.75	2.789
EV3	43	2.148

AASHTO Legal Vehicles		
Type3	25	2.959
Type3S2	36	3.104
Type3_3	40	3.627

Permit Vehicles		
PL60T	60	3.393
PL65T	65	3.081

Custom Vehicle		
Custom Vehicle 1	135	2.945

Design Vehicles		
Loading Type	Rating Factor	
	Inventory	Operating
HL93	1.159	1.947

EVALUATION OF PRECAST, PRESTRESSED ADJACENT BOX BEAM BRIDGES

Bridge ID	Sample bridge 18	Load rated by	SD	Date	5/13/2025
Construction year	2007	Checked by	YM	Date	5/13/2025

1. Bridge Information

Total span*	46.00	ft
Total width	40.00	ft

Single lane width	20.38	ft
End offset	6.00	in.
Width of bearing	8.00	in.
Barrier type	TSTRR	
Width of barrier	0.00	ft each side

Design span	45.00	ft
Road way width	40.00	ft

Composite /Non composite*	Composite	
Thickness of deck slab*	6	in.

Skew/Non skew*	Skew	
Skew angle*	10	Degrees

Surfacing material	None	
Thickness	0	in.

Total number of diaphragm*	4	nos

Diaphragm number	Position from left support		Thickness	
1	1.50	ft	18.00	in.
2	15.50	ft	18.00	in.
3	29.50	ft	18.00	in.
4	43.50	ft	18.00	in.

Bridge appraisal rating	9
Condition factor	1.00

Additional beam weight	2%
Additional barrier weight	0%

2. Material Properties

a. Concrete

Required concrete compressive strength at transfer*	f'_{ci}	5.00	ksi
Specified concrete compressive strength for use in design*	f'_{c}	7.00	ksi
Deck concrete compressive strength *	f'_{c_deck}	4.50	ksi
Concrete unit weight*	w_c	0.15	kcf

Correction factor for source of concrete*	K_1	1	
Modulus of elasticity of concrete for precast beam at transfer	E_{ci}	4286.83	ksi
Modulus of elasticity of concrete for precast beam at service load	E_{c_beam}	5072.24	ksi
Modulus of elasticity of concrete for deck slab	E_{c_slab}	4066.84	ksi

b. Reinforcing Bars

Yield Strength*	f_y	60.00	ksi
Modulus of elasticity*	E_s	29000	ksi

c. Prestressing Strands

Type*	Seven-wire strand	Low-relaxation strand

Diameter	D_p	1/2	in.
Area*	A_p	0.167	in^2
Tensile strength*	f_{pu}	270	ksi
Modulus of elasticity*	E_p	28500	ksi
Yield strength	f_{py}	243	ksi
	K	0.28	

d. Surfacing Material

Type	None	
Unit weight	0	kcf

e. Barrier

Type	TSTRR	
Unit weight	0.080	kips/ft/side

3. Box Beam Section Properties

Box beam section used	Custom		
Width of each box beam	b	48	in.
Height of each box beam	h	21	in.
No of box beams		10	nos

Section Geometry

No of webs in beam		3	nos
Depth of top flange	h_f	3.0	in.
Depth of bottom flange	h_c	4.5	in.
Width of end web	b_w	5.0	in.
Width of middle web	bw_m	3.0	in.
Width of chamfer	w_h	1.5	in.

Section properties		Precast beam		Composite Beam	
Area	A	536.26	in^2	767.17	in^2
Moment of inertia	I	29030.51	in^4	62270.04	in^2
Distance from centroid to extreme bottom fiber	Y_b	9.80	in.	14.07	in^2
Distance from centroid to extreme top fiber	Y_t	11.20	in.	12.93	in^2
Section modulus for extreme bottom fiber	S_b	2962.30	in^3	4424.44	in^2
Section modulus for extreme top fiber	S_t	2592.01	in^3	6008.43	in^2

Layers of Prestressing Strands Provided		1		
Layer *	**Number**	**Position from extreme tensile face**		**Remark**
Layer 1	12	2	in.	Bottom flange
Layer 2	0	0	in.	Top flange
Layer 3	0	0	in.	Top flange
Layer 4	0	0	in.	Top flange
Debonded strands	0	0	in.	Top flange

*Note: Input layers from bottom to top of the beam

Longitudinal Reinforcement Bars

Layer	Bar no.	Area	Number	Position from extreme tensile face		Remark
Layer 1	#5	0.31	2	2	in.	Bottom flange

Shear Reinforcement

Zone	Distance to end of region from the support (ft)	Bar no.	Spacing (in.)	Area (in^2)
Region 1	4.00	#4	3	0.60
Region 2	22.50	#4	6	0.60

4. Load Rating

Load Rating Settings

Adopted beam for load rating*	Exterior beam
Riding surface condition*	Smooth surface

Vehicle types	Dynamic allowance (IM)	Use strength limit state	Use service limit state
A. Design Vehicle	33%	YES	YES
B. Ohio Legal Vehicles	33%	YES	NO
C. Specialized Hauling Vehicles	33%	YES	NO
D. Emergency Vehicles	33%	YES	NO
E. AASHTO Legal Vehicles	33%	YES	NO
F. Permit Vehicles	10%	YES	NO
G. Custom Vehicle	33%	YES	NO

Input for Service Limit State

Average annual humidity	70%
Prestressing strands condition	Severe corrosion
Concrete age at transfer	1 days
Concrete age at deck placement	28 days
Final concrete age	18250 days

Live Load Factors for Legal Vehicles

ADTT	500
Live load factor for legal vehicles	1.30

Live Load Factors for Emergency Vehicles

EV2*	1.30
EV3*	1.30

Permit Load Condition

Permit type	Routine or Annual
Frequency	Unlimited crossings
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Permit Vehicles

Vehicle type	Live load factor
PL60T	1.40
PL65T	1.40

Add custom vehicle*	YES
No of axles	19

Axle No	Load (kips)	Distance from first axle (ft)
a	20.00	0.00
b	20.00	13.50
c	20.00	18.50
d	20.00	23.50
e	19.00	38.50
f	19.00	43.50
g	19.00	48.50
h	19.00	63.17
i	19.00	68.17
j	19.00	73.17
k	19.00	77.67
l	19.00	82.67
m	19.00	87.67
n	19.00	92.17
o	19.00	97.17
p	19.00	102.17
q	19.00	116.25
r	19.00	121.25
s	19.00	126.25

Custom Vehicle Load Condition

Permit type	Special or Limited crossing
Frequency	Multiple trips(<100 crossings)
Loading condition	Mixed with traffic
DF using	One lane

Live Load Factor for Custom Vehicle

Vehicle type	Live load factor
Custom vehicle	1.40

LOAD RATING RESULTS

Load Rating Results

Ohio Legal Vehicles		
Loading Type	GVW	Rating Factor
	Tons	
2F1	15	4.936
3F1	23	3.364
5C1	40	3.460

Specialized Hauling Vehicles		
SU4	27	3.002
SU5	31	2.787
SU6	34.5	2.518
SU7	38.75	2.350

Emergency Vehicles		
EV2	28.75	2.994
EV3	43	1.958

AASHTO Legal Vehicles		
Type3	25	3.469
Type3S2	36	3.796
Type3_3	40	4.158

Permit Vehicles		
PL60T	60	4.135
PL65T	65	3.664

Custom Vehicle		
Custom Vehicle 1	183	1.931

Design Vehicles		
Loading Type	Rating Factor	
	Inventory	Operating
HL93	1.428	2.090