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Samuel Ginn College of Engineering

Research Report

DEVELOPMENT OF NOTIONAL PERMIT VEHICLES FOR COMPLEX BRIDGE RATINGS IN ALABAMA

Submitted to

The Alabama Department of Transportation

Prepared by

Rafal Roszczenko, Aneta K. Luszczynska, Andrzej S. Nowak

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16. Abstract
Notional vehicles are useful in evaluation and rating of existing bridges as well as in design of new bridges. According to current trends, the number of overloaded trucks continues to increase. Alabama Department of Transportation (ALDOT) needs an effective and rational approach to include permit vehicles in the analysis. Therefore, the objective of this research was to develop a notional vehicle or group of notional vehicles for rating of complex bridges in Alabama representing permit loads. This project utilized ALDOT permit data collected between 2013 and 2024. Load effect simulations were performed using detailed 3D analysis. The finite element (FE) models for truss and arch bridges were developed in MIDAS Civil software. Dead load from the models was compared and validated based on the designers' hand calculations specified in the original technical drawings. The discrepancy between these two datasets was approximately 10%, which can be attributed to the exclusion of steel connection weight in the finite element models. This variance was considered acceptable for the purpose of this research. Then, live load calculations were performed by running almost 300,000 overloaded permits and permit candidates through every complex bridge FE model resulting in total number of 606,463,020 load points. Superload permits were excluded from this analysis. Midas Civil NX (2025) enabled powerful automation by utilizing dedicated Python libraries. Statistical parameters were computed for every notional vehicle candidate based on over 21 billion permit-to-candidate ratios for every considered truss bridge element which formed the basis for the selection criteria. Presented approach aims to reduce the number of vehicles required for complex bridge rating by introducing representative notional truck and helps with permits issuance process. Overloaded vehicles that produce a load effect lower than the developed notional vehicle, can apply for a permit without performing complex numerical analysis. The research was specifically focused on truss bridges, resulting in the development of notional permit vehicle tailored to this structural type.

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Andrzej S. Nowak (PI)
Rafal Roszczenko, Aneta K. Luszczynska

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ABSTRACT

Notional vehicles are useful in evaluation and rating of existing bridges as well as in design of new bridges. According to current trends, the number of overloaded trucks continues to increase. Alabama Department of Transportation (ALDOT) needs an effective and rational approach to include permit vehicles in the analysis. Therefore, the objective of this research was to develop a notional vehicle or group of notional vehicles for rating of complex bridges in Alabama representing permit loads. This project utilized ALDOT permit data collected between 2013 and 2024. Load effect simulations were performed using detailed 3D analysis. The finite element (FE) models for truss and arch bridges were developed in MIDAS Civil software. Dead load from the models was compared and validated based on the designers' hand calculations specified in the original technical drawings. The discrepancy between these two datasets was approximately 10%, which can be attributed to the exclusion of steel connection weight in the finite element models. This variance was considered acceptable for the purpose of this research. Then, live load calculations were performed by running almost 300,000 overloaded permits and permit candidates through every complex bridge FE model resulting in total number of 606,463,020 load points. Superload permits were excluded from this analysis. Midas Civil NX (2025) enabled powerful automation by utilizing dedicated Python libraries. Statistical parameters were computed for every notional vehicle candidate based on over 21 billion permit-to-candidate ratios for every considered truss bridge element which formed the basis for the selection criteria. Presented approach aims to reduce the number of vehicles required for complex bridge rating by introducing representative notional truck and helps with permits issuance process. Overloaded vehicles that produce a load effect lower than the developed notional vehicle, can apply for a permit without performing complex numerical analysis. The research was specifically focused on truss bridges, resulting in the development of notional permit vehicle tailored to this structural type.

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Chapter 1

INTRODUCTION

Vehicle traffic is continuously increasing, and the proportion of heavy vehicles to regular traffic is becoming more prevalent. Both the Weigh-in-Motion data and the number of permits issued are steadily increasing. While keeping such growth, an efficient method is needed for issued permits to ensure adequate safety and carrying capacity on bridges in Alabama.

The American Association of State Highway and Transportation Officials (AASHTO LRFD 2020) specifies notional vehicles for bridge design. However, they do not take into account the site-specific traffic for individual regions and states. There is a considerable variation in overload permit vehicles in different states. Most states have their own notional vehicles and use them to evaluate the carrying capacity of bridges for permit loads. Currently, Alabama does not have a notional vehicle to represent permit traffic.

Routine ratings of bridges should be typically conducted every 2 to 4 years except for special cases that require evaluation every year. This procedure is intended to provide adequate safety for users of the bridge and also help to identify problems at an early stage. This can greatly reduce maintenance costs and extend the service life of the bridge. The load evaluation process considering both design and permit vehicles is in accordance with AASHTO, particularly Manual for Bridge Evaluation (AASHTO MBE 2018). The procedure considers geometry of the bridge, type of materials and, importantly, the predicted traffic patterns. However, the analysis for simple bridges with the main structure consisting of linear girders is not complicated and can be conducted using the available software such as AASHTOWare. Bridge rating can be calculated for various vehicles in traffic flow with minimal computational effort and reduced calculation time. Additionally, more advanced software is available on the market which allows to determine bridge rating for complex structures, but consideration of a larger number of permit vehicles on many bridges is not an effective approach.

The primary objective of this project is to develop notional permit vehicles that accurately represent the load effects caused by the actual permit vehicles operating in Alabama, specifically for truss and arch bridges. The developed notional models can be used to improve the efficiency of evaluating complex bridge structures under permit traffic conditions. The expected result is a notional permit vehicle, which will support more consistent and effective bridge rating practices in Alabama.

Chapter 2

LITERATURE REVIEW

2.1 PERMIT TRAFFIC

Highway traffic can be considered as a combination of legal vehicles (satisfying FHWA Bridge Formula), grandfathered vehicles, permit vehicles and illegally overloaded vehicles. This study is focused on the development of notional vehicles for rating for permit traffic. The available permit data includes records from 2013 to 2024. The ALDOT Maintenance Offices issues 500-600 permits per day.

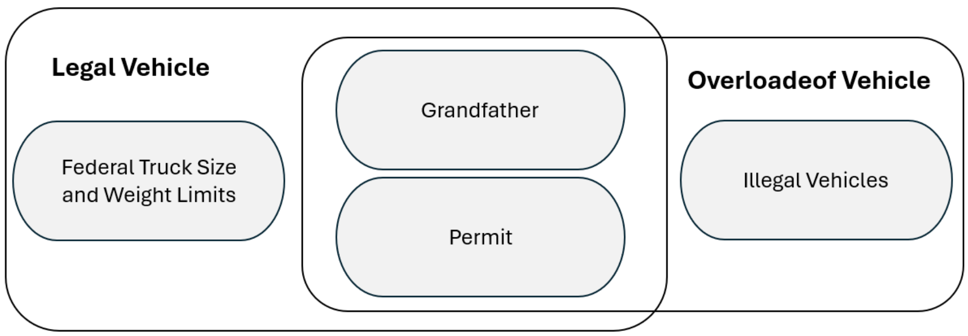


Figure 2-1. Traffic Structure.

2.2 AASHTO BRIDGE RATING

The AASHTO Manual for Bridge Evaluation outlines detailed procedures and standards for assessing bridge capacity to withstand traffic loads. Bridge rating allows to determine the maximum load a bridge can safely carry.

Bridge inspections and evaluations are regularly conducted every two to four years, depending on age, condition, structural type, ADTT and so on. The LRFR methodology consists of three distinct evaluations: (1) design, (2) legal, and (3) permit load rating. Inventory rating assesses the bridge capacity under standard design loads, while in operating rating a reduced live load factor is specified. Legal loads refer to vehicles that comply with federal truck size and weight regulations. The AASHTO MBE provides a set of standard legal vehicles, such as Type 3, 3S3, and 3-3 trucks, as well as specialized hauling vehicles (SU4–SU7). Permit loads are caused by overweight vehicles that have permission to operate on designated routes and bridges. Since AASHTO MBE does not define any standard notional permit vehicle, each state may develop its own truck model based on local traffic characteristics.

Evaluation of an existing bridge according to AASHTO MBE involves calculation of a rating factor (RF) using the following equation:

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

where:

C	-	live load carrying capacity
$(\gamma_{DC})(DC)$	-	factored dead load effect due to structural components and attachments
$(\gamma_{DW})(DW)$	-	factored dead load effect due to wearing surface and utilities
$(\gamma_P)(P)$	-	factored permanent loads other than dead load effect
$(\gamma_{LL})(LL + IM)$	-	factored live load effect with dynamic impact

A bridge is capable to carry live load if RF ≥ 1, otherwise the bridge is not adequate and has to be posted or strengthened. Evaluating bridge performance under overweight trucks can require the use of specialized software or analytical techniques.

Table 6A.4.5.4.2a-1—Permit Load Factors: γ_L

Permit Type	Frequency	Loading Condition	*DF*[a]	*ADTT* (one direction)	Load Factor by Permit Weight Ratio[b]: 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	>5,000	1.4	1.35	1.30
				=1,000	1.35	1.25	1.20
				<100	1.30	1.20	1.15
	Unlimited Crossings (Reinforced Concrete Box Culverts)[c]	Mix with traffic (other vehicles may be on the bridge)	One lane	All *ADTT*s	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 *ADTT*s	1.20		
	Multiple Trips (less than 100 crossings)	Mix with traffic (other vehicles may be on the bridge)	One lane	All *ADTT*s	1.40		

Notes:
[a] *DF* = LRFD-distribution factor. When 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 Article 6A.5.12.

Figure 2-2. Live Load Factors for Permit Vehicles According to AASHTO MBE.

AASHTO MBE does not define a specific notional permit truck but provides a table of live load factors applicable to various permit types. These factors, shown in Figure 2-2, range from 1.10 to 1.40 depending on the permit category and the ratio of permit load to legal load. It is important to recognize that live load factors serve as safety margins in the Load and Resistance Factor Rating (LRFR). The live load factor is determined in the reliability-based calibration to assure the minimum reliability index β, equal to 2.50 for the existing structures. Reliability index, β is 3.5 for newly designed structures.

2.3 ALDOT BRIDGE RATING

Bridge rating procedures in Alabama follow the standards and recommendations outlined in the AASHTO Manual for Bridge Evaluation (MBE). These procedures involve an assessment of bridge structural capacity and safety under live load.

The ALDOT Manual for Bridge Evaluation (ALDOT) specifies a set of vehicles to be used in routine bridge rating analyses. The Alabama rating vehicle set includes standard AASHTO trucks such as HS-20, HL-93, and 3S2, along with state-specific modified truck configurations. Figure 2-3 illustrates the vehicles utilized in bridge evaluation processes.

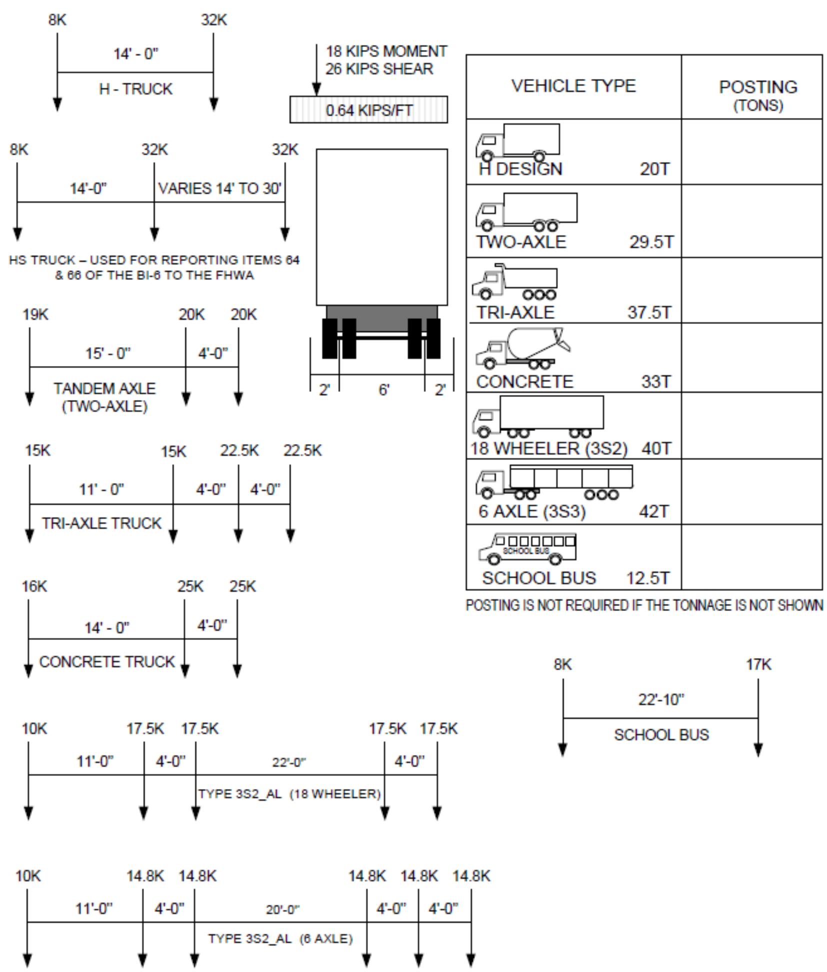


Figure 2-3. ALDOT posting vehicles (ALDOT).

There are currently no standardized permit vehicles designated for bridge evaluation purposes in Alabama. Therefore, it is necessary to develop representative notional vehicle or set of vehicles depending either on bridge type or length, that reflect the characteristics of permit traffic within the state. This process requires an extensive numerical analysis, including a detailed traffic data evaluation. Once developed, these notional permit vehicles can be effectively applied in bridge rating procedures involving permit loads.

The proposed methodology is designed to generate one or more representative vehicle configurations that streamline the rating process. By reducing the number of individual permit trucks considered in calculations, this approach supports more efficient and cost-effective evaluation of bridge capacity under permit load conditions.

2.4 NOTIONAL PERMIT TRUCKS

Due to the varying parameters of trucks and the specifics of each region, state DOTs developed their individual vehicles (Lou et al. 2018). As early as 1994 there was information about an overloaded vehicle evaluation for the state of Tennessee (Chou et al. 1999). Currently, many states have an individual solution for permit models. Especially in the eastern states of the country such as New York (Lou et al. 2018; New York State Department of Transportation 2021), New Jersey (New Jersey Department of Transportation 2016), Pennsylvania (Laman and Shah 2016), Connecticut (Connecticut Department of Transportation 2003), Virginia (Walus 2020), Ohio (Ghosh et al. 2011) and Florida (FHWA 2022). The remaining states on the west coast include Washington (FHWA 2022), Oregon and California (Lou et al. 2018). It demonstrates that the notional vehicles are widely used throughout the United States. The numerous states adopt similar methodologies for notional vehicle applications, particularly in assessing existing bridge structures which facilitates the integration of hundreds of permit vehicles within a unified computational model. In addition, California Department of Transportation also utilizes developed vehicles to assess fatigue and dynamic loading conditions (Caltrans 2020). Detailed reliability-based procedure for development of notional permit truck for Florida using simple and two equal span continuous bridges was described by Stawska (2021). Examples of notional vehicles used in various states are shown in Figure 2-4.

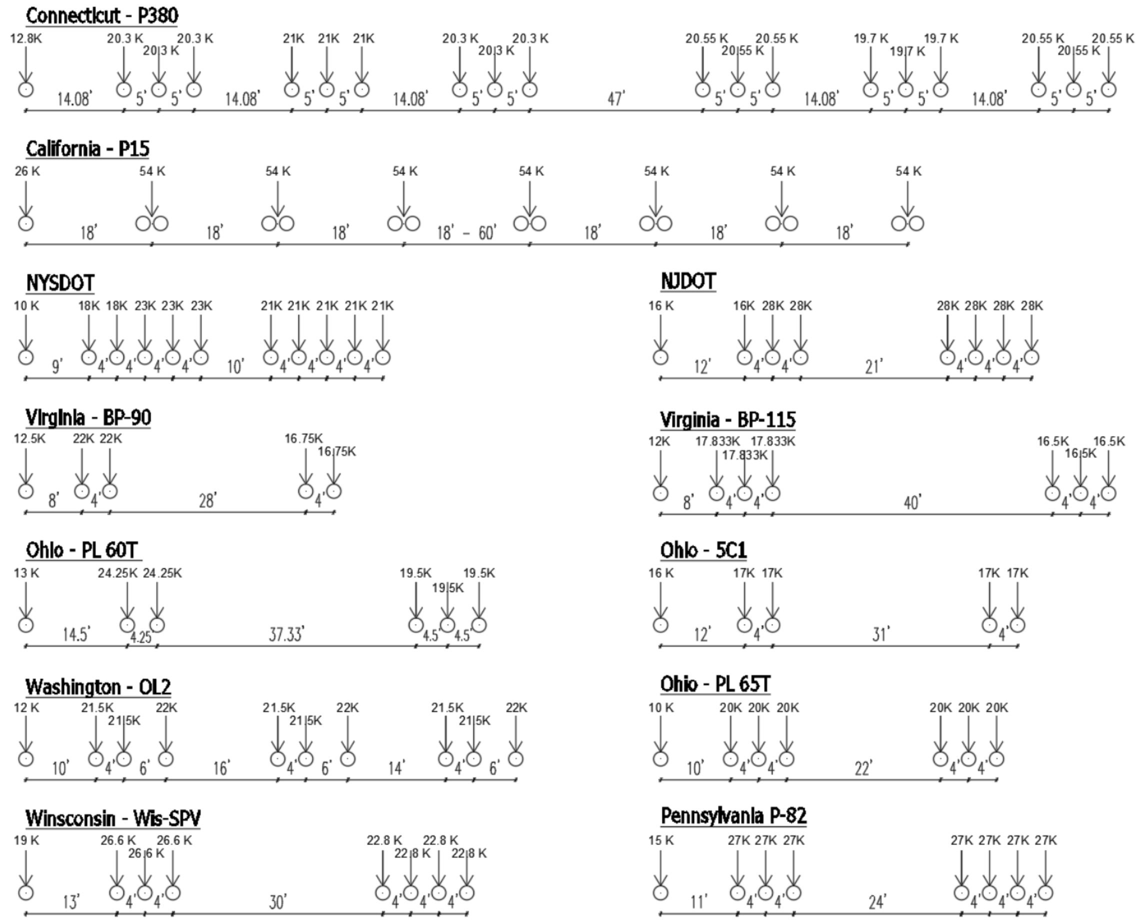


Figure 2-4. Examples of notional vehicles in different states (Lou et al. 2018).

Most of these notional vehicles were developed for simple girder bridges rather than complex bridges. Wyoming notional truck was derived on the basis of single-span and two-spans with different lengths ranging from 30 to 200 ft (Baker and Puckett 2016). The vehicle for Wisconsin DOT was analysed for simply supported, 2-span, and 3-span continuous girders Tabatabai and Zhao 2012). In all mentioned studies, the analysis was limited to 2D beam elements. It is widely recognized that existing bridges, particularly those featuring complex designs, cannot be accurately represented by a single beam model. Correia et al. (2006) highlighted this limitation and proposed the use of an additional precast-arch model. Furthermore, research considering the transverse direction has been conducted by Ghosn et al. (2011), utilizing variable spacing between 4 and 12 feet in the transverse direction alongside variable lengths longitudinally. While the literature outlines evaluation approaches implemented in other states, there is a lack of three-dimensional analysis of complex structures. Consequently, there is a need to develop a notional vehicle for analyzing complex bridges in Alabama using 3D modelling which do not currently exist.

2.5 RELIABILITY BASED-METHODS

The acceptability criterion for load and resistance factors in both AASHTO Specifications and the MBE is determined by their alignment with the target reliability index. Load and resistance factors are established through a reliability-based calibration procedure (Nowak 1999). The target reliability index for newly designed steel and concrete elements is set at 3.5, whereas for existing bridge components, it is set at 2.5.

The calibration procedure developed for determining the live load rating factor is outlined as follows. It begins with the selection of representative complex bridge types, such as trusses and arches. Limit state functions are then formulated, and relevant load and resistance parameters are identified. Appropriate statistical models are assumed for both load and resistance, where permit load is used to represent the live load. Reliability indices for selected bridge components are subsequently calculated using either Cornell's formula or Monte Carlo simulations (Nowak and Collins 2012). The target reliability index for permit vehicles is set at $\beta_T = 2.5$. Based on this criterion, the corresponding live load factor is derived for candidate of the notional permit vehicle. This approach aligns with the calibration methodologies established in the AASHTO MBE.

Chapter 3

PERMIT DATA

3.1 PERMIT STRUCTURE IN ALABAMA

In the state of Alabama, as in other states, the entity responsible for issuing permits for oversized and overweight vehicles is the Department of Transportation. The Alabama Department of Transportation (ALDOT) has established a set of laws and regulations governing the operation of such vehicles. Permits in Alabama are issued through ALPASS, the state's automated online system for managing oversize and overweight (OS/OW) vehicle permits. Any vehicle that does not comply with standard traffic regulations must obtain a travel permit. Table 3-1 presents the types of permits currently in effect, along with their descriptions. The numerical codes shown in the table, which correspond to ALDOT's official nomenclature, have been adopted throughout this report and are used in place of the full permit type names for consistency and clarity.

Table 3.1. ALDOT permit types.

Permit Type	Number	Description
A1-Equipment OS	110	Oversized equipment permits
A1-House	111	Oversize stick-built house
A2-Equipment OW	112	Overweight equipment permit
A2-Sealed Container	113	Overweight shipping container
A3-Equipment OS/OW	114	Oversized and Overweight equipment permit
B1-Mobile Homes	120	Oversized mobile homes
C1-Modular Homes/Boats	130	Oversized boast or portable buildings
A-Annual	210	Annual permit for equipment
B-Annual	220	Annual permit for mobile home
C-Annual	230	Annual permit for modular homes boat or portable building
D-Annual	240	Annual permit for sealed ocean-going container
E-Annual	260	Annual permit for construction project equipment
F-Annual	300	Annual permit for emergency tow
A-Routing Authorization	310	Routing authorization for oversized and overweight equipment
B-Routing Authorization	320	Routing authorization for mobile homes

In Alabama, as in other states, the authority responsible for issuing permits for oversized and overweight vehicles is the Department of Transportation. The Alabama DOT has established a set of laws and regulations governing the operation of such vehicles. Permits are issued through ALPASS, the state's automated online system for managing oversize and overweight (OS/OW) vehicle permits. Any vehicle that does not conform to standard traffic requirements must apply for an appropriate travel permit. Table 3-1 details the current permit types and associated descriptions. For clarity and consistency throughout this report, the numerical codes from ALDOT's official nomenclature are used in place of full permit names.

3.2 PERMIT DATA AND QUALITY CONTROL

Permit data covering the years 2013 to 2104 was provided by ALDOT. This dataset contains information such as permit type, trip origins and destinations, approved travel routes, axle spacing and weights, as well as the gross vehicle weight (GVW) of permitted vehicles. The responsibility for applying for permits and entering related data into Alabama's consent sheet lies with the company or driver handling the transport of overloaded trucks. The database serves as an official record of registered vehicles. In most instances, entries are correctly reported and do not require additional filtering. However, some records within the dataset are incomplete or lack certain fields in the table which are necessary for load computations. To ensure the integrity of subsequent calculations, basic filters are applied to exclude incomplete or questionable records. This step is particularly important in the initial phase of the research since incorrect elimination of data may result in significant underestimation or overestimation of traffic-induced load effects on bridges (Luszczynska et al. 2025). The comprehensive data assessment procedure is illustrated in Figure 3-1.

An important criterion incorporated into the filtering process was the minimum axle spacing. Due to the units used in the permit form, it is likely that some drivers entered incorrect values. A threshold of 3 feet was established as the minimum allowable distance between axles, and vehicles not meeting this criterion were excluded from the dataset. This filter is crucial for calculations, as unrealistically short axle spacing would result in an excessive concentration of loads within tandem configurations, which is technically infeasible. An additional filter was applied to remove duplicate records. This step eliminated identical vehicles whose load effects would be the same, thereby significantly reducing the computational time required for processing such a large volume of data.

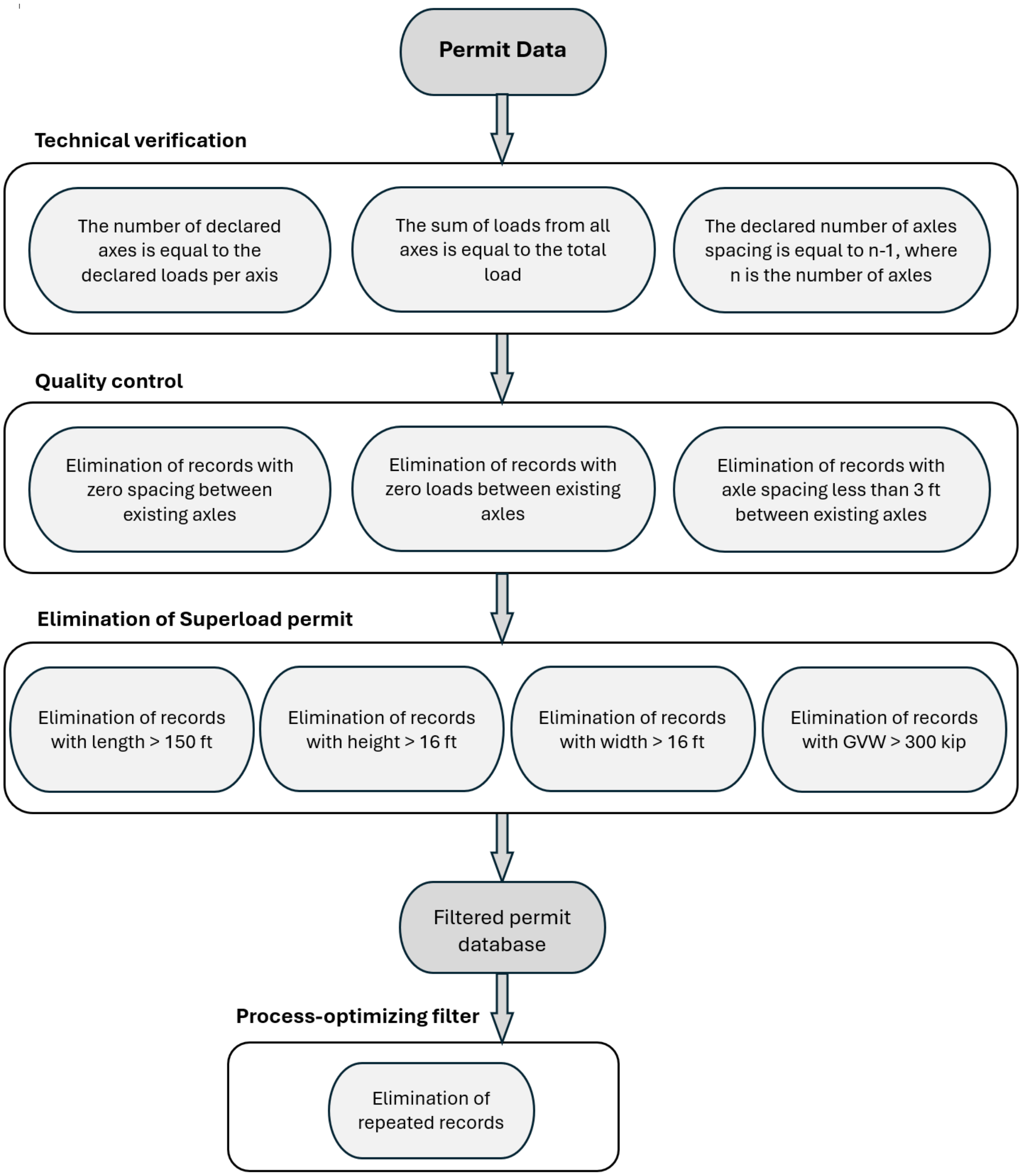


Figure 3-1 Flowchart of data selection for permit load analysis.

An important criterion in the filtering process was setting a minimum axle spacing. Given the units specified on the permit application, it is likely that some values were entered incorrectly. To address this, a threshold of 3 feet was set as the minimum acceptable distance between axles. Any vehicles failing to meet this requirement were excluded from the dataset. This threshold is essential for accurate calculations, as unrealistically short axle spacing would result in excessive concentration of loads within tandem configurations which is technically unfeasible. Furthermore, a duplicate records filter was applied, removing identical vehicle entries whose load effects would be identical.

This step considerably reduced the computational efforts required for processing the massive volume of data.

3.3 QUANTITATIVE OVERVIEW OF PERMIT DATA

Dataset shared by Alabama Department of Transportation in Excel format encompasses the years 2013 through 2024. Filtering was performed according to the specifications described in Figure 3-1. The most commonly issued permit types in Alabama were identified and are presented in Figure 3-2. In addition, the number of permits issued on annually basis was studied. Permit statistics for 2013 to 2024 are shown in Figure 3-3. Between 2015 and 2019, a steady increase in the number of issued permits was observed. In 2020, there was a significant decline, which can likely be attributed to the COVID-19 pandemic. Following 2020, the upward trend resumed, reaching levels previously observed between 2015 and 2017. Except for year 2022, annual growth has exceeded 5% since 2020. In 2024, the growth rate reached 7.4%, and data from the first quarter of 2025 suggest that this trend will persist. Furthermore, the number of issued permits has increased by roughly 22% since 2020 and nearly 40% compared to statistics from 2015.

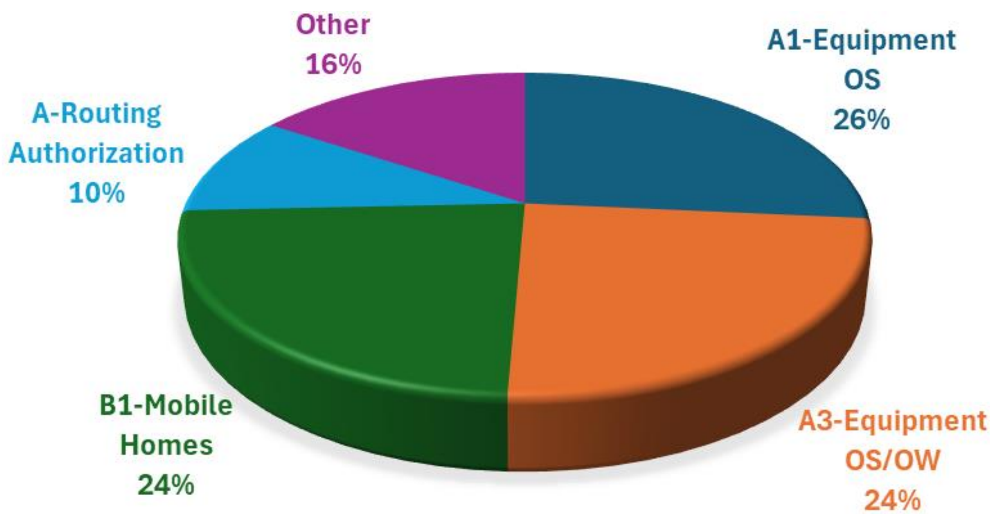


Figure 3-2. Distribution of permit types as a percentage of total permits issued in 2024.

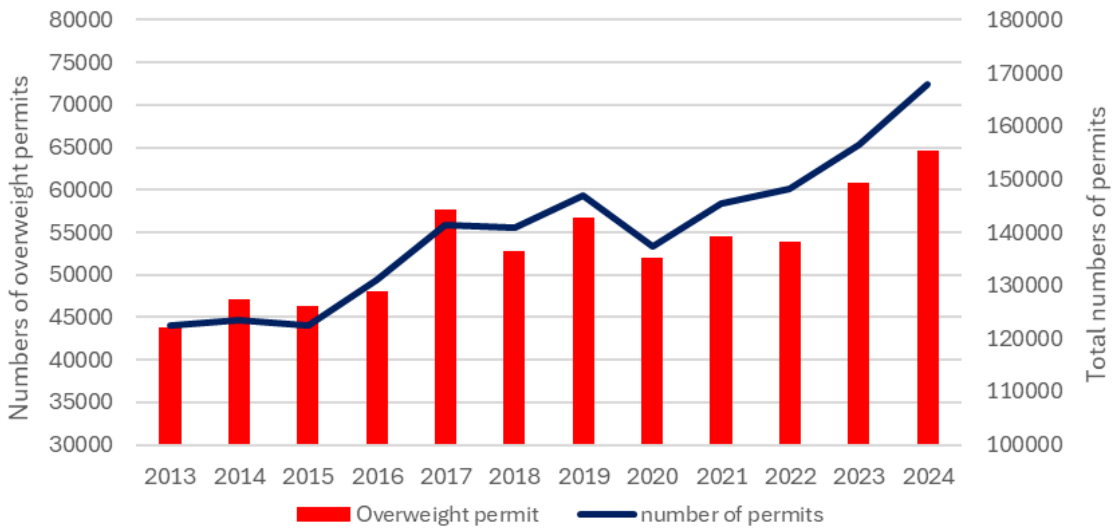


Figure 3-3. Number of permits issued in the years 2013-2024 and number of overweight permits.

The ongoing project focuses on overweight vehicles with permit types 112, 113, 114, and 310. These records contain full load data on truck configuration, such as axle weights and spacings, allowing for thorough analysis. Figure 3-4 illustrates the distribution of the primary permit types considered in this research. For each group, the number of issued permits is presented within the last decade. Notably, there is a steady increase in the A-3 Equipment OS/OW category, except for a temporary decline in 2021.

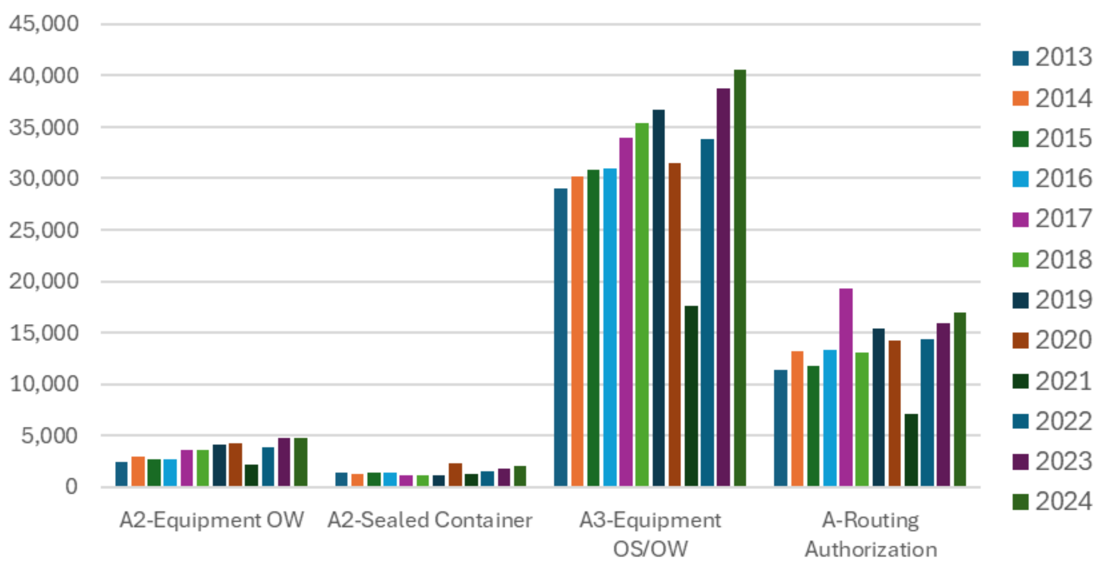


Figure 3-4. Number of annually issued permits by year (2013-2024).

Permit issuance in this category has resumed its growth, aligning once again with trends seen before 2020. Across all four permit types examined, significant increases were noted throughout the study period: type 112 grew by 62%, type 113 by 70%, type 114 by 34%, and type 310 by 28%. Figure 3-5 illustrates the percentage breakdown for each permit type. The data indicates that the proportion of overweight vehicles has remained relatively stable over the years, except for 2022, when a noticeable deviation can be observed.

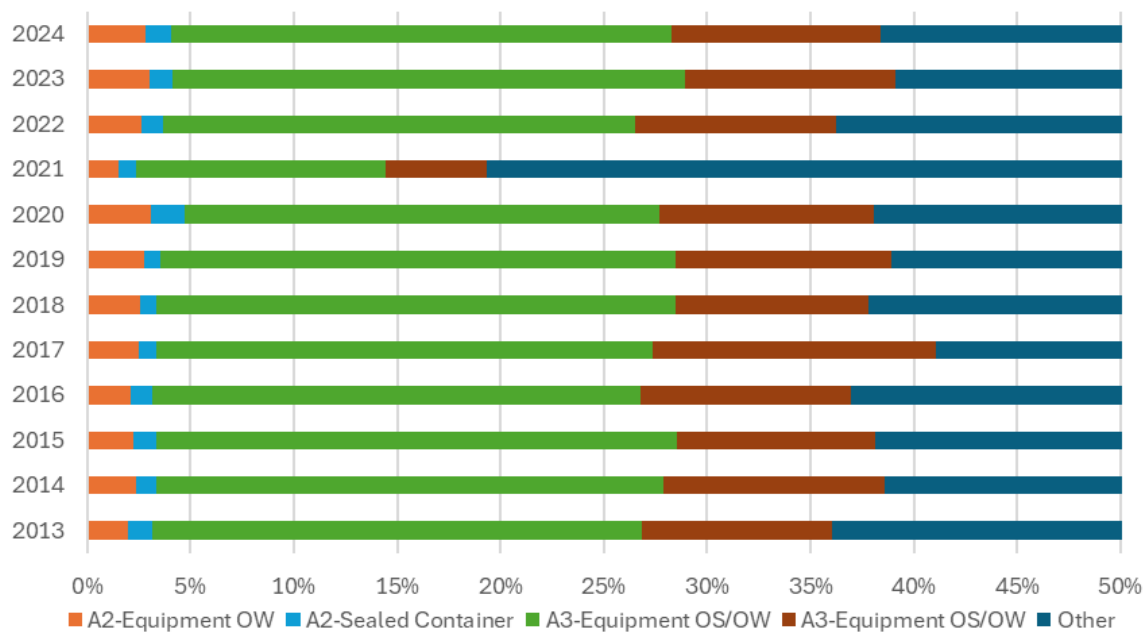


Figure 3-5. Percentage distribution of the analyzed types in the total number of issued permits.

3.4 SUPERLOAD PERMITS

In Alabama, permits for over-dimensional vehicles and excessive load combinations are issued. Trucks exceeding one or more thresholds established by Alabama DOT (Table 3-2), related to gross vehicle weight and certain dimensional limits, are classified as “Superload”. Due to their unique axle configurations and impact on infrastructure, a refined analysis is required prior to approval in order to determine whether such permits can be granted. Therefore, after discussion with ALDOT, it was decided that vehicles falling under the Superload category are excluded from the notional vehicle development process. These cases represent exceptional occurrences and would distort the results derived from the permits dataset, which is intended to reflect typical vehicle configurations and loading conditions within the state.

Table 3.2. Thresholds for Superload permits in Alabama.

Width	16 feet
Height	16 feet
Length	150 feet
Weight	300,000 lbs. gross weight

3.5 STABILITY OF DATA

Process of developing the notional permit vehicle for rating is based on data from previous years. It is necessary to predict the future traffic trends in comparison to existing records. Over the past five years, the number of permits has increased dynamically. During development of candidate for notional permit vehicle, data from 2020 to 2024 was used. Furthermore, the data was divided by individual years and types. The variability of live load effect by year and permit type was very low. Only a few individual cases at the upper and lower tails of distribution revealed minor differences. However, no specific patterns can be identified. Detailed distributions of axial forces, shear forces, and bending moments are presented in Appendix B.

The stability of the data suggests that the rise in permit numbers seen in Figure 3-3 does not impact how live load effects are distributed on bridges. It's important to note that this trend excludes superload vehicles, as they are not part of the research project or this assumption. Additionally, it's reasonable to believe that truck axle configurations and weight limits for single, tandem, and tridem axles will likely remain unchanged in the near future.

It is assumed that traffic trends remain consistent, supporting the continued use of the developed notional permit vehicles for rating purposes over the long term. However, if legal load limits, the definition of Superload vehicles, or other influential factors change and were not accounted for in this project, updating the notional permit vehicles or confirming their accuracy will be required.

Chapter 4

COMPLEX BRIDGES IN ALABAMA

4.1 BRIDGE STATISTICS

The National Bridge Inventory (NBI) serves as a critical source of information on bridges across the United States. This extensive database captures key details related to bridge design, structural condition, and operational characteristics. It includes data on dimensions, structural components, traffic volumes, maintenance history, inspection outcomes, and performance ratings. For the purpose of this study, the 2022 NBI dataset was utilized to assess Alabama's bridge infrastructure. The NBI database reports that Alabama has a total of 9,738 bridges and 6,443 culverts.

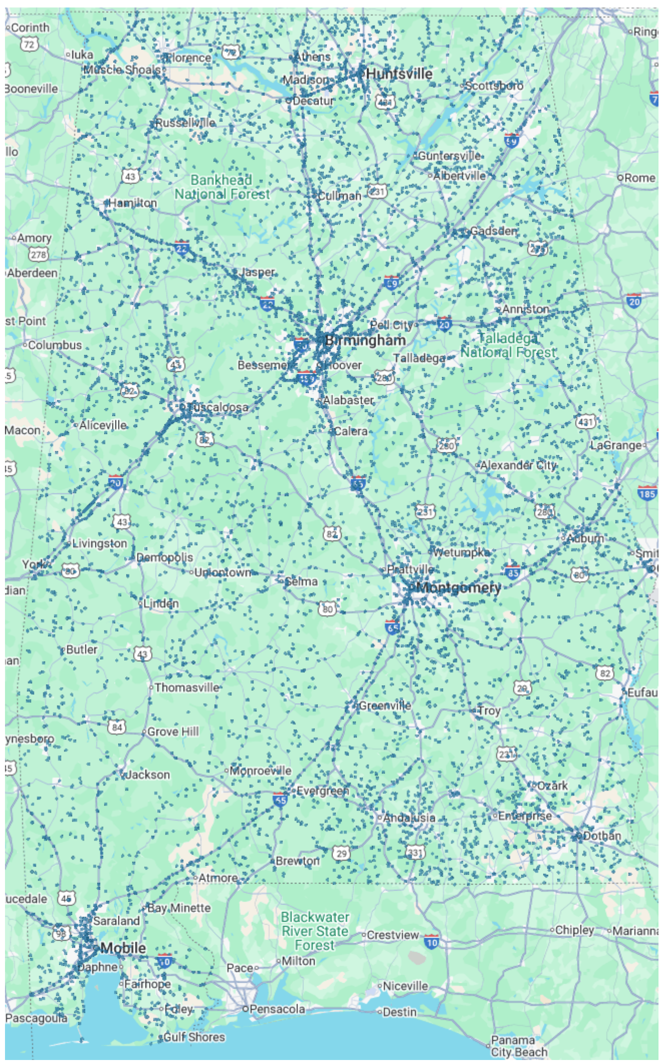


Figure 4-1 Bridges in Alabama.

Figure 4-2 illustrates the predominant structural categories of bridges. Beam girder bridges account for approximately 50% of all structures, followed by channel bridges at 23%, and T-beam bridges at 20%. Additionally, an assessment of construction materials was conducted, and Figure 4-3 displays the distribution of bridges based on selected material types.

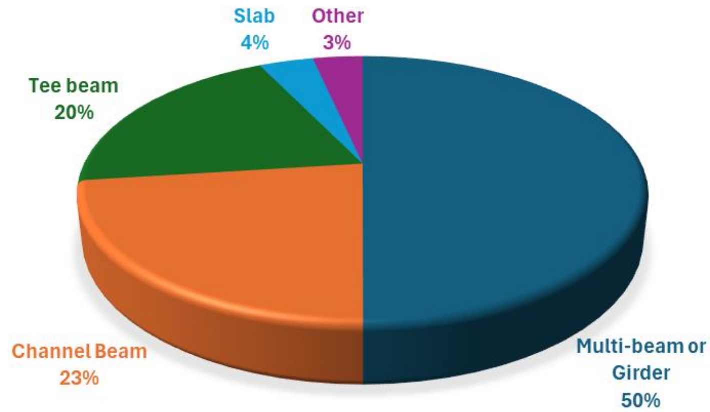


Figure 4-2. Distribution of bridge structural type in Alabama.

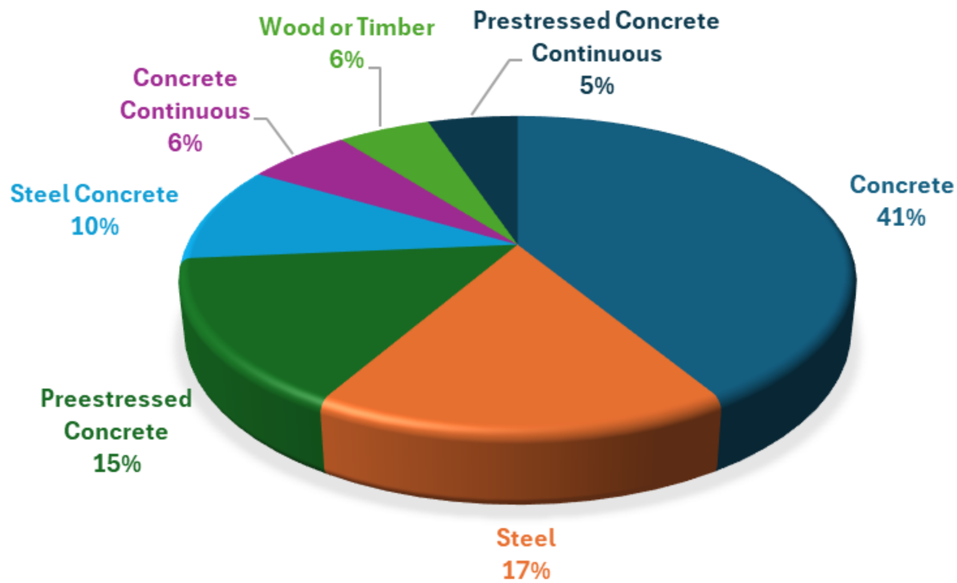


Figure 4-3. Distribution of main span material type in Alabama.

4.2 COMPLEX BRIDGES

Complex bridges do not represent the majority of existing structures, but they require special attention during load rating and maintenance procedures. Due to their structural complexity, the distribution of internal forces is not typical and often cannot be simplified into basic calculation models. Complex bridges in Alabama can be divided into several types. Figure 4-4 illustrates the percentage distribution of these bridges, while Figure 4-5 presents the division by material type of construction. Complex bridges have been identified based on NBI database, with over half categorized as truss bridges and nearly half are constructed using steel, as illustrated in Figure 4-5.

In the analysis of bridge types and the subsequent development of the notional vehicle, it was essential to consider several factors such as:

- support conditions,
- number of spans,
- types of connections.

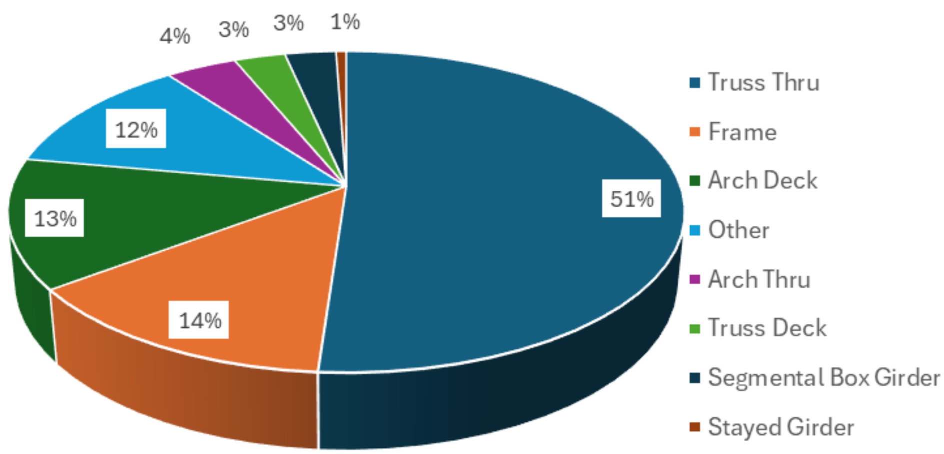


Figure 4-4. Distribution of structural types for complex bridges in Alabama.

The span length distribution of complex bridges differs significantly from that of the general bridge population in Alabama. Complex bridges, such as truss and arch types, often feature much longer spans due to their structural capabilities and design flexibility. In contrast, girder bridges are typically limited in span length by economic considerations and construction feasibility. While some complex bridges with shorter spans exist, these are often older structures built at a time when "long-span" girder bridge solutions were not yet widely available. Therefore, when selecting representative bridges for this project, it is important to account for these differences. This analysis provides a foundation for identifying key characteristics of complex bridges in Alabama that are relevant to the development of the notional vehicle.

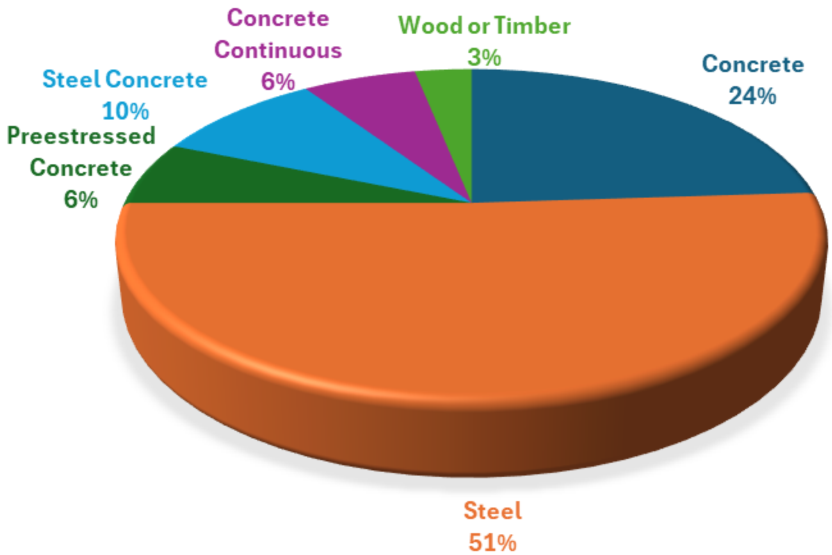


Figure 4-5. Distribution of main span material type for complex bridges.

4.3 TRUSSES AND ARCHES

As part of this research report, a notional vehicle was developed with a focus on two primary bridge types, as established with ALDOT during the initial phase of the project. Truss and arch bridges, being complex structures, require comprehensive analysis to accurately account for internal forces, unlike simpler girder bridges. A detailed evaluation of these bridge types is essential for the proper design of the notional vehicle. The analysis considered several factors including structural type, span length, construction material, geographic location, and road classification. Due to the predominance of permit vehicle routes and the localized nature of certain roads, some bridges were excluded from the research. Figure 4-6 shows the location of the bridges taken into consideration in current research project.

Selection of representative structures is a critical step in the development of the notional vehicle. To support this process, a detailed analysis of truss and arch bridges in Alabama was conducted to gather the necessary data. Figure 4-7 presents the percentage distribution of bridge types within the truss and arch categories according to National Bridge Inventory (NBI). This summary helps identify key characteristics for further analysis.

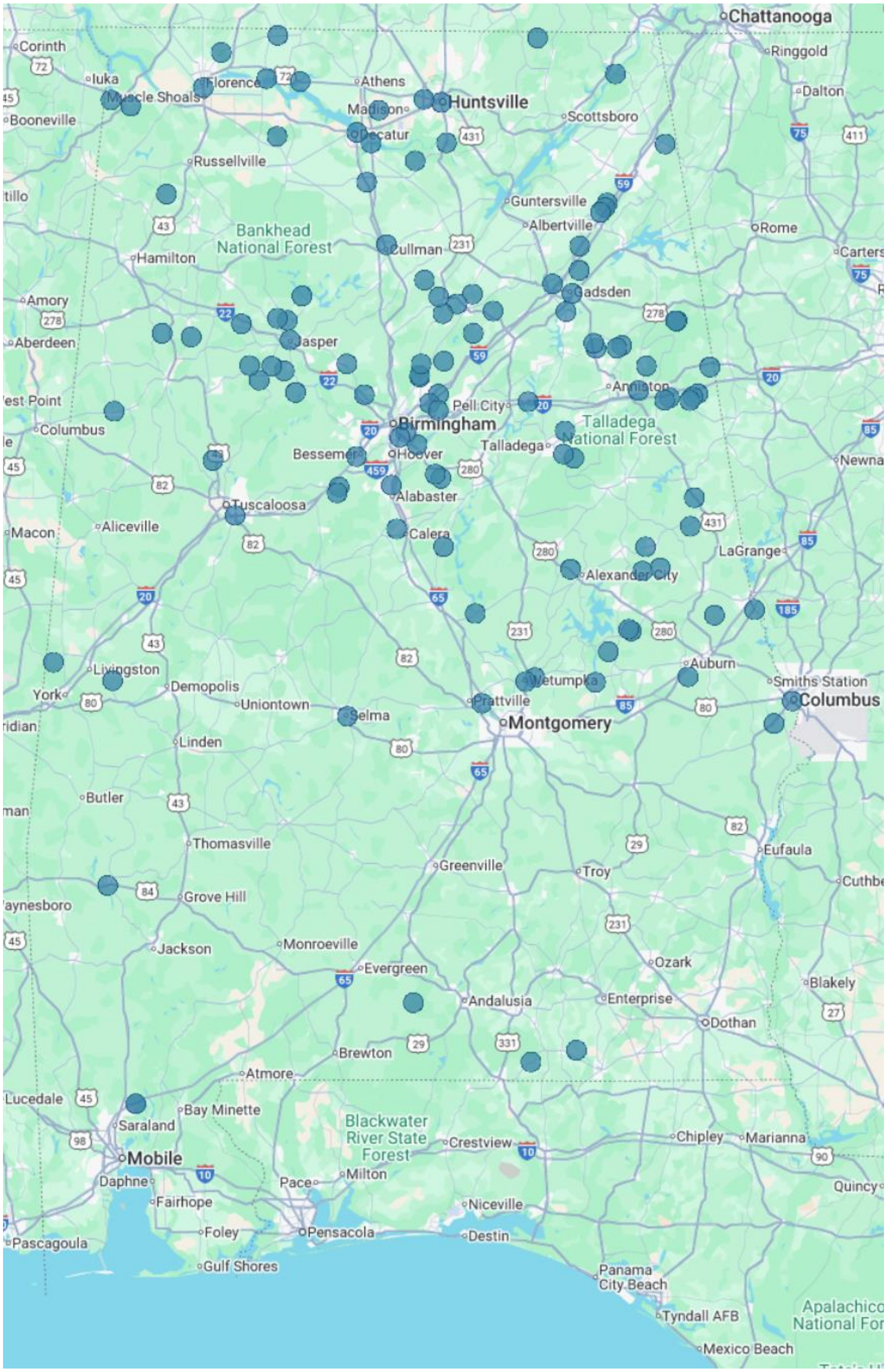
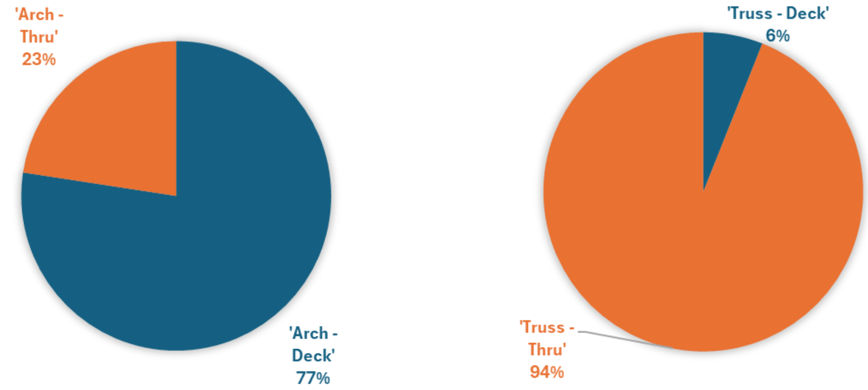
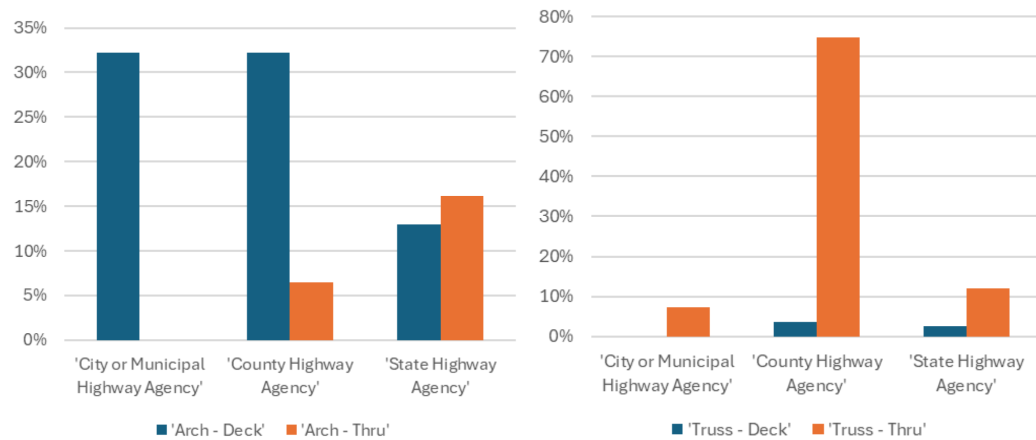


Figure 4-6. Locations of truss and arch bridge structures across Alabama.



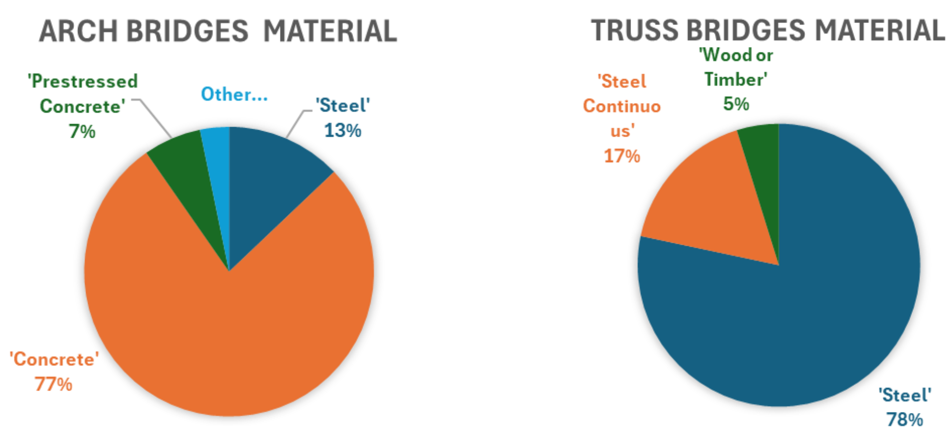
(a) (b)

Figure 4-7. Distribution of bridge structures by type: (a) arch and (b) truss.



(a) (b)

Figure 4-8. Distribution of bridge owner agency for: (a) arches and (b) trusses.



(a) (b)

Figure 4-9. Distribution of bridge material for: (a) arches and (b) trusses.

Another important distinction concerns the ownership of the structure or, more precisely, its jurisdictional location. It is important to note that not all bridge types are loaded by permitted traffic. Figure 4-8 shows how arch and truss bridges are distributed according to ownership, while Figure 4-9 displays distribution by material type which is important both for categorizing the bridges in present research and for choosing the appropriate load factor. Based on Figure 4-9, it can be observed that the type of structure is determined by material: trusses are typically made of steel, while arches are usually constructed from concrete. However, in this particular instance, one out of every ten bridges is made from steel.

Another important parameter considered in the analysis is the main span length of arch and truss bridges presented in Figures 4-10 and 4-11 accordingly. In both cases, there is a noticeable concentration of spans below 100 ft. However, numerous long-span structures are also present. This is especially evident in the case of arch bridges, where two structures feature spans of 800 ft.

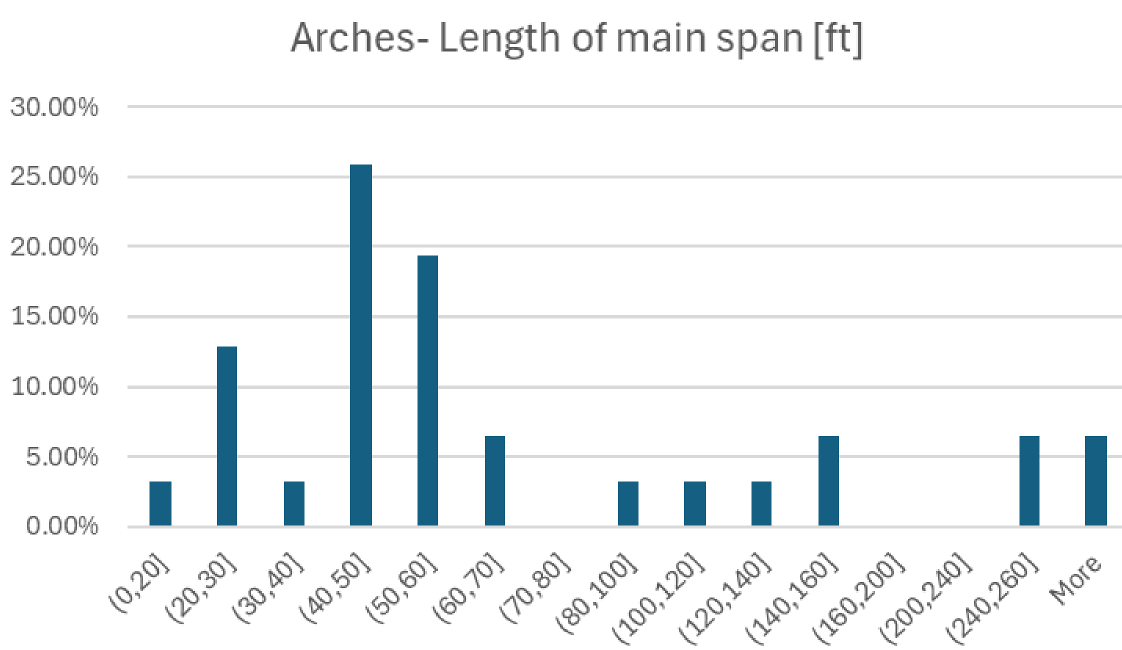


Figure 4-10. Main Span Length Distribution for Arch Bridges.

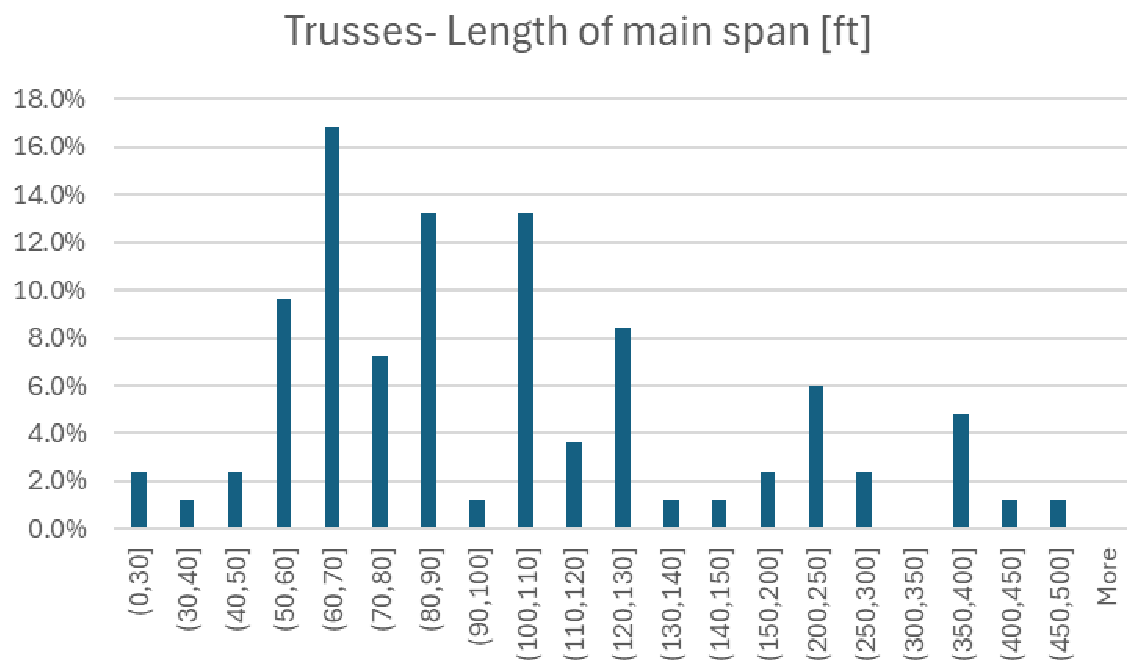


Figure 4-11. Main Span Length Distribution for Truss Bridges.

This statistic should be interpreted with caution, as it aggregates data from all bridge structures without considering roadway classification. Based on route data, it can be observed that the majority of heavy vehicle traffic occurs on state and interstate highways. In contrast, traffic on local routes is generally limited to permitted vehicles due to the geometric and structural constraints of the roads and bridges.

Figure 4-12 illustrates the distribution of main span lengths for truss and arch bridges owned by the State Highway Agency. Presented data reveals a significant deviation in proportions when compared to the overall statistical trends. For arch bridges, the distribution encompasses both short spans (less than 100 ft) and long-span structures. In contrast, truss bridges predominantly feature spans exceeding 200 ft.

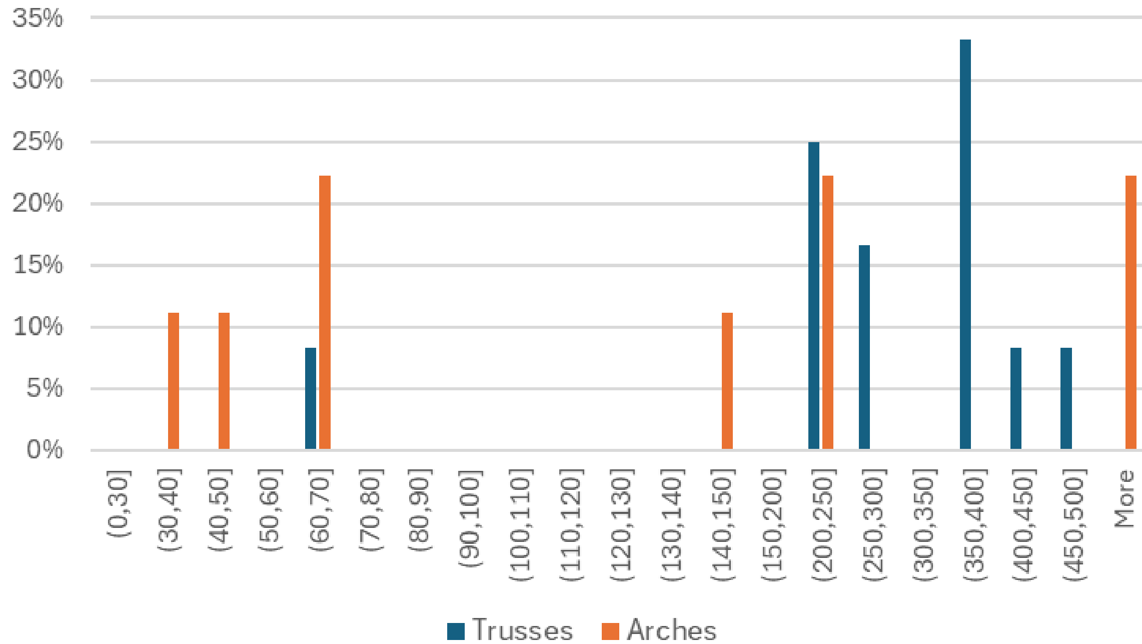


Figure 4-12. Main Span Length Distribution for State Highway Agency Bridges.

Another source of complex bridge data provided by ALDOT included both inspection reports and technical drawings. These documents served as the basis for a detailed analysis aimed at identifying key characteristics of complex bridges. The extracted information was subsequently used for development of statistical summaries of selected bridge parameters, such as span lengths and structural types.

Chapter 5

DEVELOPMENT OF NOTIONAL PERMIT CANDIDATES

5.1 INTRODUCTION

Candidates for notional permit vehicles should be suitable for all bridge structures within the selected category. The vehicle configuration was developed based on criteria described in detail in the following subsection. However, it was assumed that the notional vehicle does not need to correspond to any existing or realistic vehicle. This approach allows for flexibility in design while ensuring compatibility with the structural characteristics of the bridges under consideration.

5.2 HEAVY TRAFFIC CHARACTERISTICS

The development of notional vehicle candidates was based on a detailed analysis of permit data collected over the past five years. The comparison focused on key characteristics such as gross vehicle weight (GVW) of trucks, individual axle spacings and axle weights. Probabilities were assigned to each category to reflect their frequency and relevance. Additionally, axle spacings within tandem and tri-axle configurations were considered to better assess potential load concentration scenarios. Figure 5-1 illustrates the annual distribution of gross vehicle weight, confirming minimal variation across the years. Similar analyses were conducted for other parameters, yielding consistent conclusions.

Figure 5-2 presents the distribution of axle counts for permitted vehicles. The data indicate limited variability across the years, with seven-axle vehicles representing the highest percentage contributing to total distribution. For heavier vehicles, the number of axles typically ranges between 10 and 13. However, their overall proportion is significantly lower compared to seven-axle configurations.

Figure 5-3 shows the annual distribution of steering axle load, while Figure 5-4 illustrates the spacing between the first and second axles. In Figure 5-4, several peaks are observed: at shorter distances specifically 6 ft and 9 ft and at higher frequencies, each exceeding 10% of the total, for spacings between 15 and 18 ft. The distribution of first axle loads is concentrated around 12 kips and 14 kips, with smaller peaks also occurring at 18 kips and 20 kips.

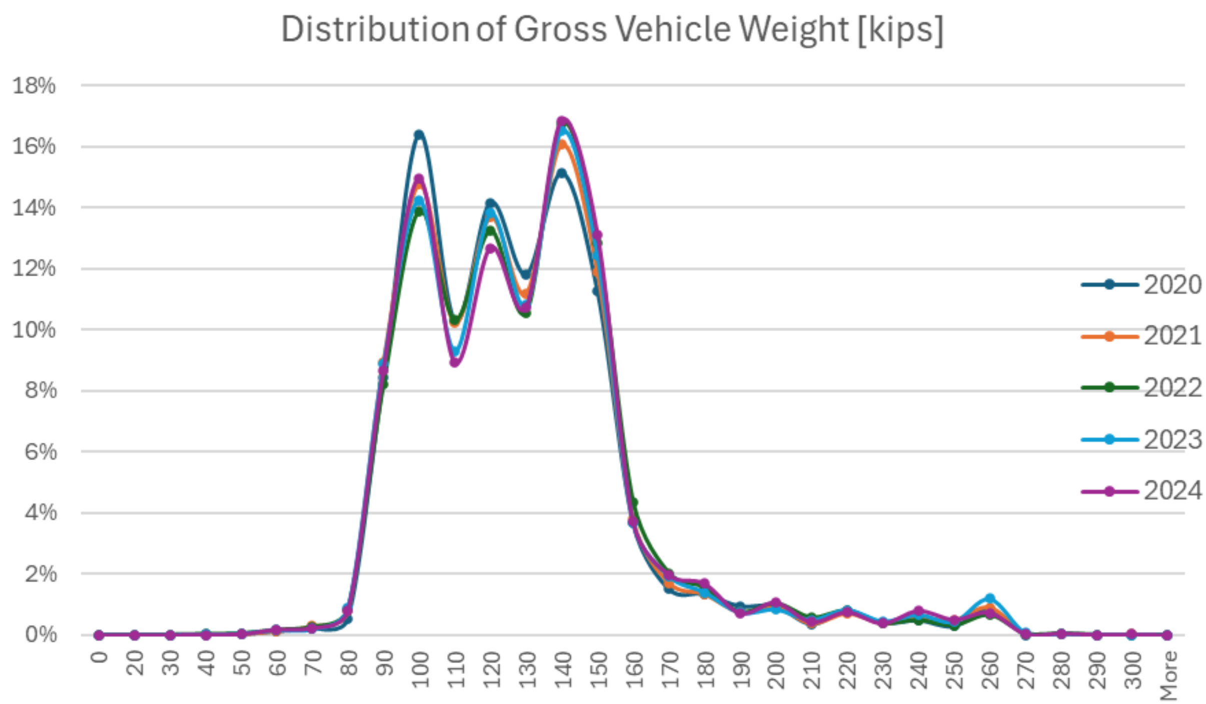


Figure 5-1. Annual distribution of Gross Vehicle Weight (GVW).

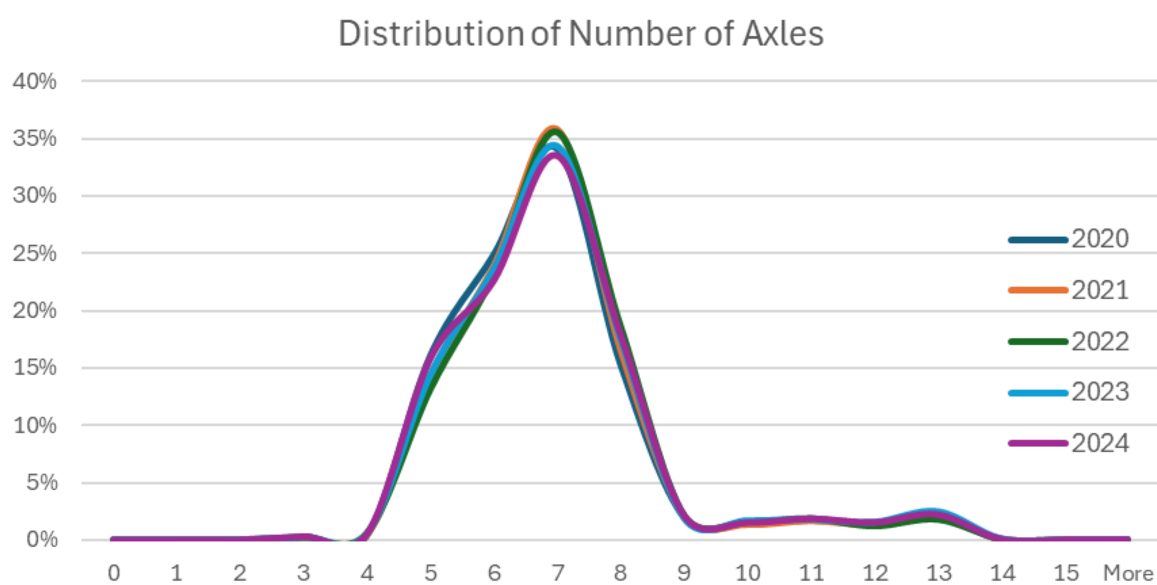


Figure 5-2. Annual distribution of number of axles for permit

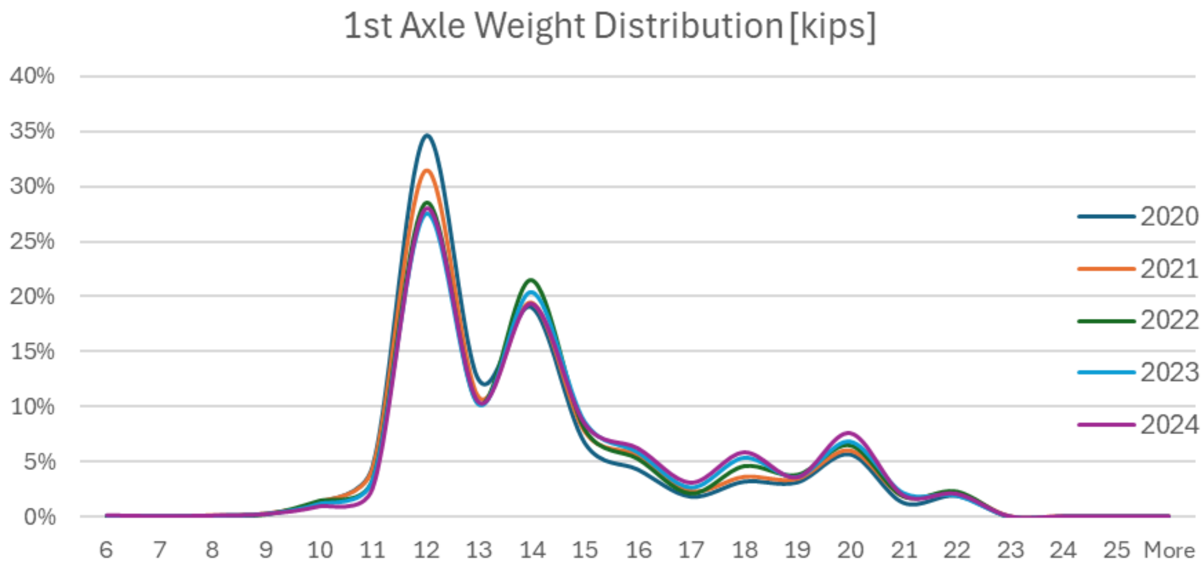


Figure 5-3. Annual distribution of 1st axle weight.

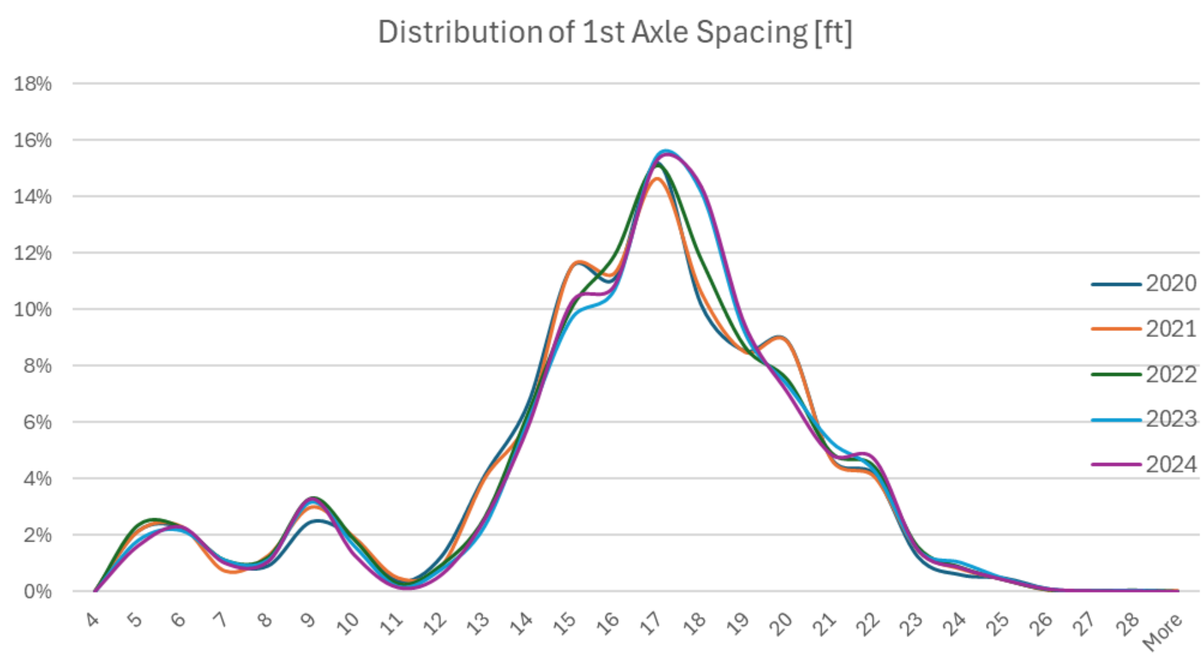


Figure 5-4. Annual distribution of 1st axle spacing.

As part of the detailed analysis, cumulative data from the last five years was analyzed. Figure 5-5 shows the weight distributions for the first six axles, while Figure 5-6 presents the distributions for the first seven distances between individual axles. In case of axle weights, it is evident that the distribution for the first axle differs significantly from those of the subsequent axles. Similarly, spacing between the first and second axles demonstrates a distinct concentration relative to other axle pairs. In addition to the predominance of values within the 4–5 ft range, corresponding to tandem and tridem configurations, there is also a significant clustering observed in the 33–40 ft range. This extended spacing typically characterizes vehicles equipped with long trailers.

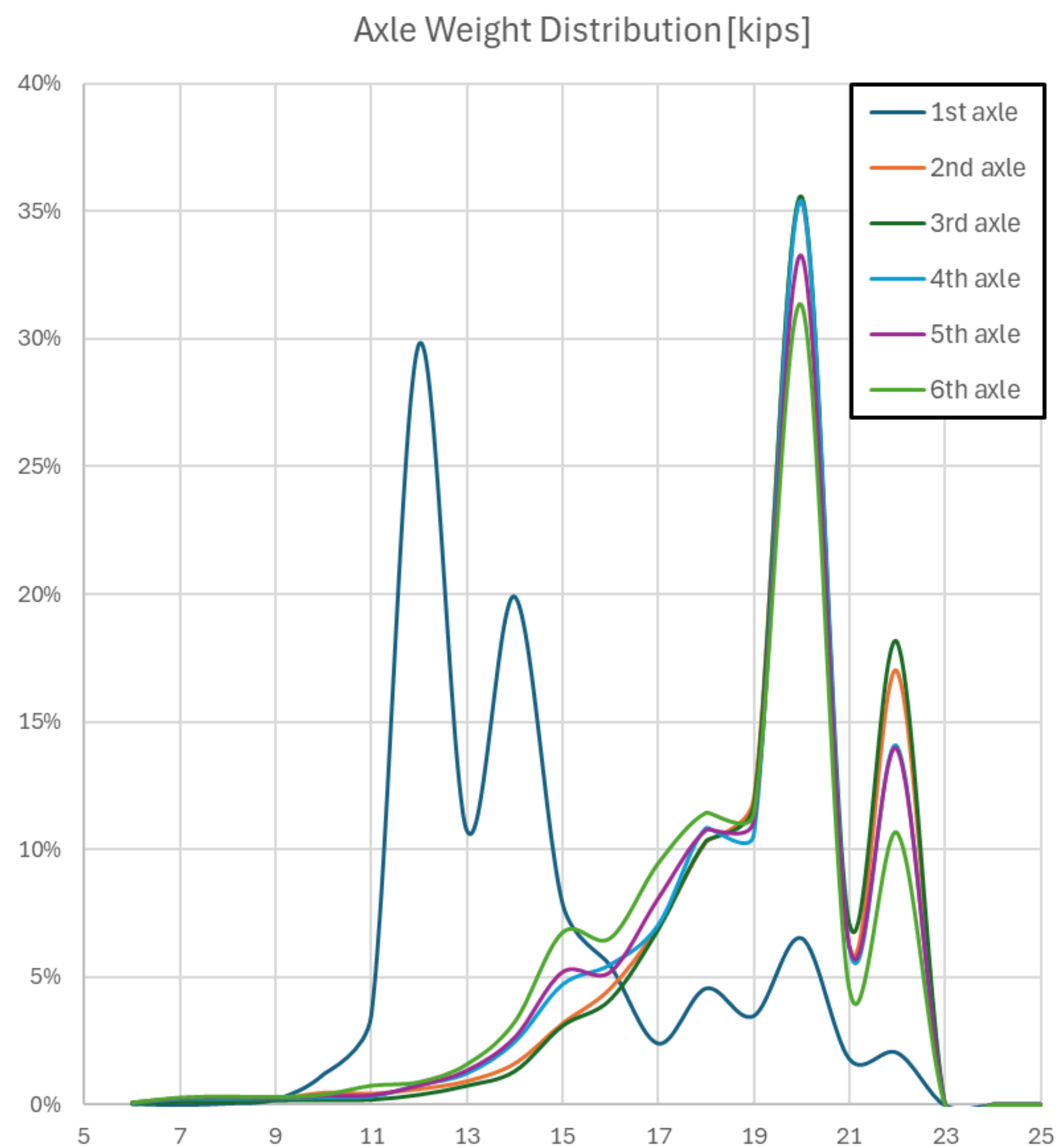


Figure 5-5. Distribution of Axle Weights for the First Six Axles.

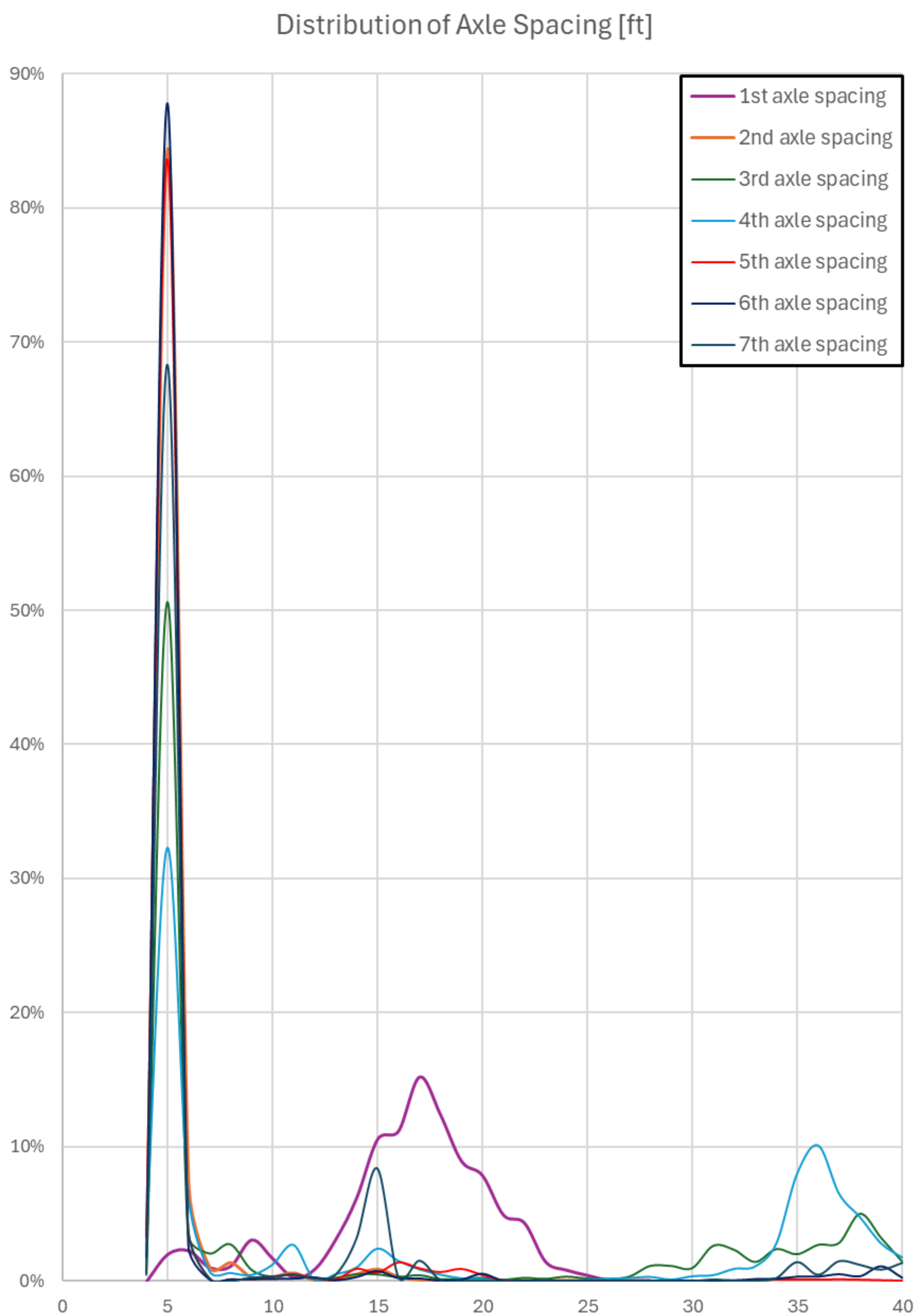


Figure 5-6. Distribution of Spacing Between the First Eight Axles.

5.3 CANDIDATE GROUPS OF NOTIONAL PERMIT VEHICLES

Based on the presented load and spacing ranges, as well as an iterative development procedure, combinations of notional permit vehicle candidates were generated. Analysis of overloaded vehicle characteristics using permit database shared by Alabama Department of Transportation allowed to select candidates. Thirteen different groups with total number of 164,891 notional permit vehicle candidates were developed and presented in Table 5-1, 5-2 and 5.3. Various combinations of axle count and axle configuration including loads and spacings were considered. The axle weight and spacing are the variable that change in the iterative procedure for every 2 kips and 2 ft accordingly, except for tandem and tridem axle spacing changing in 1 ft increment.

The first group of candidates is illustrated in Figure 5-7, and detailed spacing parameters are provided in Table 5-1. This group represents shorter vehicles. However, due to load concentration, such configurations may be critical, particularly in case of short-span bridges or structural types where forces are distributed over a limited deck area. The accompanying Figure 5-7 presents schematic proportions of vehicle characteristics, including axle load and axle spacing ranges for the first five candidates. This visualization illustrates the procedure used to generate groups of notional permit vehicle candidates. The approach enables consideration of a wide range of possible configurations in order to identify representative overload vehicle types.

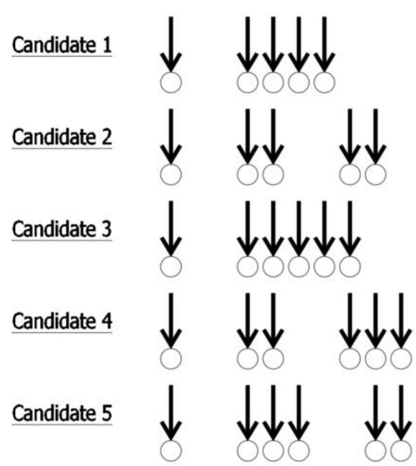


Figure 5-7. Considered range of axle load and spacing for candidates 1-5.

Table 5.1. Axle weight and spacing ranges for notional permit candidates 1 to 5.

Axle Number	Candidate 1		Candidate 2		Candidate 3		Candidate 4		Candidate 5	
	Axle Weight [kip]	Spacing Range [ft]	Axle Weight [kip]	Spacing Range [ft]	Axle Weight [kip]	Spacing Range [ft]	Axle Weight [kip]	Spacing Range [ft]	Axle Weight [kip]	Spacing Range [ft]
1	10 - 14	12 - 22	10 - 14	12 - 22	10 - 14	12 - 22	10 - 14	12 - 22	10 - 14	12 - 22
2	16 - 24	4 - 8	16 - 24	4 - 8	16 - 24	4 - 8	16 - 24	4 - 8	16 - 24	4 - 8
3	16 - 24	4 - 8	16 - 24	28 - 36	16 - 24	4 - 8	16 - 24	28 - 36	16 - 24	4 - 8
4	14 - 26	4 - 8	16 - 26	4 - 8	14 - 26	4 - 8	16 - 24	4 - 8	16 - 24	28 - 36
5	14 - 26	-	16 - 26	-	14 - 26	4 - 8	16 - 28	4 - 8	16 - 28	4 - 8
6	-	-	-	-	14 - 26	-	16 - 28	-	16 - 28	-
7	-	-	-	-	-	-	-	-	-	-

Another group of candidate vehicles is based on configurations with the most frequently occurring axle counts. These vehicles represent the largest portion of permit dataset and are illustrated through schematic diagrams in Figure 5-8 and described in Table 5-2.

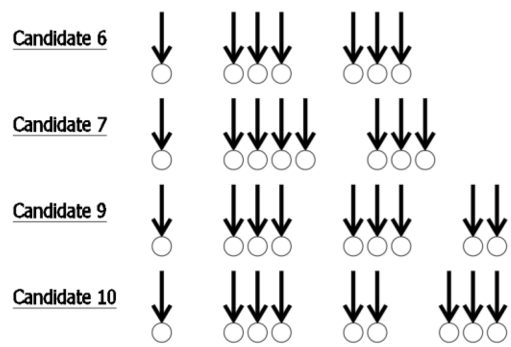


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Figure 5-8. Considered range of axle load and spacing for candidates 6-7,9-10.

Table 5.2. Axle weight and spacing ranges for notional permit candidates 6 to 10.

Axle Number	Candidate 6		Candidate 7		Candidate 9		Candidate 10	
	Axle Weight [kip]	Spacing Range [ft]	Axle Weight [kip]	Spacing Range [ft]	Axle Weight [kip]	Spacing Range [ft]	Axle Weight [kip]	Spacing Range [ft]
1	10 - 14	12 - 22	10 - 14	12 - 22	10 - 14	12 - 22	12 - 14	12 - 22
2	16 - 24	4 - 8	16 - 24	4 - 8	16 - 24	4 - 8	16 - 24	4 - 8
3	16 - 24	4 - 8	16 - 24	4 - 8	16 - 24	4 - 8	16 - 24	4 - 8
4	16 - 24	30 - 40	16 - 24	4 - 8	16 - 24	30 - 40	16 - 24	30 - 36
5	16 - 28	4 - 8	16 - 24	30 - 40	16 - 28	4 - 8	16 - 28	4 - 8
6	16 - 28	4 - 8	16 - 28	4 - 8	16 - 28	4 - 8	16 - 28	12 - 18
7	16 - 28	-	16 - 28	4 - 8	16 - 28	10 - 18	16 - 28	4 - 8
8	-	-	16 - 28	-	16 - 28	4 - 8	16 - 28	4 - 8
9	-	-	-	-	16 - 28	-	16 - 28	-

The next group of candidates corresponds to the longest vehicles, typically those with more than ten axles. Candidate configurations with 10 to 13 axles are illustrated in Figure 5-9, while detailed ranges of axle loads and axle spacing are provided in Table 5-3. These figures present schematic proportions of the vehicles and serve to visualize the procedure used to generate groups of notional permit vehicle candidates. This approach allows for the consideration of a wide range of possible configurations in order to identify representative overload vehicle types. Additionally, this group of vehicles has a particularly significant impact on long-span bridges due to their size, which allows them to be positioned within the central portion of the span.

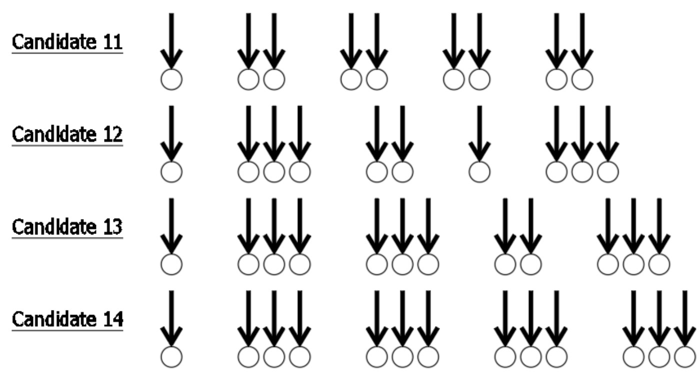


Figure 5-9. Considered range of axle load and spacing for candidates 11-14.

Table 5.3. Axle weight and spacing ranges for notional permit candidates 11 to 14.

Axle Number	Candidate 11		Candidate 12		Candidate 13		Candidate 14	
	Axle Weight [kip]	Spacing Range [ft]	Axle Weight [kip]	Spacing Range [ft]	Axle Weight [kip]	Spacing Range [ft]	Axle Weight [kip]	Spacing Range [ft]
1	12 - 14	12 - 22	12 - 14	12 - 22	12 - 14	12 - 22	12 - 14	12 - 22
2	16 - 24	4 --8	16 - 24	4 - 8	16 - 24	4 - 8	16 - 24	4 - 8
3	16 - 24	16 - 24	16 - 24	4 - 8	16 - 24	4 - 8	16 - 24	4 - 8
4	16 - 28	4 - 8	16 - 24	10 - 18	16 - 24	10 - 18	16 - 24	10 - 18
5	16 - 28	16 - 24	16 - 24	4 - 8	16 - 24	4 - 8	16 - 24	4 - 8
6	16 - 28	4 - 8	16 - 24	10 - 18	16 - 24	4 - 8	16 - 24	4 - 8
7	16 - 28	16 - 24	16 - 24	10 - 18	16 - 24	30 - 40	16 - 24	30 - 42
8	16 - 28	4 - 8	14 - 26	4 - 8	16 - 22	4 - 8	14 - 28	4 - 8
9	16 - 28	-	14 - 26	4 - 8	16 - 22	10 - 18	14 - 28	4 - 8
10	-	-	14 - 26	-	16 - 22	4 - 8	14 - 28	10 - 18
11	-	-	-	-	16 - 22	4 - 8	14 - 28	4 - 8
12	-	-	-	-	16 - 22	-	14 - 28	4 - 8
13	-	-	-	-	-	-	14 -- 28	-

Chapter 6

LIVE LOAD MODELS FOR FEM ANALYSIS OF TRUSS BRIDGES

6.1 TRUSS BRIDGES

The rating process for truss bridges is complex due to the structural characteristics, the number of components and connections, the variety of materials used, and most importantly, their age. Statistics show that 58% of truss bridges in Alabama are more than 75 years old, and 75% are over 50 years old (Luszczynska et al. 2025). As a result, the maintenance and load rating of these structures is particularly important.

Due to the complexity of the structural system and the underlying design assumptions, simplifying this type of bridge to a beam element is not adequate. The distribution of internal forces among chords, verticals, and diagonals cannot be accurately captured using simplified methods. As a result, the Finite Element Method (FEM) was used. This numerical approach enables a detailed analysis of load effects in all primary structural components considered in the study. Although the FEM process is time-consuming since it requires the development of a precise model and the application of load cases involving hundreds of thousands of vehicles, it provides the level of analytical accuracy necessary for this research. Such accuracy is essential for the development of representative notional permit vehicles.

6.2 REPRESENTATIVE TRUSS BRIDGES – FINITE ELEMENT MODELS

The first bridge selected for analysis is the Project S-149(6) – Bridge over Sipsey River, located in Winston County. This structure is a steel through-truss bridge consisting of three spans: the interior span measures 360 ft, while the exterior spans are 301 ft 2 in and 300 ft, respectively. The bridge was modeled using Midas Civil software, employing the finite element method (FEM) to accurately reflect the geometry and cross-sectional properties of the existing structure.

The FEM model provides a detailed representation of the bridge, excluding minor components such as connection plates and joint details, which were intentionally omitted due to the primary objectives of the study. The main goal was to evaluate the structural response under permit vehicle loading, rather than to perform a full-scale analysis including the response of structural connections of bridge elements. To validate the model, the dead load results obtained from the FEM analysis were compared with the designer's hand calculations presented in original technical drawing provided by ALDOT. The difference between these two datasets was approximately 10%, which corresponds to the weight of steel connections not included in the FEM model. This discrepancy was deemed acceptable for the scope of the research. An overview of the FEM model is presented in

Figure 6-1, illustrating the bridge's span configuration and structural layout. Detailed live load analysis of this bridge was also described by Luszczynska et al. (2024).

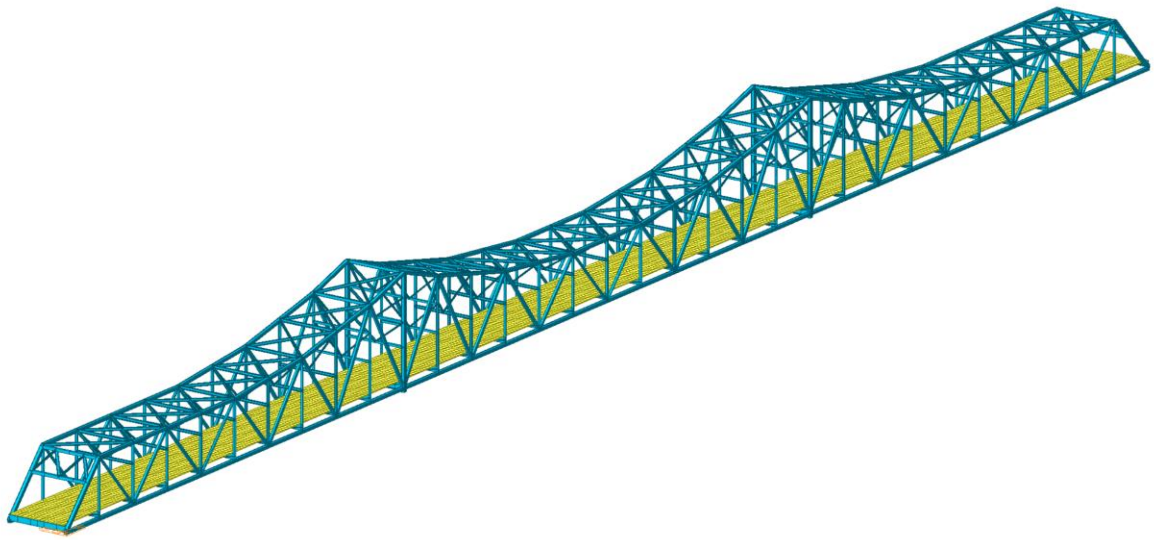


Figure 6-1. General view of the Bridge over Sipsey River main truss - FE Model.

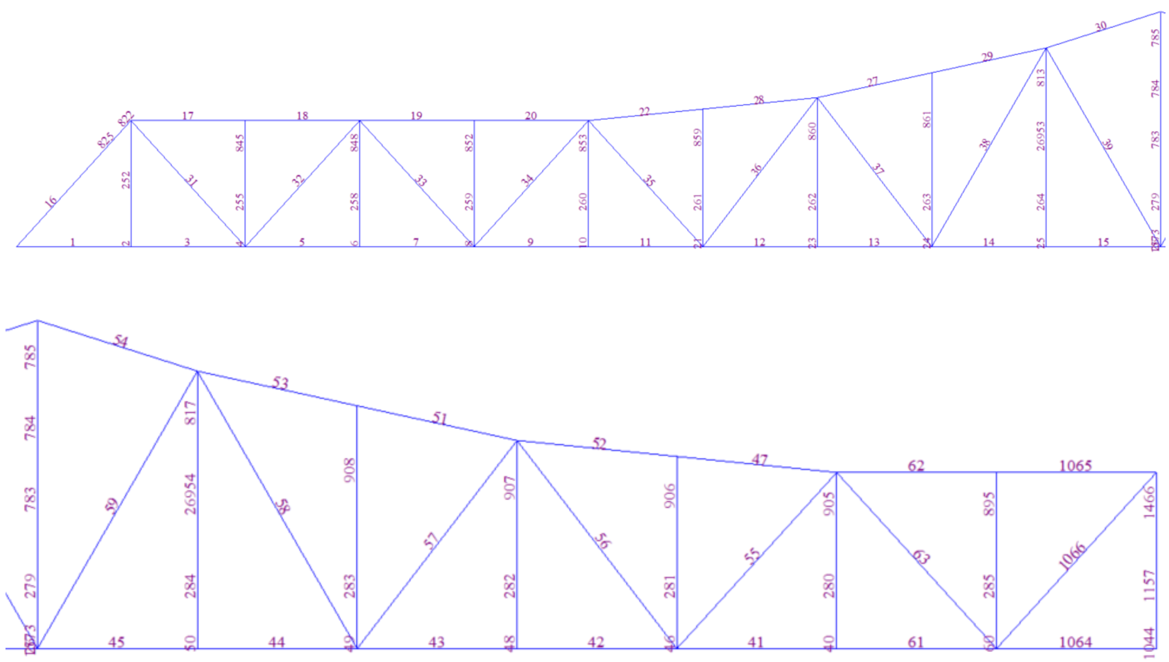


Figure 6-2. Numbering of elements in model: top - external span, bottom - internal span.

The truss model consists of over 2,500 linear elements (beam and truss types) and approximately 5,000 plate elements. For detailed analysis, a subset of 203 elements belonging to one of the truss section was selected. The model was loaded with both actual permit vehicles and candidate notional vehicles. Additionally, each vehicle was incrementally run across the bridge in 1-foot steps, and the maximum load effect for each element was determined for every vehicle. The vehicles were positioned on the deck in such a configuration to maximize loading on one side of the truss in order to induce the highest possible force effects.

The next modeled truss bridge is the structure associated with Project No. ABC-16, located in Clarke and Choctaw Counties, spanning the Tombigbee River near the town of Coffeeville. This bridge is a three-span steel truss structure, with the main span measuring 400 ft, and the two outer spans measuring 265 ft each. The bridge features a complex configuration, combining elements of both through-truss and deck-truss designs. An overview of the FEM model is presented in Figure 6-3, showing the span arrangement and structural layout. To facilitate interpretation of the analysis results, Figure 6-4 presents numbering system of structural members. This numbering is consistent with the output data from the FEM analysis and will be referenced throughout the discussion of results.

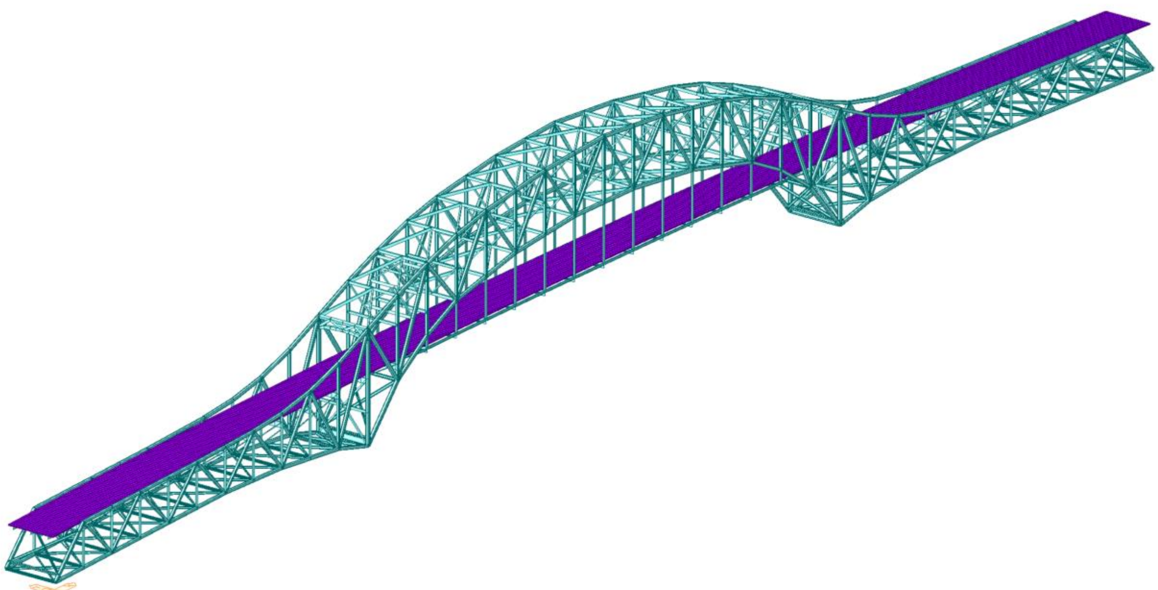


Figure 6-3. General view of the Coffeeville Bridge - FE Model.

Truss model consists of over 3,600 linear elements (beam and truss types) and approximately 7,300 plate elements. For detailed analysis, a subset of 233 elements belonging to one of the truss section was selected. Considered elements consist of top and bottom chords, posts, diagonals and hangers.

The model was loaded with both actual permit vehicles and candidate notional vehicles. Additionally, each vehicle was incrementally run across the bridge in 1-foot steps and the maximum load effect for each element was determined for every vehicle.

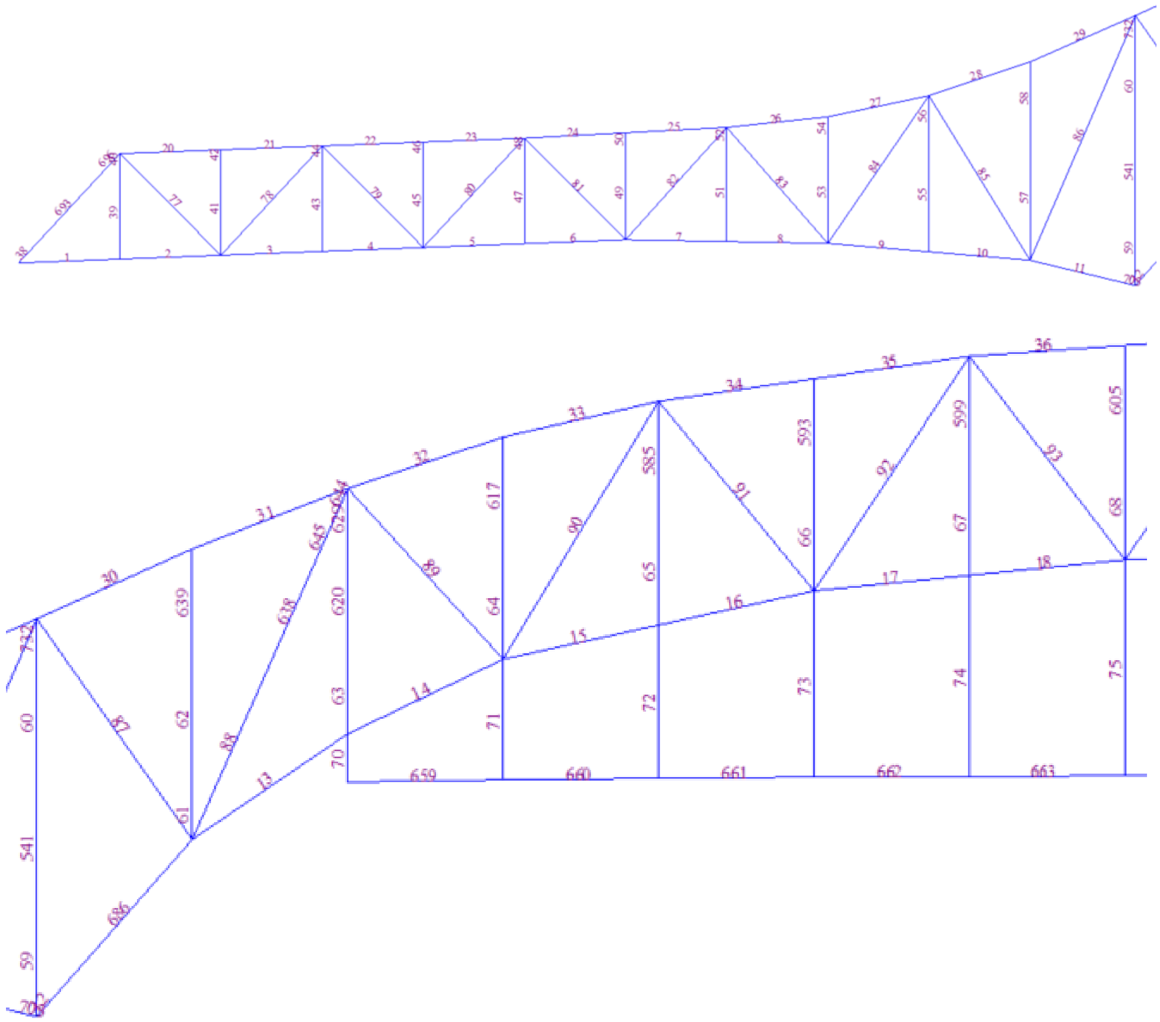


Figure 6-4. Numbering of elements in model: top - external span, bottom - internal span.

The next modeled truss bridge is the structure associated with Project No. ABC-18, located in Chilton- Coosa Counties, spanning the Coosa River. This bridge is a three-span steel deck truss structure, with the main span measuring 300 ft and the two outer spans measuring 225 ft each. The truss model consists of over 3,900 linear elements (beam and truss types) and approximately 12,000 plate elements. For further analysis, a subset of 123 elements belonging to one of the truss sections was selected including top and bottom chords, posts, as well as diagonals. An overview is presented in Figure 6-5, whereas Figure 6-6 shows the utilized numbering system.

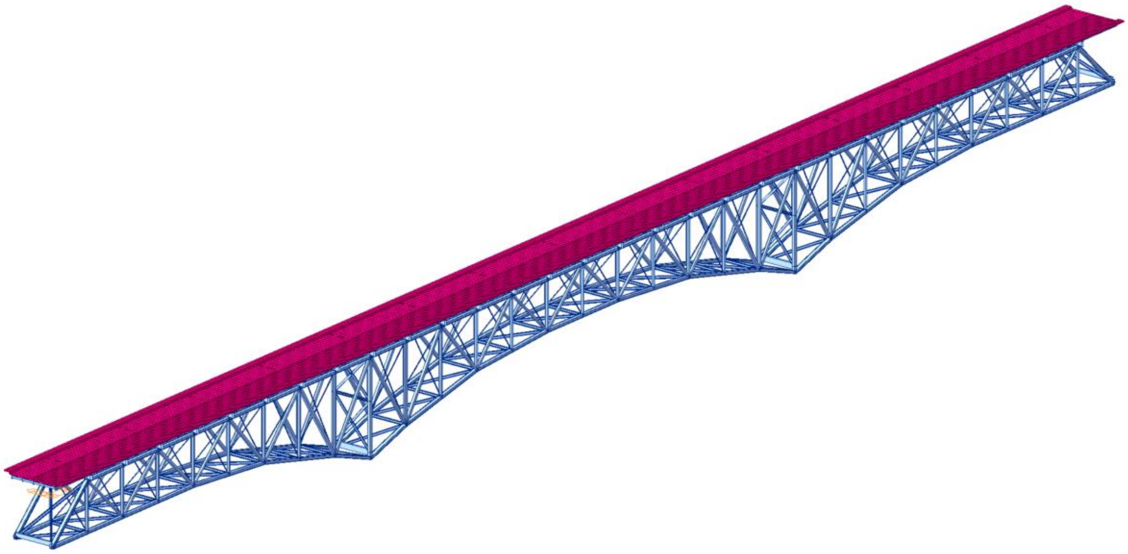


Figure 6-5. General view of the Bridge - FE Model.

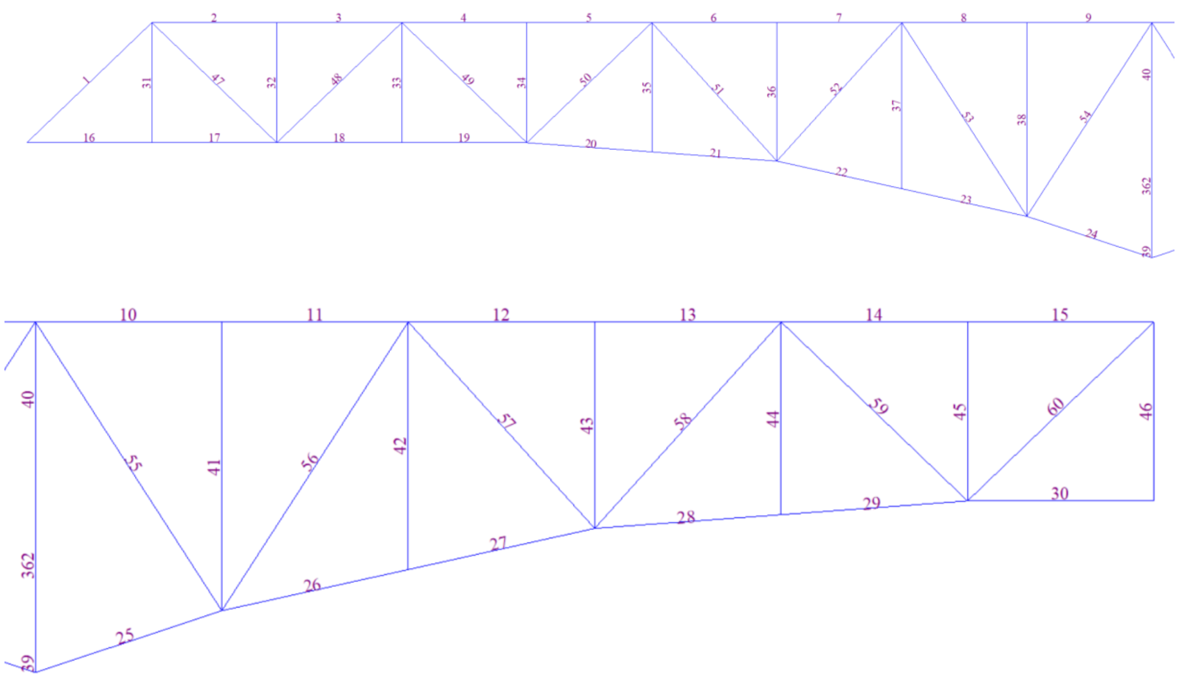


Figure 6-6. Numbering of elements in model: top - external span, bottom - internal span.

The next truss bridge modeled for the conducted analysis is the structure associated with Project No. ABC-4, located in St. Clair and Talladega Counties, spanning the Coosa River. This bridge is a simple-span steel structure, with the main span measuring 200 ft. The truss model consists of over 1,100 linear elements (beam and truss types) and approximately 2,600 plate elements. For the analysis, a subset of 43 elements belonging to one of the truss sections was selected.

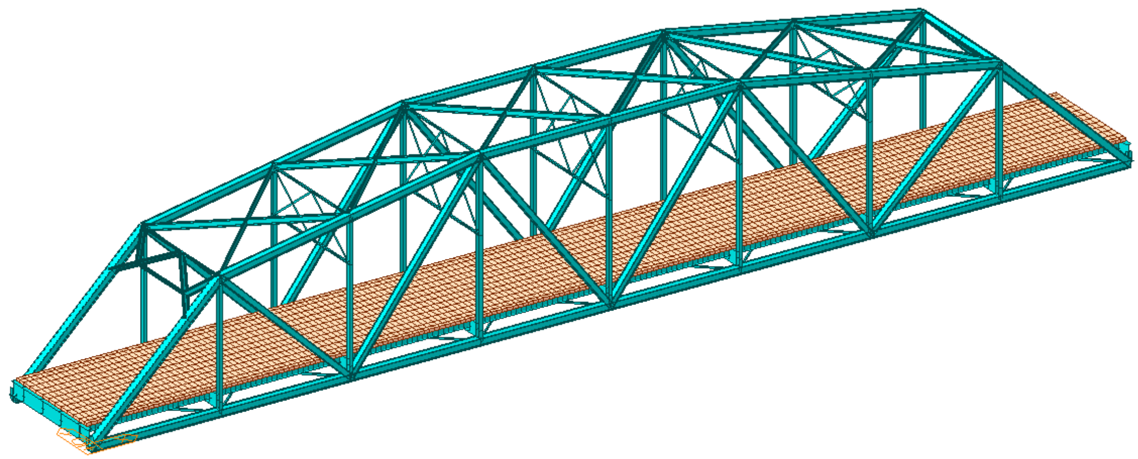


Figure 6-7. General view of the Bridge - FE Model.

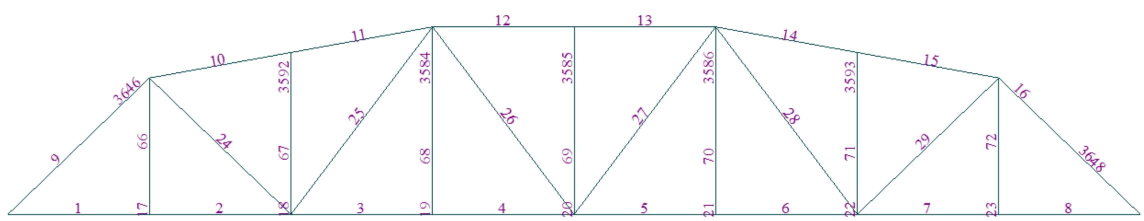


Figure 6-8. Numbering of elements in the model.

The next truss bridge modeled for the conducted analysis is the structure associated with Project No. BR 0002(550), located in Colbert and Lauderdale Counties, spanning the Tennessee River. This bridge is a simple-span steel structure, with the main span measuring 200 ft. The truss model consists of over 1,200 linear elements (beam and truss types) and approximately 2,600 plate elements. For the analysis, a subset of 33 elements belonging to one of the truss sections was selected.

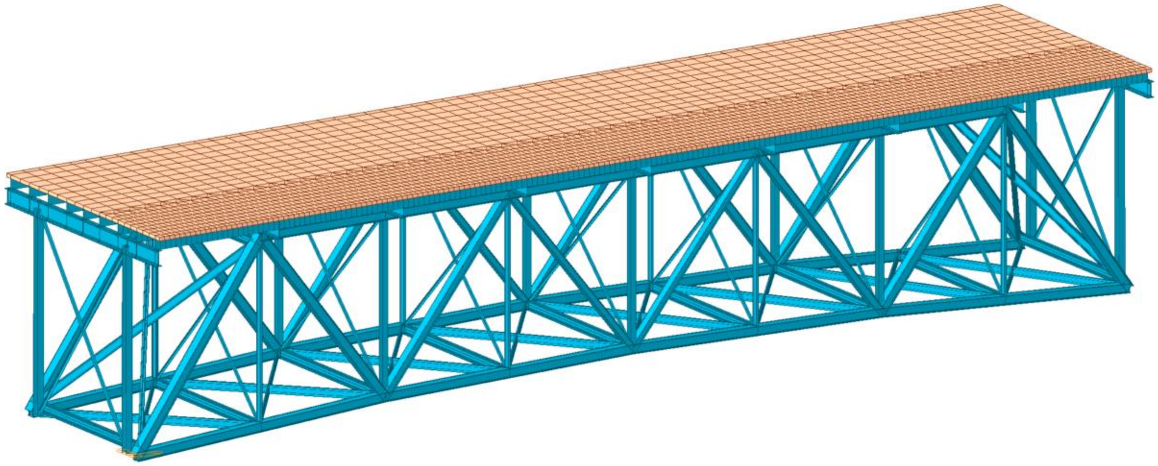


Figure 6-9. General view of the Bridge - FE Model

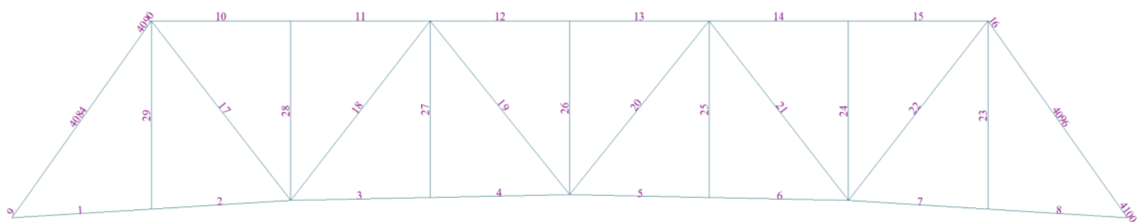


Figure 6-10. Numbering of elements in the model.

6.3 ANALYSIS RESULTS

As a result of the calculations, the maximum load effect for each individual element was determined. The database of resulting internal forces contains a large number of cumulative distribution function (CDF) plots. Therefore, selected graphs showing the calculated load effects for individual elements under permit vehicles and notional vehicle candidates are included in Appendix B.

Chapter 7

LIVE LOAD MODELS FOR FEM ANALYSIS OF ARCH BRIDGES

7.1 ARCH BRIDGES

Another category of structures examined in this project is arch bridge. Arches present greater variability in their possible configurations compared to truss bridges, due to the broader selection of applicable materials. Examples include deck arches, half-through true arches, and through deck-stiffened arches.

7.2 REPRESENTATIVE TRUSS BRIDGES – FINITE ELEMENT MODELS

The first arch bridge modeled for the conducted analysis is the structure associated with Project No. BRF–0117(506), located on the Lookout Mountain Parkway section of SR-117, near the town of Mentone. This bridge spans the West Fork of Little River and is designed as a concrete arch bridge with a single span measuring 100 ft. An overview of the FEM model is presented in Figure 7-1, showing the bridge's geometry and structural layout. To facilitate interpretation of the analysis results, Figure 7-2 presents the member numbering system, which aligns with the FEM output and will be referenced in the subsequent results section. The arch model consists of over 440 linear elements (beam and truss types) and approximately 2,200 plate elements. For the analysis, a subset of 152 elements belonging to one of the arch sections was selected.

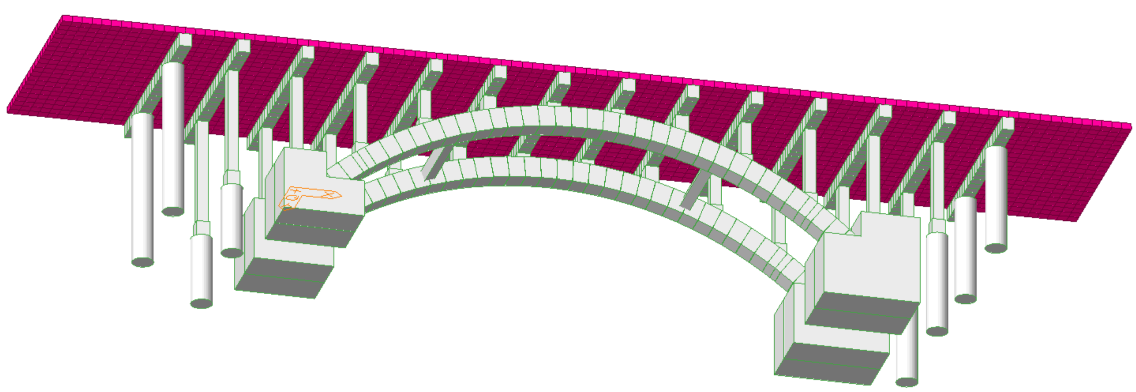


Figure 7-1. General view of the West Fork Bridge - FE Model.

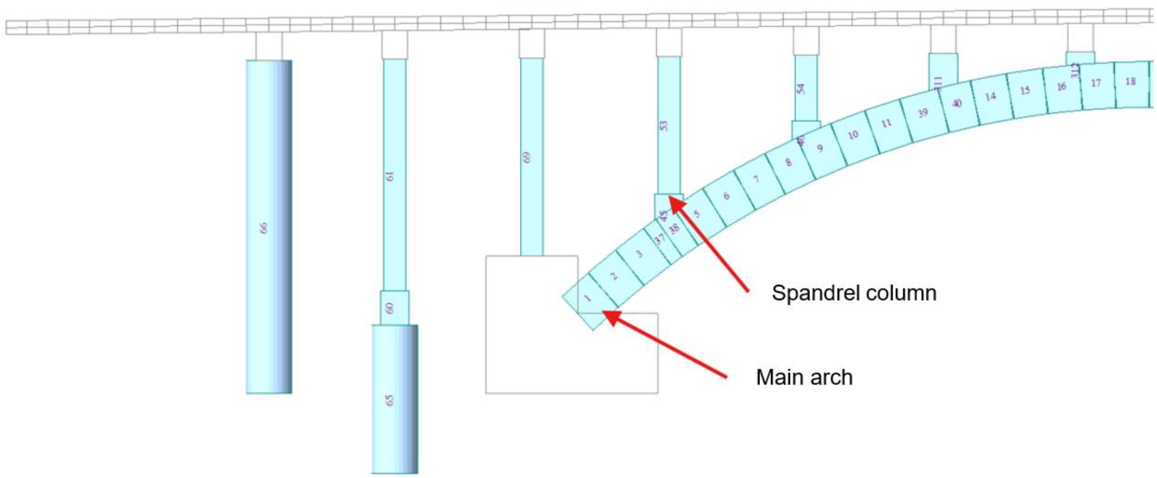


Figure 7-2. Numbering of elements in the model for West Fork Bridge.

The next arch bridge modeled for the conducted analysis is the structure associated with Project No. NO.RPF-IMF-NHF-1059(387). The arch bridge of the Interstate 20/59 over McFarland Boulevard is located in Tuscaloosa. The bridge has a single span of 250 ft. The arch model consists of over 1,650 linear elements (beam and truss types) and approximately 3,100 plate elements. For the analysis, a subset of 71 elements belonging to one of the arch sections was selected. An overview of the FEM model is presented in Figure 7-3, showing the bridge's geometry, whereas Figure 7-4 shows the utilized numbering system.

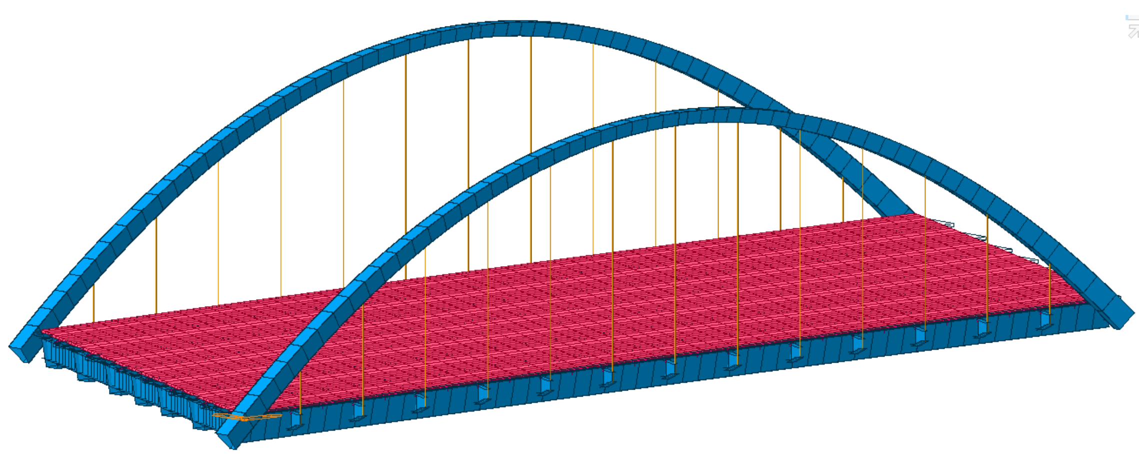


Figure 7-3. General view of the Arch Bridge in Tuscaloosa - FE Model.

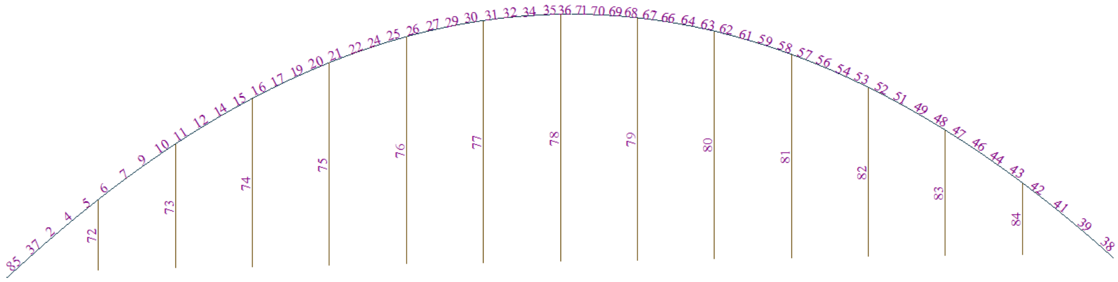


Figure 7-4. Numbering of elements in the model for Arch Bridge in Tuscaloosa.

The next arch bridge modeled for the conducted analysis is the bridge associated with Project No. I-65 – 1 (85) 23, on the Interstate route 65. This bridge crosses the Mobile River Delta near the Mobile. Structure classified as an arch bridge, features a span of 800 feet. Its geometric characteristics and visual representation are provided in Figure 7-5. The ach model consists of over 4,100 linear elements (beam and truss types) and approximately 14,300 plate elements. For the analysis, a subset of 129 elements belonging to one of the truss sections was selected.

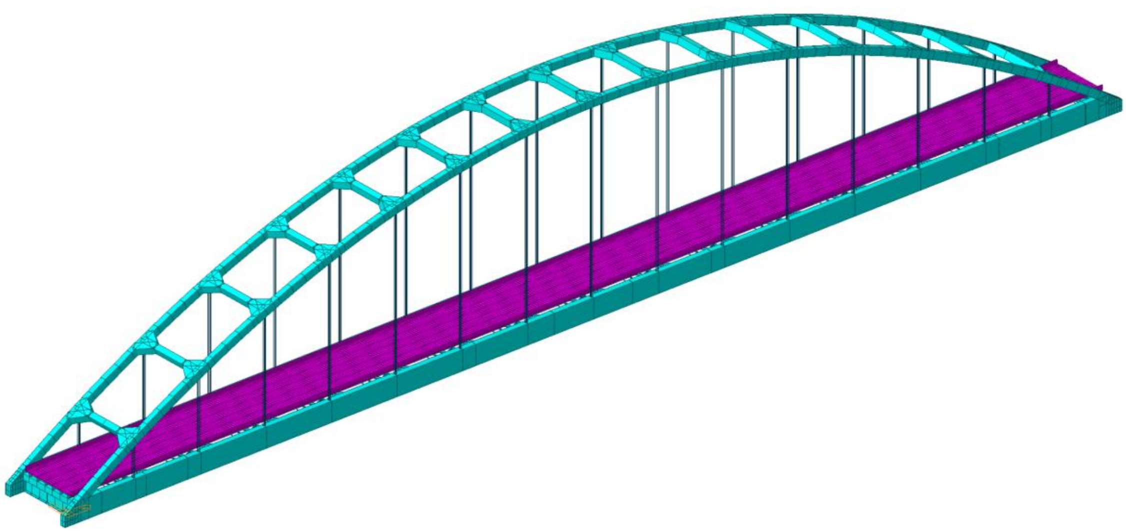


Figure 7-5. General view of the Arch Bridge in Mobil - FE Model.

The next arch bridge modeled for the conducted analysis is the structure associated with Project No. BHPF-000(540). The arch bridge of the US-80 over Alabama River is located in Selma. The arch is the part of bigger structure in Selma. The arch model consists of over 740 linear elements (beam and truss types) and approximately 1,500 plate elements. For the analysis, a subset of 43 elements belonging to one of the arch sections was selected. An overview of the FEM model is presented in Figure 7-6, showing the bridge's geometry, whereas Figure 7-7 shows the utilized numbering system.

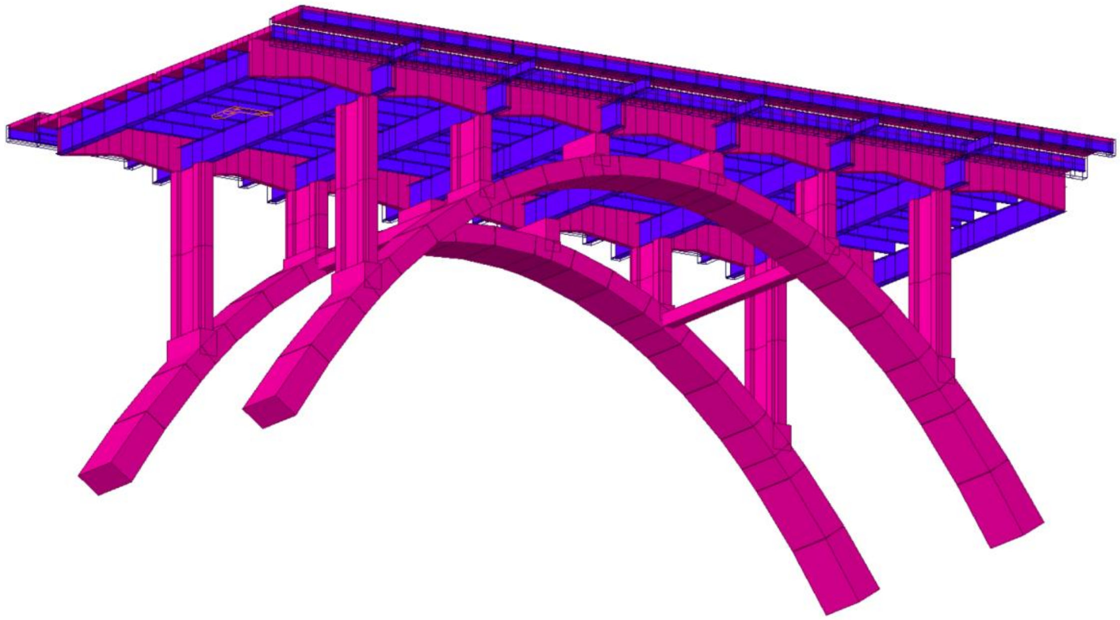


Figure 7-6. General view of the Arch Bridge in Selma - FE Model.

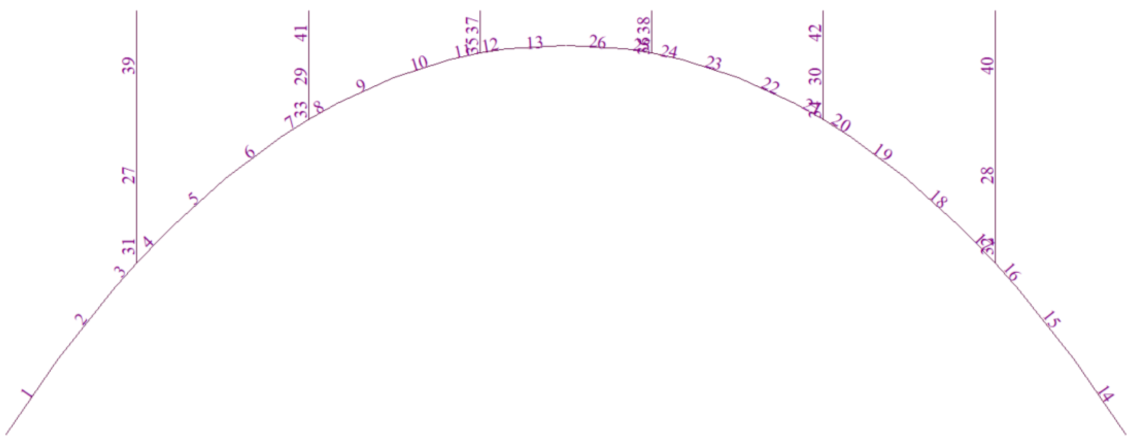


Figure 7-7. Numbering of elements in the model for Arch Bridge in Selma.

Chapter 8

NOTIONAL PERMIT VEHICLES FOR TRUSS BRIDGES RATINGS

8.1 METHODOLOGY FOR THE DETERMINATION OF THE NOTIONAL PERMIT VEHICLE

The process of selecting a notional vehicle and the criteria involved is very important as it determines the compliance of the notional vehicle with the external conditions defined by permit trucks and ensures a rational and economic approach to the rating process.

First, a set of notional permit vehicle candidates was developed, and their statistical parameters of live load were determined, including bias factors, standard deviations and coefficients of variation. Additionally, the percentage of vehicles exceeding the bias factor of 1.0 was established for each candidate, for each of the considered truss bridge models, for each truss element and for each load case, depending on the vehicle's position on the bridge. These parameters provide the basis for selecting notional permit vehicles that ensure consistent safety across different bridges and load cases. The distribution of internal forces and the importance of each force depend on the type of structure. In structures where the main load-bearing element is a beam, the most important forces are bending moments and shear forces. In long bridge structures, the axial force becomes more important. This is especially true for truss bridges, where the axial force is the most significant. Depending on the assumed structural model, bending moments and shear forces can also be important when checking the top and bottom chords of the truss. The span lengths of truss bridges considered in this study were greater than 200 ft. For this reason, one of the main criteria used to select notional candidates was the 90th quantiles for the lowest mean percent exceeding bias factor of 1.0. Candidates that significantly exceed axial forces compared to permit vehicles were rejected. Due to bending moments and shear forces occurring in the top and bottom chords, additional conditions were included in the analysis for selected elements. Based on the lowest variation of bias factors for these internal forces, the candidates with the lowest variation were identified. All chord elements were considered. The process of selecting a notional permit vehicle from the candidates is shown in Figure 8-1.

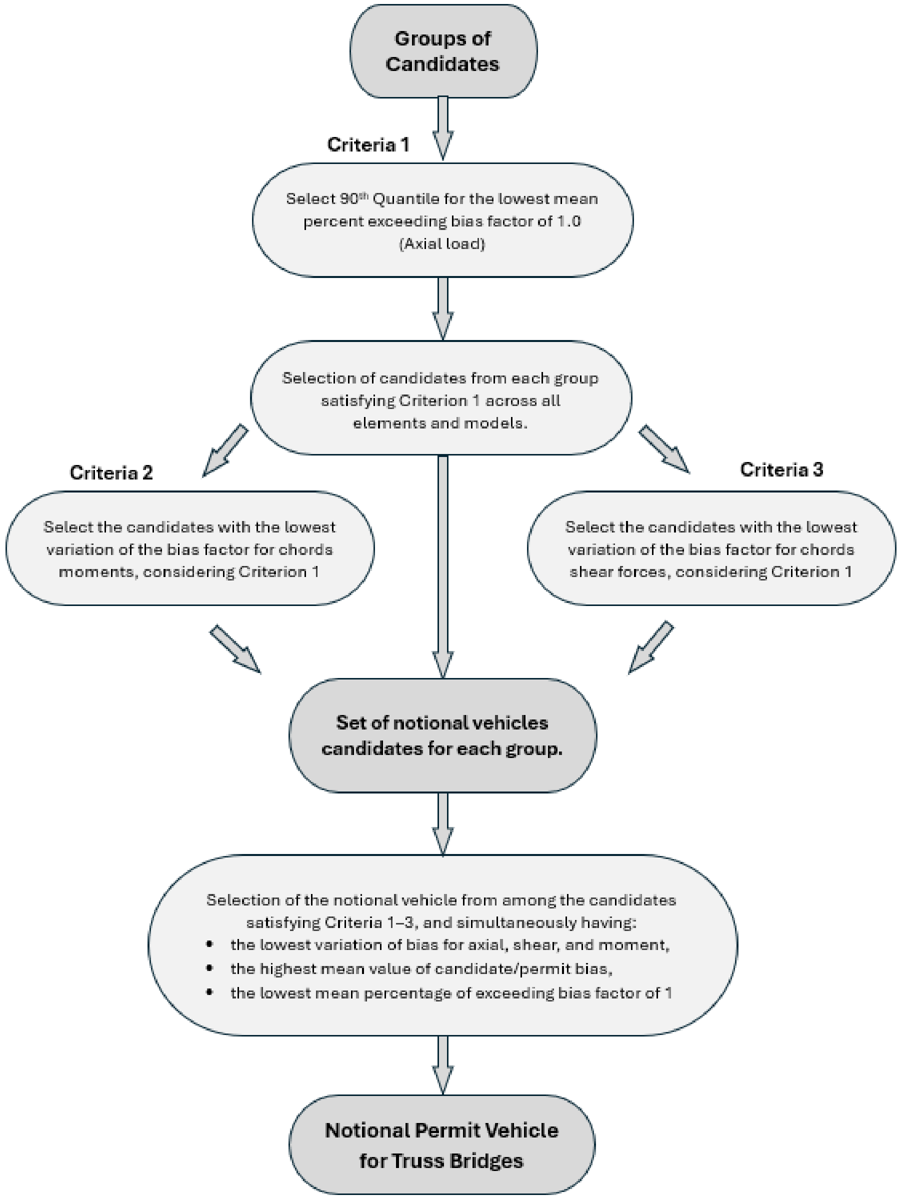


Figure 8-1. Process for determining a notional permit vehicle for truss bridges.

The previous criterion resulted in approximately 100 vehicles for each group. In the final stage of selection of the notional permit vehicle, three conditions were applied:

- the lowest variation of bias factors for axial, shear, and moment,
- the highest mean value of the candidate-to-permit bias ratio,
- the lowest mean percentage of vehicles exceeding a bias factor of 1.0.

The variation of bias factors relates to relationship of permit-to-candidate ratio, and variation between elements as well as different bridges. The second condition ensured that the number of permit vehicles, expressed as a ratio to the candidate, was similar. The third criterion determined the percentage of the heaviest vehicles generating the highest forces, that exceed those induced by the proposed candidate.

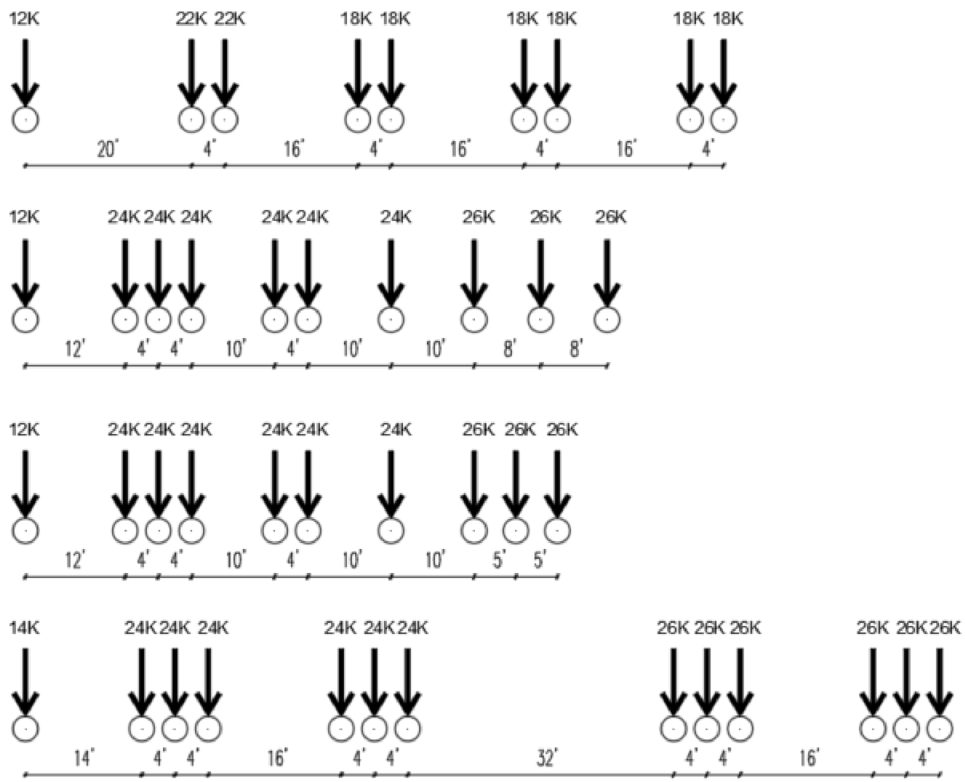


Figure 8-2. Examples of the candidates of group no. (11, 12, 12, 14)

8.2 NOTIONAL PERMIT VEHICLE FOR TRUSS BRIDGES IN ALABAMA

The notional permit vehicle for truss bridge rating in Alabama is shown in Figure 8-3. It is a 9-axle vehicle. The first axle has a load of 14 kip. Next, there is a tri-axle group with 24 kip on each axle. After that, there is a tandem and another tri-axle group, each axle carrying 28 kip.

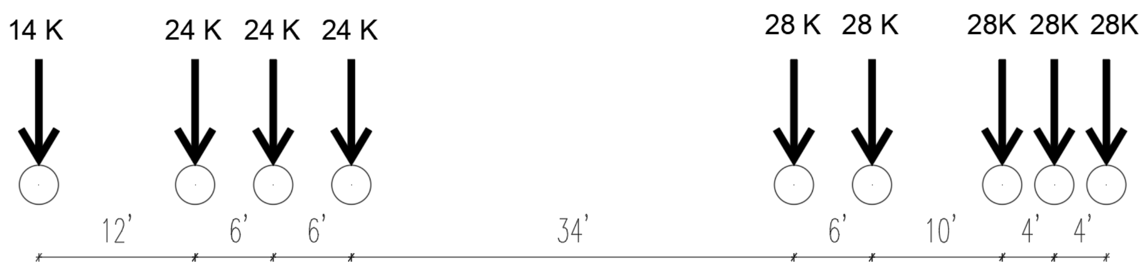


Figure 8-3. Notional permit vehicle for truss bridges rating in Alabama.

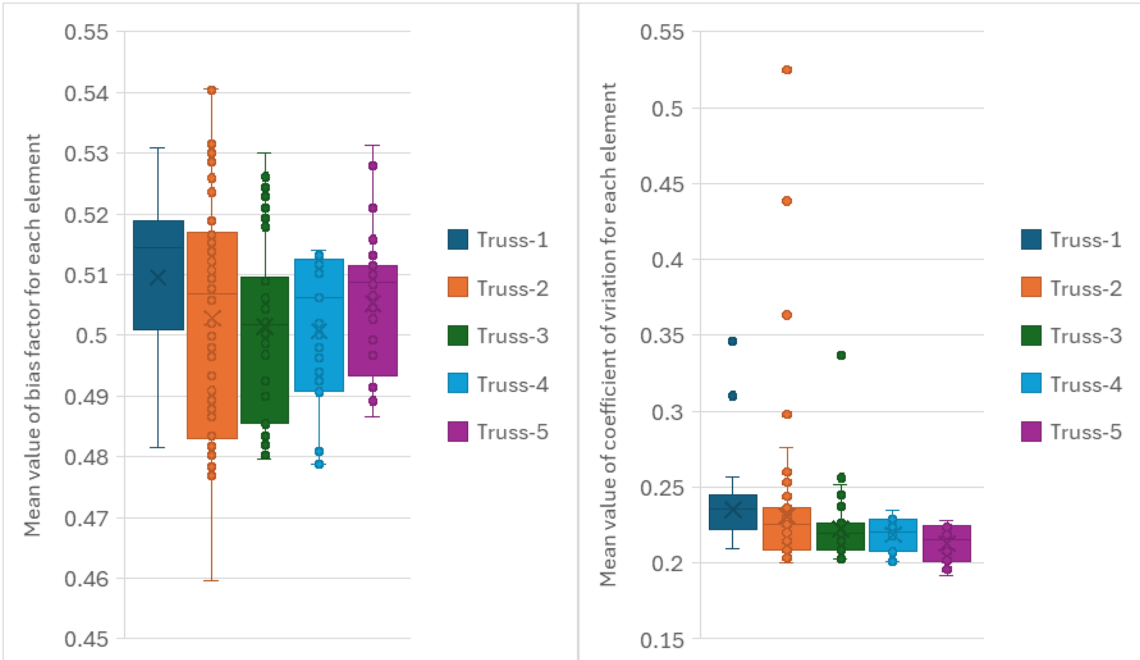


Figure 8-4. Statistical parameters of axial force for the Notional Permit Vehicle.

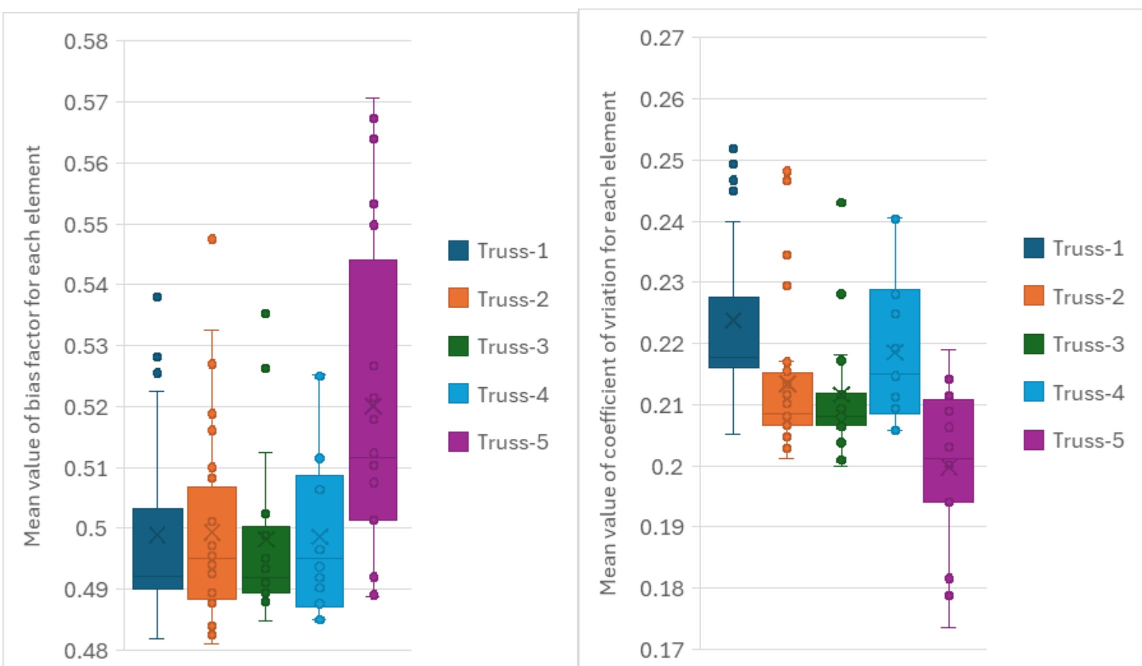


Figure 8-5. Statistical parameters of bending moment for the Notional Permit Vehicle.

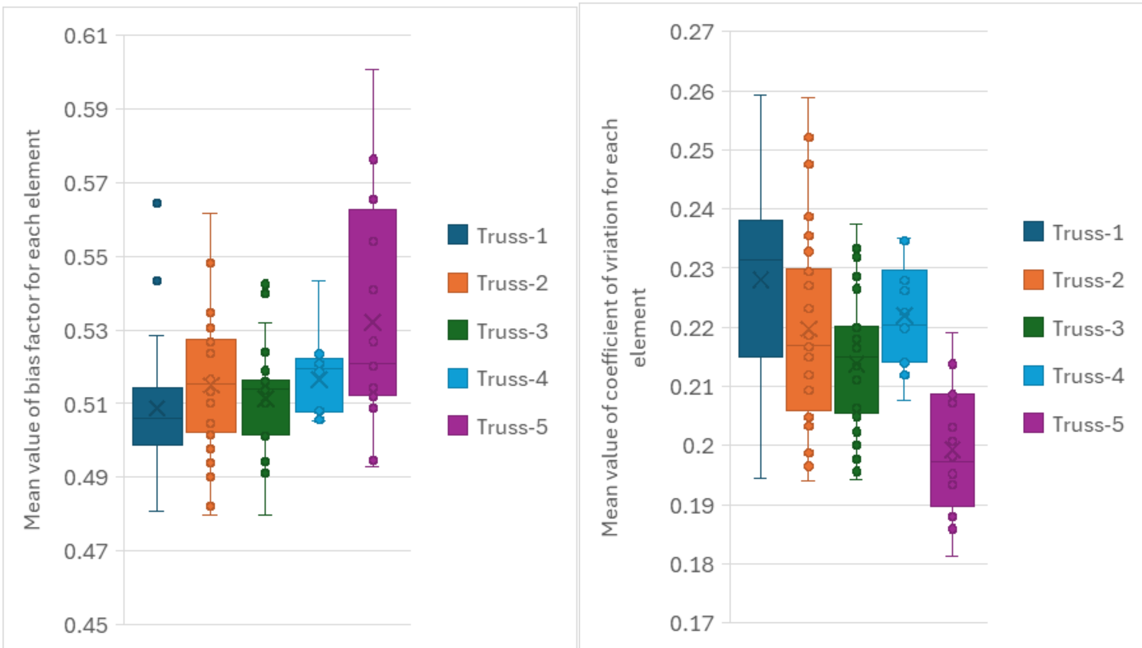


Figure 8-6. Statistical parameters of shear force for the Notional Permit Vehicle.

Chapter 9

SUMMARY

The increasing number of overloaded vehicles on public roads presents a growing challenge for the evaluation and rating of existing bridges. To address it, ALDOT requires a rational and effective approach to include permit vehicles in bridge rating procedures. Historically, Alabama lacked notional permit vehicles specifically calibrated for truss and arch bridge structures that are often complex and aging.

This research aims to develop representative notional vehicles that reflect permit load characteristics and can be used in rating of truss and arch bridges. The study utilized ALDOT permit data from the years 2013 to 2024. However, to optimize the internal force calculation process in MIDAS Civil software, the dataset was selectively reduced. This allowed for an efficient analysis while maintaining the integrity of the results.

To validate the accuracy of bridges modelled in MIDAS Civil software, dead load from the FEM analysis was compared with the designer's hand calculation specified in the technical drawings provided by ALDOT. The discrepancy between these two datasets was approximately 10%, which can be attributed to the exclusion of steel connection weights in the FEM model. This variance was considered acceptable for the purpose of this research.

Using detailed 3D finite element models developed based on original technical drawings, the study simulated load effects for over 130,000 permit vehicles and more than 165,000 candidate configurations across selected complex bridge structures. Superload permits were excluded from the scope of the analysis. The integration of large-scale databases with advanced FEM software enabled accurate modeling of structural behavior under permit traffic, particularly for bridges nearing the end of their service life.

Implementation of notional truck simplifies the rating process by reducing the number of individual vehicles required for analysis, improving efficiency and consistency in evaluating complex bridge types. It is recommended to continue research to develop efficient analytical tools and expand the methodology to include notional permit vehicles for other bridge types beyond truss structures. These advancements will support the maintenance, safety, and longevity of Alabama's bridge infrastructure and contribute to a more effective and streamlined rating process.

Chapter 10

NUMERICAL AND COMPUTATIONAL CHALLENGES

The total number of 164,891 notional permit vehicle candidates was developed based on overloaded vehicle characteristics. Alabama permit database for years 2020-2024 includes 750,000 permits. However, most of them were issued for oversize trucks which are not of interest in current research project. Filtered permit data used for live load analysis consists of 131,089 overweight vehicles. Therefore, the total number of combinations included in load ratio calculations was equal to 21,615,000,000 for every single bridge element considered in analysis.

Design projects for complex bridges in Alabama were received from ALDOT including 9 truss and 6 arch structures. Detailed finite element models were developed for 5 selected truss bridges using provided technical drawings with total number of over 42,000 elements. In addition, FE models for 4 arch bridges were completed. The increment of the applied moving load was assumed to achieve the high accuracy of the results and varied depending on the model. Thus, total number of 606,463,020 load points were calculated for all truss bridges since 295,980 vehicles including permits and permit candidates were run through each of finite element model. Midas Civil software used for modeling and live load analysis is not compatible with Linux, therefore the High Performance Computer Cluster (HPCC) could not be used to run the simulations and reduce computational time. However, Midas Civil NX (2025) allowed powerful automation through using dedicated Python libraries.

Similarly, HPCC could not be used for computations of statistical parameters due to large size of resulting files and lack of connection with Box Drive providing unlimited cloud-based storage platform. For that reason, bias ratio, standard deviation, mean and coefficient of variation for every load case was computed using simultaneously 41 computers in the Department of Civil and Environmental Engineering at Auburn University. Additionally, the percentage of vehicles that exceeded the bias factor of 1.0 was determined for every candidate and load combination. Computed parameters provided a basis to select notional permit vehicle that provide uniform safety and consistent reliability for different truss bridges and load cases. It was decided to reduce the number of possible permit candidates by taking 90th quantiles which allowed selection of representative vehicles from each permit candidate group.

The size of finite element models following the calculation of live load effects was estimated to be over 100 TB. Therefore, the calculated files were regularly deleted after exporting the axial force results required for subsequent statistical analysis. Procedure for development of notional vehicle was successfully completed for complex truss bridges. Similar analysis is recommended for arch bridge structures using finite element models already developed and presented in first part of current report.

Chapter 11

CONCLUSIONS AND RECOMMENDATIONS

The objective of the project was the development of notional vehicles for evaluation of complex bridges in Alabama. The focus was on truss and arch structures. This required collection and processing of permit data, development of Finite Element Method models of selected representative complex bridges, running candidates for notional vehicles and recommendation of selected notional vehicle or a set of vehicles to ALDOT. The conclusions and recommendations are summarized as follows:

1. Permit database was provided by ALDOT with over 750,000 records for the last five years. A comprehensive analysis has demonstrated that the data is relatively stable.
2. When comparing internal distributions over the past five years, the probability patterns remain largely consistent. One of the key conclusions is that, despite a 7% annual increase in the number of issued permits and variability in transported cargo, the internal forces generated by permit vehicles remain stable and comparable.
3. The major effort was required for computation of all runs of candidates for notional vehicles using specially developed procedure including influence line analysis. Each vehicle was run at increment equal to approximately one foot at a time. Values of internal forces were calculated and recorded for each of the considered elements.
4. Load rating analysis is essential for maintaining an adequate level of structural safety and plays a critical role in infrastructure management and planning future maintenance.
5. The use of notional vehicles improves the accuracy of bridge load ratings by better reflecting realistic load configurations, which reduces uncertainty in structural assessments associated with the exclusion of permit vehicle effects. Standardized notional vehicles also enhance structural safety by enabling consistent risk evaluation across bridge inventories, allowing for more effective prioritization of maintenance and rehabilitation efforts.
6. The observed data stability indicates that it is feasible to define a notional vehicle for a specific bridge type. Furthermore, due to the consistency of data, such a vehicle can be considered valid for use over the coming years.
7. Incorporating notional vehicles into the design of new bridges ensures long-term durability and cost-efficiency by accounting for future traffic demands and evolving permit vehicle characteristics.

Based on the extensive research and analysis conducted throughout this project, the following items are recommended to support future development and implementation of notional permit vehicles:

1. It is recommended to incorporate the developed notional vehicle into widely adopted rating guidelines, which will improve load rating accuracy for truss bridges by better capturing permit vehicle effects.
2. It is advised to initiate work on notional vehicles for additional purposes already identified by other states, such as fatigue evaluation.
3. After the notional vehicle is introduced into widespread use and integrated into the rating process, it is recommended to perform a data stability check after a 10-year interval. This will help to verify whether evolving patterns in the transportation system have affected the load effects compared to current values.
4. For older but critical bridges originally designed for different vehicle types, it is recommended to develop custom notional vehicles. This will help extend the bridge's service life by identifying the specific permit vehicles that travel through these structures and adjust live load effects accordingly, while maintaining safety.
5. The algorithms and procedures necessary for the development of notional vehicles have been successfully established. Therefore, it is recommended to perform similar analysis for arch FE models presented in current report as well as for other types of complex structures such as curved ramps, floorbeam system, cable-stayed and segmental box girder bridges.
6. The outcome of this project is a notional vehicle for rating process representing Alabama permit traffic. However, developed live load model accounts only for the scenario in which the permit vehicle is the sole vehicle on the bridge, in contrast to the actual situation. Further work is recommended to encompass the simultaneous occurrence of permit vehicles with other vehicles. This case may be especially important for long-span bridges which require special attention and therefore separate probabilistic studies are needed.

REFERENCES

AAHSTO, American Association of State Highway and Transportation Official. 2020. "AASHTO LRFD Bridge Design Specification, 9th Edition." American Association of State Highway and Transportation Officials. Washington, DC.

AASHTO, American Association of State Highway and Transportation Official. 2018. "Manual for Bridge Evaluation, 3rd Edition." Washington, DC: AASHTO.

ALDOT. 2021. "Bridge Inspection Manual for Inventory and Appraisal of Alabama Bridges." Alabama Department of Transportation, Maintenance Bureau.

ALDOT. 2022. "Standard Specifications for Highway Construction." Alabama Department of Transportation.

ALDOT. 2023. "Structural Design Manual." Alabama Department of Transportation, ALDOT Bridge Bureau.

Babu, Anjan Ramesh, Olga Iatsko, J. Michael Stallings, and Andrzej S. Nowak. 2019. "Application of WIM and Permit Data," May. https://trid.trb.org/view/1636331.

Bae and Oliva. 2009. "Bridge Analysis and Evaluation of Effects under Overload Vehicles-Phase I." CFIRE 02-03.

Barker, Michael. 2013. "Review and Revision of Overload Permit Classification ORBP Report No. RC-1589." Michigan Department of Transportation. https://www.michigan.gov/documents/mdot/MDOT-ORBP-RC-1589-ReviewOverloadClass-ONLINE_412641_7.pdf.

Barker, Michael, and Jay Puckett. 2016. "Assessment and Evaluations of I-80 Truck Loads and Their Load Effects." FHWA. https://rosap.ntl.bts.gov/view/dot/32469.

BridgeTech, Inc. Assessment and Evaluations of I-80 Truck Loads and Their Load Effects. December 2016. By Michael Barker and Jay Puckett. rosap.ntl.bts.gov/view/dot/32469.

California Department of Transportation. 2020. "California Amendments to AASHTO LRFD Bridge Design Specifications – 8th Edition."

Chowdhury, Putman, Pang, Dunning, Dey, and Chen. 2013. "Rate of Deterioration of Bridges and Pavements as Affected by Trucks," December. https://trid.trb.org/view/1308651.

Chou, Karen C., James H. Deatherage, Terry D. Leatherwood, and Amjad J. Khayat. 1999. "Innovative Method for Evaluating Overweight Vehicle Permits." Journal of Bridge Engineering, vol. 4, no. 3, pp. 221-227. American Society of Civil Engineers, doi.org/10.1061/(ASCE)1084-0702(1999)4:3(221).

Connecticut Department of Transportation. 2023. "Bridge Design Manual, Revisions 2/11."

Correia, João Pedro Ramôa Ribeiro, and Fernando António Baptista Branco. "New Methodology: Permit Checking of Vehicular Overloads." Journal of Bridge Engineering, vol. 11, no. 3, 2006, pp. 274-281. doi.org/10.1061/(ASCE)1084-0702(2006)11:3(274).

Culmo, Michael P., John T. DeWolf, and Michael R. DelGrego. 2004. "Behavior of Steel Bridges Under Superload Permit Vehicles." Transportation Research Record 1892 (1): 107–14. https://doi.org/10.3141/1892-12.

Elkins, Lori, and Christopher Higgins. 2008. "Development of Truck Axle Spectra from Oregon Weigh-in-Motion Data for Use in Pavement Design and Analysis," January. https://trid.trb.org/view.aspx?id=849621.

Federal Highway Administration. 2022. "Advancing Bridge Load Rating: State of Practice and Frameworks." Office of Infrastructure, Office of Bridges and Structures.

Federal Highway Administration. 2022. "Appendix to Advancing Bridge Load Rating: State of Practice and Frameworks – Sample State." Office of Infrastructure, Office of Bridges and Structures.

Fiorillo, Graziano, and Michel Ghosn. 2014. "Procedure for Statistical Categorization of Overweight Vehicles in a WIM Database." Journal of Transportation Engineering 140 (5): 04014011. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000655.

Gao, Lubin. 2012. "Reliability-Based Evaluation of Bridge Live Load Carrying Capacity in United States." Public Works Research Institute. https://www.pwri.go.jp/eng/ujnr/tc/g/pdf/28/28-3-2_Gao.pdf.

Ghosn, Michel, Graziano Fiorillo, Volodymyr Gayovyy, Tenzin Getso, Sallem Ahmed, and Neville Parker. 2015. "Effects of Overweight Vehicles on NYSDOT Infrastructure," September. https://trid.trb.org/view/1375435.

Ghosn, Michel, Bala Sivakumar, and Feng Miao. 2011. "Load and Resistance Factor Rating (LRFR) in NYS: Volume I, Final Report." Department of Civil Engineering, The City College of The City University of New York.

Ghosn, Michel, Bala Sivakumar, Fred Moses, Transportation Research Board, National Cooperative Highway Research Program, and Transportation Research Board. 2011. Protocols for Collecting and Using Traffic Data in Bridge Design. Washington, D.C.: National Academies Press. http://www.nap.edu/catalog/14521.

Hayworth, Rebecca, X. Sharon Huo, and Lei Zheng. 2008. "Effects of State Legal Loads on Bridge Rating Results Using the LRFR Procedure." Journal of Bridge Engineering 13 (6): 565–72. https://doi.org/10.1061/(ASCE)1084-0702(2008)13:6(565).

Laman, Jeffrey A., and Andrzej S. Nowak. 1996. "Fatigue-Load Models for Girder Bridges." Journal of Structural Engineering 122 (7): 726–33. https://doi.org/10.1061/(ASCE)0733-9445(1996)122:7(726).

Laman, Jeffrey A., and Meet Shah. 2016. "Assessment of Current Design Loads for Permit Vehicles: Final Report." The Thomas D. Larson Pennsylvania Transportation Institute, Commonwealth of Pennsylvania Department of Transportation.

Lawson, David J., Cheng Lok (Caleb) Hing, and Jason A. Carota. 2013. “Bridge Load Rating of a Super Load Using AASHTO LRFR.” In Structures Congress 2013, 668–79. Pittsburgh, Pennsylvania, United States: American Society of Civil Engineers. https://doi.org/10.1061/9780784412848.059.

Leahy, Cathal, Eugene J. OBrien, Bernard Enright, and Donya Hajializadeh. 2015. “Review of HL-93 Bridge Traffic Load Model Using an Extensive WIM Database.” Journal of Bridge Engineering 20 (10): 04014115. https://doi.org/10.1061/(ASCE)BE.1943-5592.0000729.

Liao, Chen-Fu, Indrajit Chatterjee, and Gary A. Davis. 2015. “Implementation of Traffic Data Quality Verification for WIM Sites.” Report. Center for Transportation Studies University of Minnesota. http://conservancy.umn.edu/handle/11299/173634.

Lou, Peng, Hani Nassif, and Paul Truban. 2018. “Development of Live Load Model for Strength II Limit State in AASHTO LRFD Design Specifications.” Transportation Research Record 2672 (41): 11–23. https://doi.org/10.1177/0361198118756874.

Luszczynska, Aneta K., Rafal Roszczenko, and Andrzej S. Nowak. 2024. „Fusion of Weigh-in-Motion and Permit Data.” 7th International Bridge Conference of Ralph Modjeski, Bydgoszcz, Poland.

Luszczynska, Aneta K., Rafal Roszczenko, and Andrzej S. Nowak. 2025. „Permit-Based Live Load Model for Complex Truss Bridges.” 12th New York City Bridge Conference, New York.

Luszczynska, Aneta K., Jeffrey J. LaMondia, and Andrzej S. Nowak. 2025. " Quality Evaluation of Weigh-in-Motion Traffic Data for Bridge Live Load Modeling." Transportation Research Record: Journal of the Transportation Research Board (under review).

Minervino, Charles, Bala Sivakumar, Fred Moses, Dennis Mertz, and William Edberg. 2004. “New AASHTO Guide Manual for Load and Resistance Factor Rating of Highway Bridges.” Journal of Bridge Engineering 9 (1): 43–54. https://doi.org/10.1061/(ASCE)1084-0702(2004)9:1(43).

Moses, Fred. 2001. Calibration of Load Factors for LRFR Bridge Evaluation. NCHRP Report 454. Washington, D.C: National Academy Press.

Nassif, Hani, Kaan Ozbay, Hao Wang, Robert Noland, Peng Lou, Sami Demiroluk, Dan Su, Chaekuk Na, Jingnan Zhao, and Miguel Beltran. 2015. “Impact of Freight on Highway Infrastructure in New Jersey.”

New York State Department of Transportation. 2021. “LRFD Bridge Design Specifications.”

New Jersey Department of Transportation. 2016. “Design Manual for Bridges & Structures.”

Nichols, Andrew, and Darcy Bullock. 2004. “Quality Control Procedures for Weigh-in-Motion Data.” FHWA/IN/JTRP-2004/12, 2795. West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284313299.

Nowak, A. S. 1999. “Calibration of LRFD Bridge Design Code. NCHRP Report 368.” Transportation Research Board. National Research Council.

Nowak, Andrzej S., and T. Tharmabala. 1988. “Bridge Reliability Evaluation Using Load Tests.” Journal of Structural Engineering 114 (10): 2268–79. https://doi.org/10.1061/(ASCE)0733-9445(1988)114:10(2268).

Ohio Department of Transportation. 2009. “Impacts of Permitted Trucking on Ohio’s Transportation System and Economy.”

Sivakumar, Bala, Fred Moses, Gongkang Fu, and Michel Ghosn. 2007. “Legal Truck Loads and AASHTO Legal Loads for Posting.” https://doi.org/10.17226/23191.

Stawska, Sylwia. 2021. "Impact of Overloaded Vehicles on Bridges. Doctoral Dissertation." Auburn University, Civil and Environmental Engineering Department. Alabama.

Tabatabai, Hassan, and Qiang Zhao. "Evaluation of a Permit Vehicle Model Using Weigh-in-Motion Truck Records." Journal of Bridge Engineering, vol. 17, no. 2, 2012, pp. 389-392. American Society of Civil Engineers, doi.org/10.1061/(ASCE)TE.1943-5436.0000234.

Walus, Kendal R. 2020. "Instructional & Informational Memorandum IIM-S&B-86.4: Load Rating and Posting of Structures, Bridges, and Culverts." Virginia Department of Transportation, Structure and Bridge Division.

Wu, Dayong, Junxuan Zhao, Honchao Liu, and Changwei Yuan. 2019. “The Assessment of Damage to Texas Highways Due to Oversize and Overweight Loads Considering Climatic Factors.” International Journal of Pavement Engineering 20 (7): 853–65. https://doi.org/10.1080/10298436.2017.1353392.

Zhao, Jian, and Habib Tabatabai. 2012. “Evaluation of a Permit Vehicle Model Using Weigh-in-Motion Truck Records.” Journal of Bridge Engineering 17 (2): 389–92. https://doi.org/10.1061/(ASCE)BE.1943-5592.0000250.

Appendix A

Technical Drawings and Finite Element Model Representations

Project S-149(6) – Bridge over Sipsey River, located in Winston County - Duncan Bridge

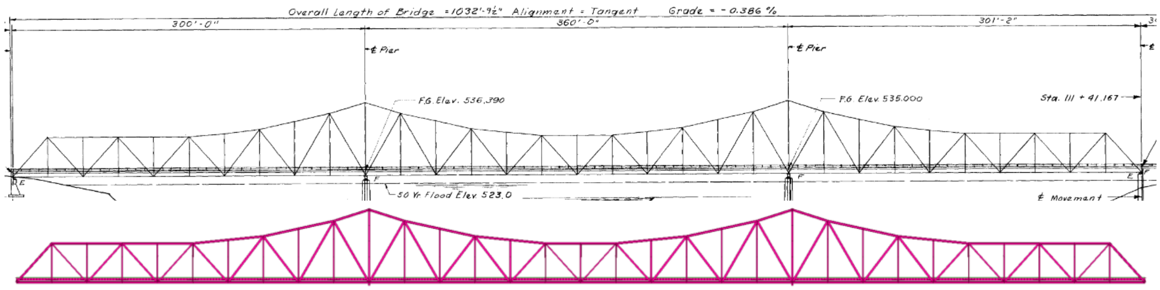


Figure A-0-1. Longitudinal view: technical drawing (top) and FE model (bottom) – Truss_1

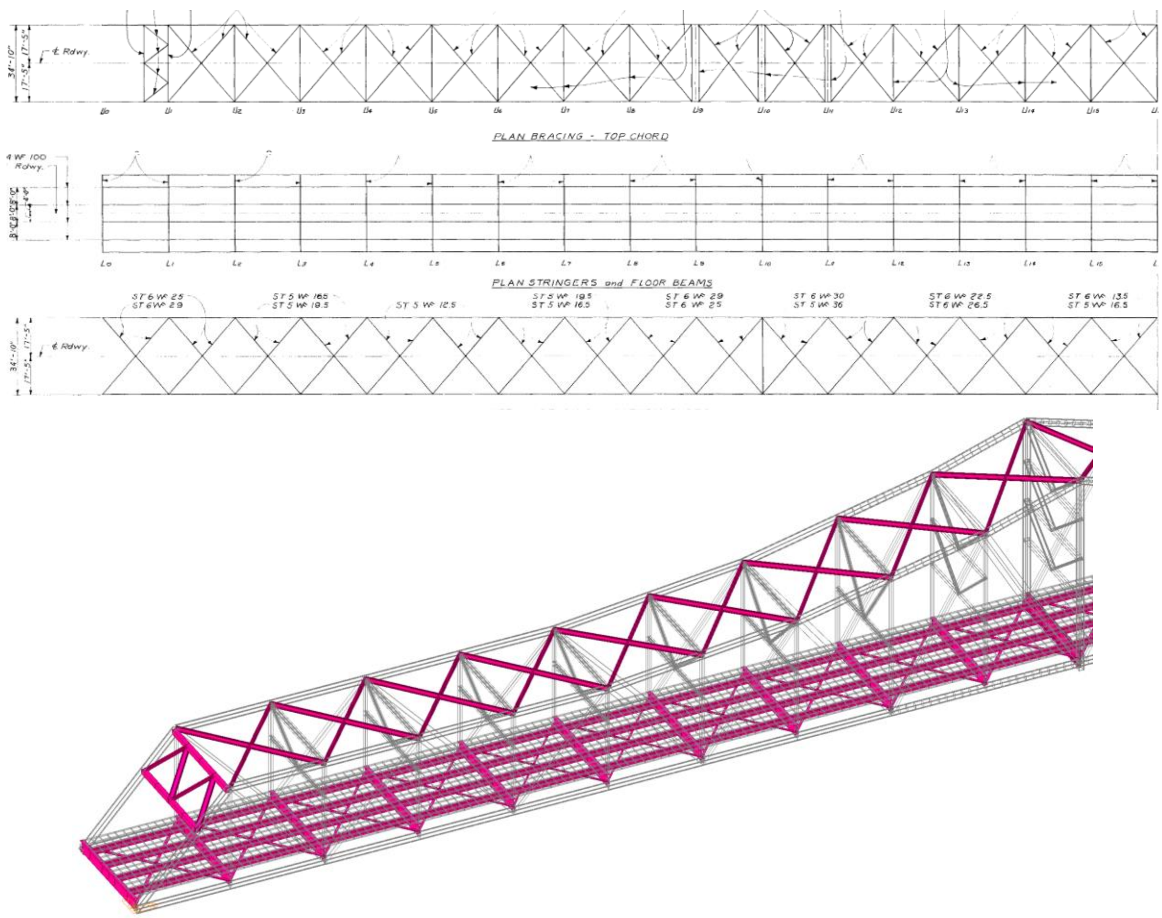


Figure A-0-2. View of top and bottom lateral bracing, stringer–floorbeam system: technical drawing (top) and FE model (bottom) - Truss_1

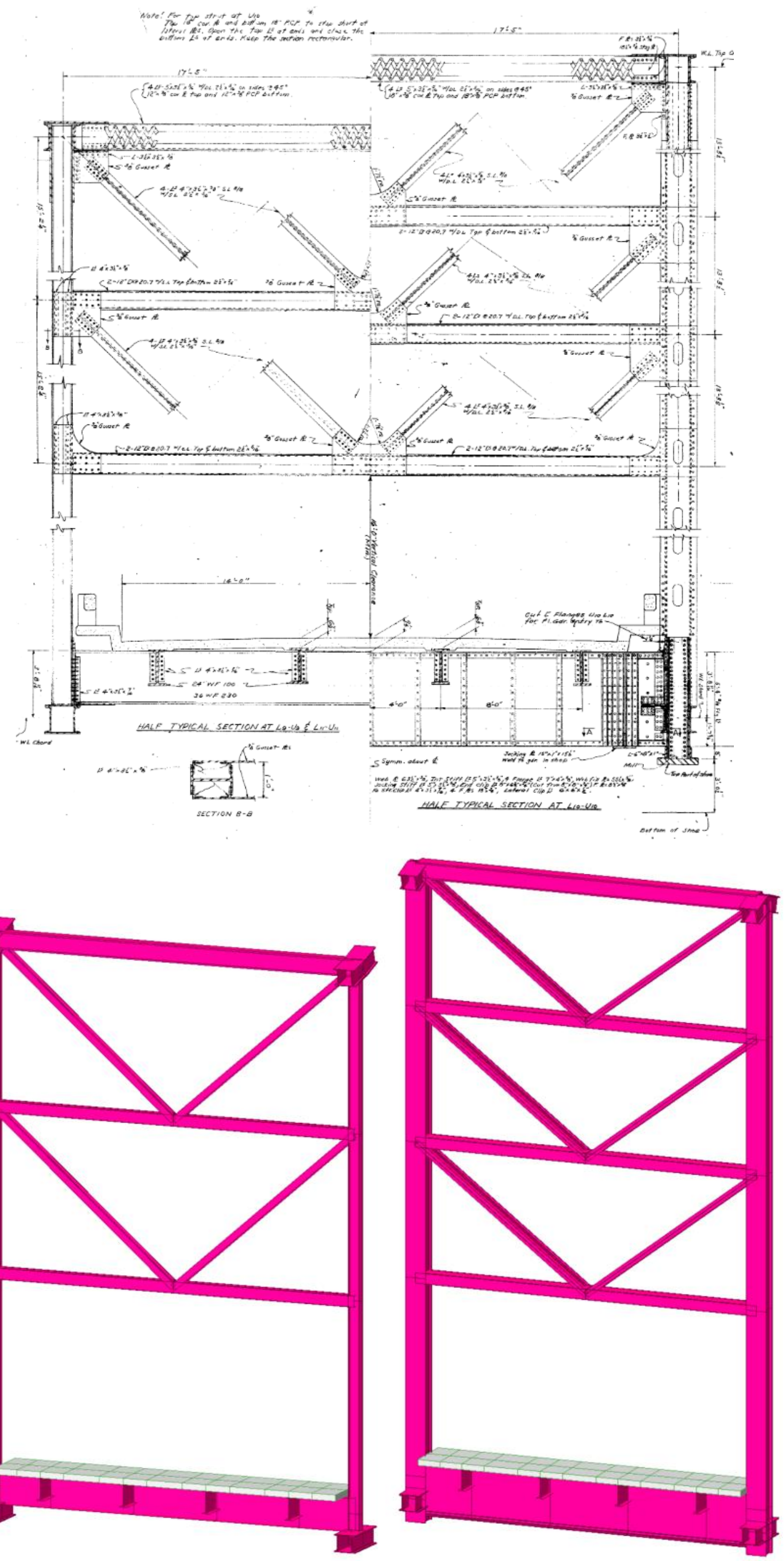


Figure A-0-3. View of typical sway bracing and section above support: technical drawing (top) and FE model (bottom) - Truss_1

Project No. ABC-16, located in Clarke and Choctaw Counties - Jim Folsom Bridge

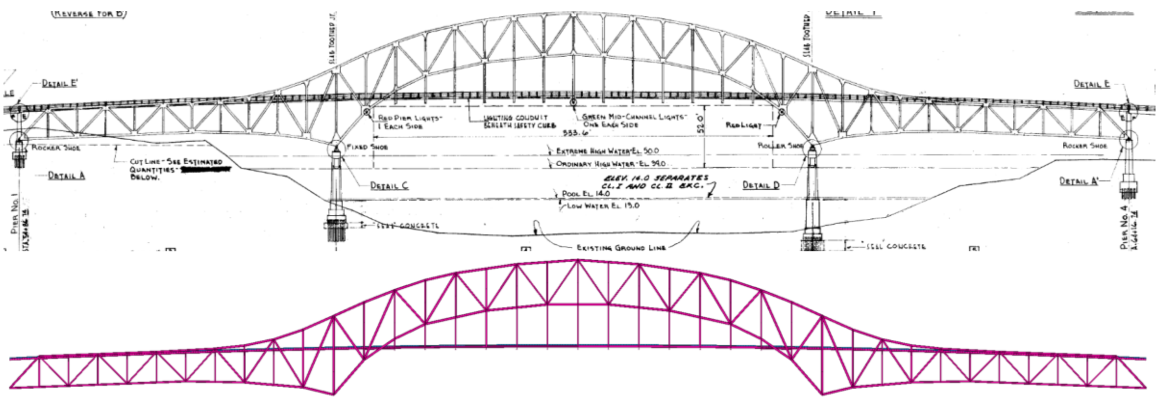


Figure A-0-4. Longitudinal view: technical drawing (top) and FE model (bottom) – Truss_2

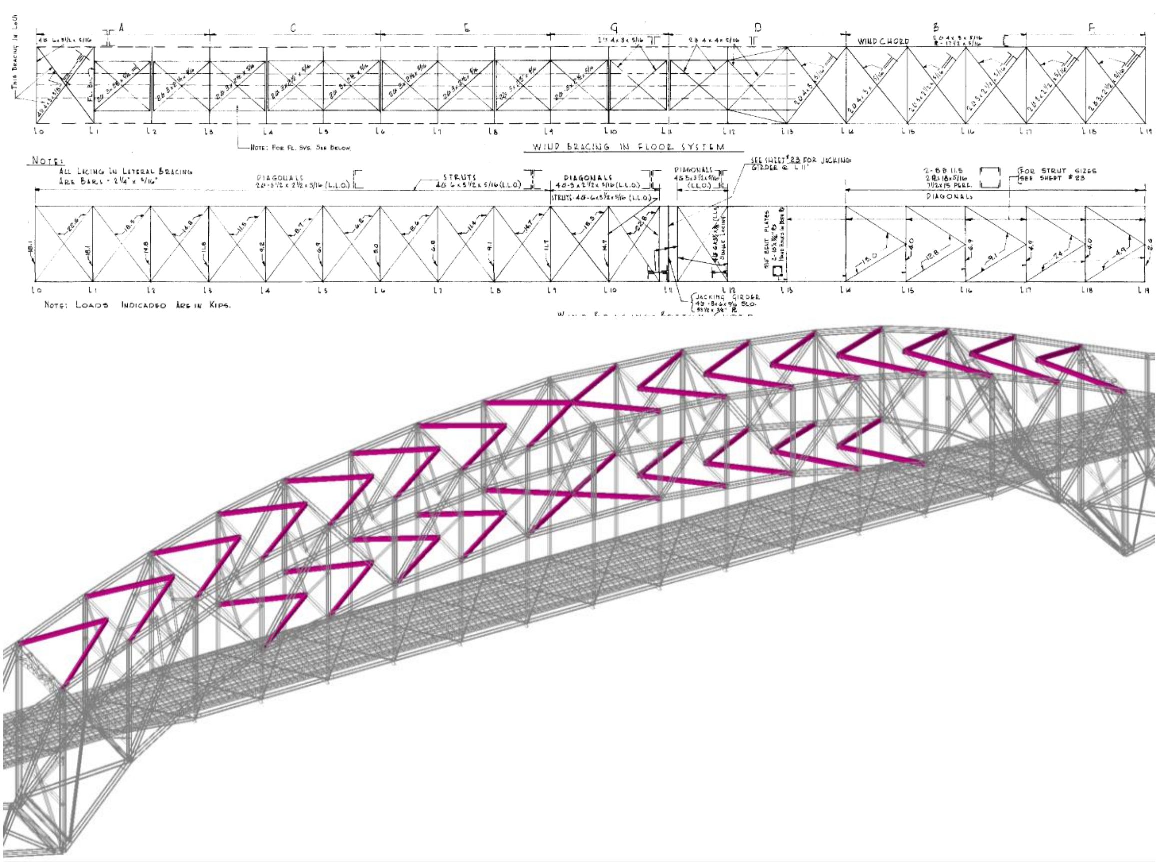


Figure A-0-5. View of top and bottom lateral bracing: technical drawing (top) and FE model- internal span (bottom) - Truss_2

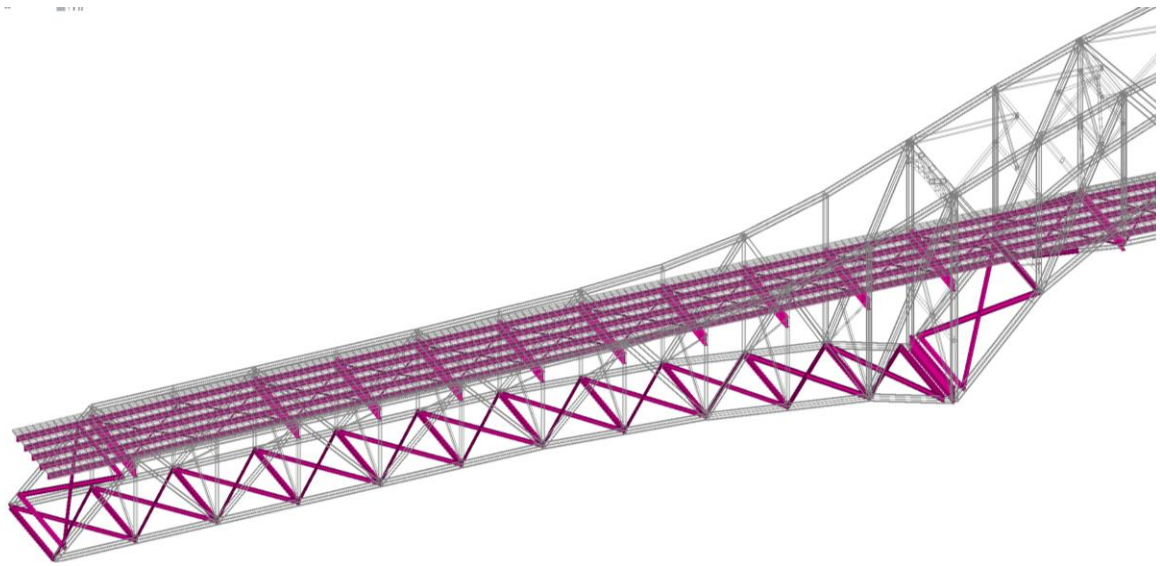


Figure A-0-6. View of bracing for top and bottom chords and stringer–floorbeam system: FE model - Truss_2

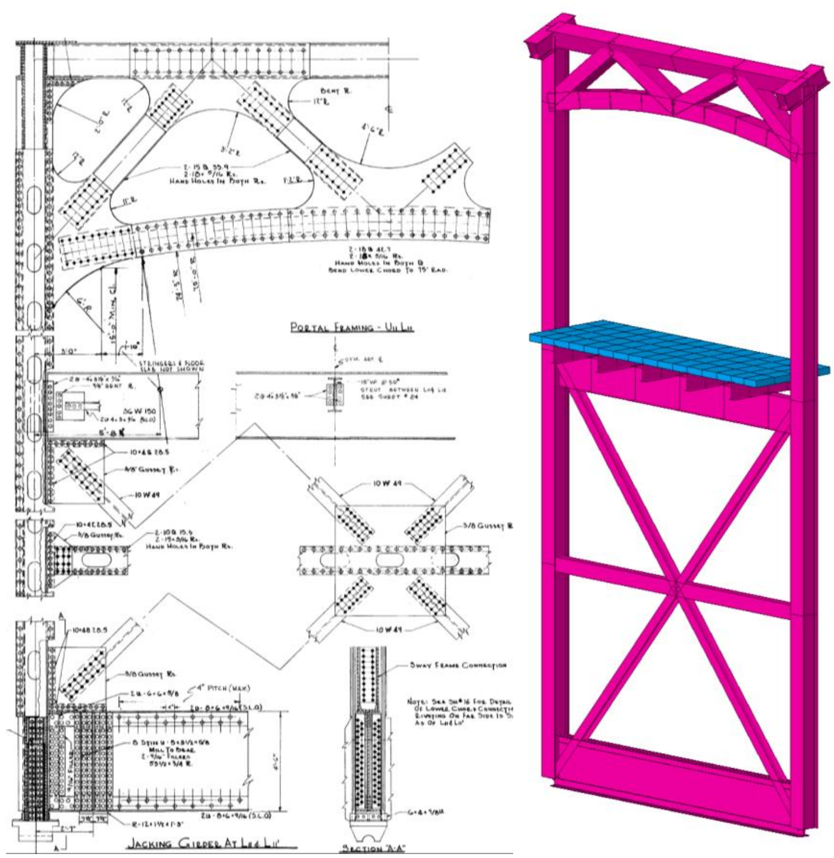


Figure A-0-7. View of sway bracing of section above support and portal framing: technical drawing (left) and FE model (right) - Truss_2

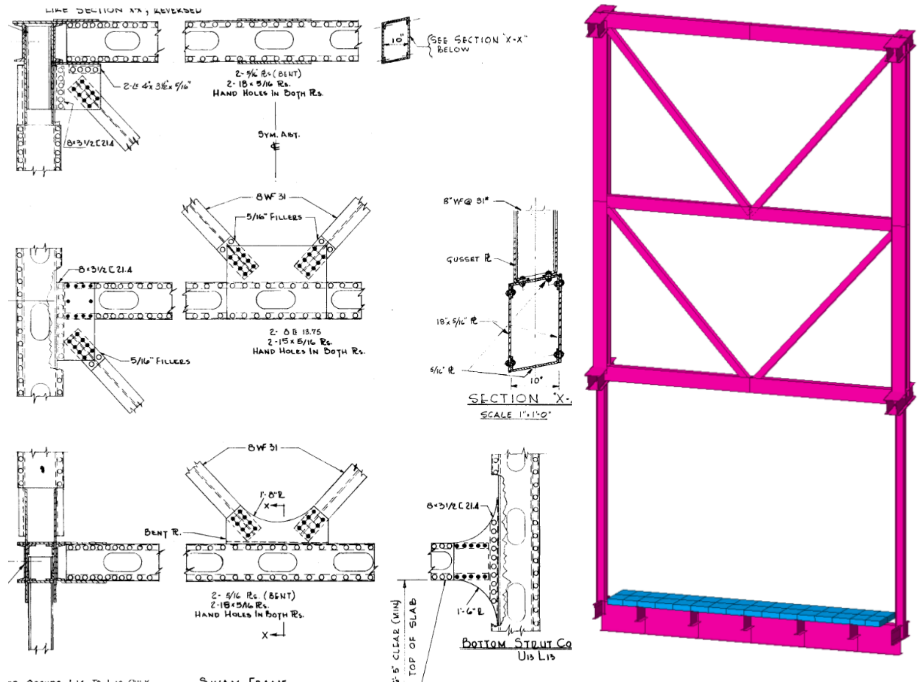


Figure A-0-8. View of typical sway bracing with hangers: technical drawing (left) and FE model (right) - Truss_2.

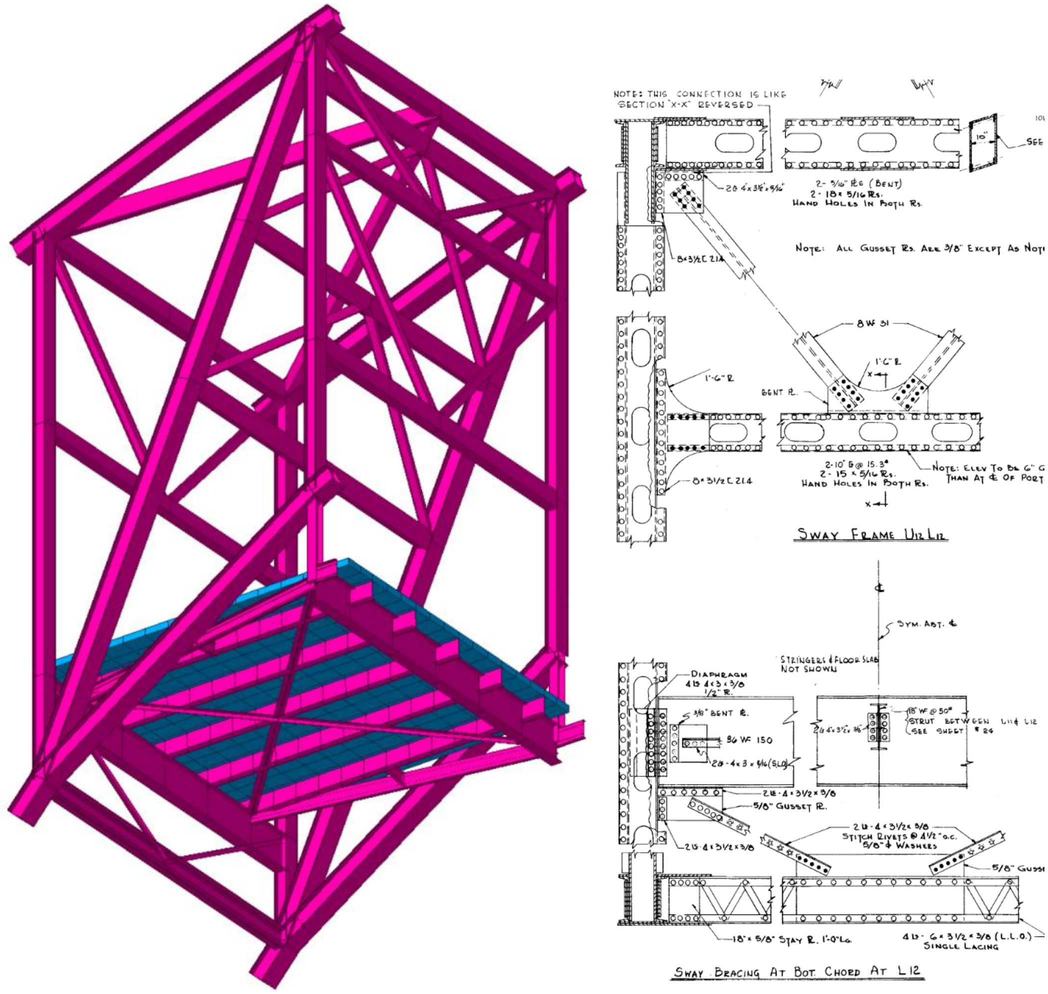


Figure A-0-9. View of sway bracing: technical drawing (left) and FE model (right) - Truss_2.

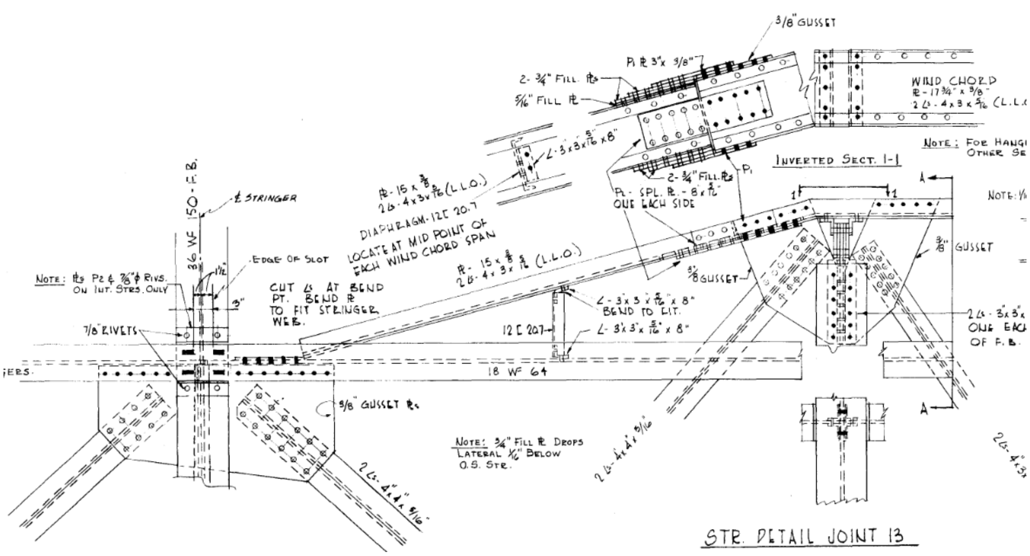


Figure A-0-10. Detail of the connection between the stringers and the wind chord.

Project No. ABC-18, located in Chilton- Coosa Counties - AL-22 Coosa River Bridge

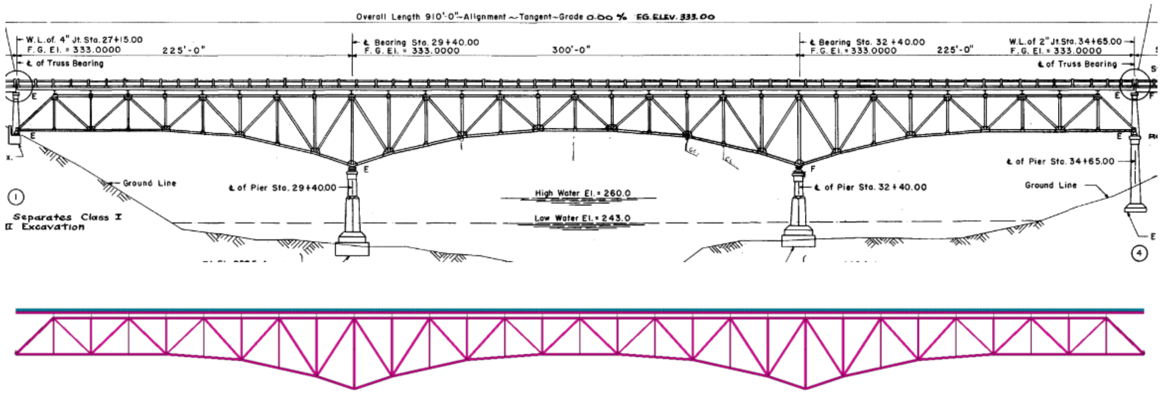


Figure A-0-11. Longitudinal view: technical drawing (top) and FE model (bottom) – Truss_3

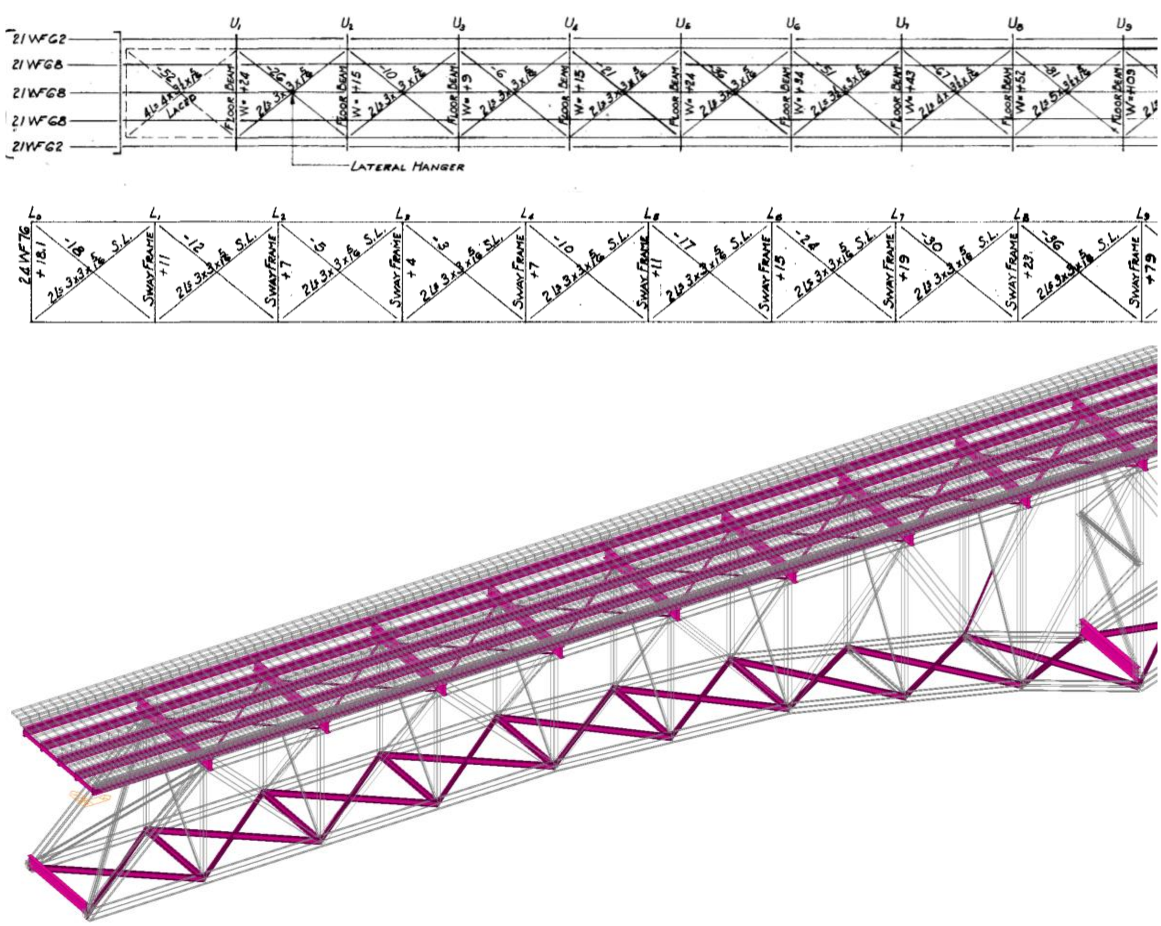


Figure A-0-12. View of top and bottom lateral bracing, stringer–floorbeam system: technical drawing (top) and FE model (bottom) - Truss_3

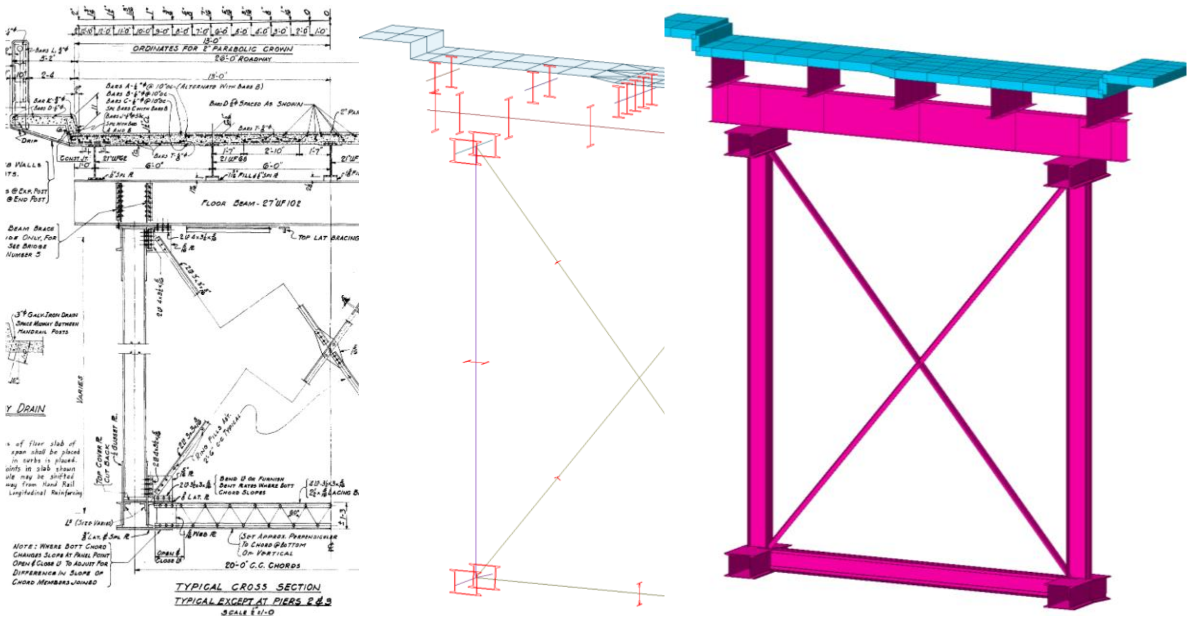


Figure A-0-13. Schematic of typical cross section: technical drawing (left) and FE model (right) - Truss_3

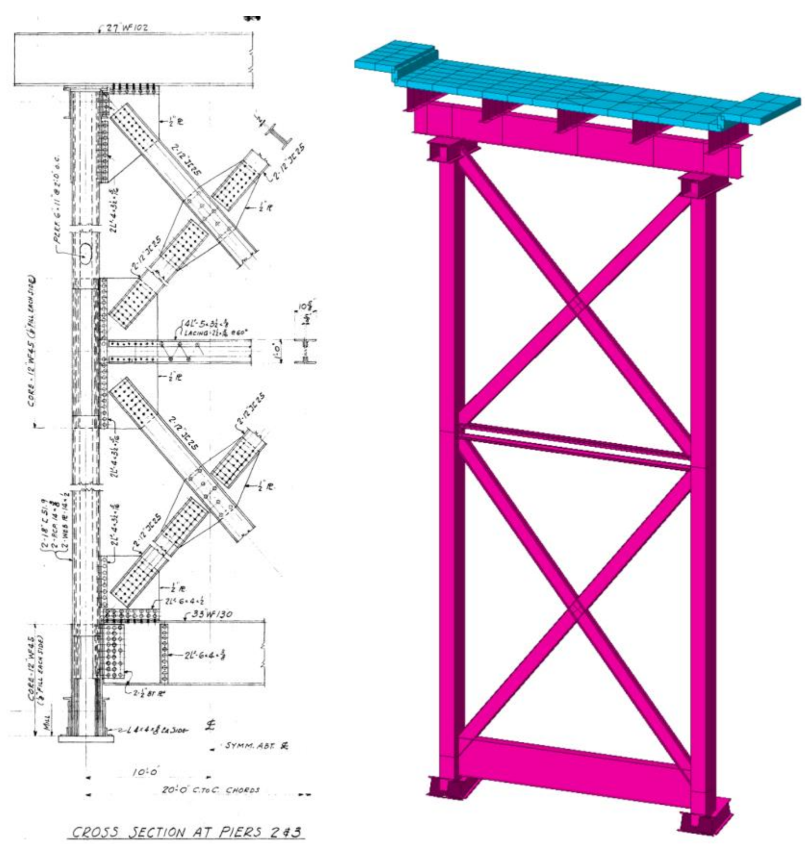


Figure A-0-14. View of cross section at piers: technical drawing (left) and FE model (right) - Truss_3.

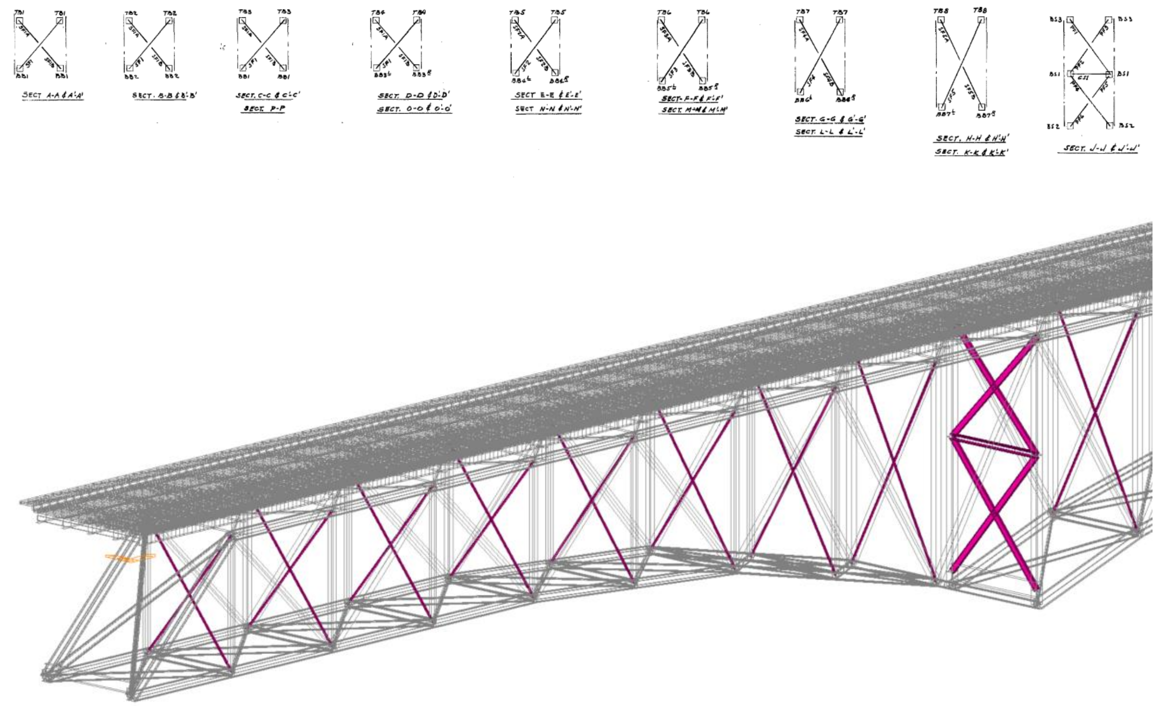


Figure A-0-15. View of sway bracing: technical drawing (left) and FE model (right) - Truss_3.

Project No. ABC-4, located in St. Clair and Talladega Counties, spanning the Coosa River

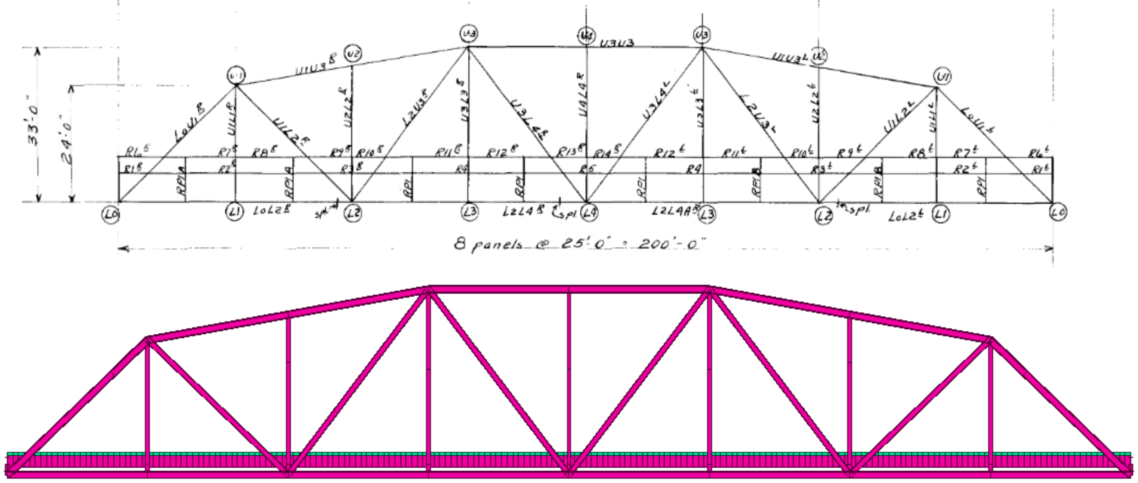


Figure A-0-16. Longitudinal view: technical drawing (top) and FE model (bottom) – Truss_4

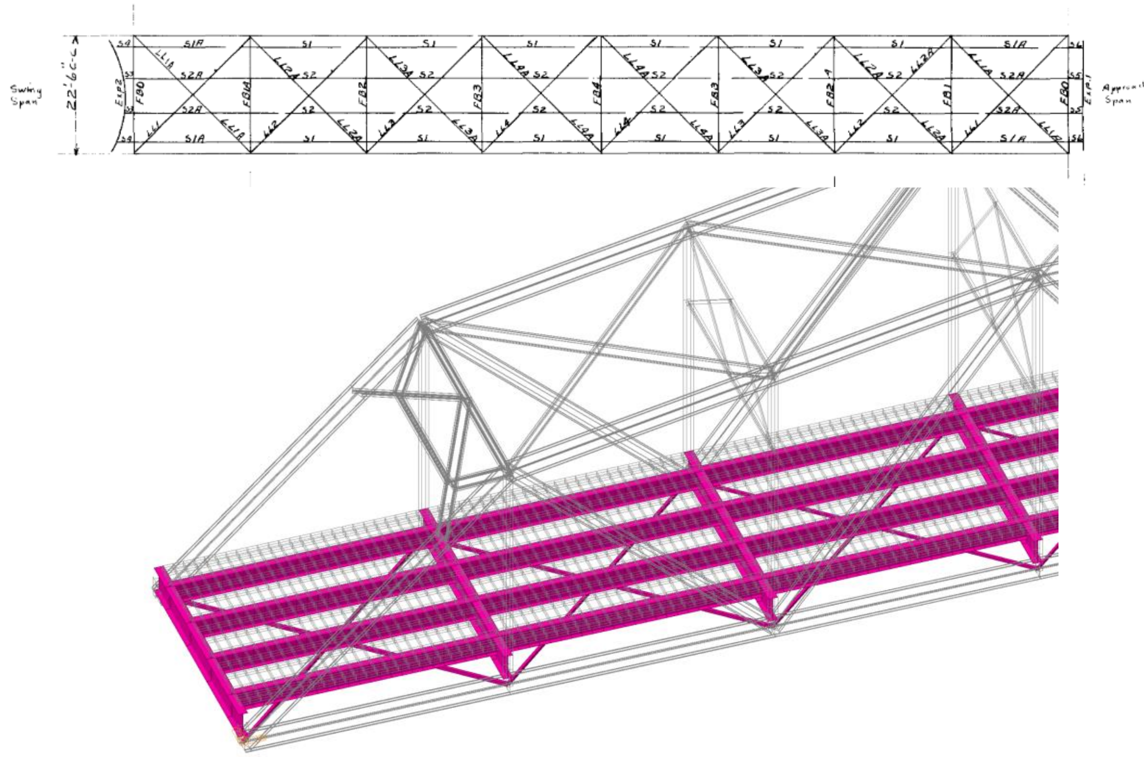


Figure A-0-17. View of bottom lateral bracing, stringer–floorbeam system: technical drawing (top) and FE model (bottom) - Truss_4

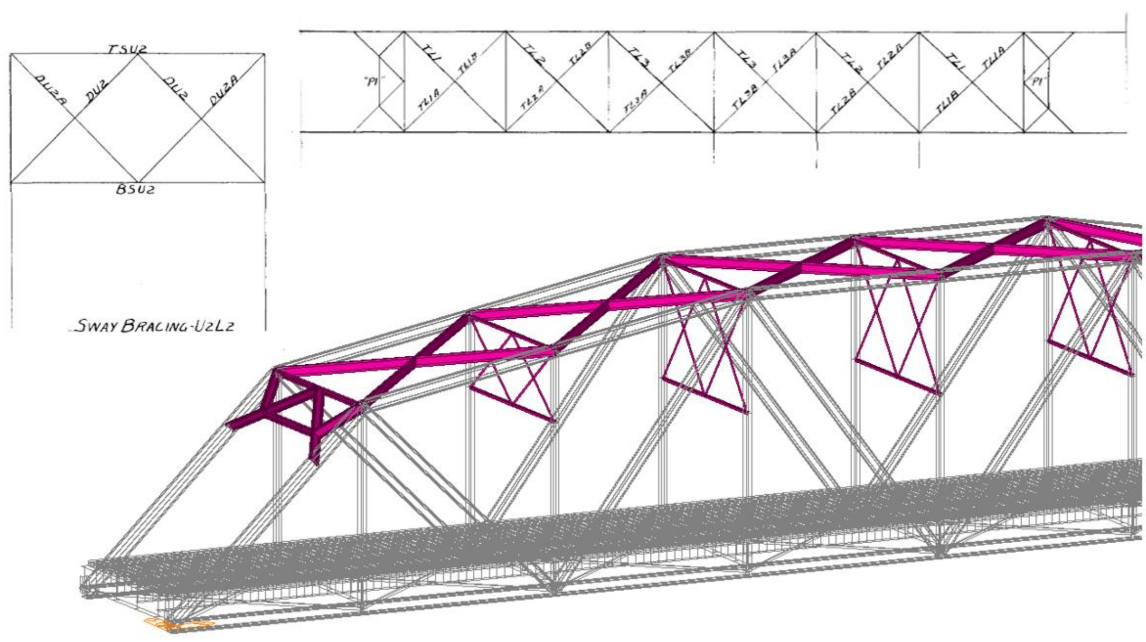


Figure A-0-18. View of top lateral bracing and sway bracing: technical drawing (top) and FE model (bottom) - Truss_4

Project No. BR 0002(550), located in Colbert and Lauderdale Counties, spanning the Tennessee River

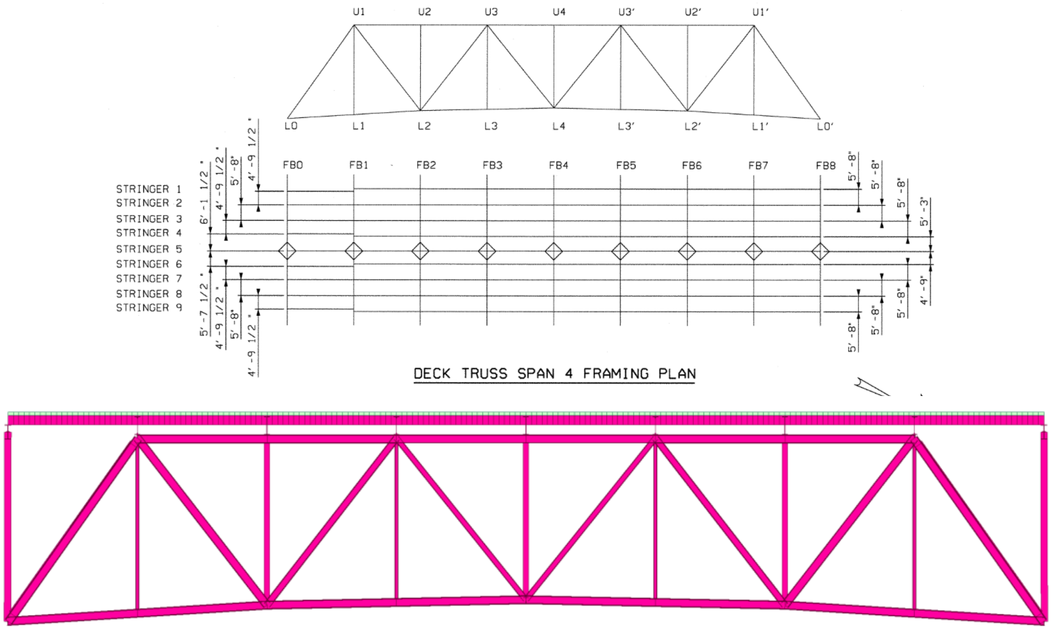


Figure A-0-19. Longitudinal view: technical drawing (top) and FE model (bottom) – Truss_5

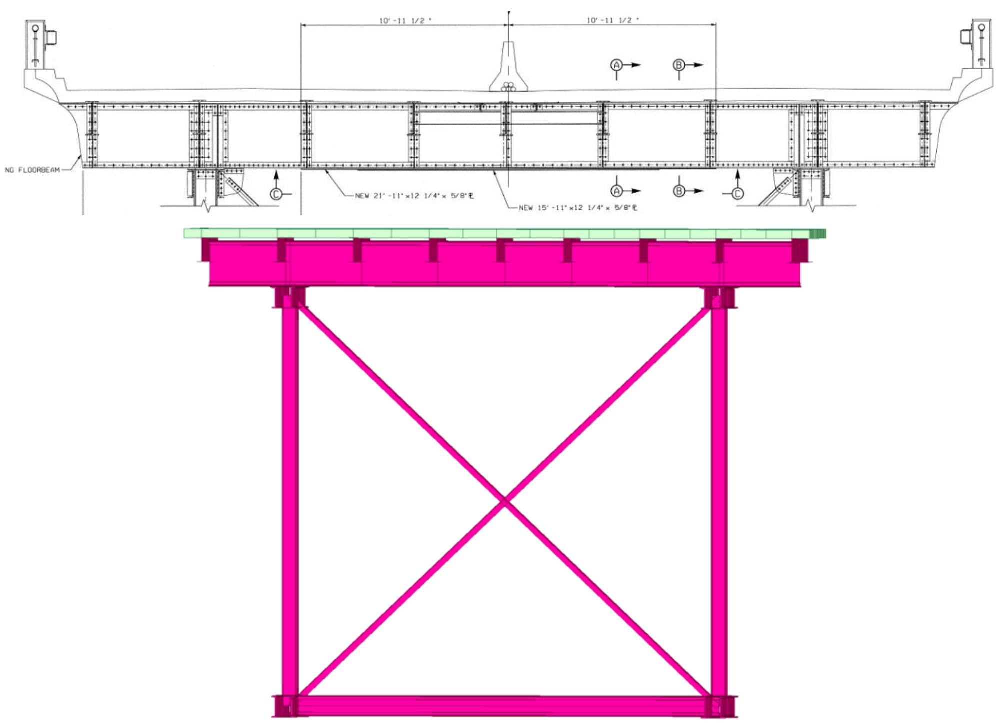


Figure A-0-20. View of typical cross section: technical drawing (top) and FE model (bottom) - Truss_5.

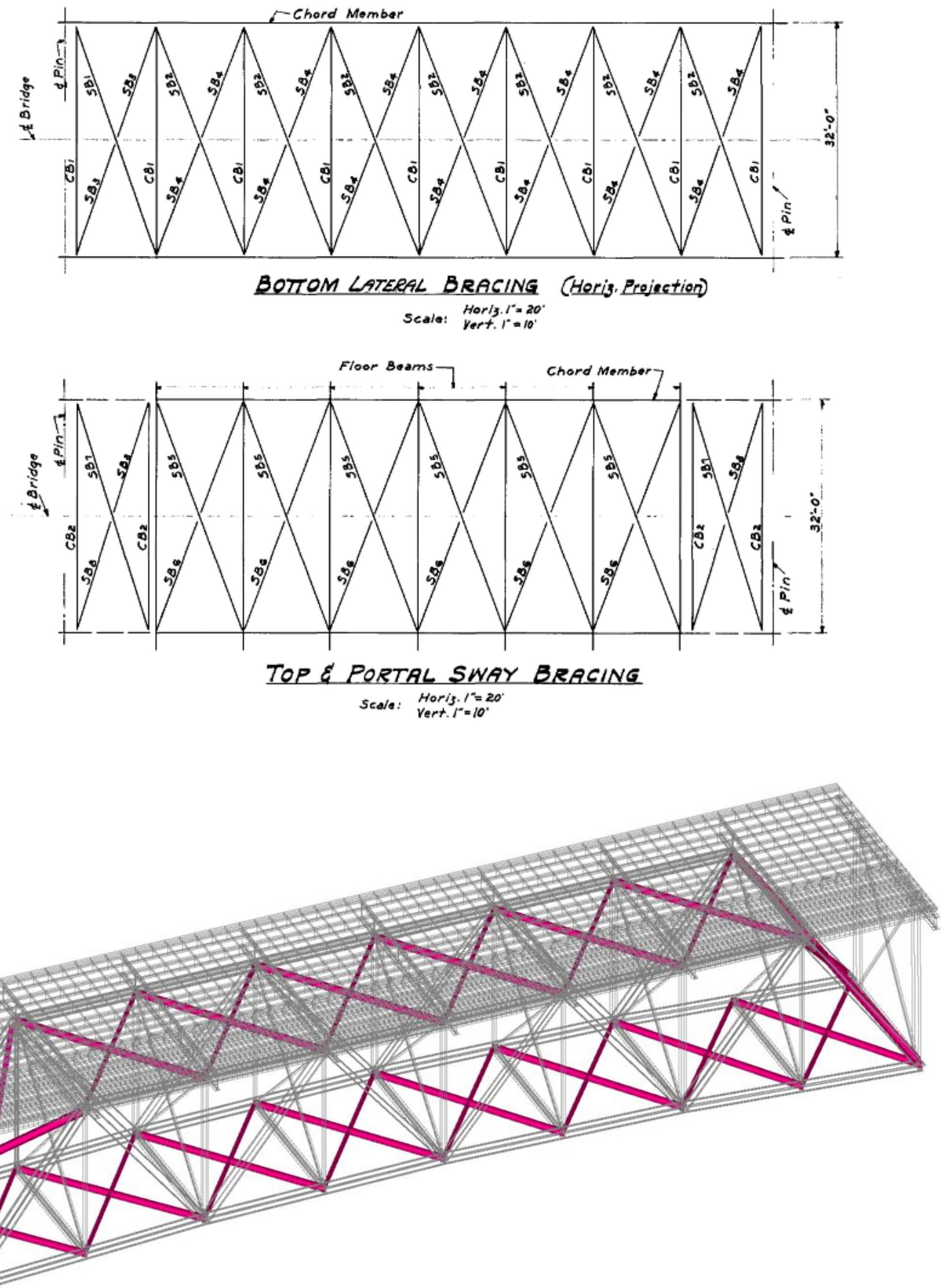


Figure A-0-21. View of top and bottom lateral bracing: technical drawing (top) and FE model (bottom) - Truss_5

Project No. BRF–0117(506), located on the Lookout Mountain Parkway section of SR-117, near the town of Mentone

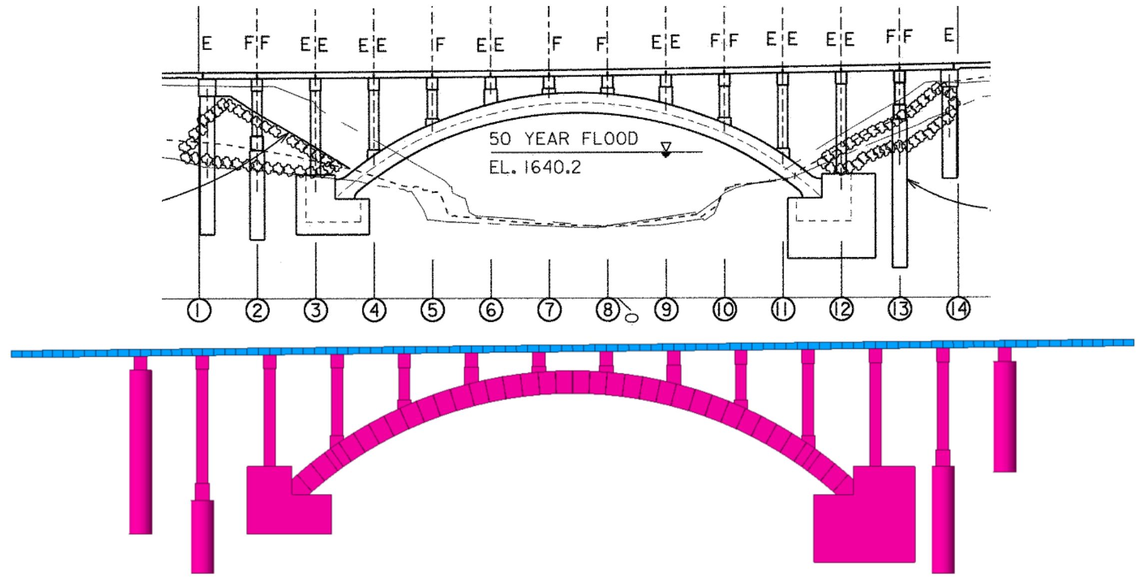


Figure A-0-22. Longitudinal view: technical drawing (top) and FE model (bottom) – Arch_1

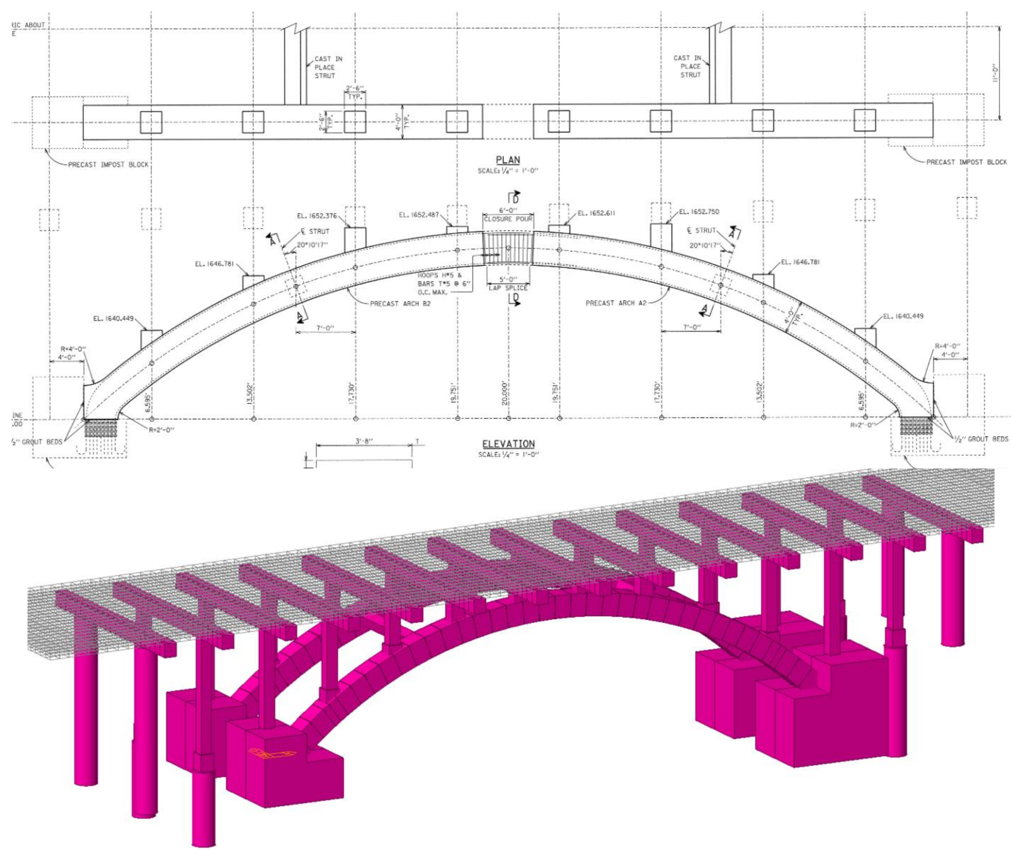


Figure A-0-23. View of the main arch with spandrel columns: technical drawing (top) and FE model (bottom) – Arch_1

Project No. NO.RPF-IMF-NHF-1059(387) over McFarland Boulevard is located in Tuscaloosa.

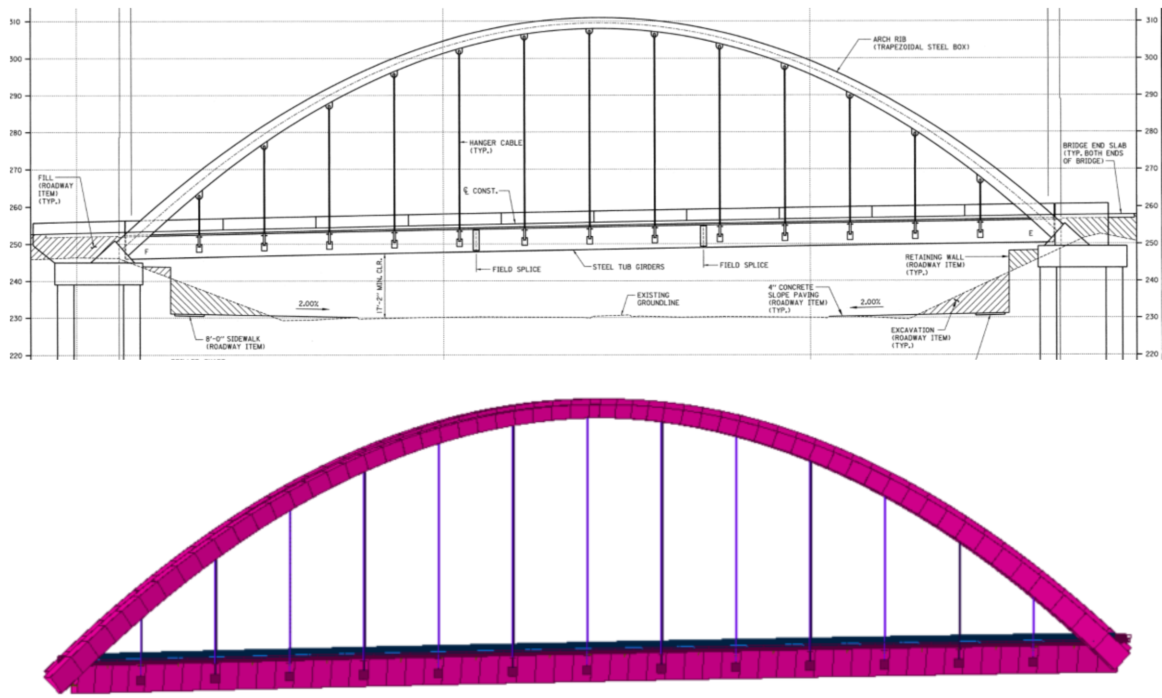


Figure A-0-24. Longitudinal view: technical drawing (top) and FE model (bottom) – Arch_2

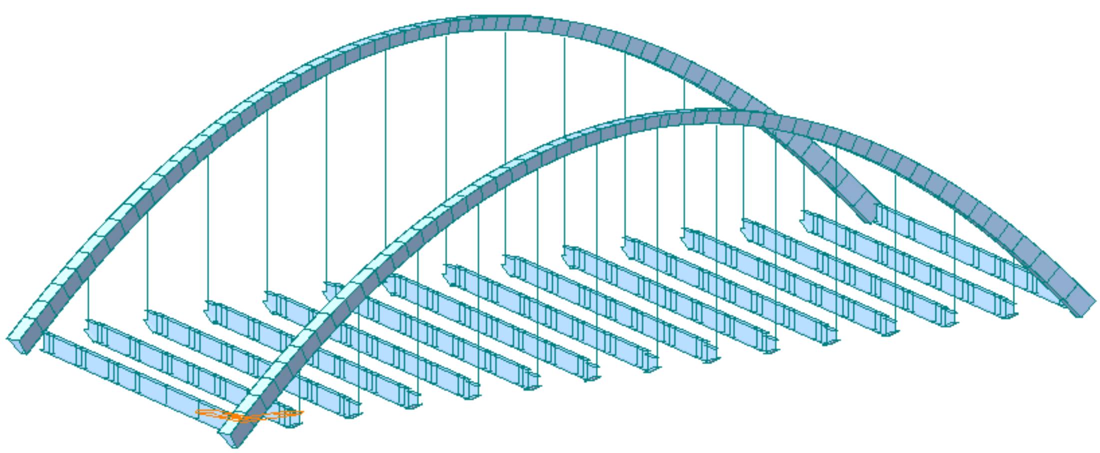


Figure A-0-25. View of the Arch structure with floor beam

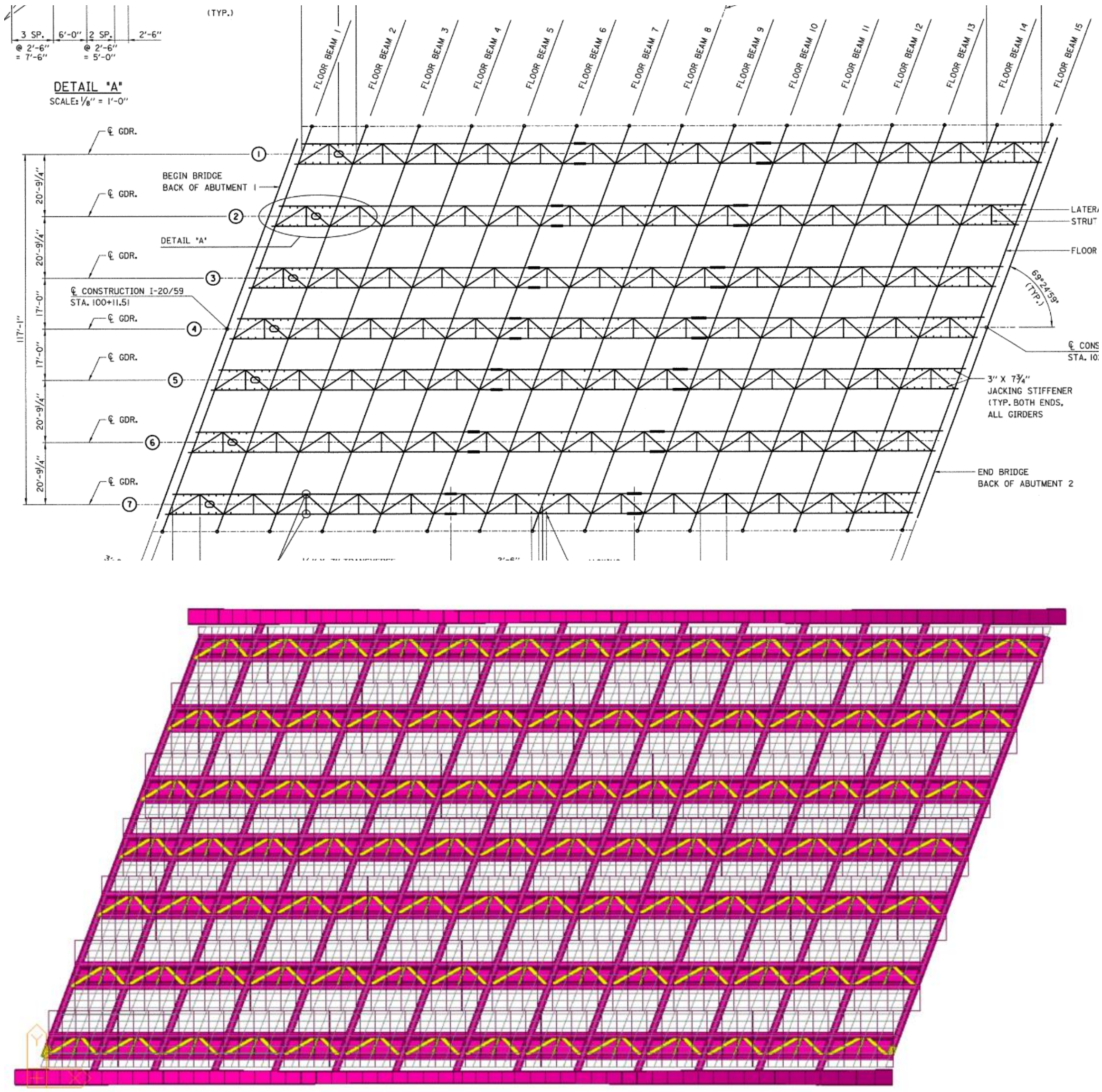


Figure A-0-26. Plan view of the floorbeam: technical drawing (top) and FE model (bottom) – Arch_2

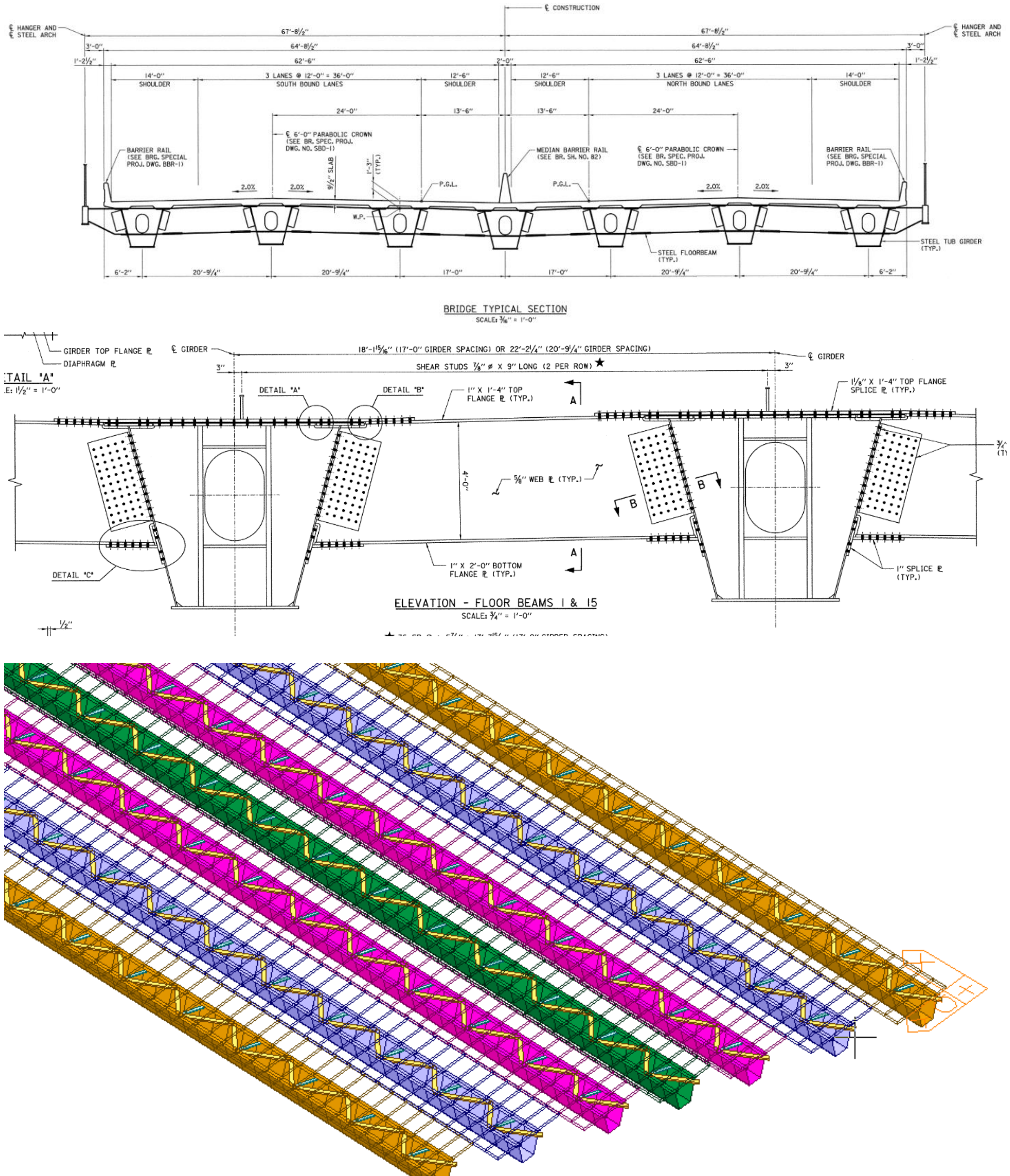


Figure A-0-27. View of floor beam: technical drawing (top) and FE model (bottom) – Arch_2

Project No. I-65 – 1 (85) 23, on the Interstate route 65, spanning the Mobile River Delta near the Mobile.

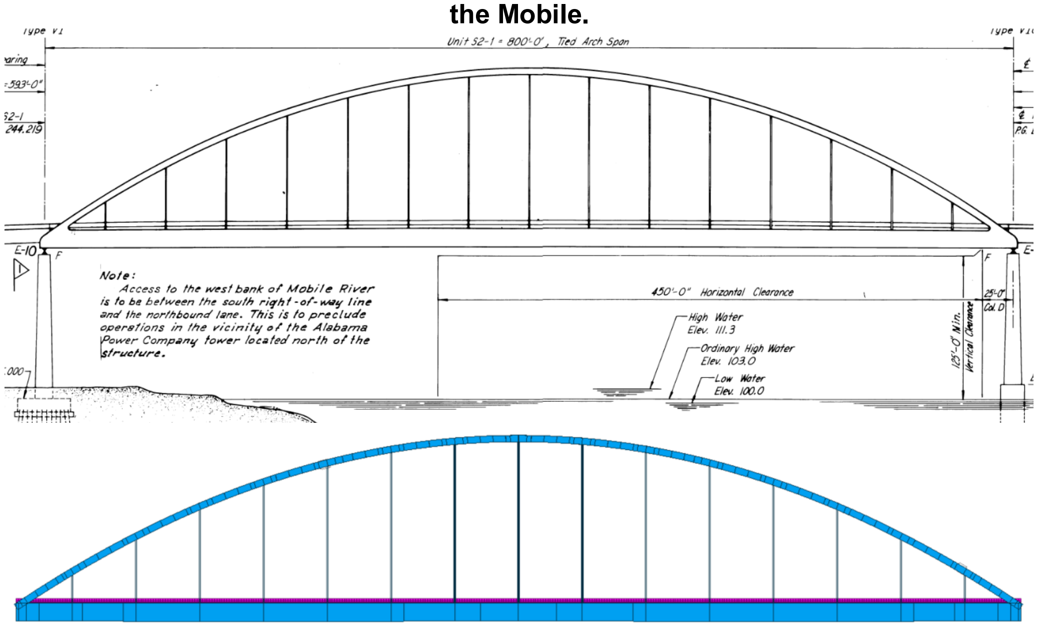


Figure A-0-28. Longitudinal view: technical drawing (top) and FE model (bottom) – Arch_3

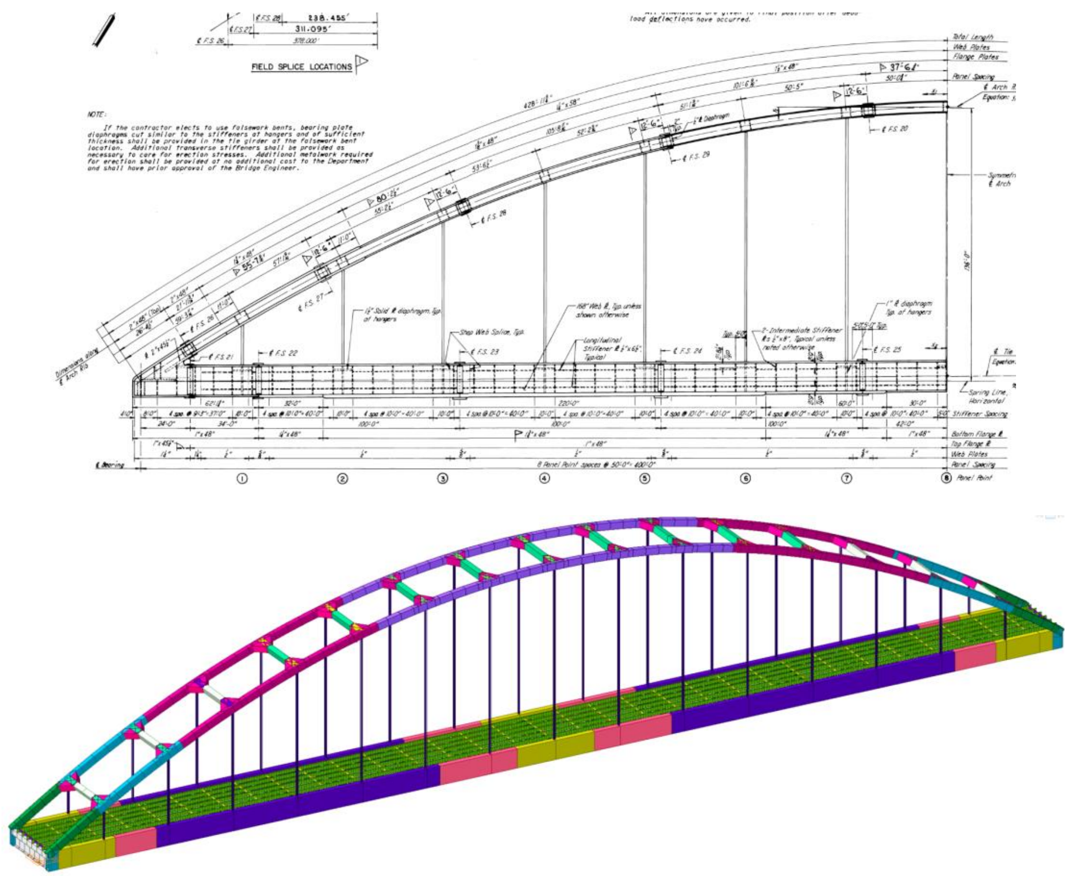


Figure A-0-29. Half elevation (top) and model view with cross-section type (bottom).

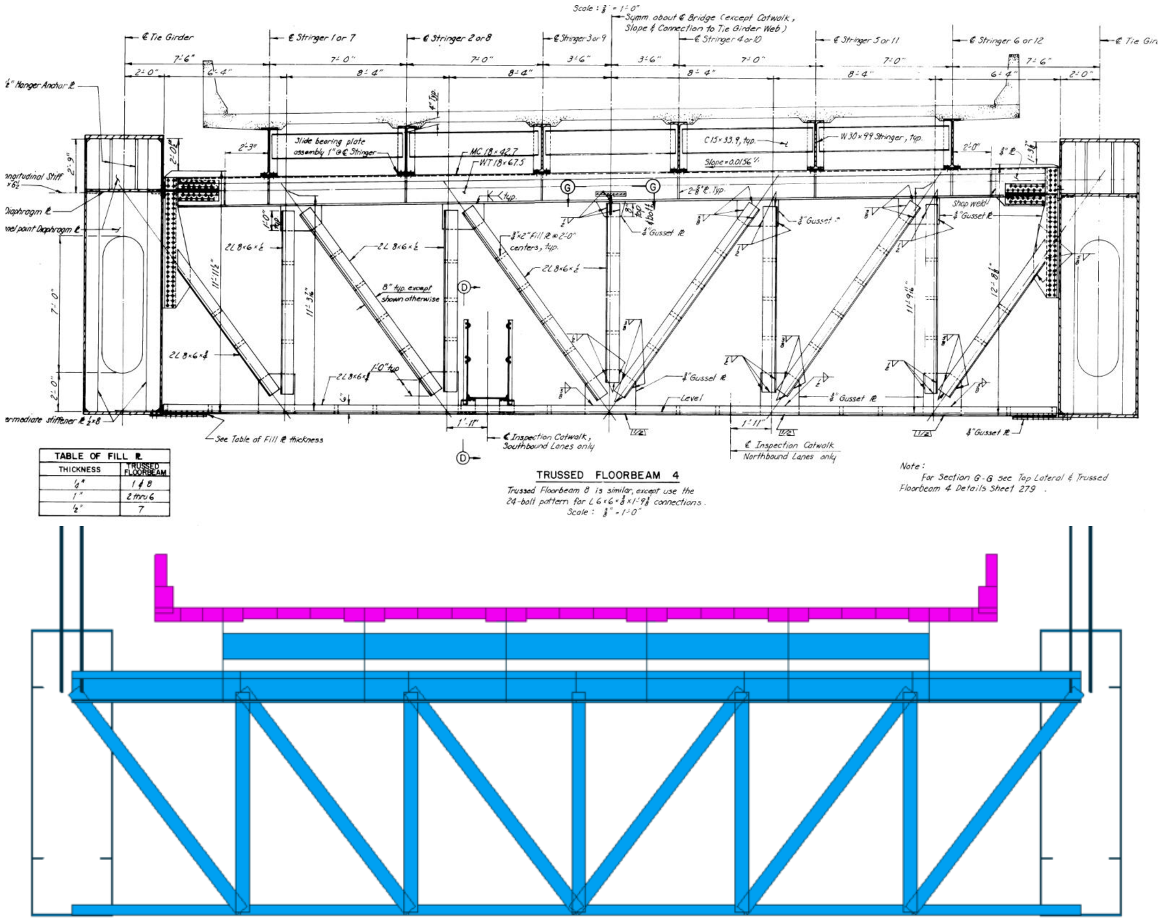


Figure A-0-30. Typical cross section of the bridge (I-65 over Mobile River): technical drawing (top) and FE model (bottom)

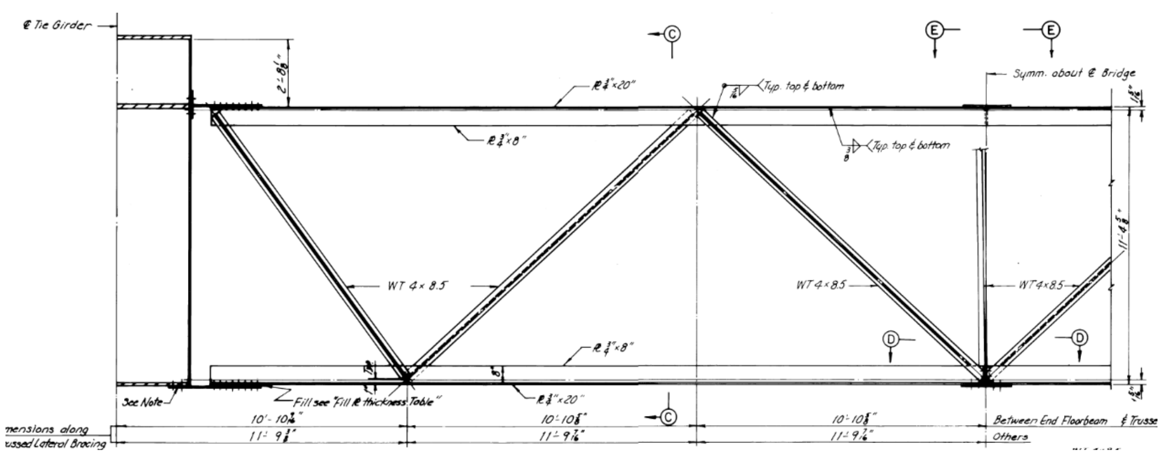


Figure A-0-31. Trussed lateral bracing of the bridge - technical drawing

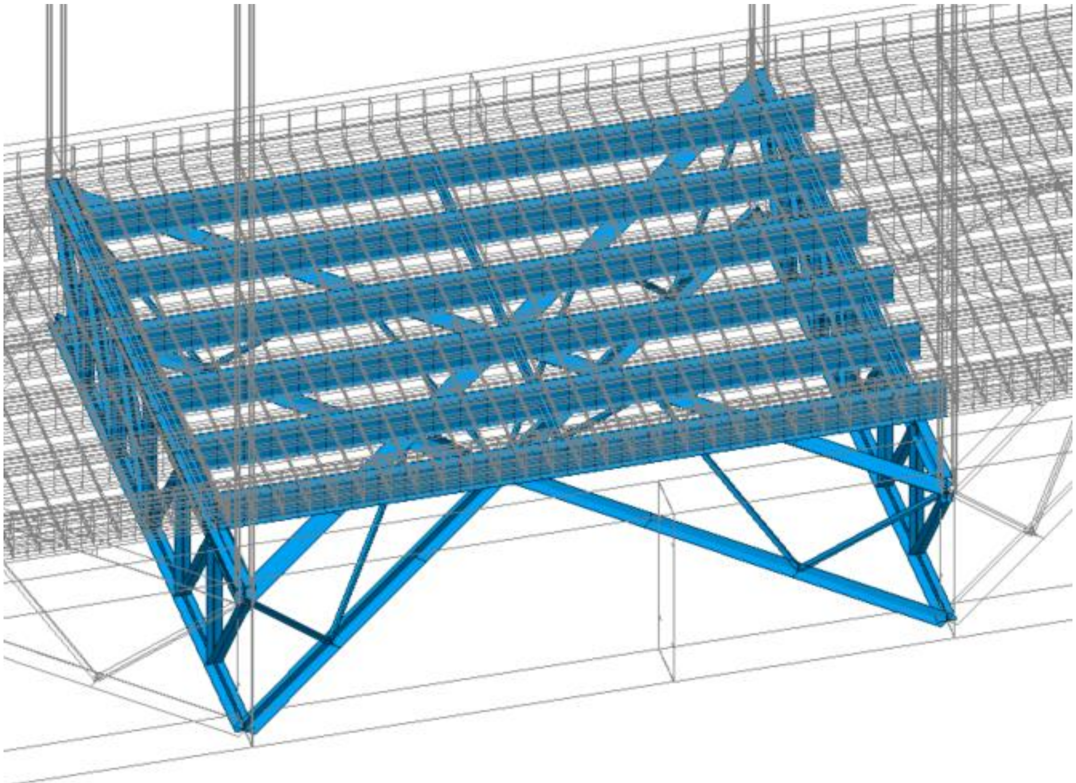


Figure A-0-32. Trussed lateral bracing of the bridge - FE model.

Project No. BHPF-000(540). The bridge over Alabama River is located in Selma.

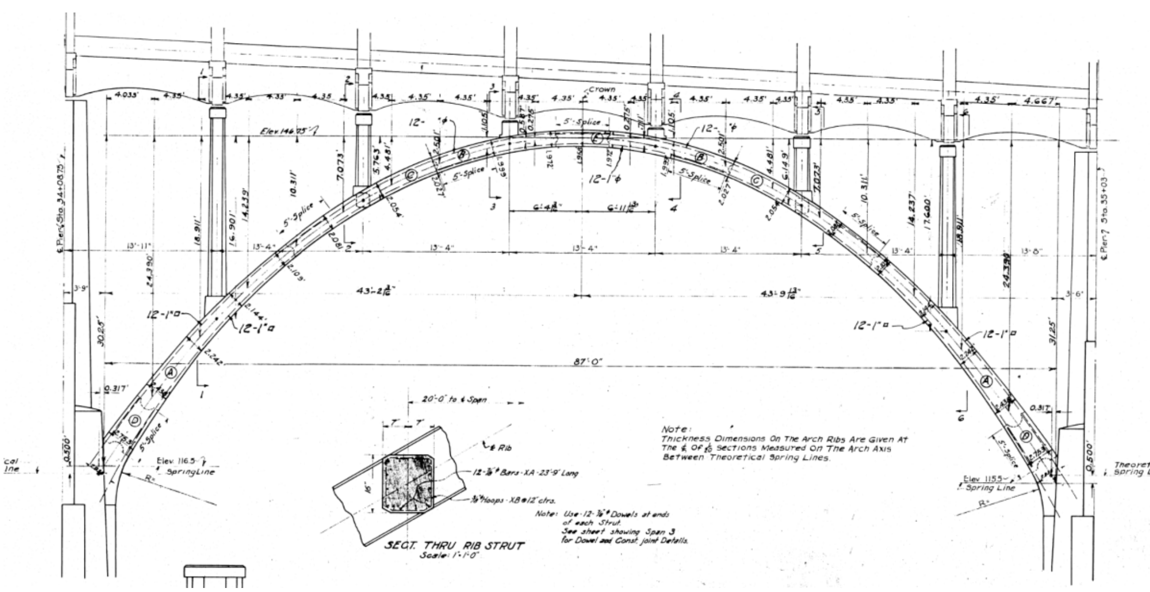


Figure A-0-33. Longitudinal view of bridge: technical drawing.

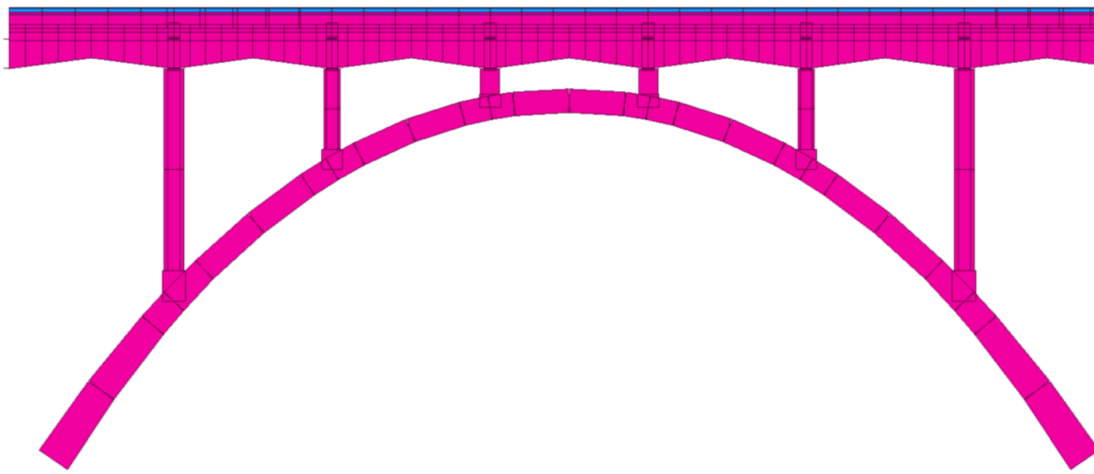


Figure A-0-34. Longitudinal view: FE model (bottom) – Arch_4

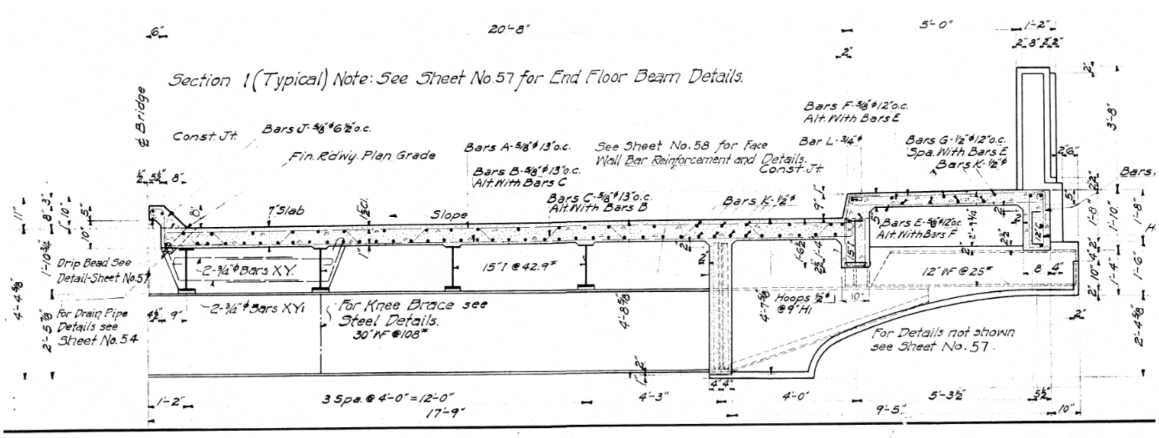


Figure A-0-35. Cross section – Arch_4

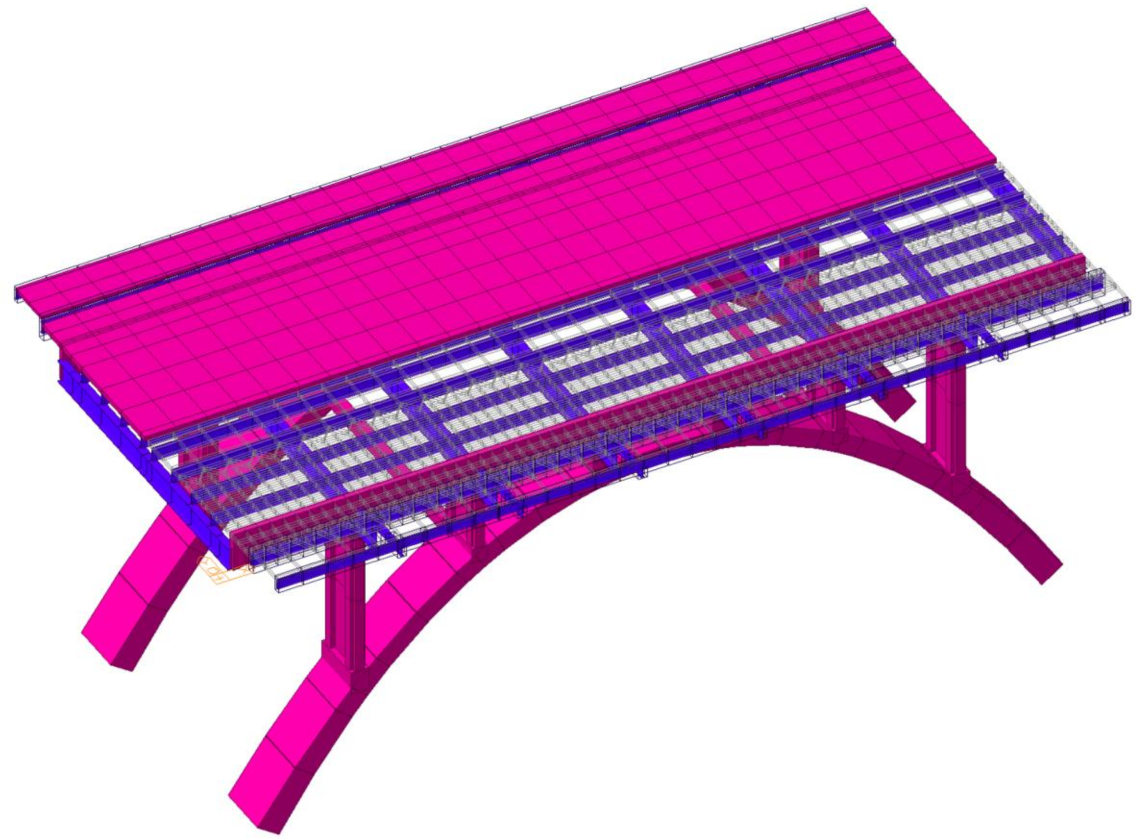


Figure A-0-36. Top view of the structural system.

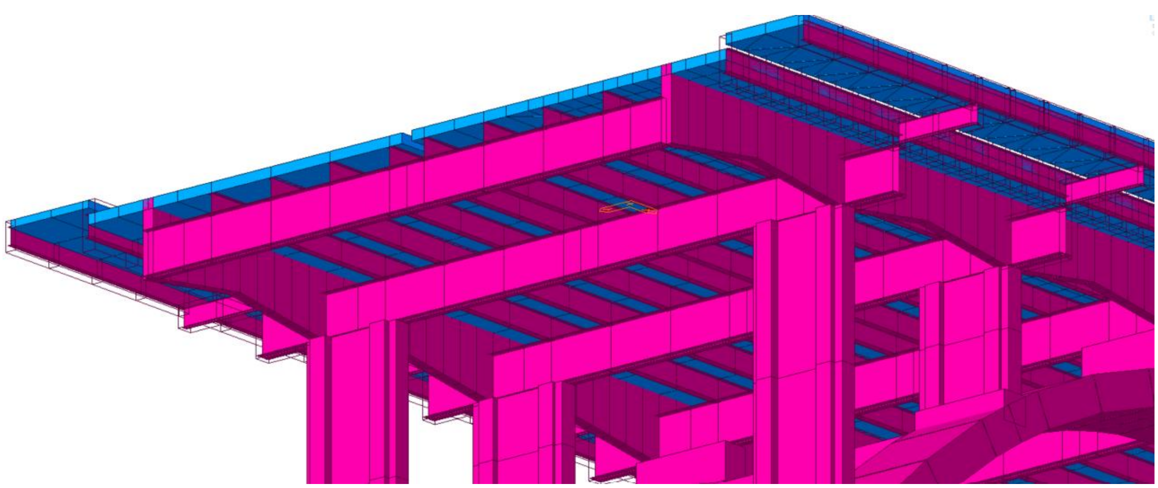


Figure A-0-37. Floor beam and support system view

Appendix B

Live Load Analysis Results for Truss Bridges

Project S-149(6) – Bridge over Sipsey River - Duncan Bridge – Results

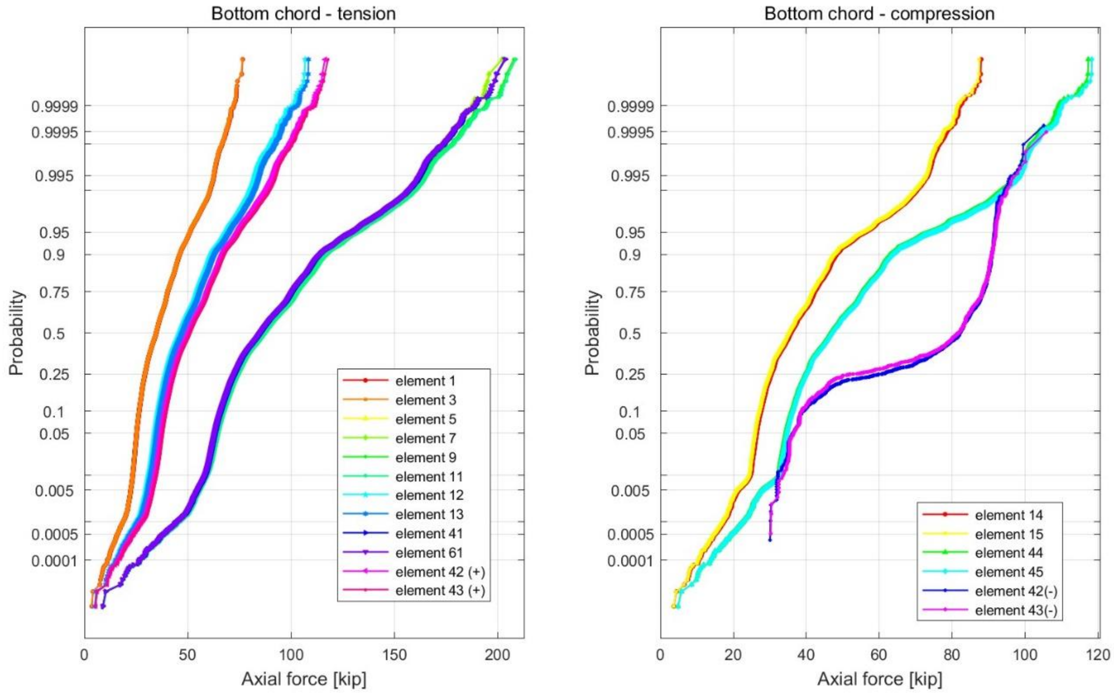


Figure B-0-1. Axial forces in the bottom chord elements - Duncan Bridge.

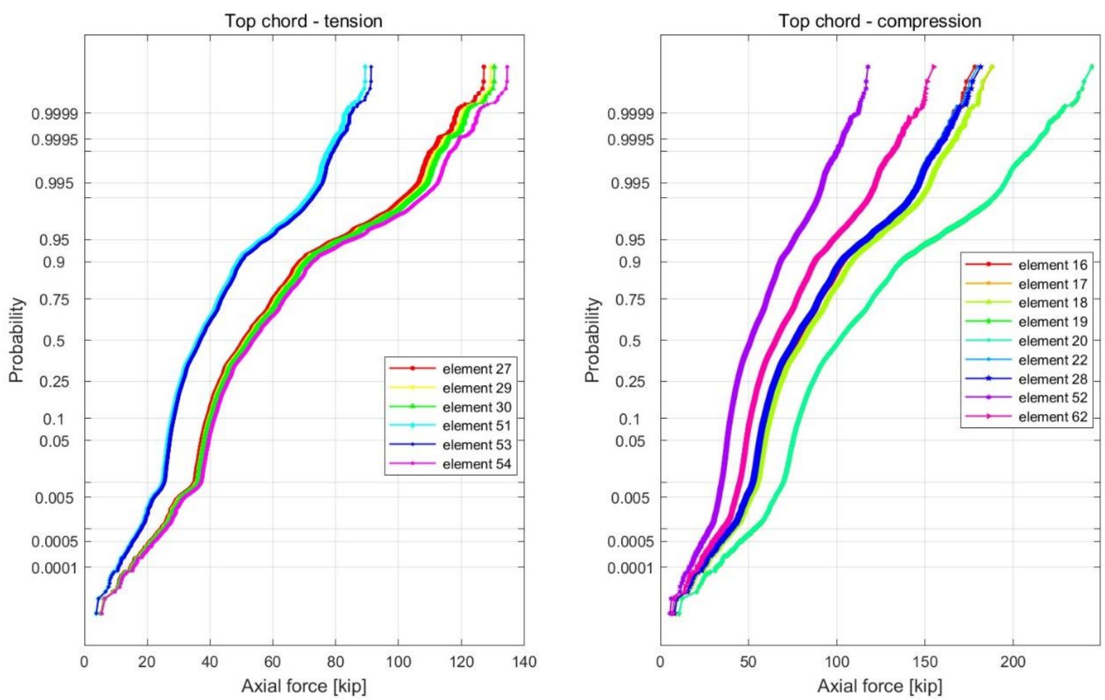


Figure B-0-2. Axial forces in the top chord elements - Duncan Bridge.

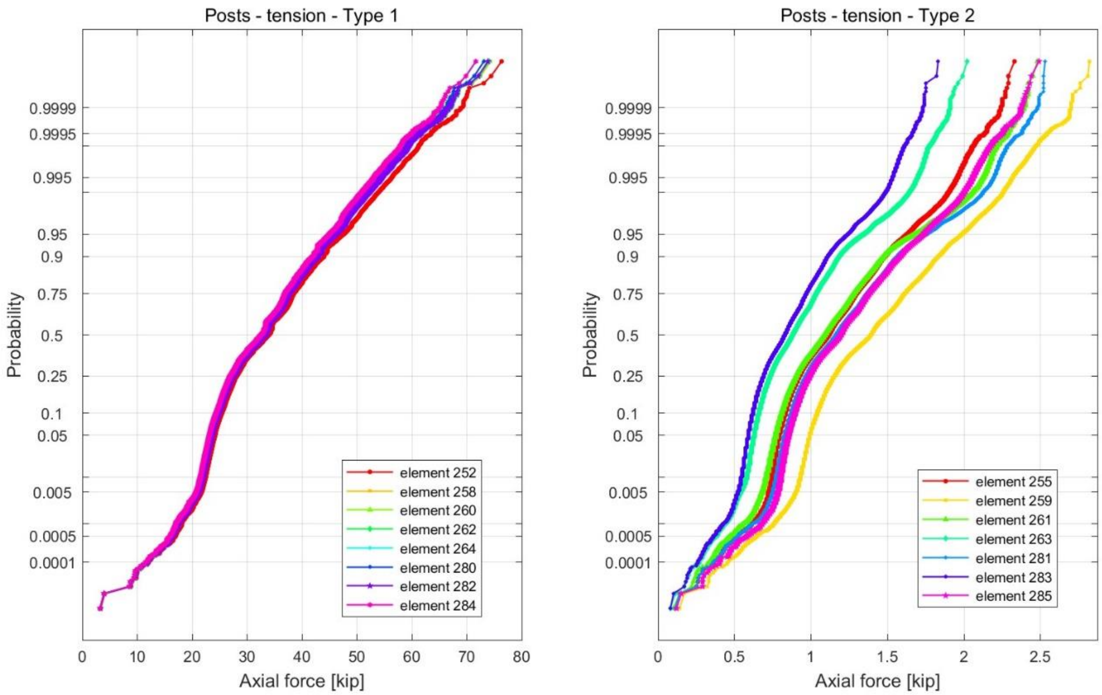


Figure B-0-3. Axial forces in the posts elements (tension) - Duncan Bridge.

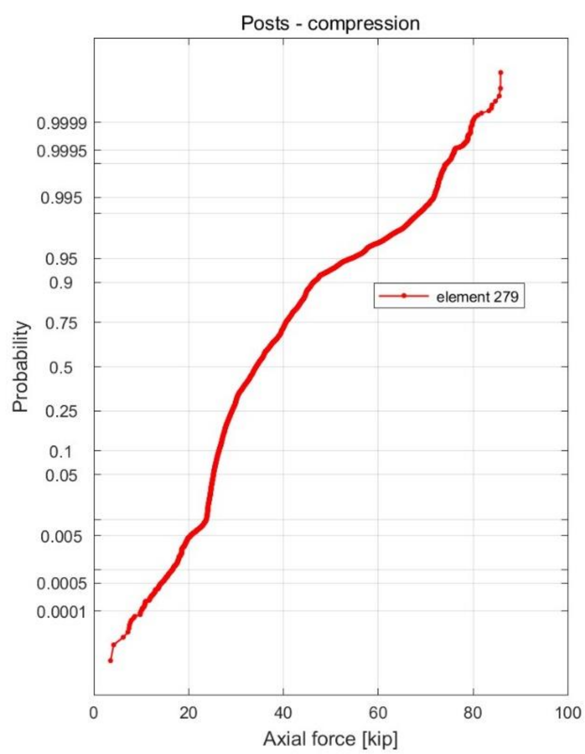


Figure B-0-4. Axial forces in the posts elements (compression) - Duncan Bridge.

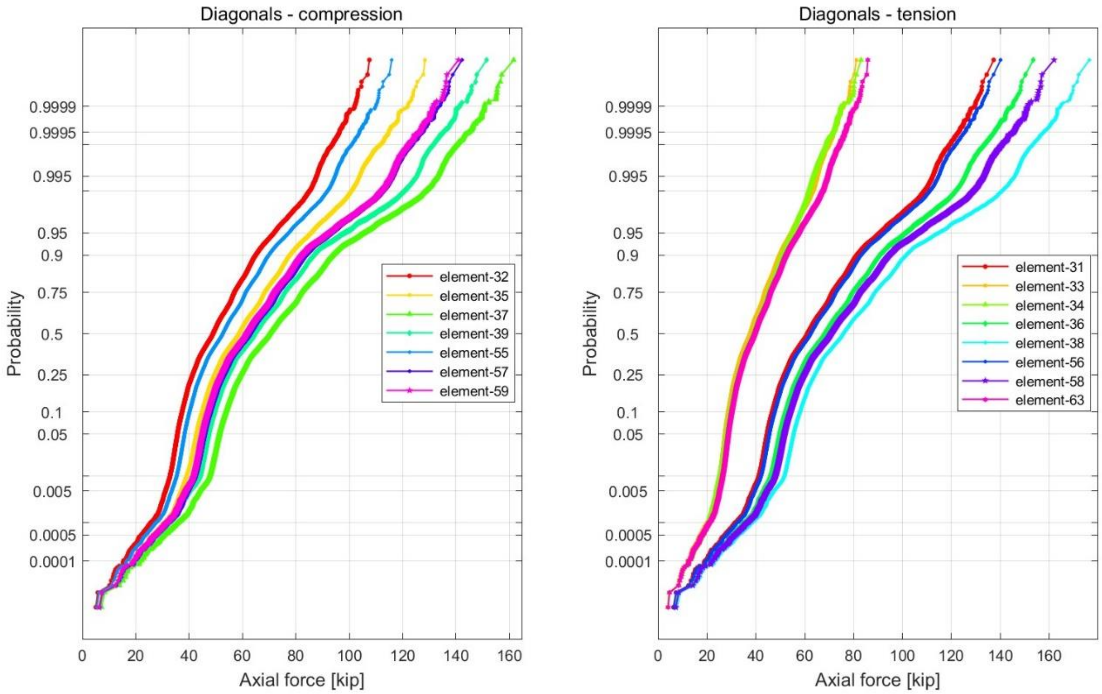


Figure B-0-5. Axial forces in the diagonal's elements - Duncan Bridge.

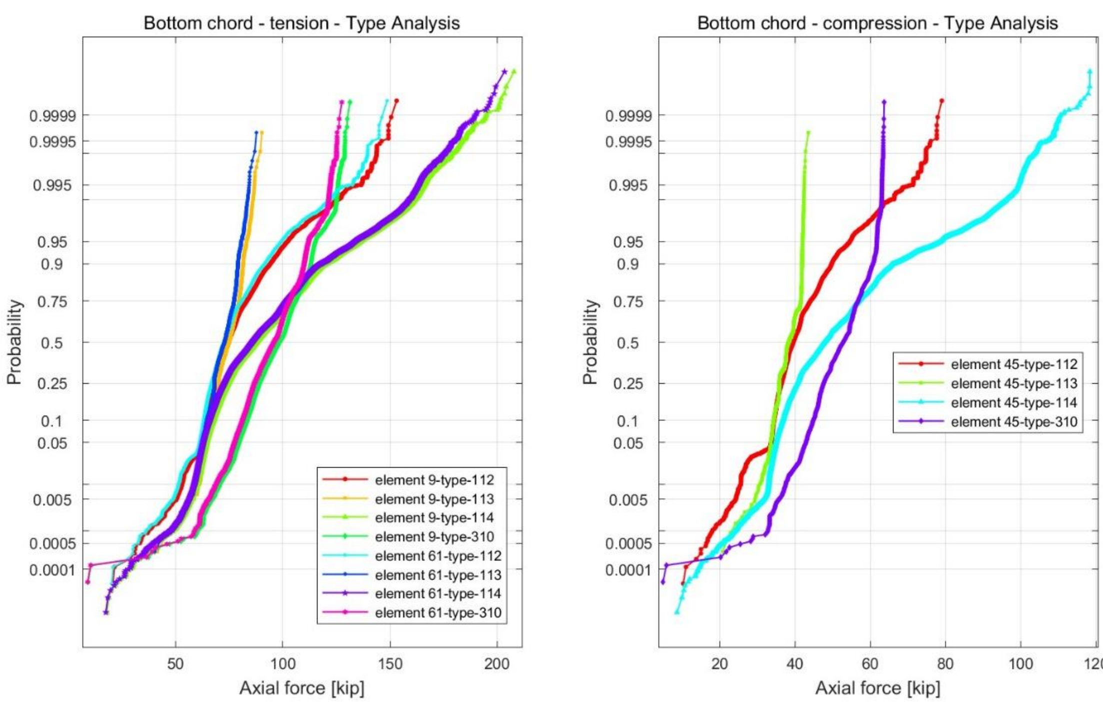


Figure B-0-6. Axial forces comparison in the bottom chord for different permit types.

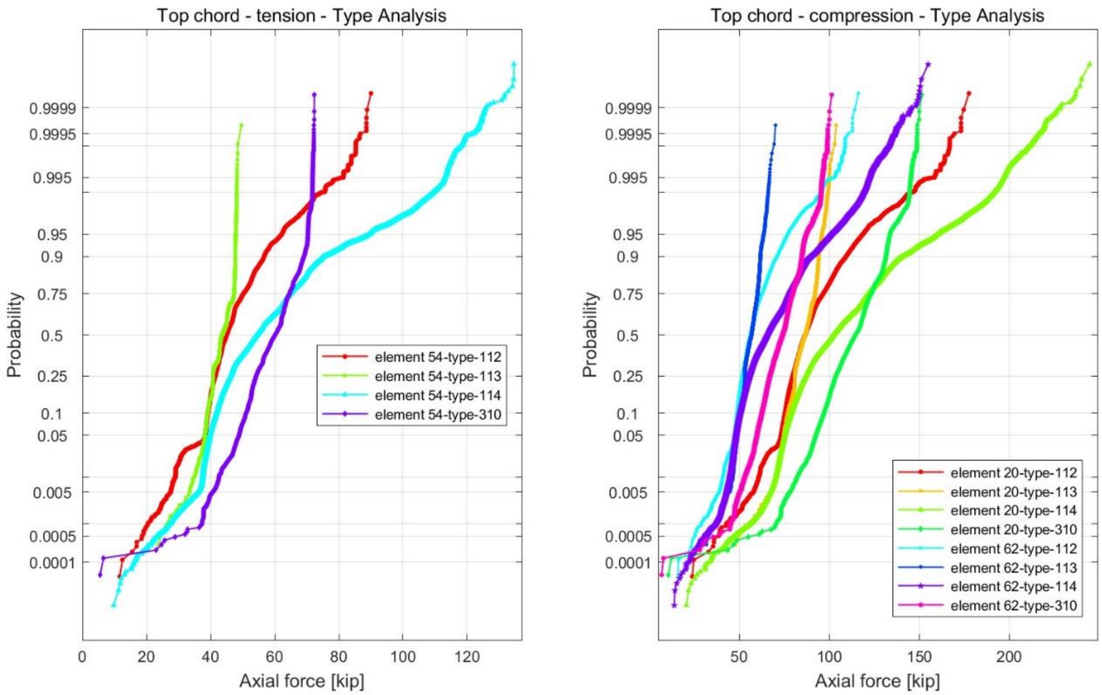


Figure B-0-7. Axial forces comparison in the top chord for different permit types.

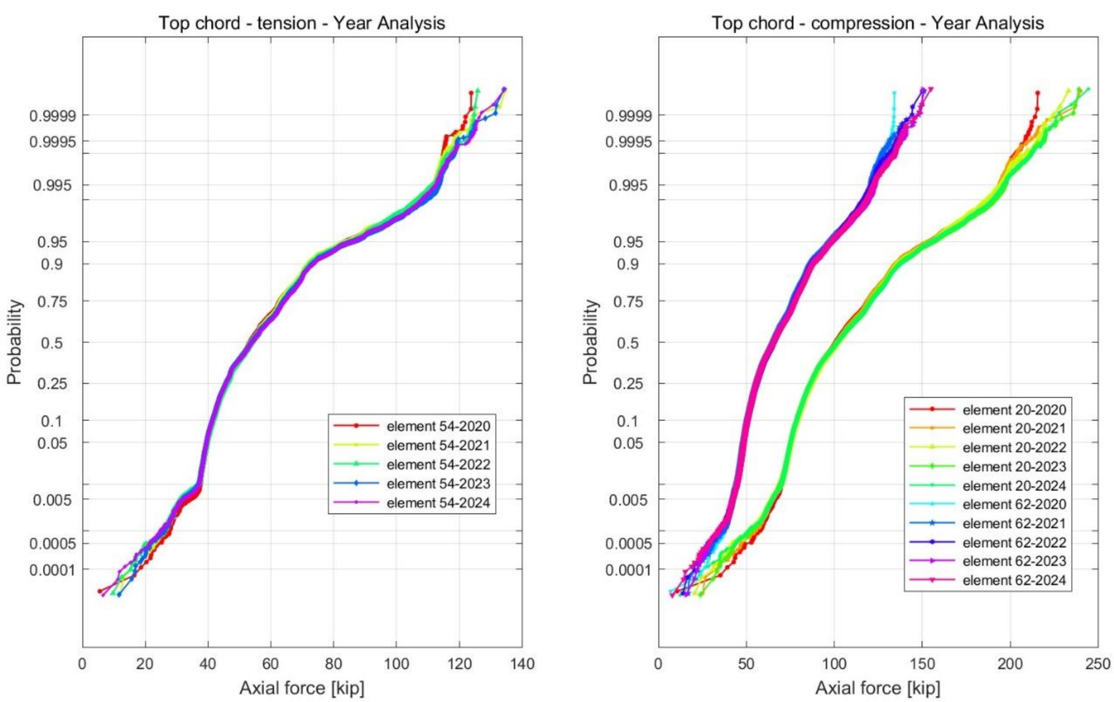


Figure B-0-8. Axial forces comparison in the top chord for different years.

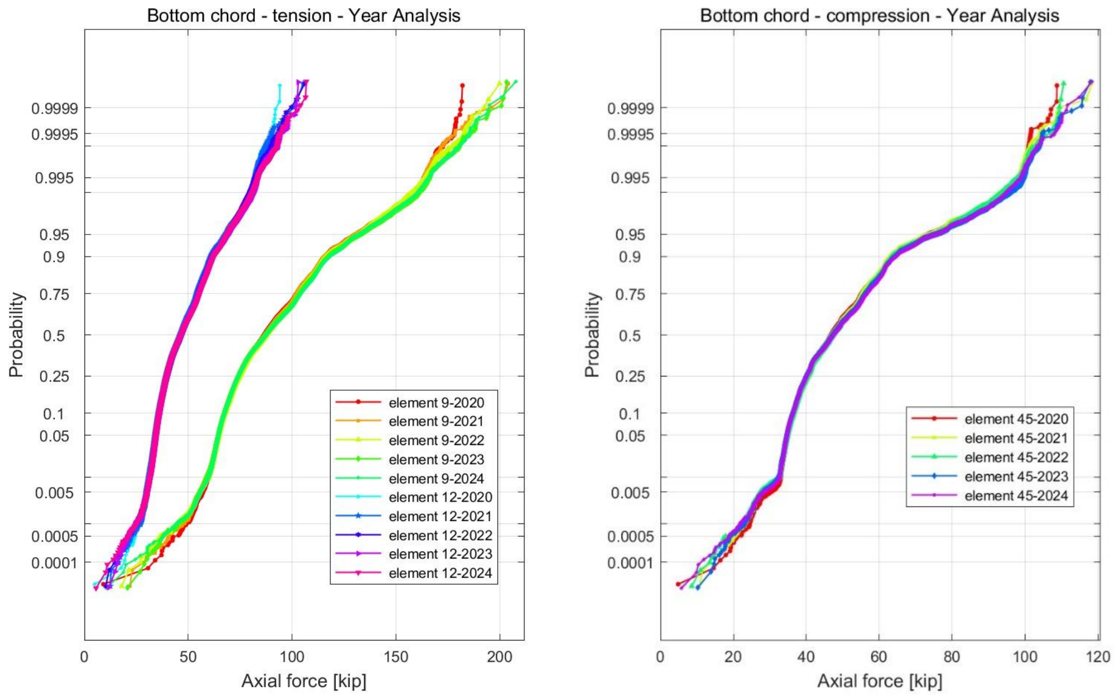


Figure B-0-9. Axial forces comparison in the bottom chord for different years.

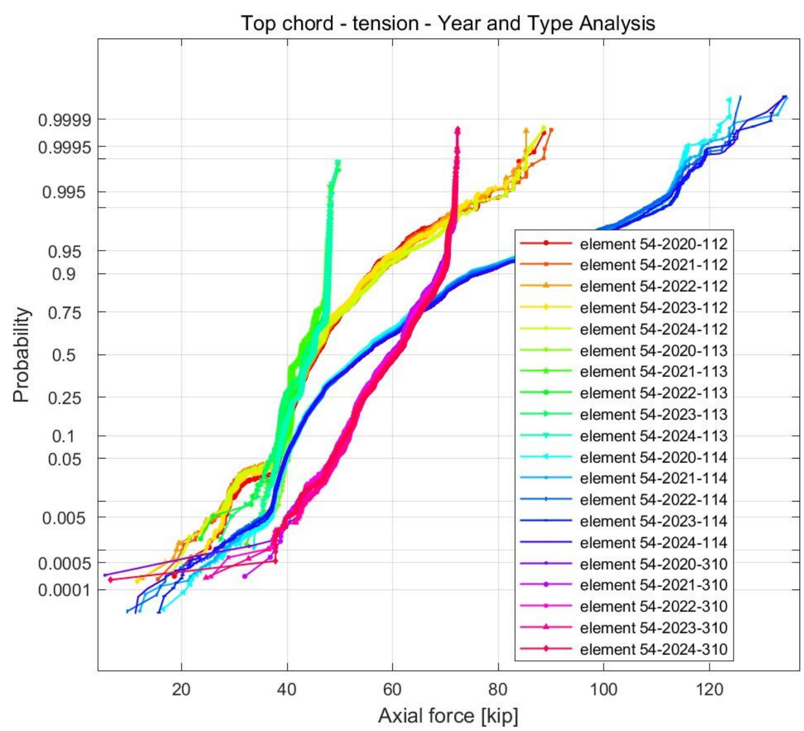


Figure B-0-10. Axial forces comparison in the top chord for different years and types.

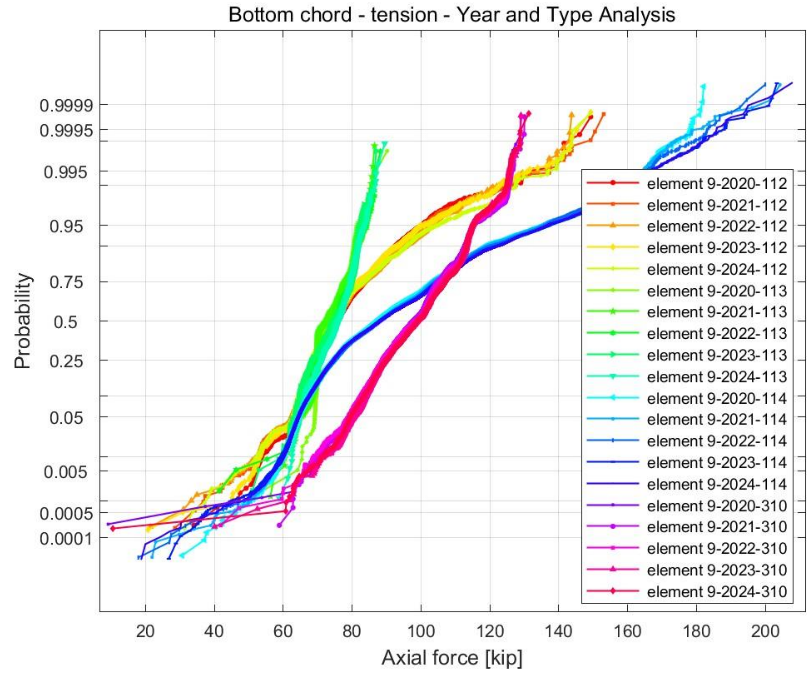


Figure B-0-11. Axial forces comparison in the bottom chord for different years and types.

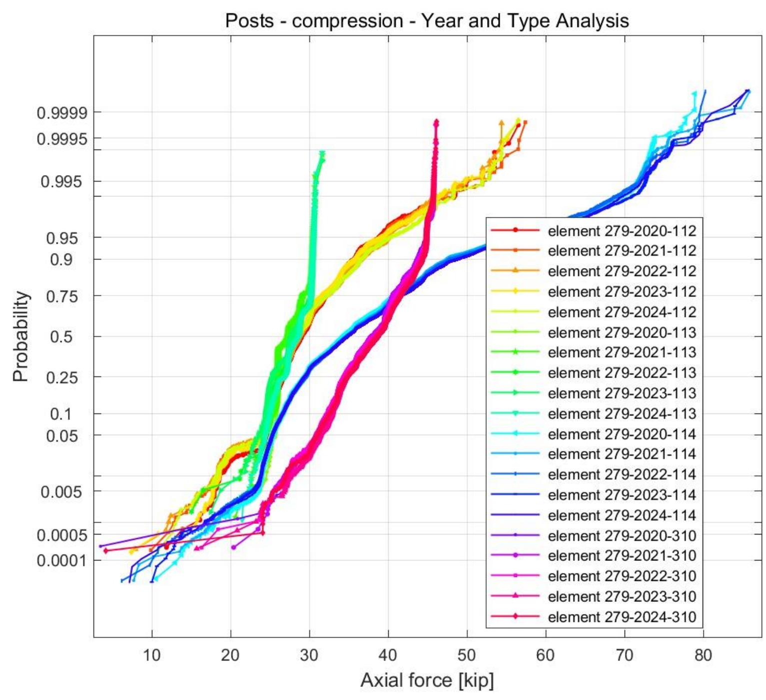


Figure B-0-12. Axial forces comparison in the posts for different years and types.

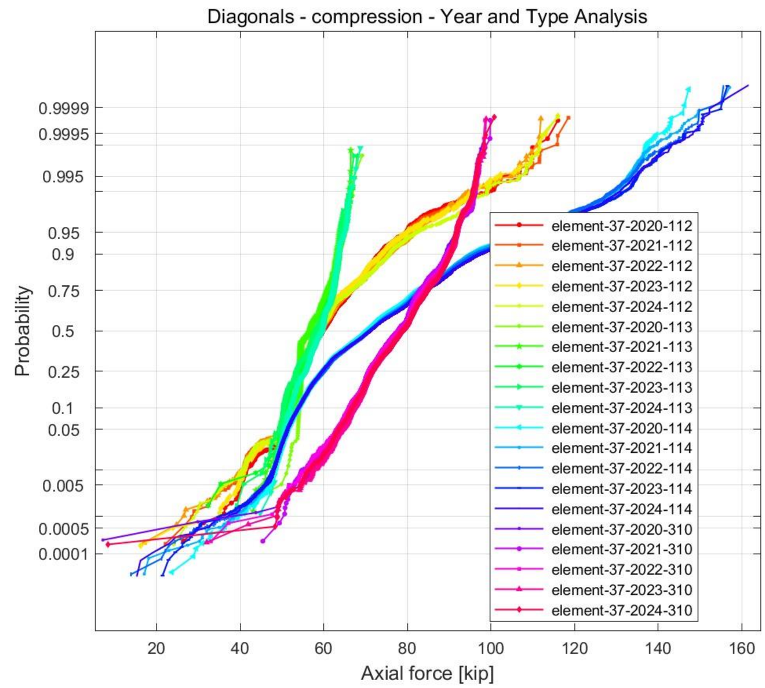


Figure B-0-13. Axial forces comparison in the diagonals for different years and types.

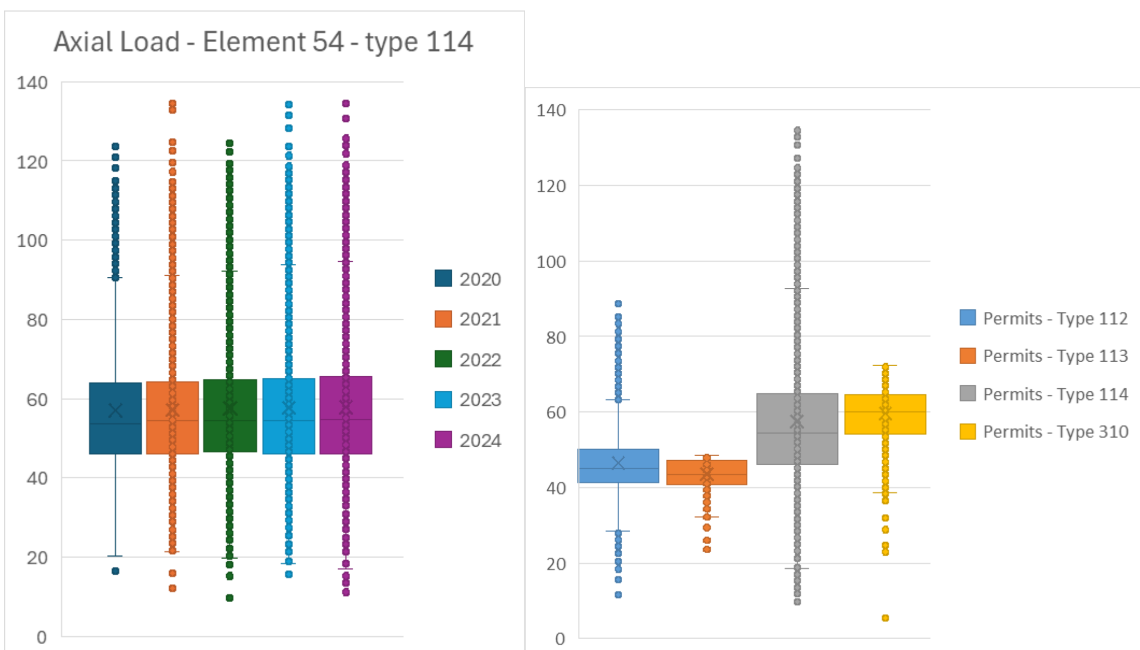


Figure B- 0-14. Statistical parameters of axial force for permits – Element 54.

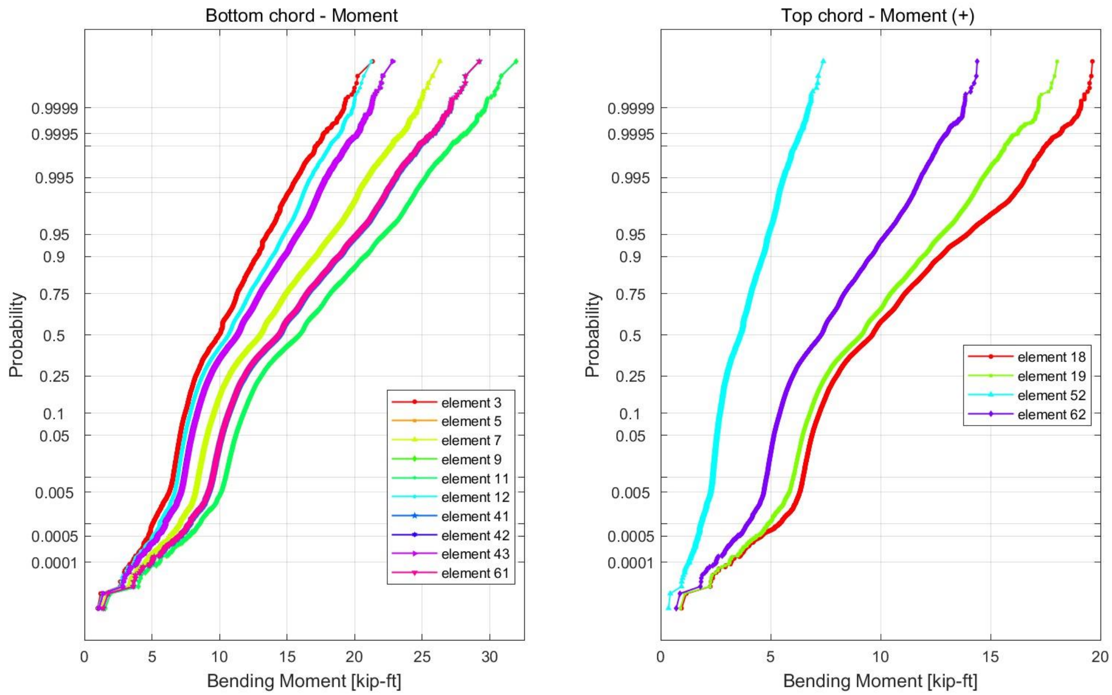


Figure B-0-15. Bending moment in the top and bottom chord elements - Duncan Bridge.

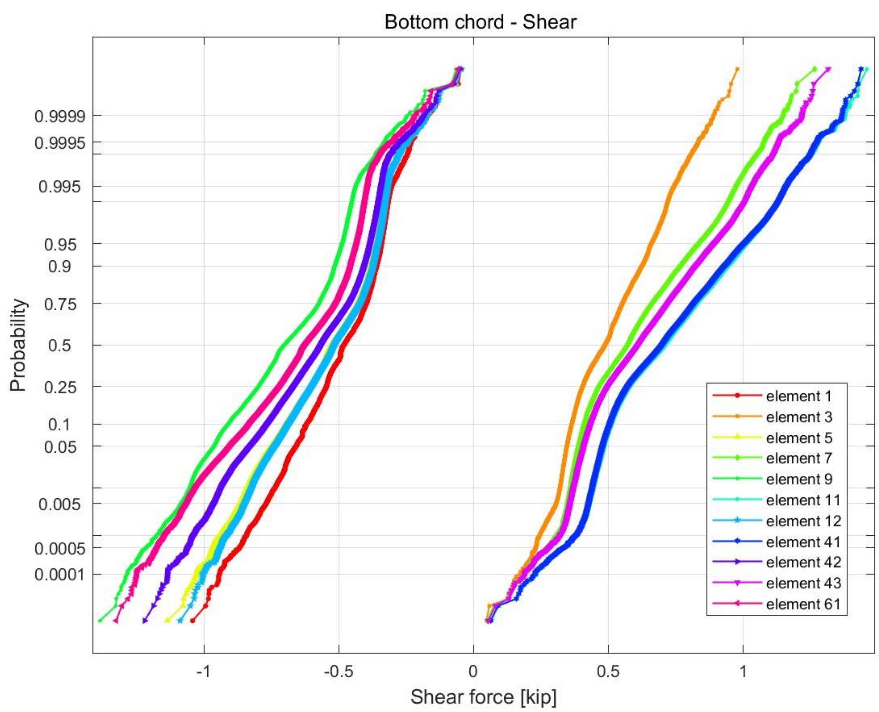


Figure B-0-16. Shear force in the bottom chord elements - Duncan Bridge.

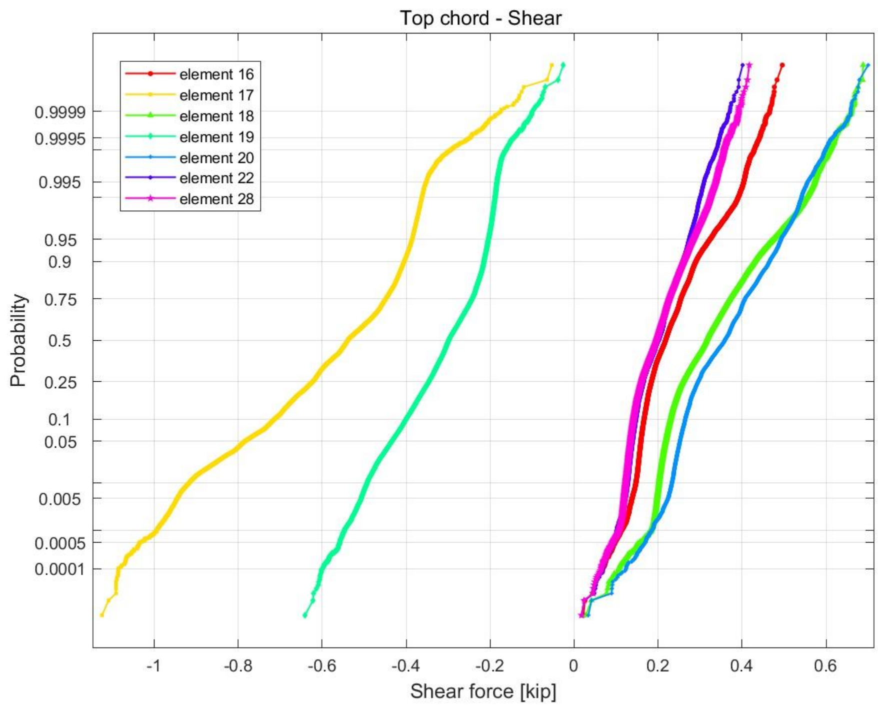
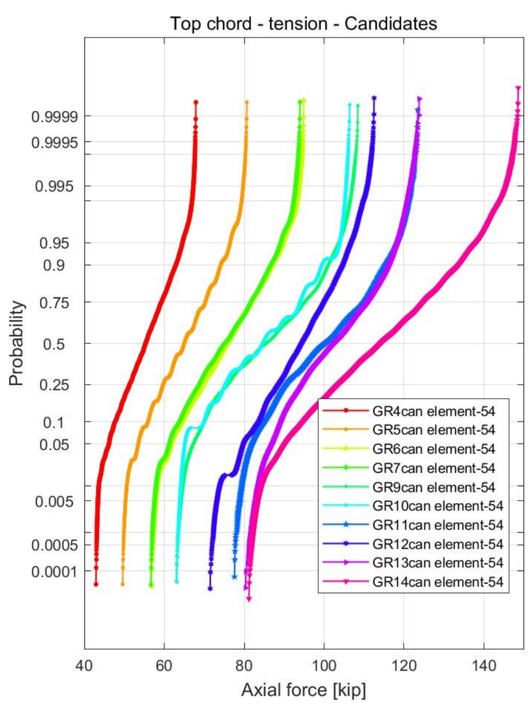


Figure B-0-17. Shear force in the top chord elements - Duncan Bridge.



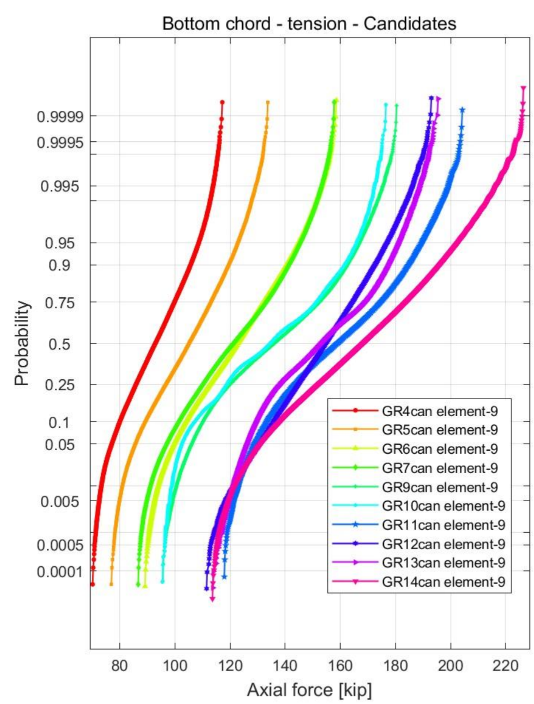


Figure B-0-18. Axial forces in the chord elements - Candidates.

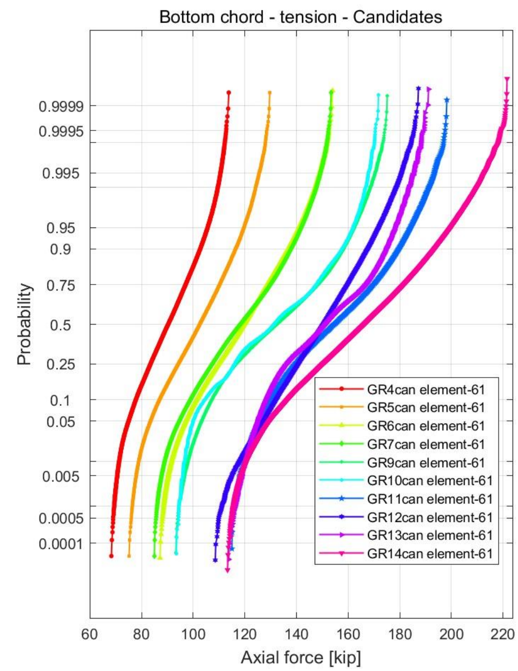


Figure B-0-19. Axial forces in the chord element 61 - Candidates.

Project No. ABC-16, located in Clarke and Choctaw Counties - Jim Folsom Bridge - Results

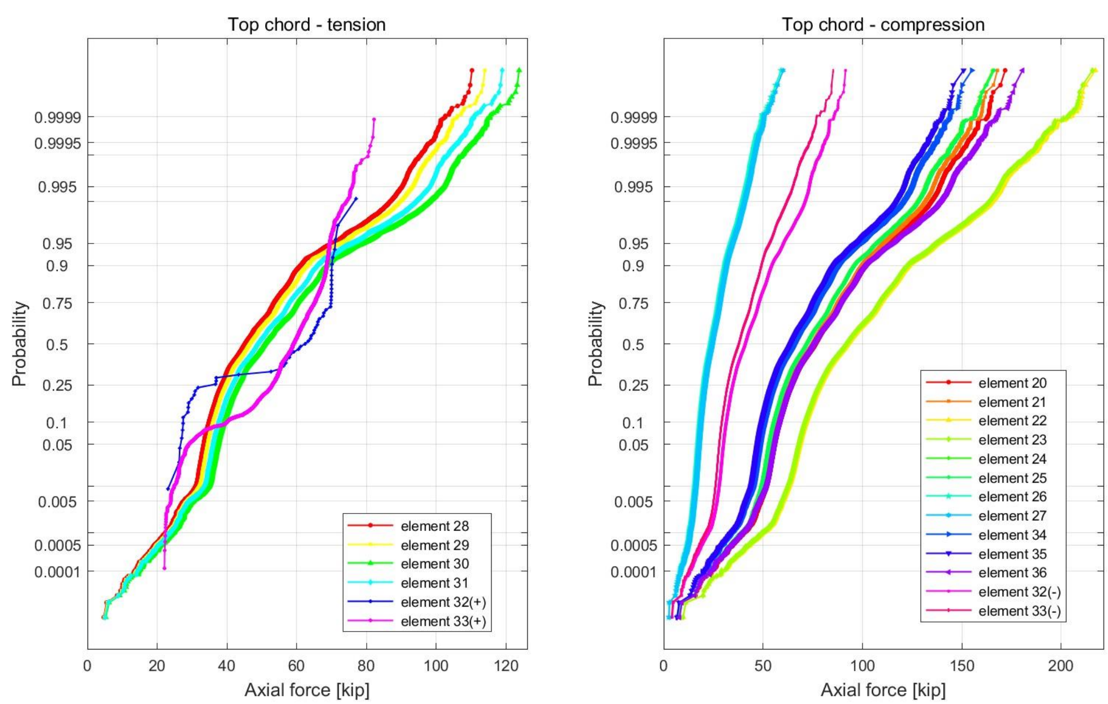


Figure B-0-20. Axial forces in the top chord elements - Jim Folsom Bridge.

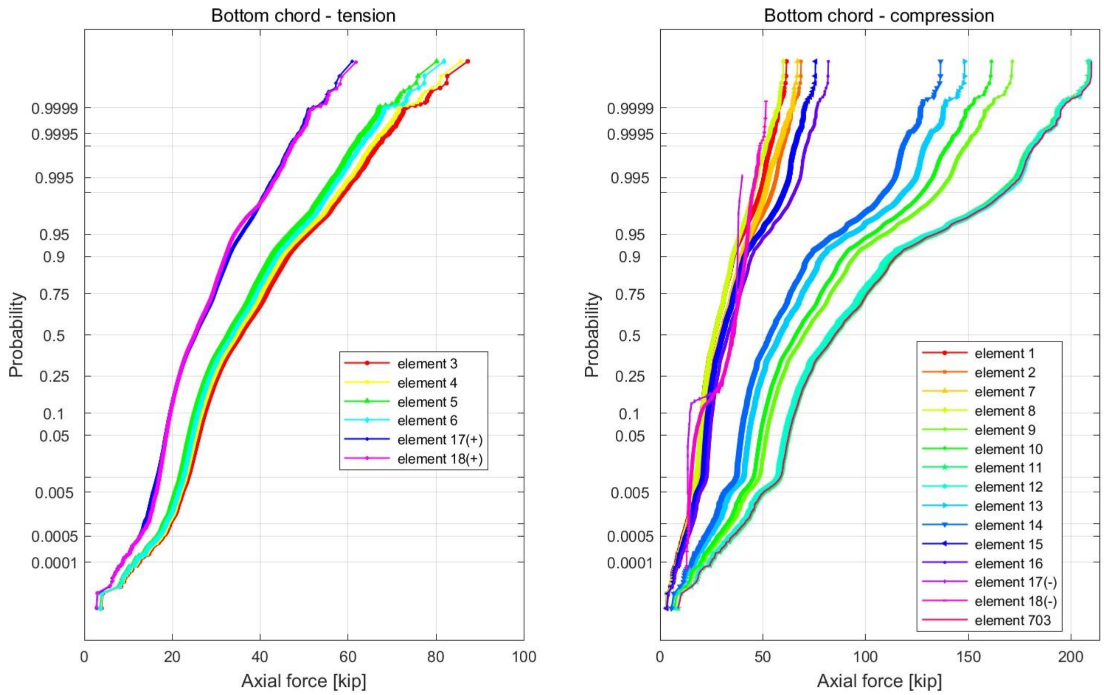


Figure B-0-21. Axial forces in the bottom chord elements - Jim Folsom Bridge.

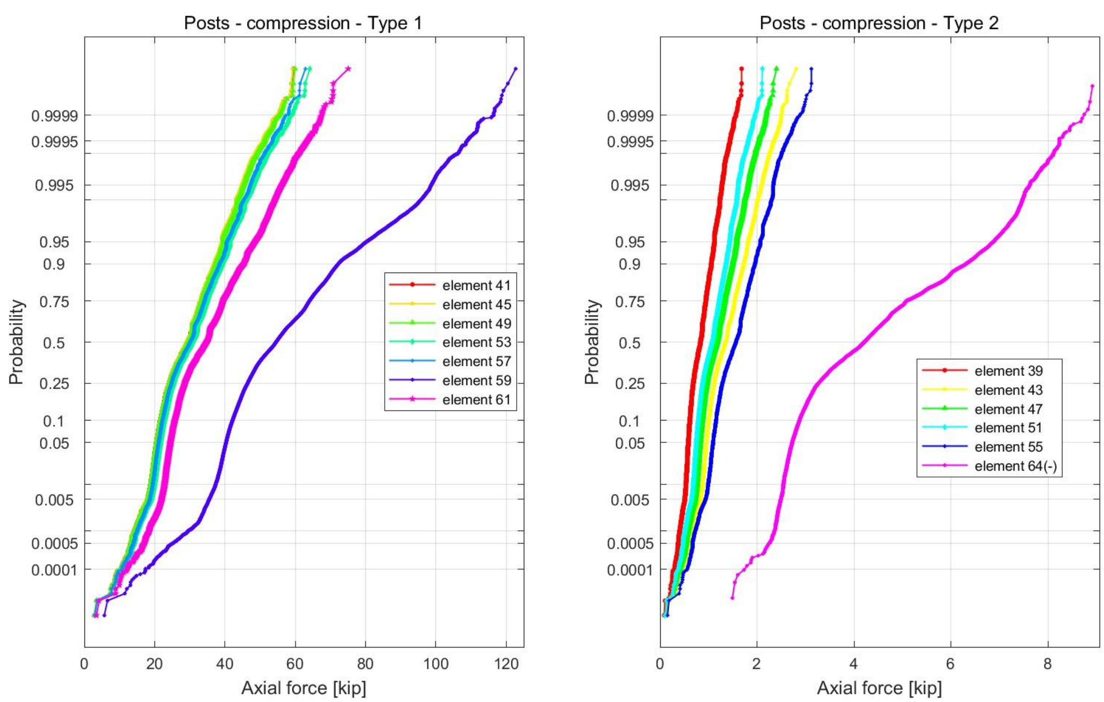


Figure B-0-22. Axial forces in the posts elements (compression) - Jim Folsom Bridge.

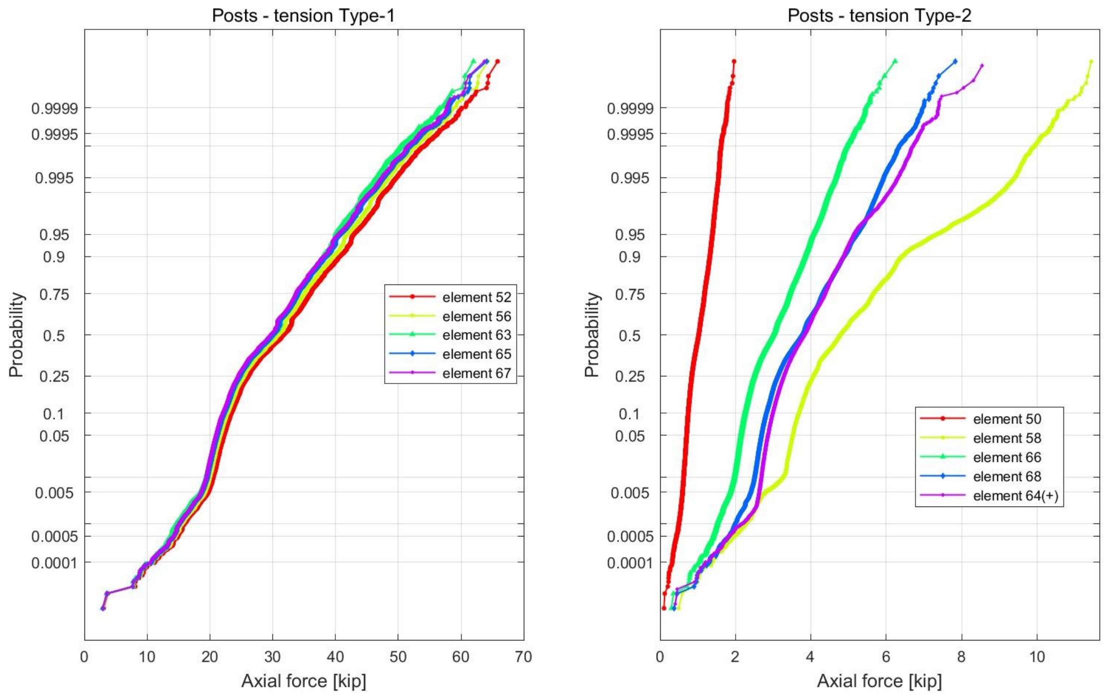


Figure B-0-23. Axial forces in the posts elements (tension) - Jim Folsom Bridge.

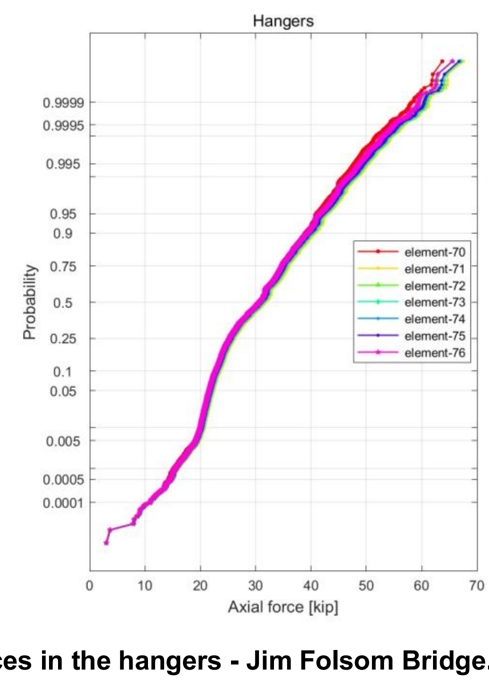


Figure B-0-24. Axial forces in the hangers - Jim Folsom Bridge.

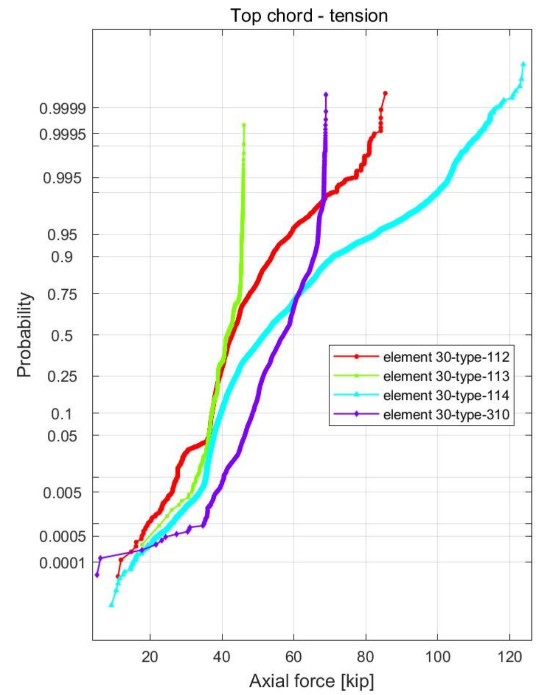


Figure B-0-25. Axial forces comparison for the top chord for different types.

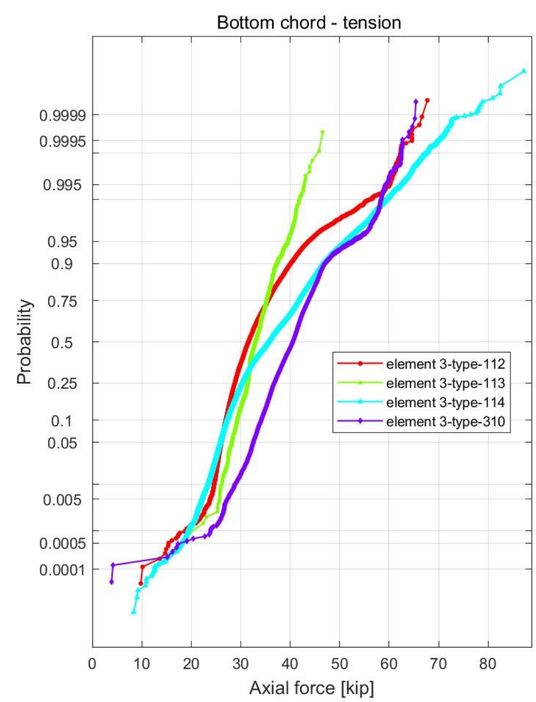


Figure B-0-26. Axial forces comparison for the bottom chord for different types.

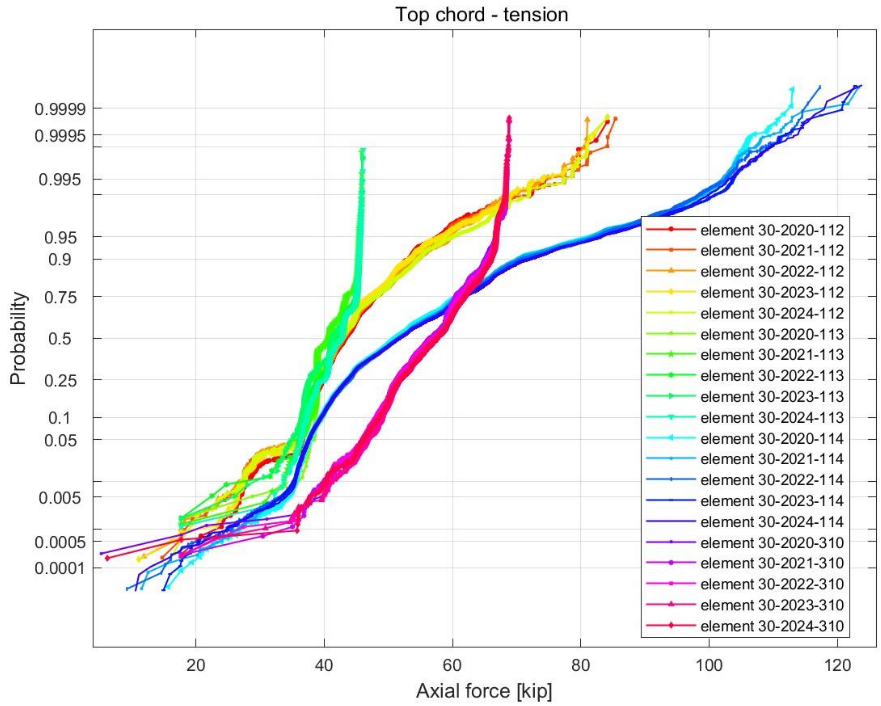


Figure B-0-27. Axial forces comparison in the top chord for different years and types.

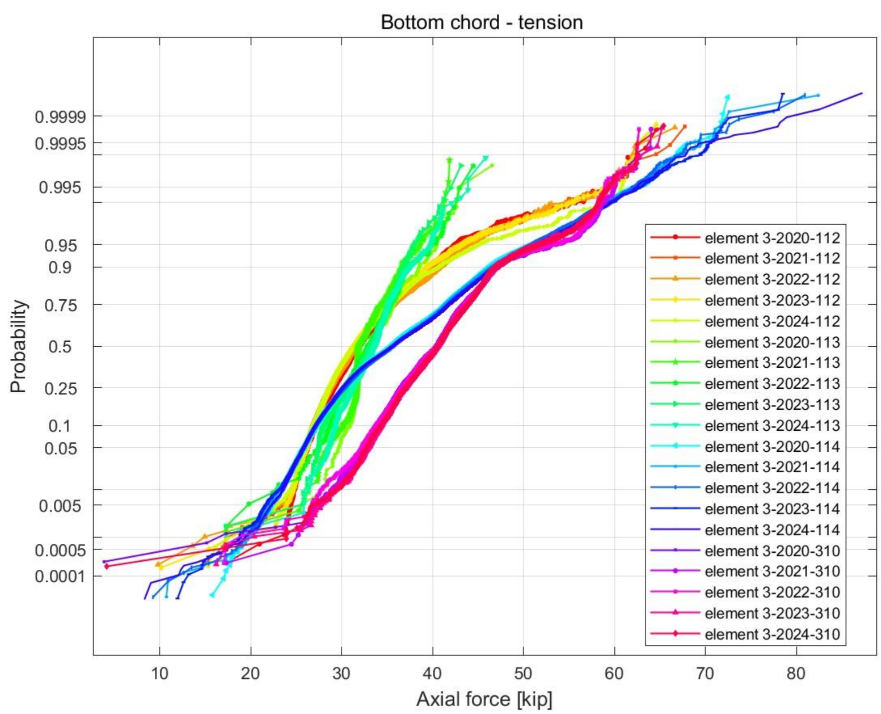


Figure B-0-28. Axial forces comparison in the bottom chord for different years and types.

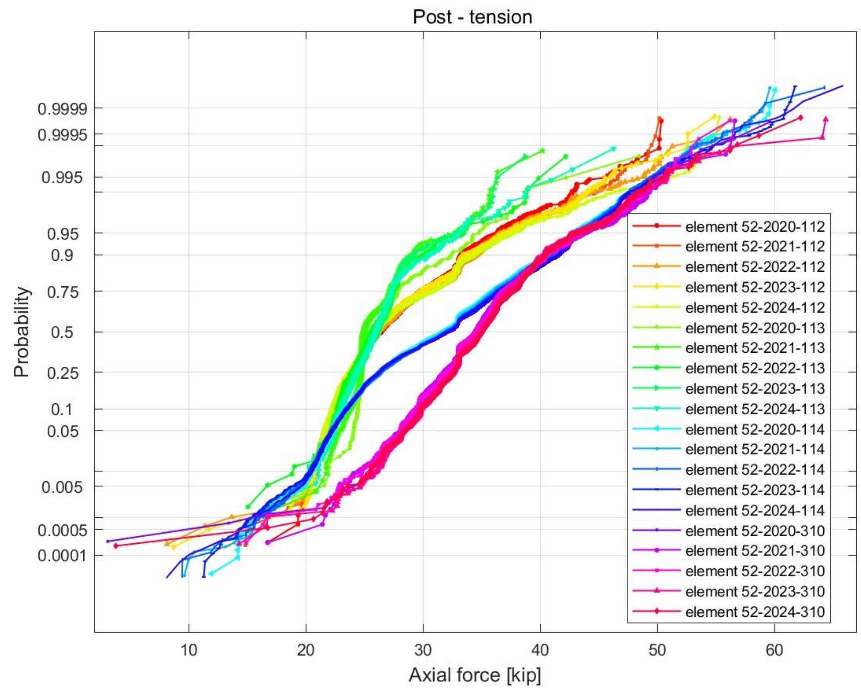


Figure B-0-29. Axial forces comparison in post no 52 for different years and types.

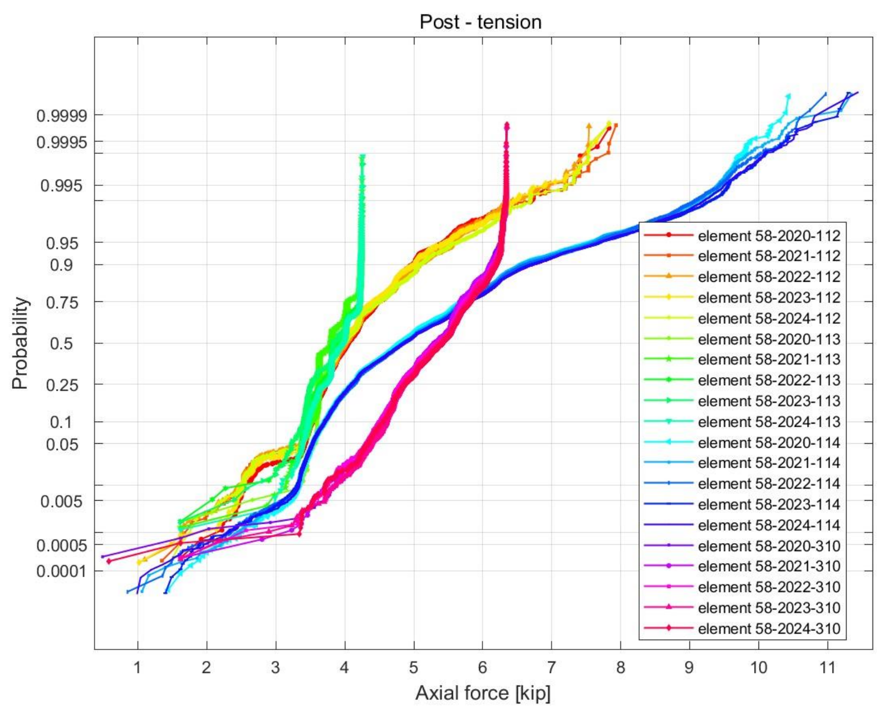


Figure B-0-30. Axial forces comparison in post no 58 for different years and types.

Project No. ABC-18, located in Chilton- Coosa Counties - AL-22 Coosa River Bridge - Results

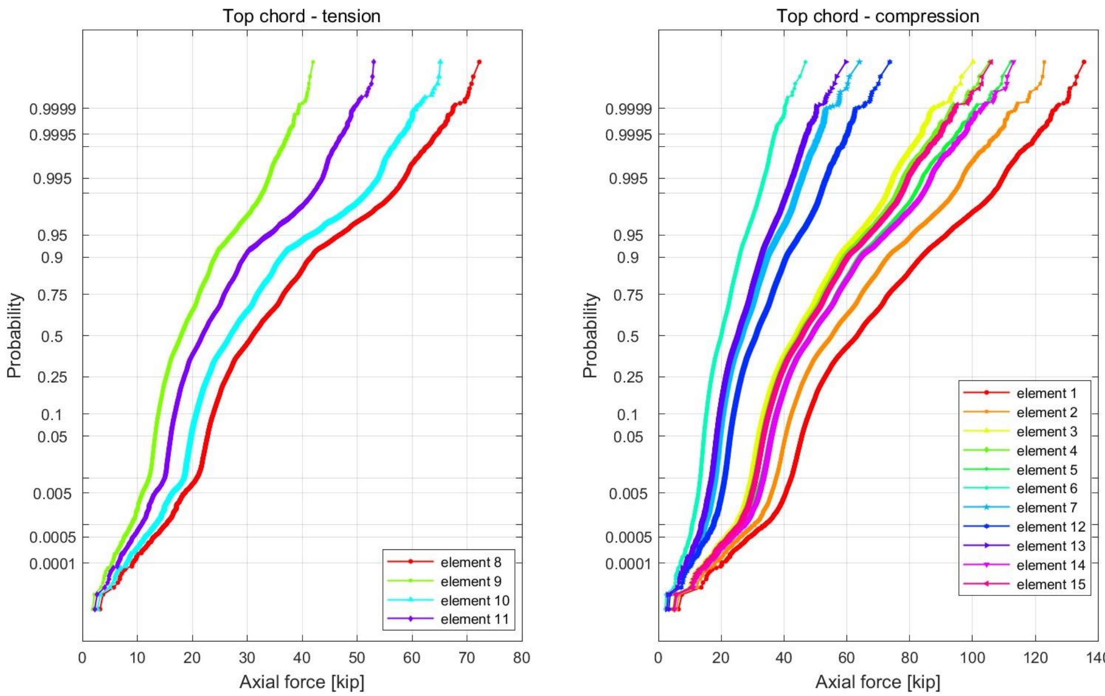


Figure B-0-31. Axial forces in the top chord elements - AL-22 Coosa River Bridge.

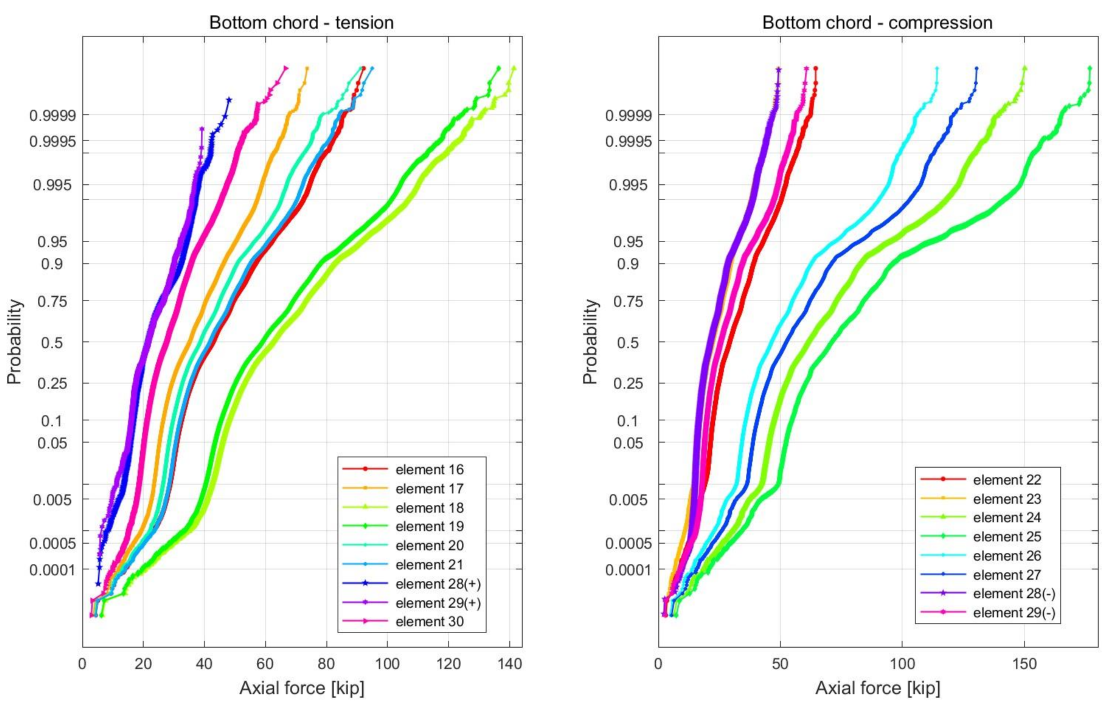


Figure B-0-32. Axial forces in the bottom chord elements - AL-22 Coosa River Bridge.

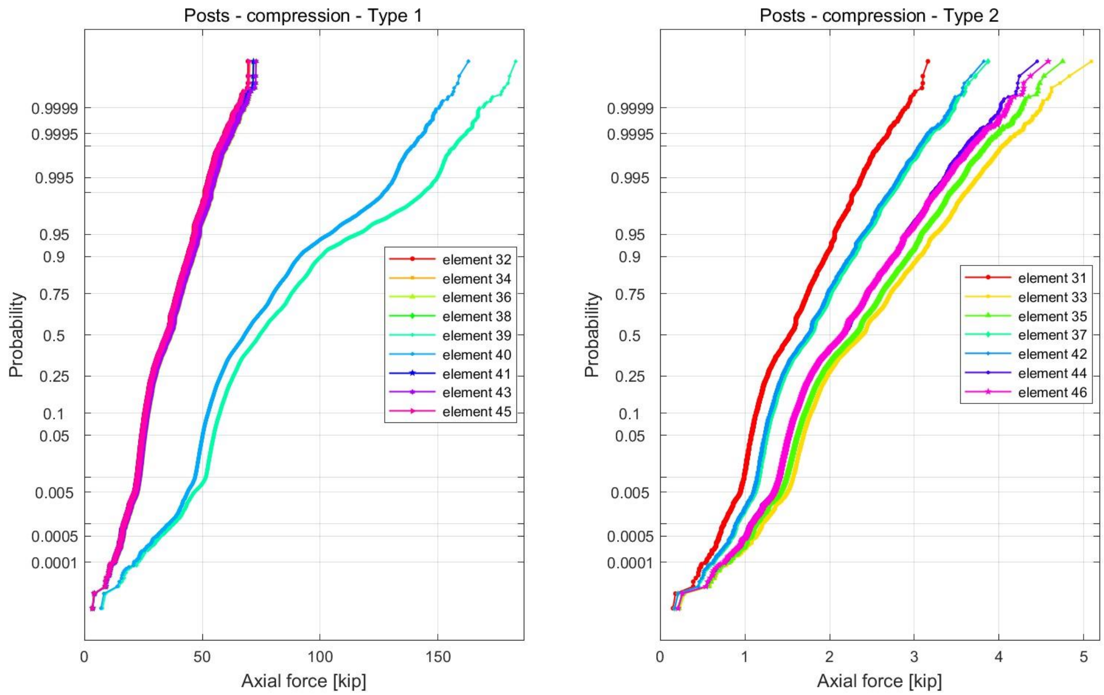


Figure B-0-33. Axial forces in the posts elements - AL-22 Coosa River Bridge.

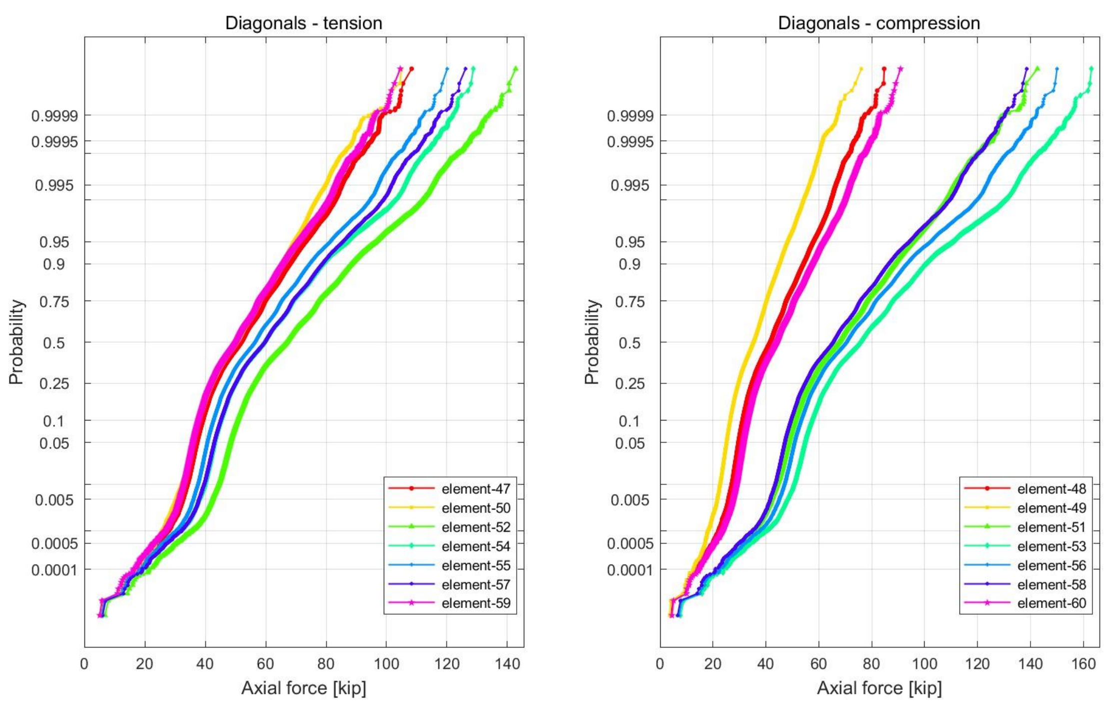


Figure B-0-34. Axial forces in the diagonals elements - AL-22 Coosa River Bridge.

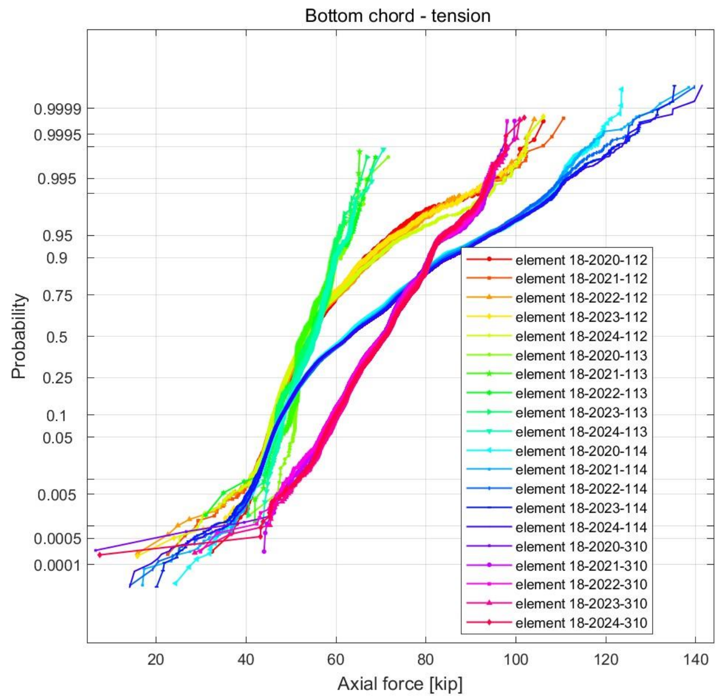


Figure B-0-35. Axial forces comparison in the bottom chord for different years and types.

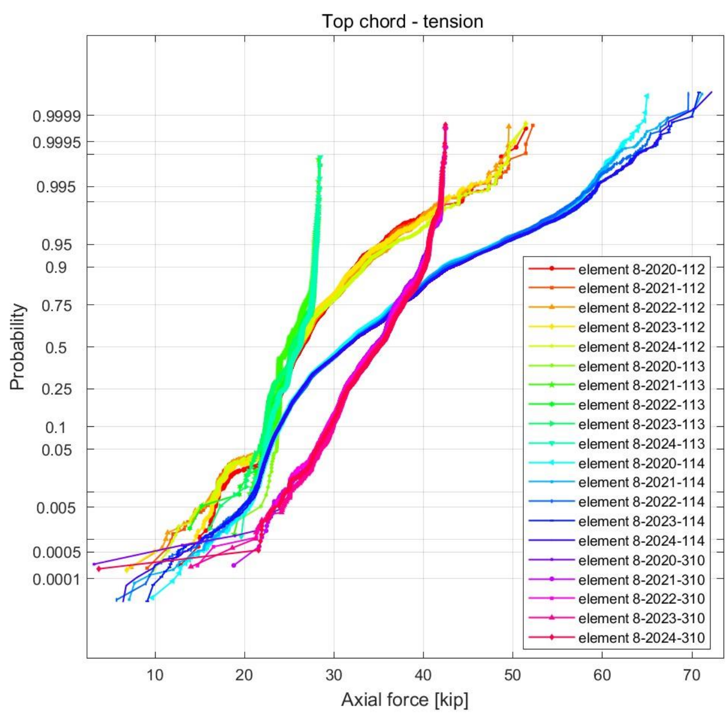


Figure B-0-36. Axial forces comparison in the top chord for different years and types.

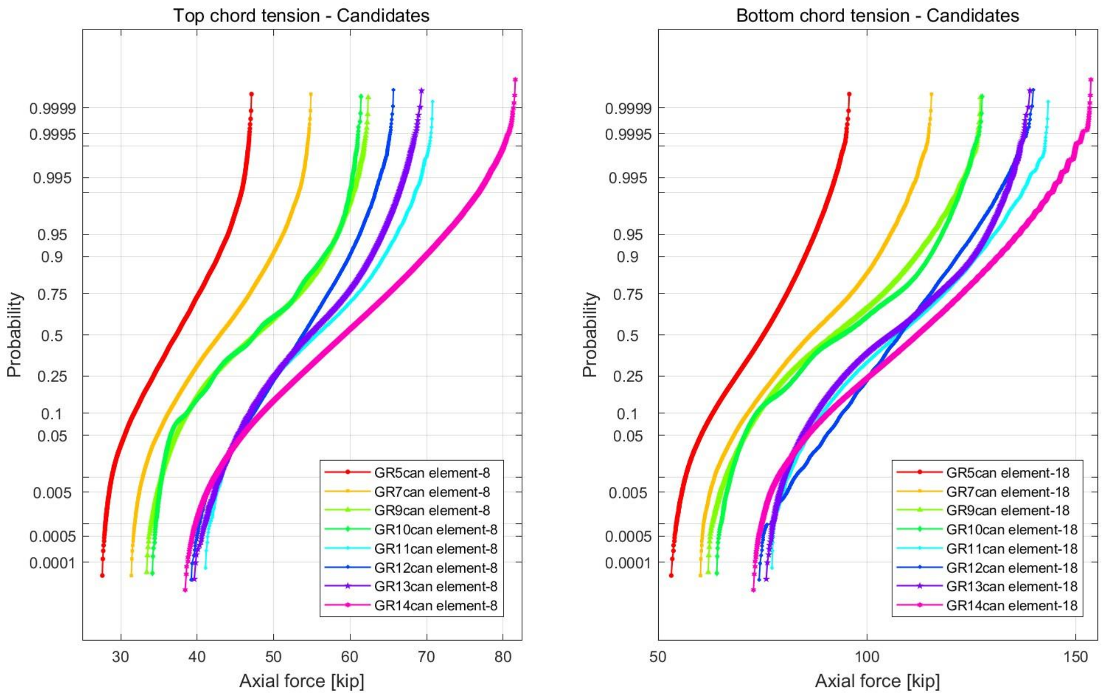


Figure B-0-37. Axial forces in the top and bottom (tension) chord elements - Candidates.

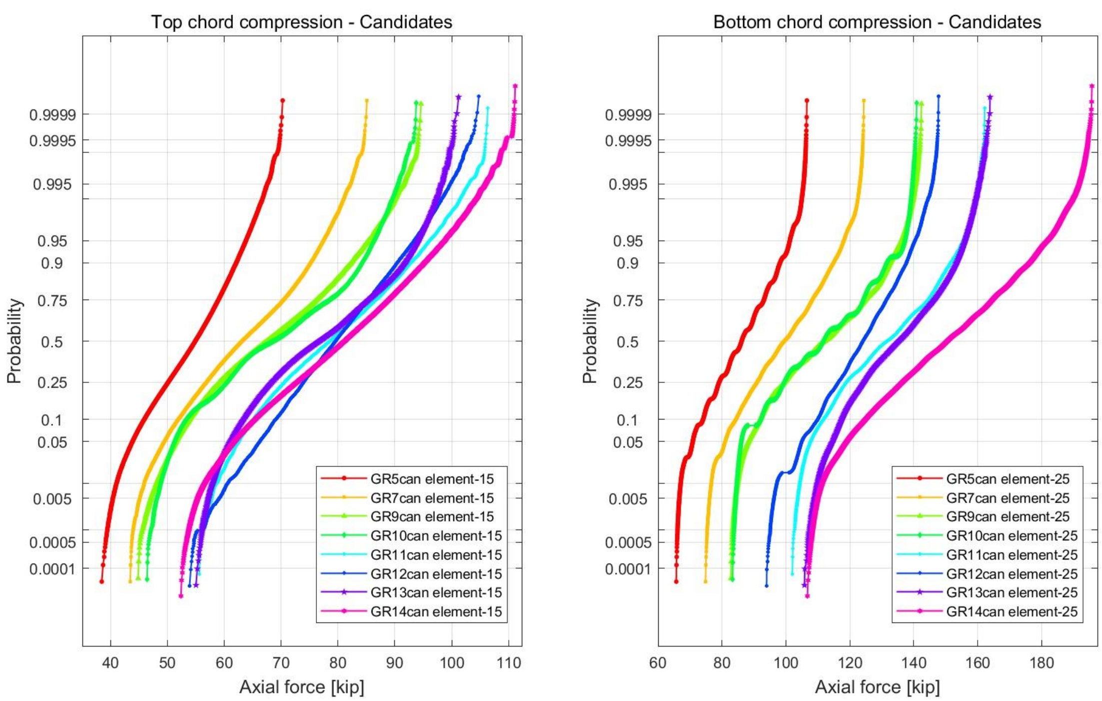


Figure B-0-38. Axial forces in the chord elements (compression) - Candidates.

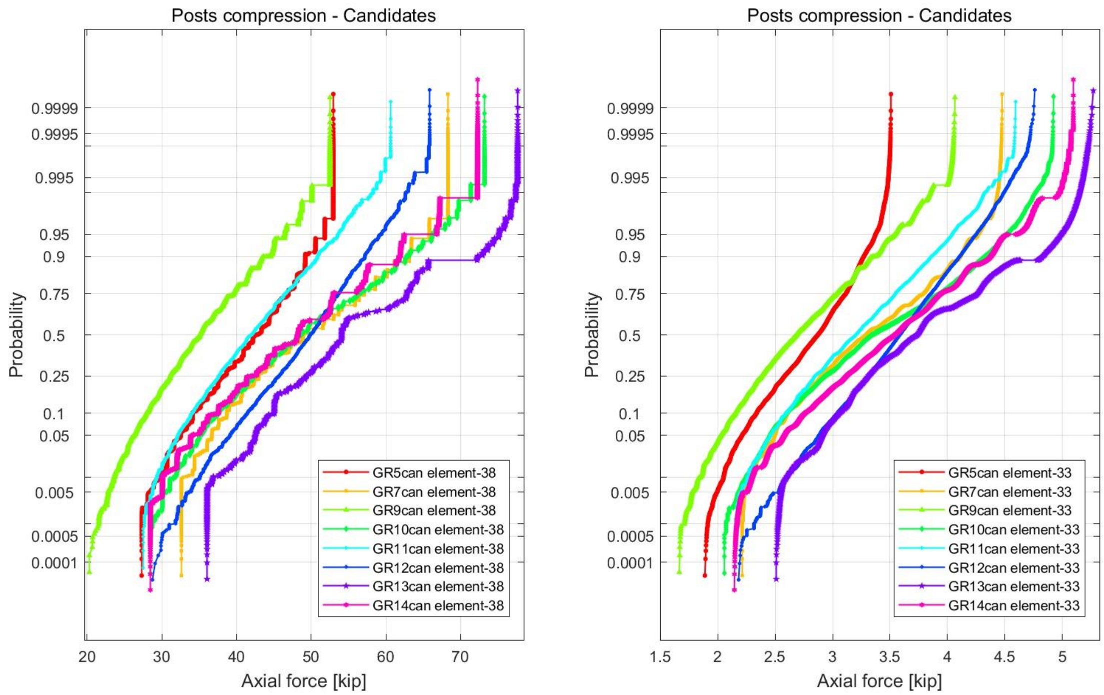


Figure B-0-39. Axial forces in the posts elements (compression) - Candidates.

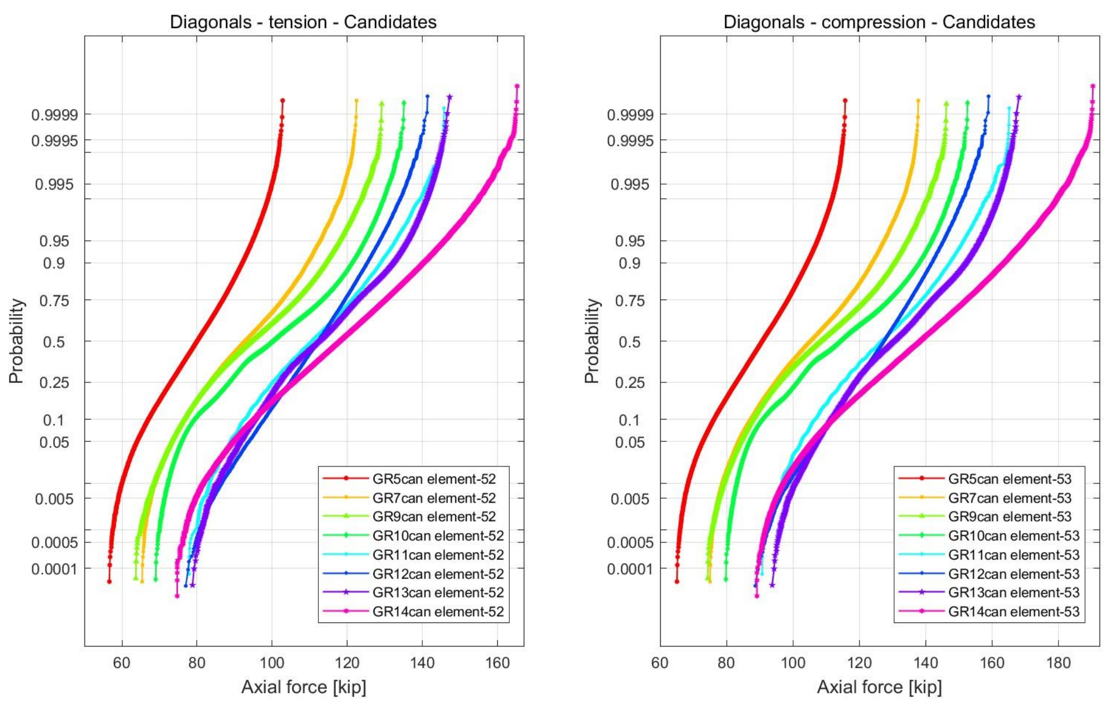


Figure B-0-40 Axial forces in the diagonals elements (compression) - Candidates.

Project No. ABC-4, located in St. Clair and Talladega Counties, spanning the Coosa River - Results

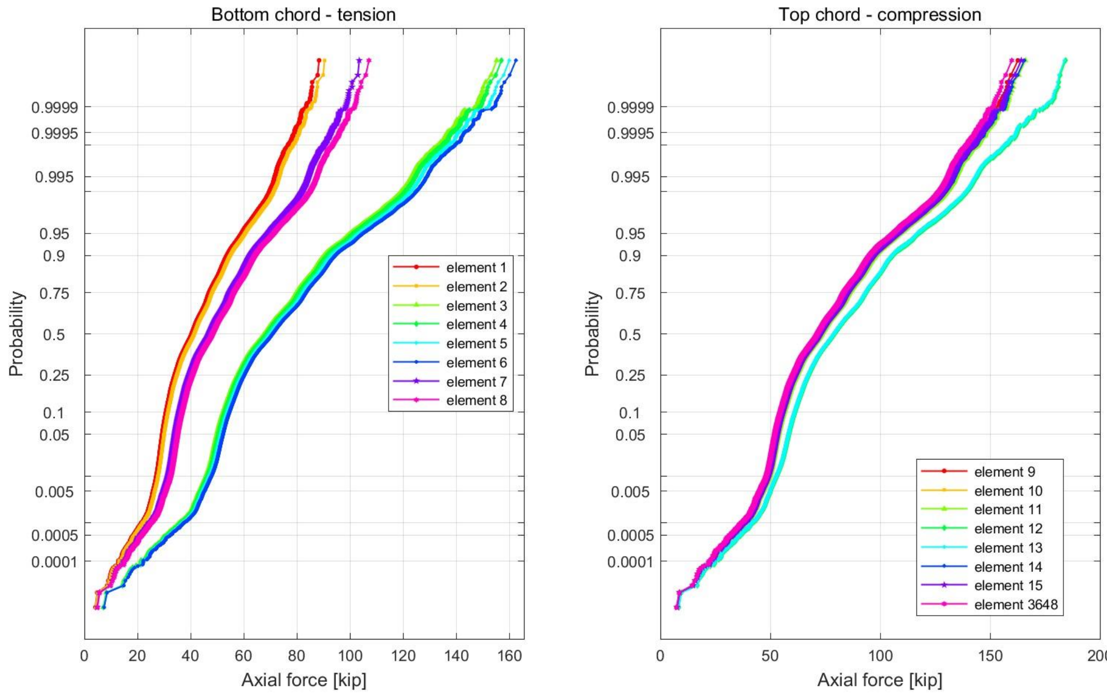


Figure B-0-41. Axial forces in the chord's elements – Truss-4.

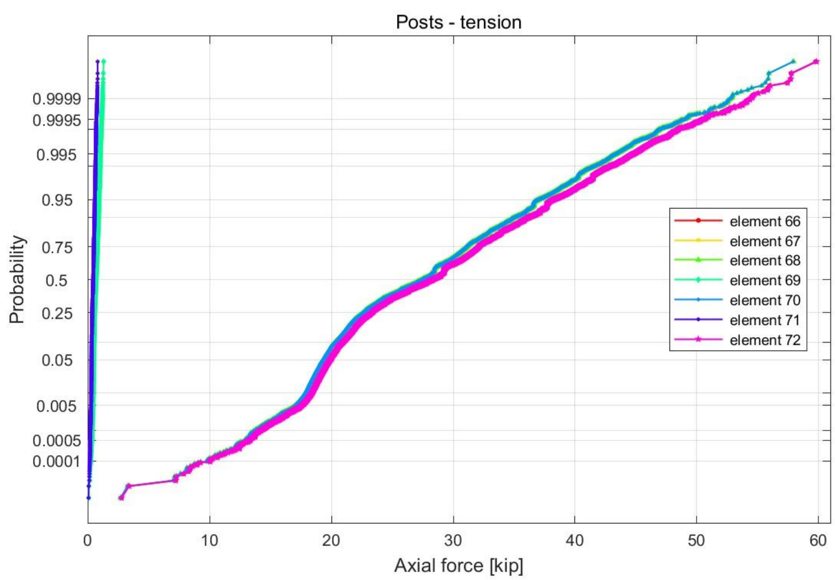


Figure B-0-42. Axial forces in the posts elements – Truss-4.

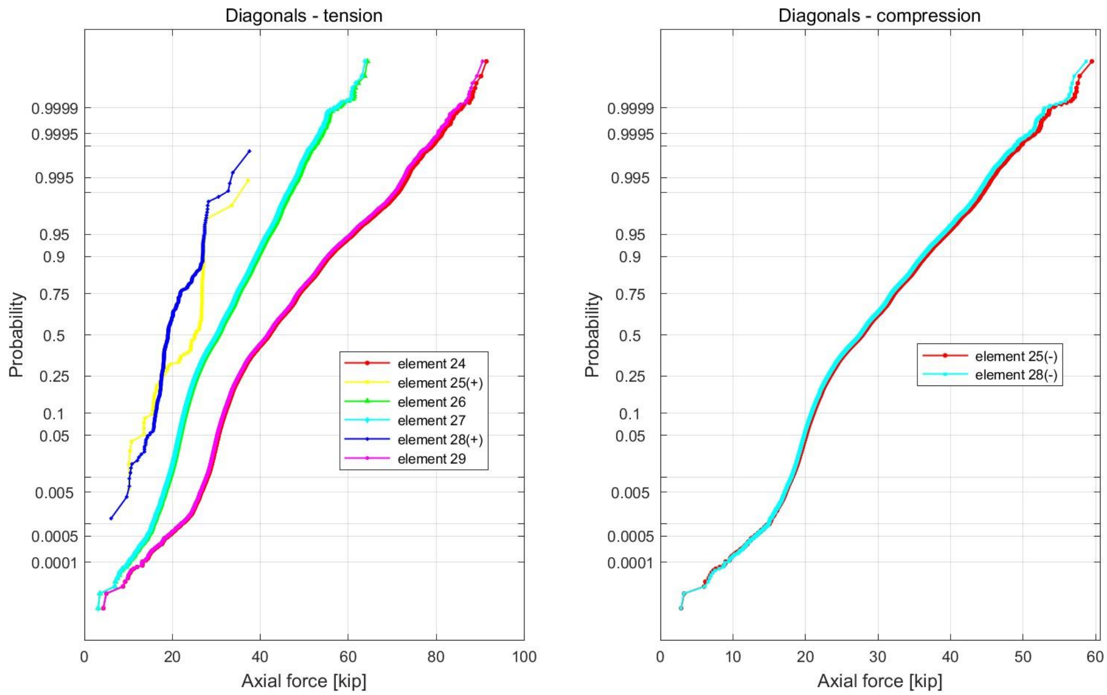


Figure B-0-43. Axial forces in the diagonal's elements – Truss-4.

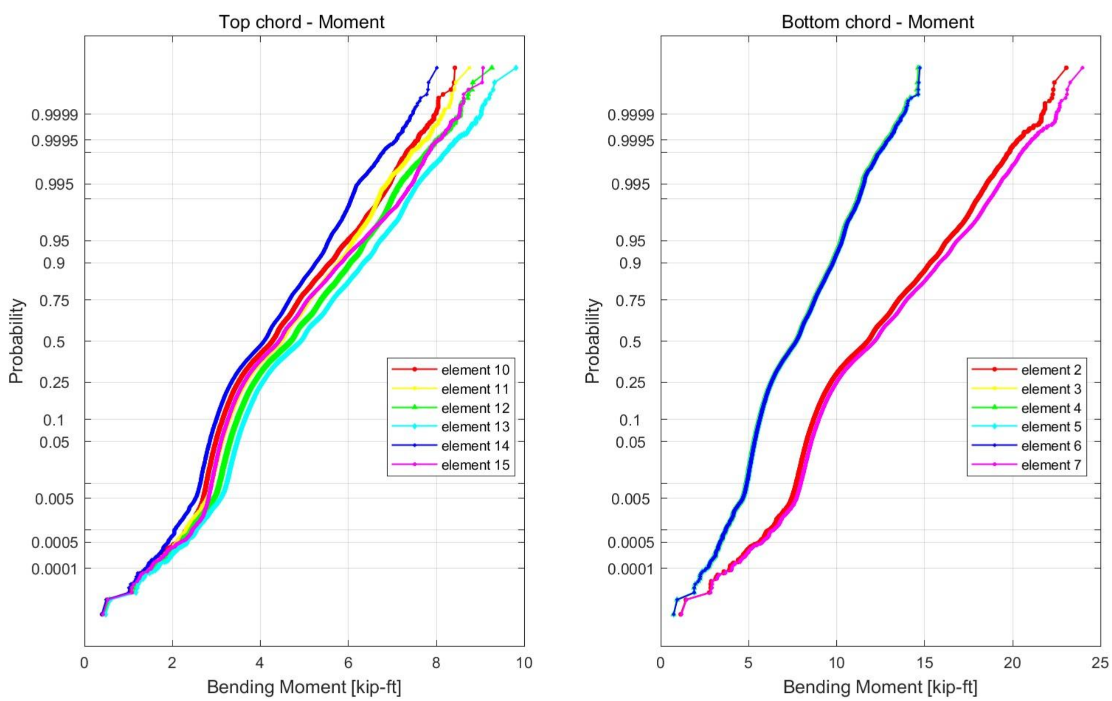


Figure B-0-44. Bending moment in the top and bottom chord elements

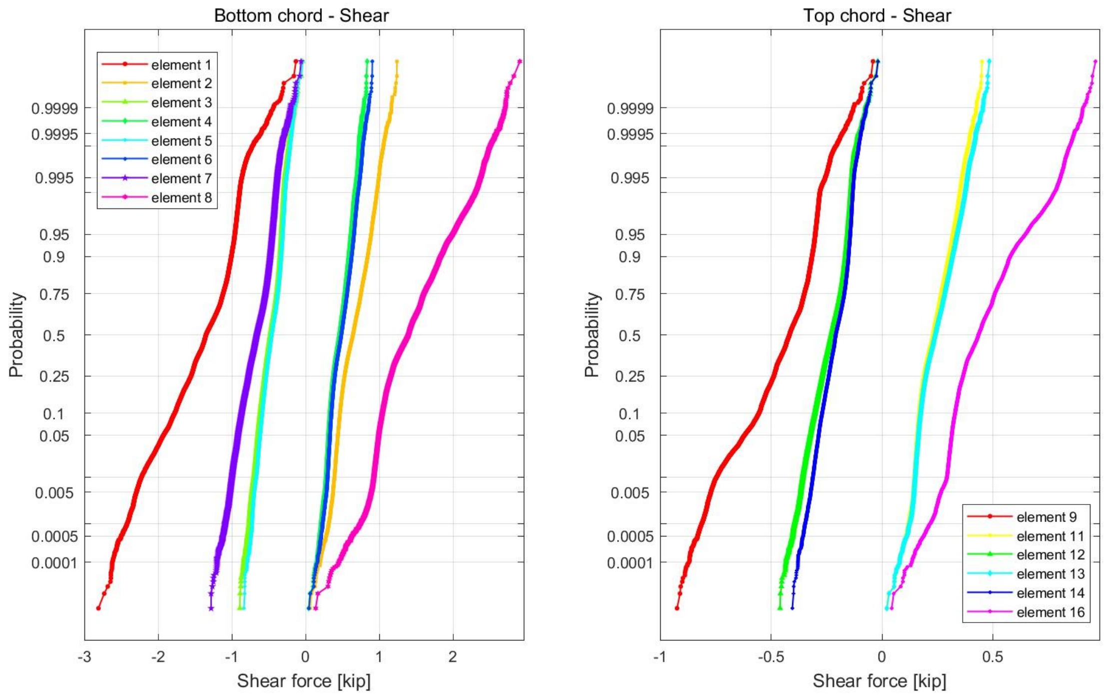


Figure B-0-45. Shear forces in the top and bottom chord elements

Project No. BR 0002(550), located in Colbert and Lauderdale Counties - Results

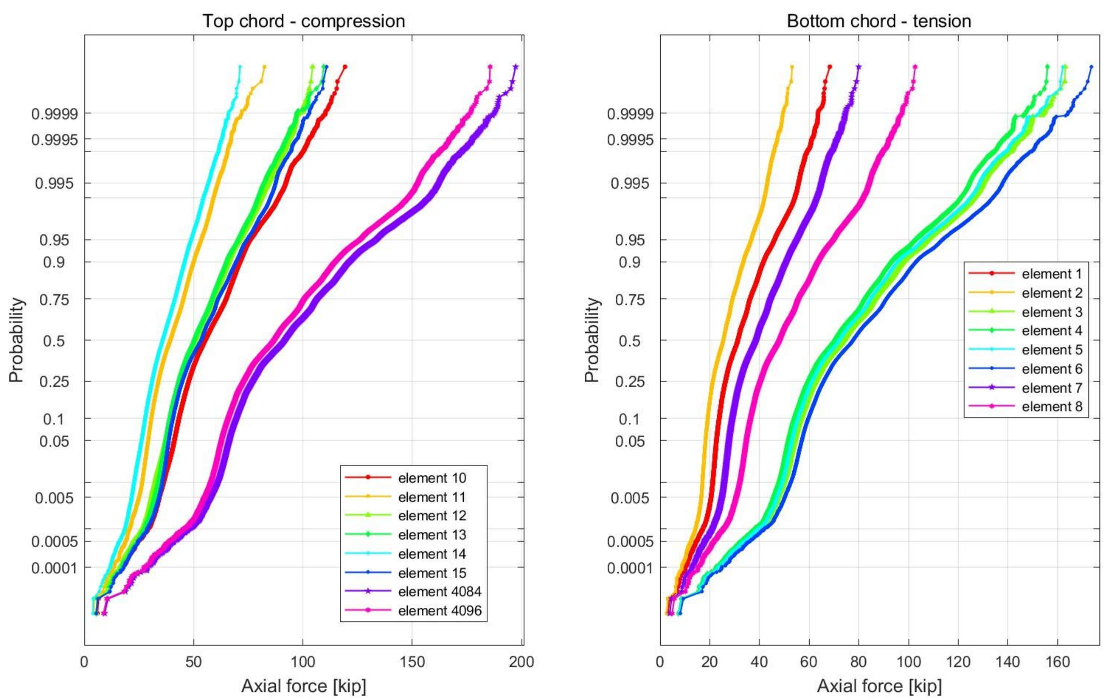


Figure B-0-46. Axial forces in the chord's elements – Truss-5.

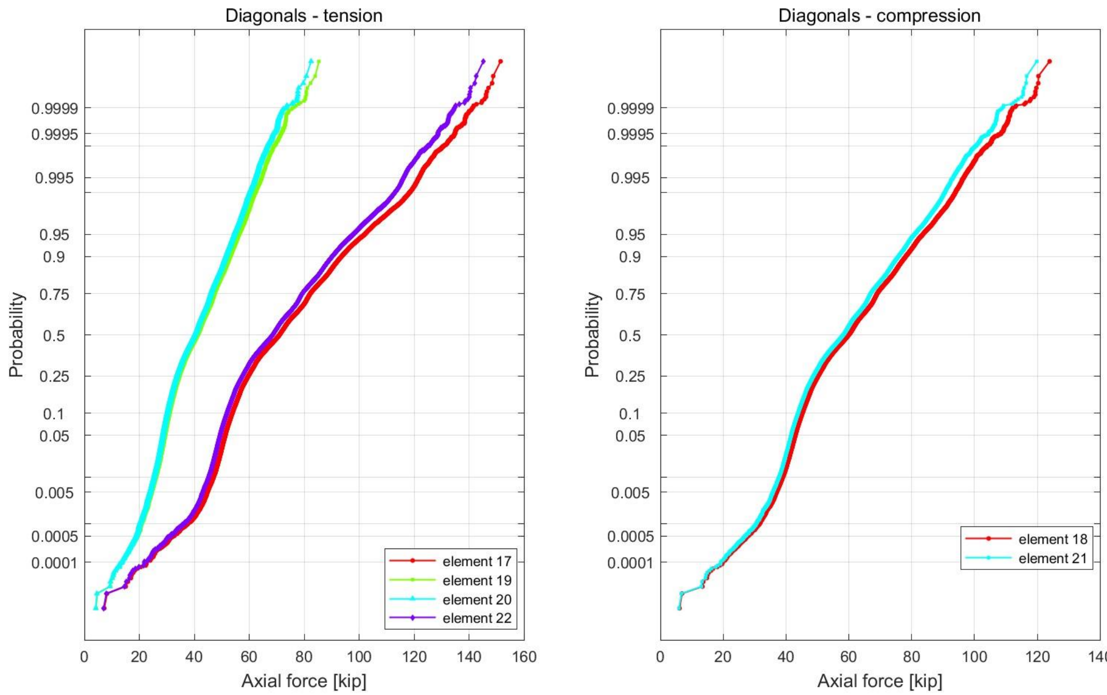


Figure B-0-47. Axial forces in the diagonal's elements – Truss-5.

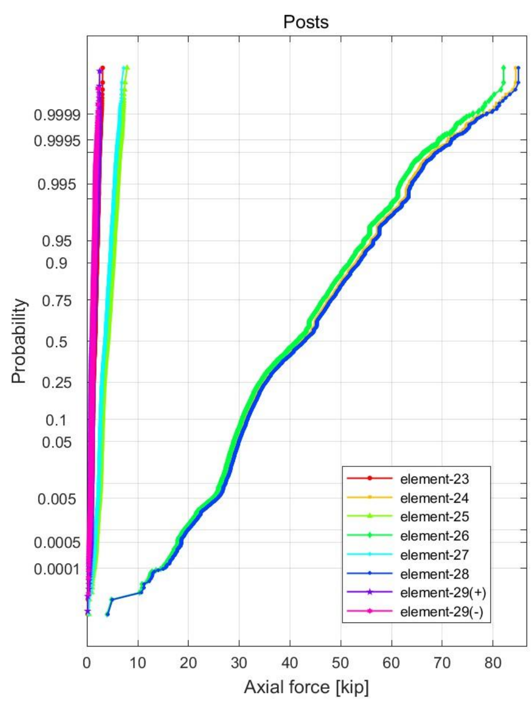


Figure B-0-48. Axial forces in the post's elements – Truss-5

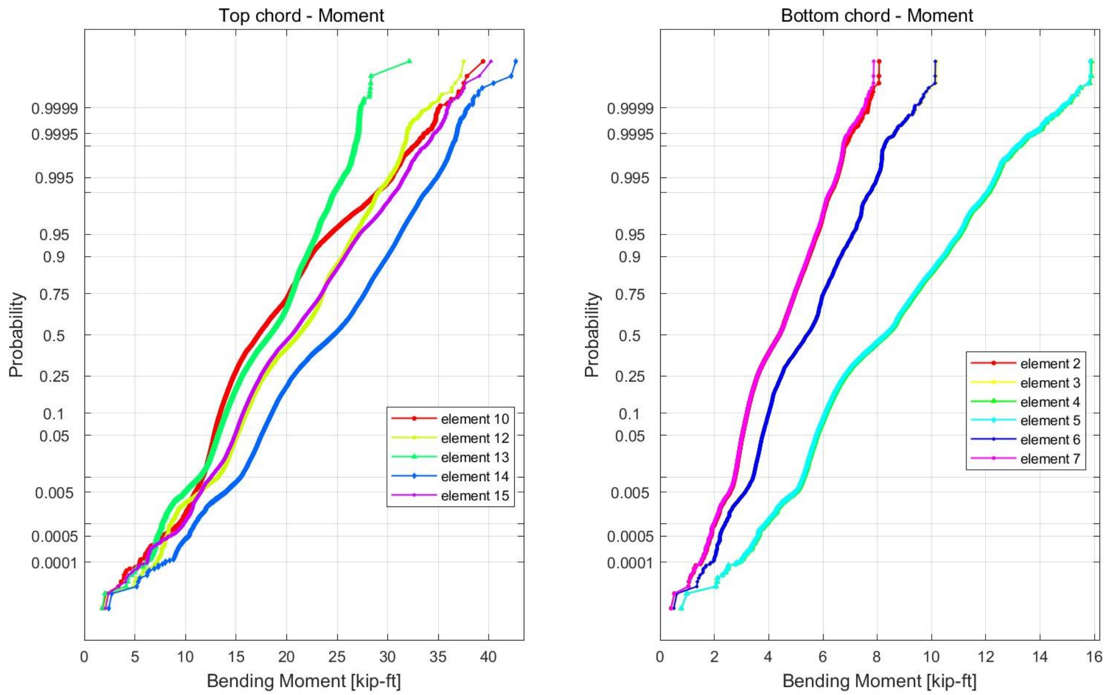


Figure B-0-49. Bending moment in the top and bottom chord elements

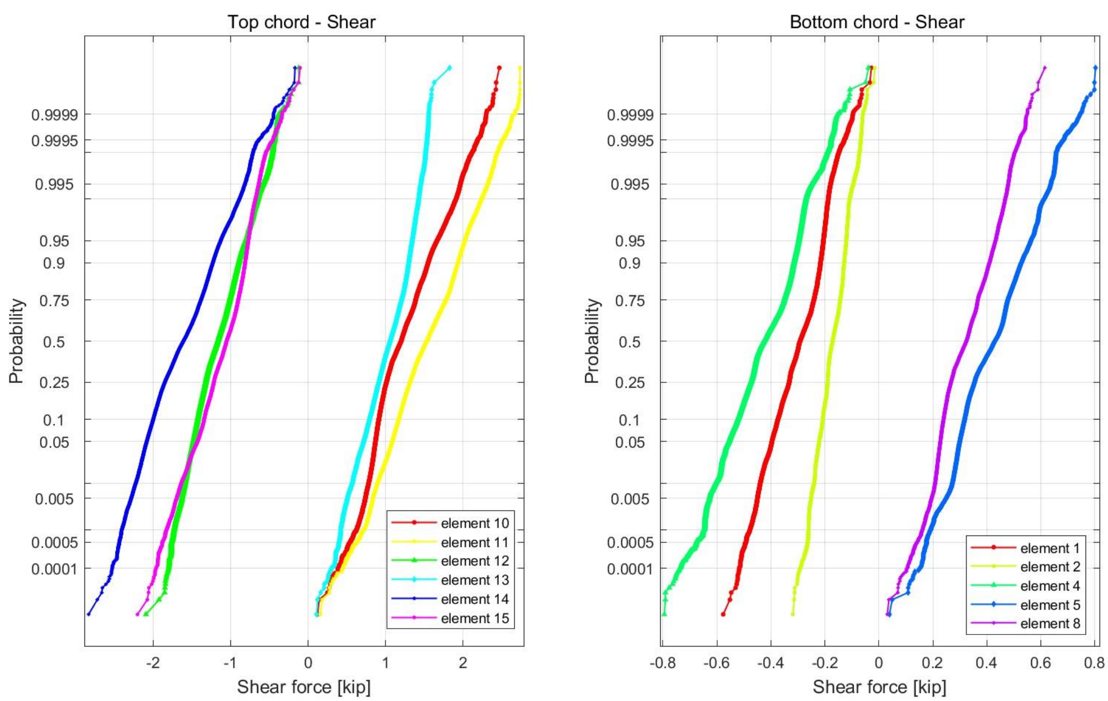


Figure B-0-50 Shear forces in the top and bottom chord elements.

Appendix C

Live Load Analysis Results for Arch Bridges

West Fork Bridge - Results

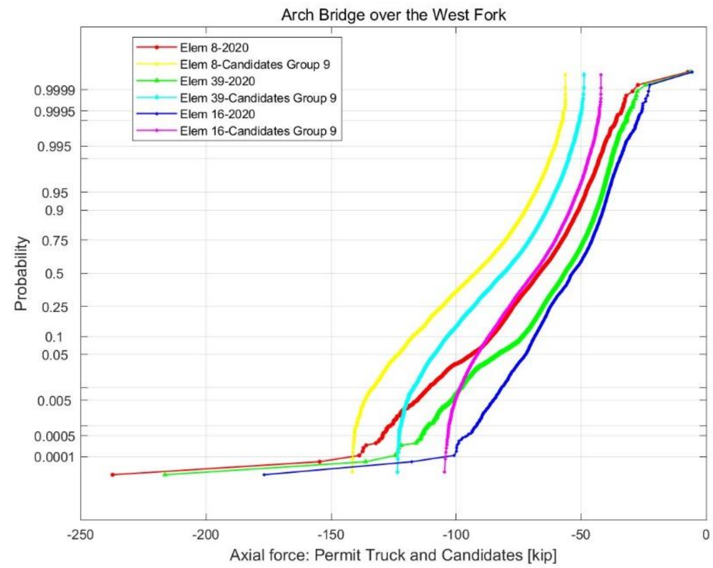


Figure C-0-1. Force variability comparison (2020) for selected arch elements (8, 39 and 16).

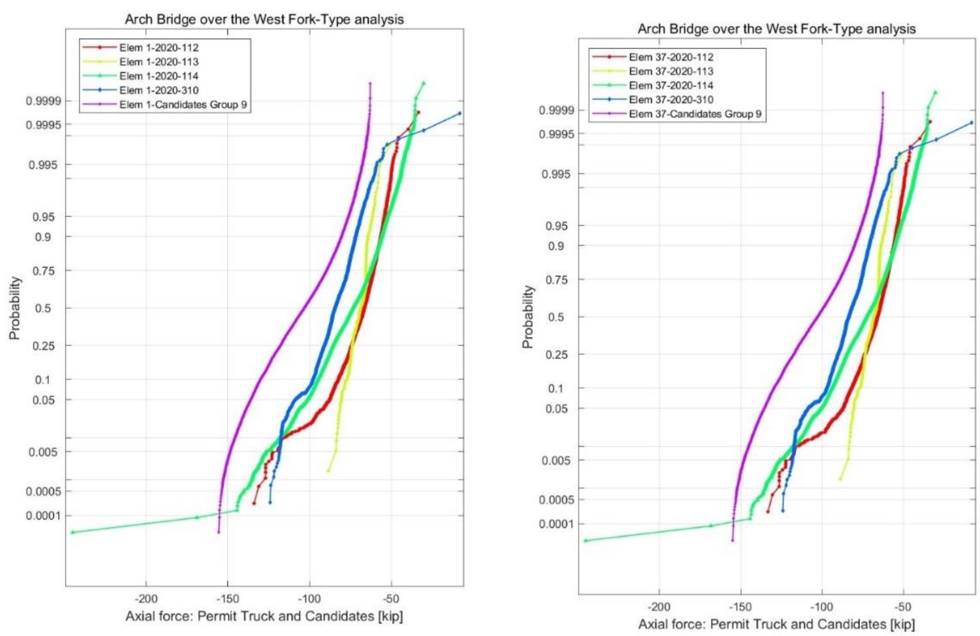


Figure C-0-2. Axial force variability analysis by permit 2020: Elem 1 (left) and Elem 37 (right).

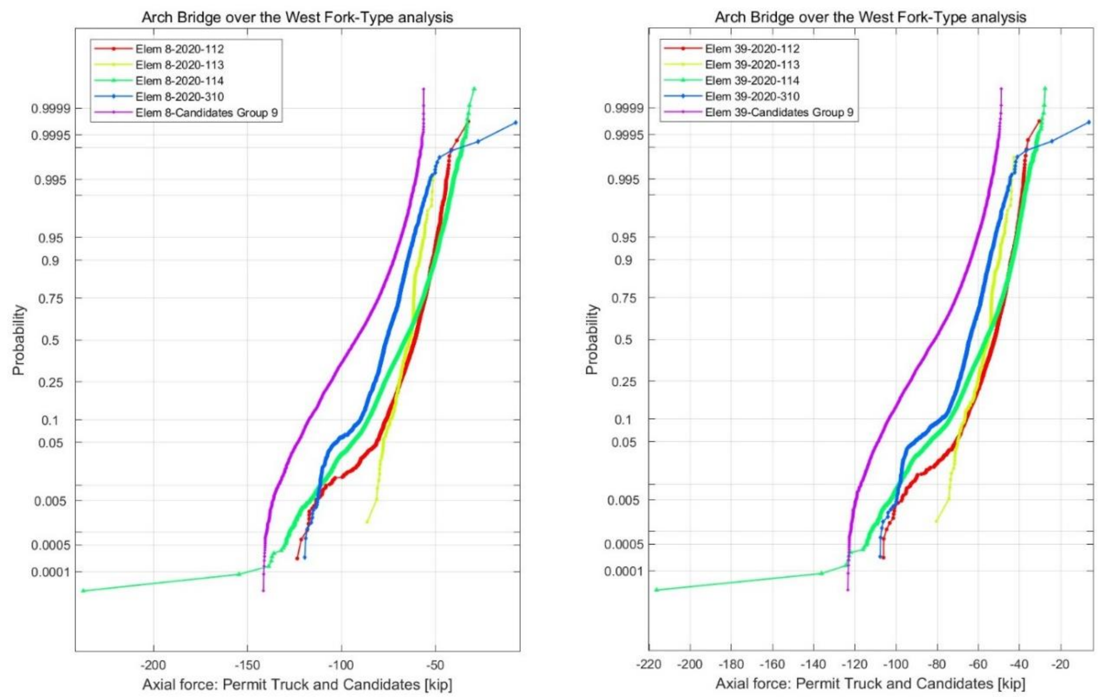


Figure C-0-3 Axial force variability analysis by permit - 2020: Elem 8 (left) and Elem 39 (right).

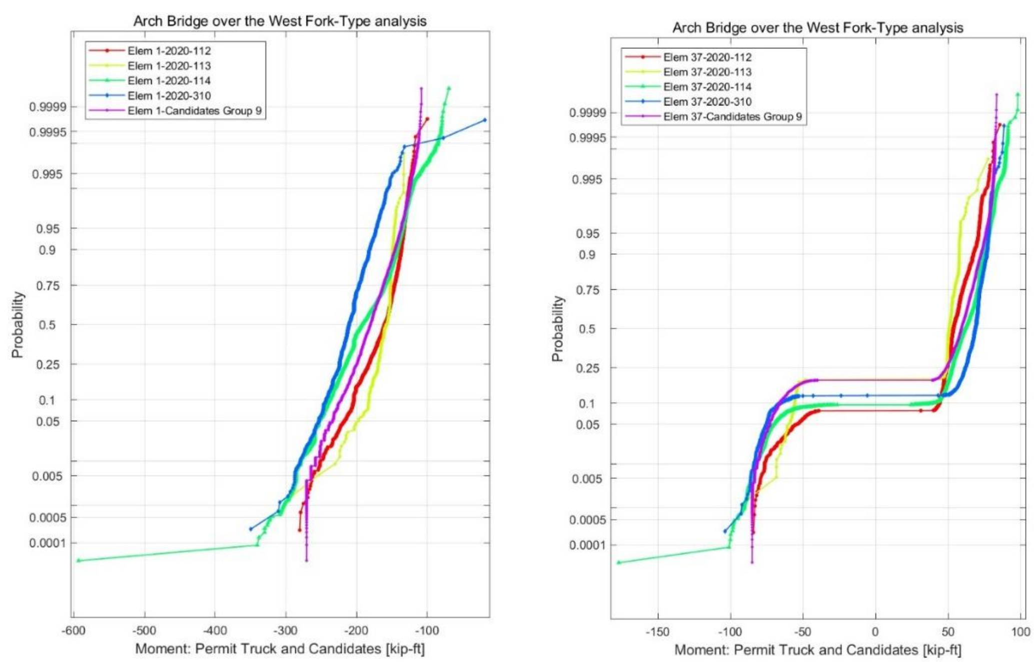


Figure C-0-4. Moment variability analysis by permit - 2020: Elem 1 (left) and Elem 37 (right).

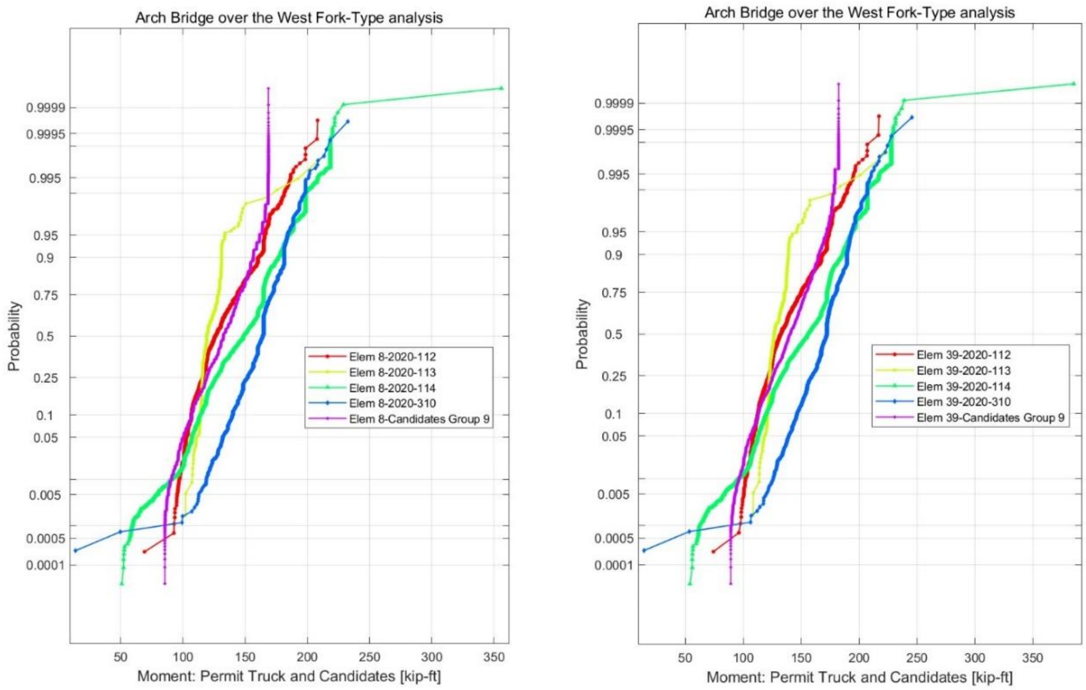


Figure C-0-5. Moment variability analysis by permit -2020: Elem 8 (left) and Elem 39 (right).

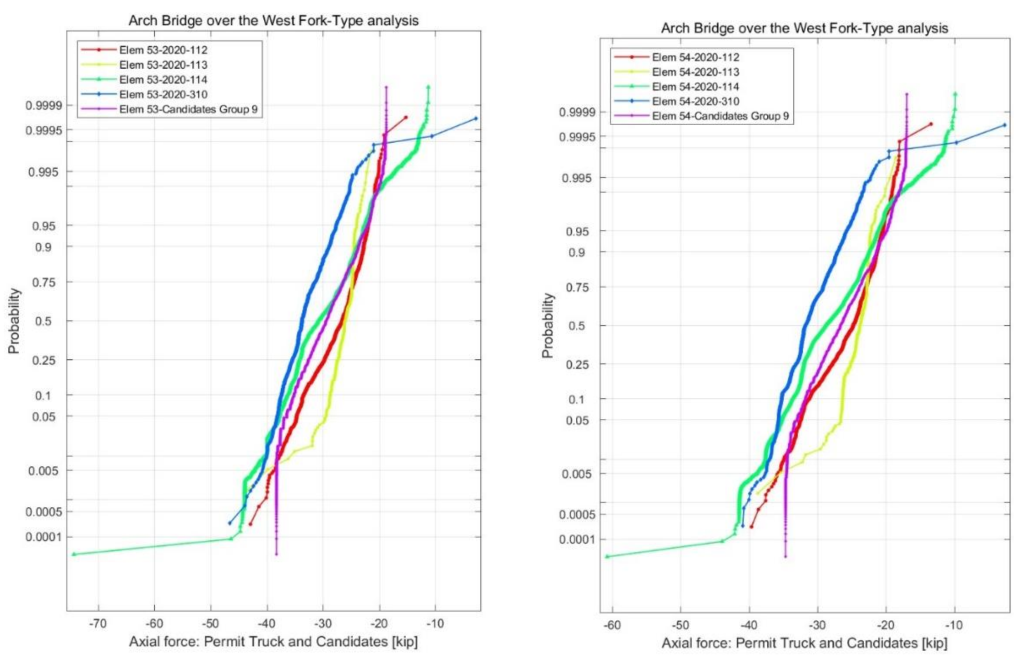


Figure C-0-6. Axial force analysis by permit - 2020: Elem 53 (left) and Elem 54 (right).

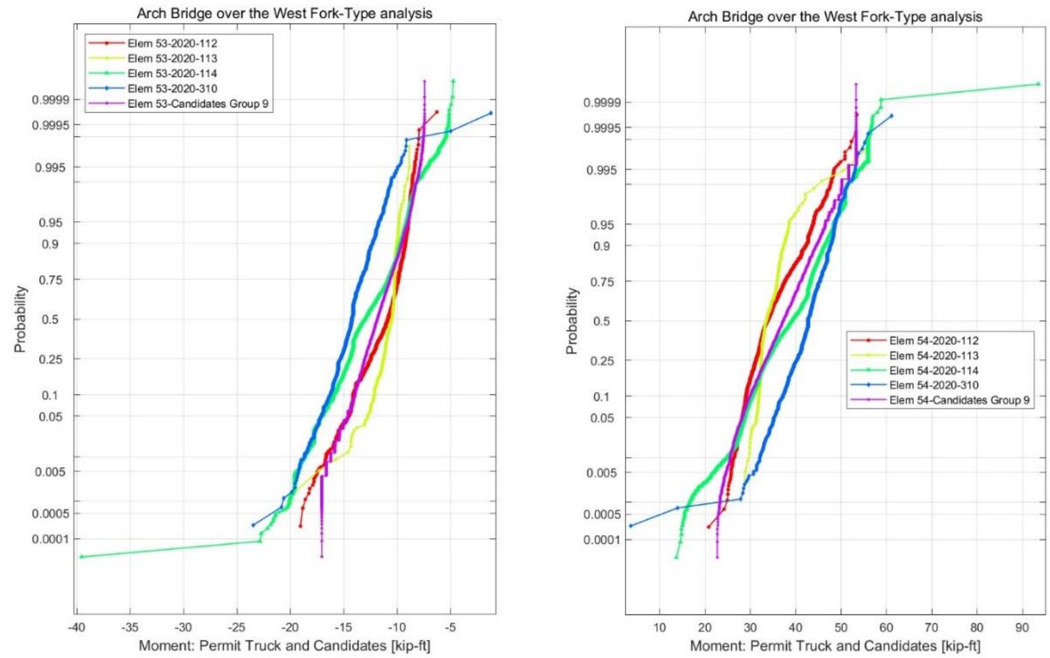


Figure C-0-7. Moment variability analysis by permit 2020: Elem 53 (left) and Elem 54 (right).

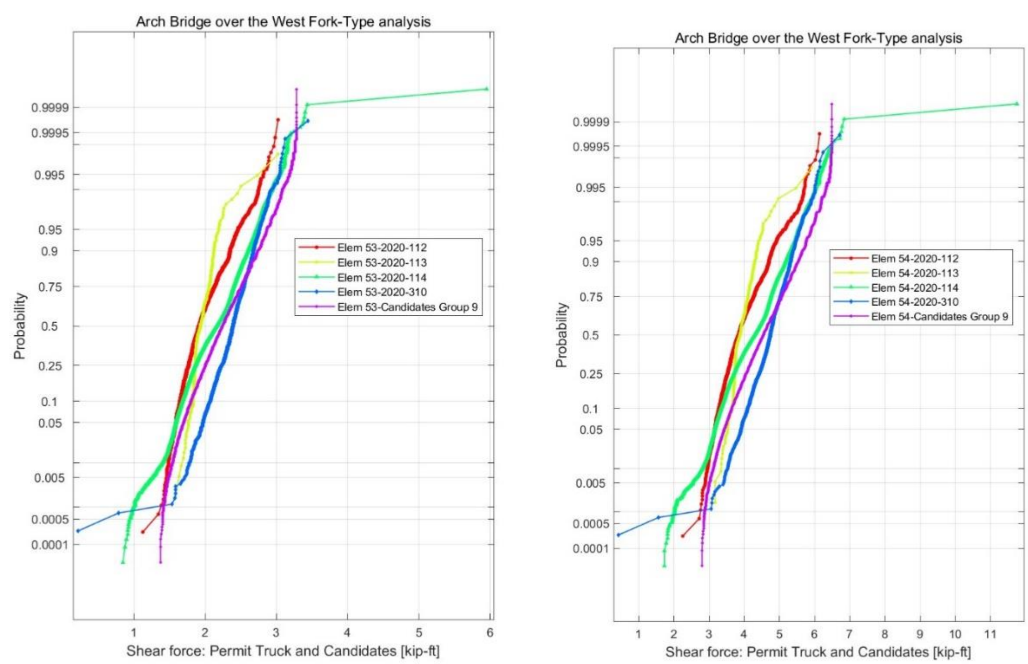
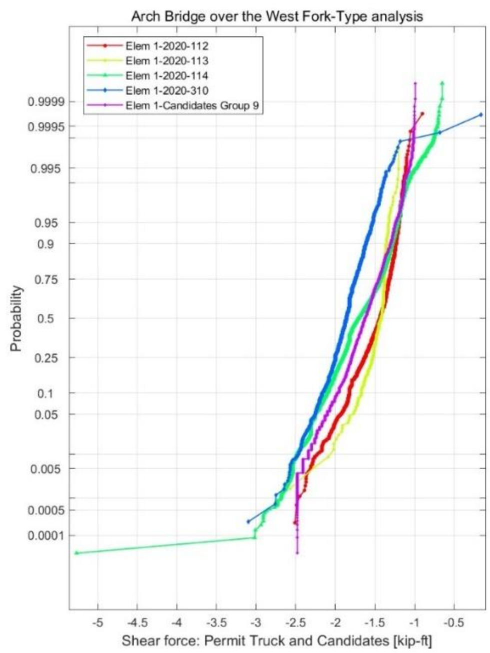


Figure C-0-8. Shear force analysis by permit 2020: Elem 53 (left) and Elem 54 (right).



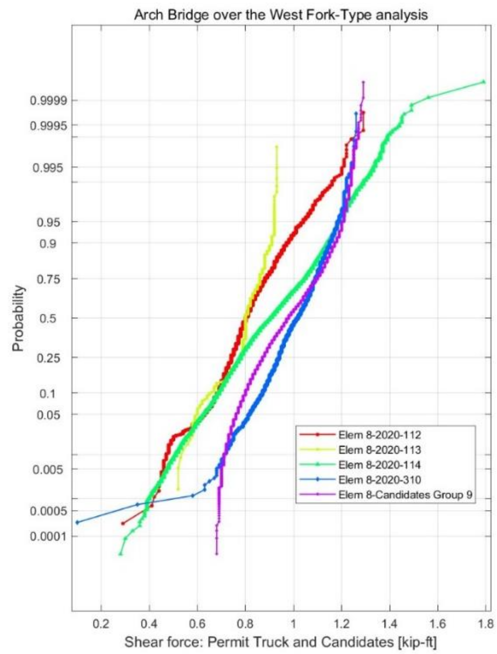


Figure C-0-9. Shear force variability analysis by permit 2020: Elem 1 (left) and Elem 8 (right).

Appendix D

Results of Reliability Analysis

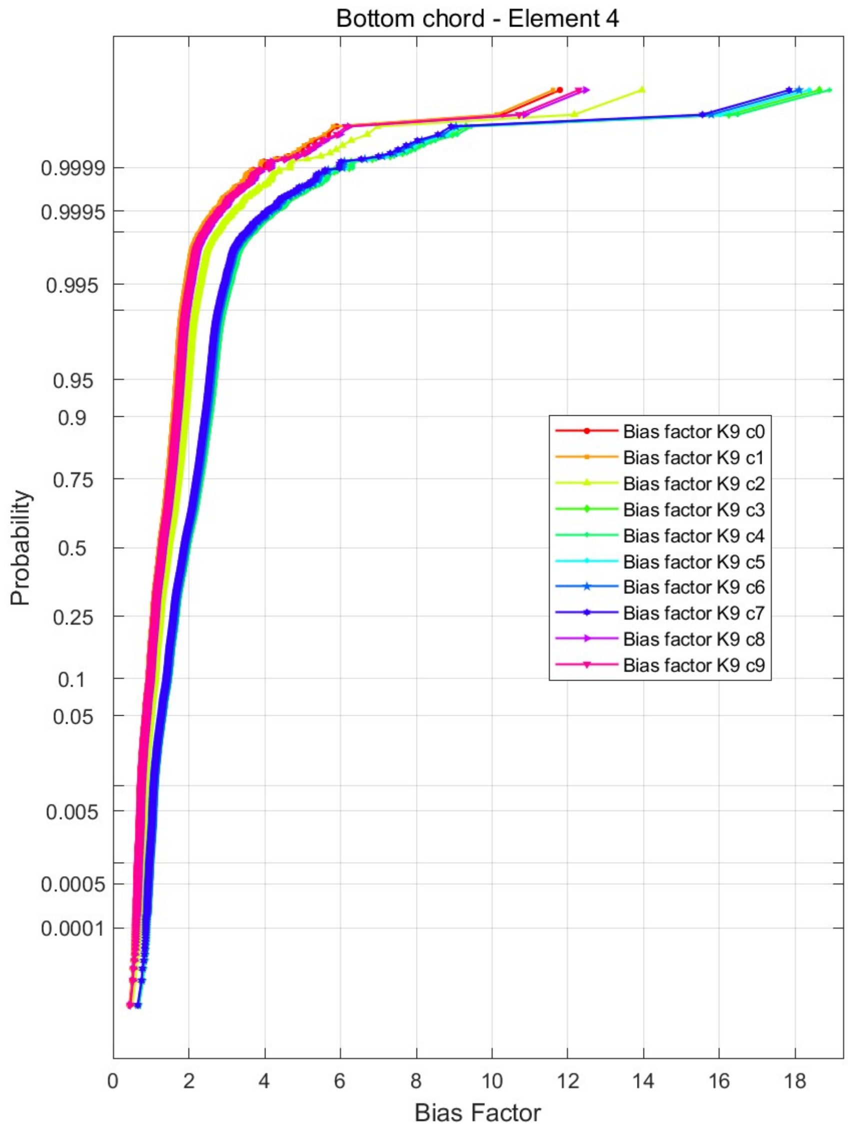


Figure D-0-1. Bias Factor for selected candidates from group 9 – element 4.

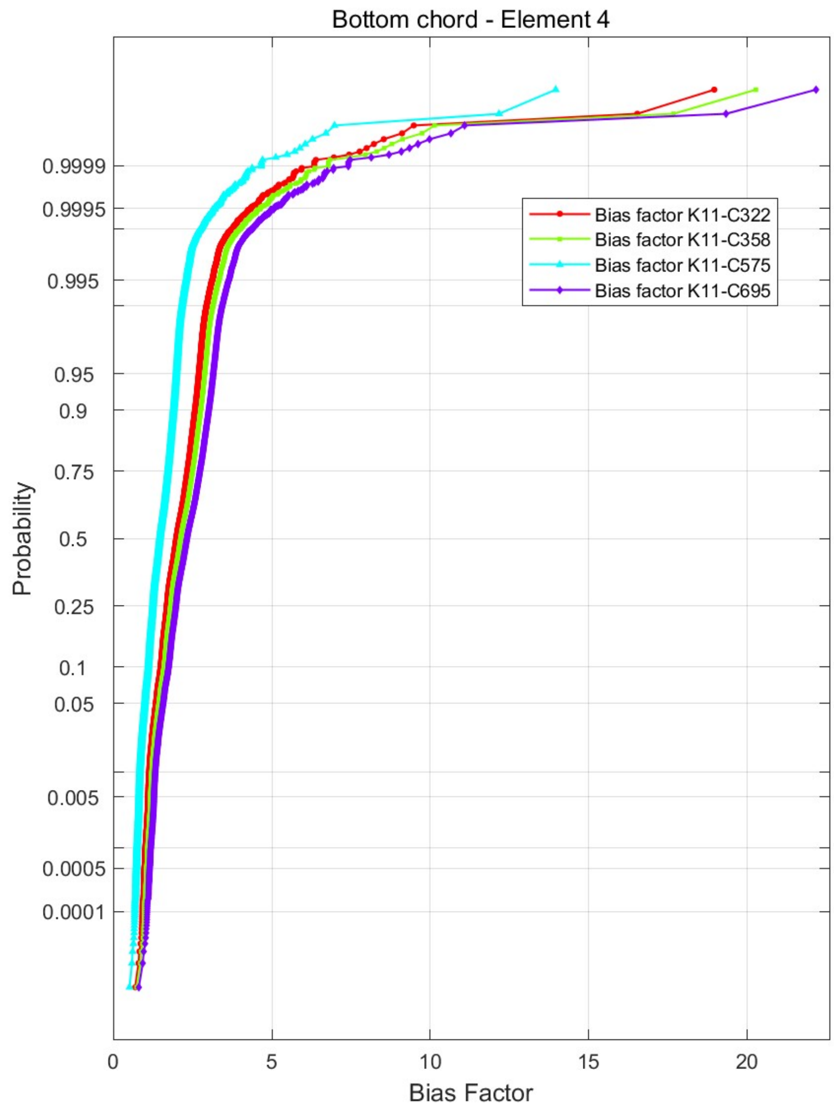


Figure D-0-2. Bias Factor for selected candidates from group 11 – element 4.

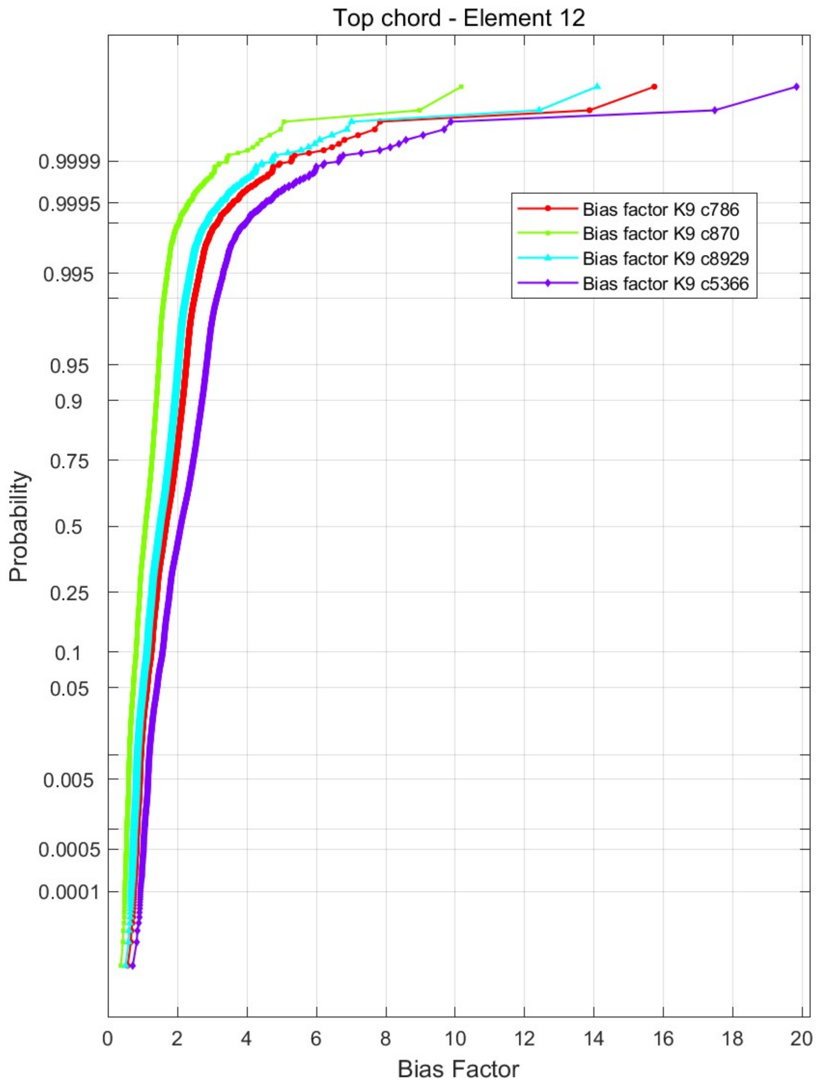


Figure D-0-3. Bias Factor for selected candidates from group 9 – element 12.

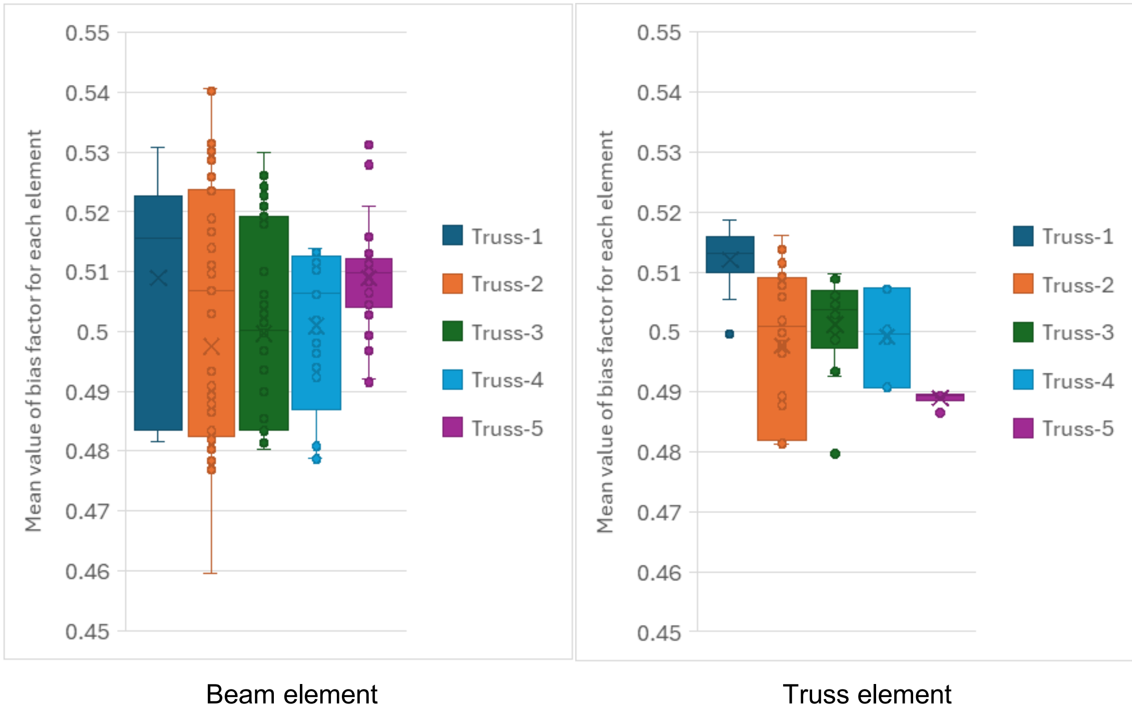


Figure D-0-4. Mean value of bias factor for each element - axial force for the Notional Permit Vehicle.

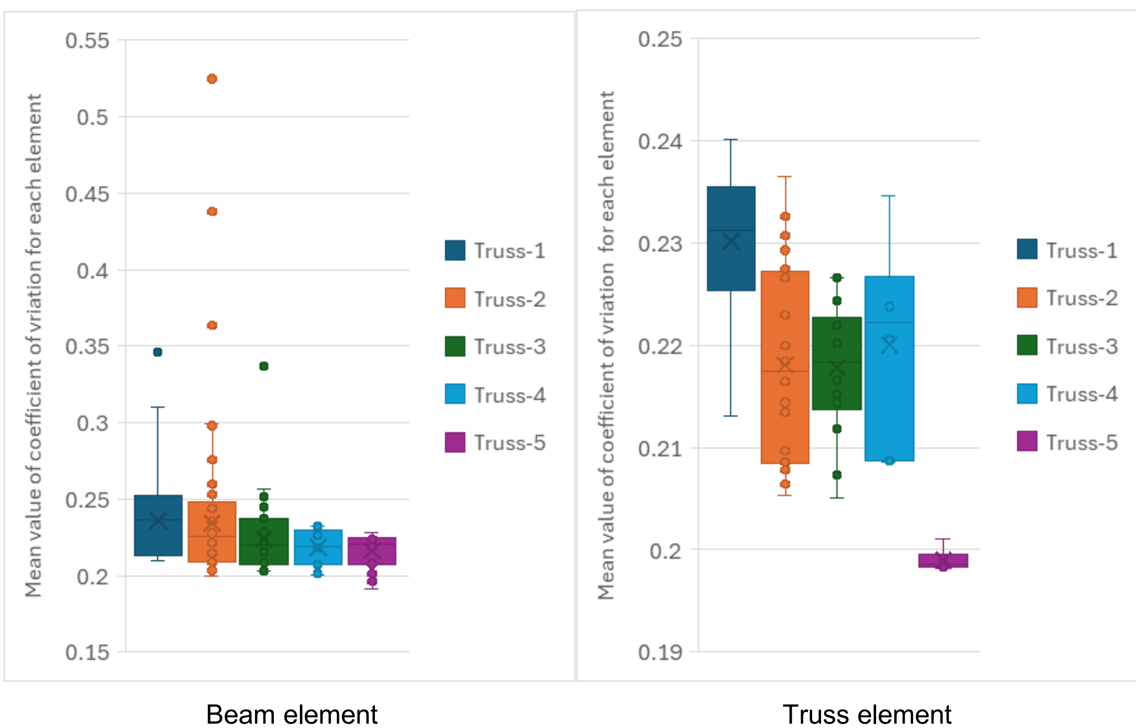


Figure D-0-5. Mean value of coefficient of variation for each element - axial force for the Notional Permit Vehicle.