Structural Categorization and Capacity Comparison of Standard-Classified Bridges

A support for bridge management assessment

Master's thesis in the Master's Program Structural Engineering and Building Technology

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Cover: A beam frame bridge retrieved from the BATMAN database.
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ABSTRACT

This master's thesis was carried out in collaboration with the Transport Administration and examines bridges with standard classification. The aim is to support future prioritization and analysis of around 3000 such bridges. This was done by studying the relationship between calculated load-bearing capacity and previous classifications, and by identifying patterns related to bridge structure, construction year, and regulation framework.

The main focus of the study is beam bridges, beam frame bridges, slab frame bridges, and slab bridges. Arch bridges and culvert bridges were also considered on a general level. The results are based on comparisons between previous standard values and newly calculated A- and B-values. The analysis was carried out using bridge data obtained from BATMAN.

The results show that the standard classification is generally representative, but there are significant variations between individual bridges, meaning the standard values do not always reflect the actual load-bearing capacity. Most bridges showed higher calculated capacities than their previous values, while some were lower. However, none were downgraded to a lower load-bearing class.

Since the results are based on a limited number of bridges, it is difficult to establish clear general trends. Nevertheless, certain patterns were identified for different bridge structures, which may be relevant for further evaluation. Slab frame bridges show the greatest variation in calculated values and also constitute to the largest group of bridges that still remain under standard classification, making them particularly interesting for further investigation.

The conclusion of the study is that the process of comparing standard values with calculated load-bearing capacities is complex, as several factors influence the final assessment. The work demonstrates that certain bridge groups may be of particular interest for further investigation and that the results can support future prioritization and management of standard-classified bridges.

Key words: Load-bearing capacity, standard classification, load-bearing assessment, A-value, B-value, Swedish Transport Administration, bridge structures, load-bearing class, BATMAN, regulations.

Kategorisering och kapacitetsanalys av schablonklassade broar
Ett underlag för utvärdering av underhållsåtgärder

Examensarbete inom masterprogrammet Structural Engineering and Building Technology

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SAMMANFATTNING

Examensarbete har genomförts i samarbete med Trafikverket och behandlar schablonklassificerade broar. Syftet med arbetet är att bidra med underlag för framtida prioritering och fortsatt analys av de ca 3000 schablonklassade broarna som finns idag. Detta har genomförts genom att undersöka hur beräknade bärighetsvärden förhåller sig till tidigare schablonklassificering samt att identifiera eventuella mönster mellan olika brotyper, konstruktionsår och regelverk.

Studien omfattar flera olika brotyper, där fokus främst har legat på balkbroar, balkrambroar, plattrambroar och plattbroar, även valvbroar och rörbroar har behandlats övergripande. Resultaten bygger på jämförelser mellan tidigare schablonvärden och nya beräknade A- och B-värden. Analysen har genomförts med hjälp av brodata hämtad ur BATMAN.

Resultaten visar att schablonklassificeringen generellt har varit representativ. Samtidigt framgår det att variationen mellan individuella broar är stor, vilket innebär att schablonvärden i flera fall inte fullt ut representerar den verkliga bärförmågan. Majoriteten av de analyserade broarna erhöll högre beräknade bärighetsvärden än sina tidigare schablonvärden, medan vissa broar fick lägre värden. Ingen av de undersökta broarna nedklassades till en lägre bärighetsklass.

Resultaten bygger på ett färre antal broar vilket gör det svårt att fastställa tydliga generella trender. Däremot identifierades vissa mönster för olika brotyper som kan vara relevanta för fortsatt utvärdering av Trafikverket. Plattrambroar har störst spridning i de beräknade värdena och samtidigt utgör den största gruppen av broar som fortfarande har schablonklassning, vilket gör dem särskilt intressanta för vidare utredning.

Slutsatsen är att processen gällande att jämföra schablonvärde med beräknade värden är komplex eftersom flera faktorer påverkar den slutliga bedömningen. Arbetet visar att vissa grupper av broar kan vara särskilt intressanta för vidare utredning och att resultaten kan användas som stöd vid framtida prioritering och förvaltning av schablonklassificerade broar.

Nyckelord: Bärförmåga, schablonklassificering, bärighetsbedömning, A-värde, B-värde, Trafikverket, brokonstruktioner, bärighetsklass, BATMAN, regelverk.

Contents

Preface

This master's thesis was carried out during the spring of 2026 at the Department of Architecture and Civil Engineering at Chalmers University, in collaboration with the Swedish Transport Administration.

The work has provided valuable insight into bridge assessment procedures, historical regulations, and the challenges associated with evaluating existing bridge structures.

We would like to express our gratitude to our supervisors, Fredrik Olsson, Christine Warg and Staffan Isaksson at the Swedish Transport Administration for their guidance, support, and valuable expertise throughout the project. We would also like to thank our academic supervisor and examiner, Joosef Leppänen at Chalmers University for constructive feedback and encouragement during the thesis work.

Gothenburg, June 2026

Ida Eliasson
Evelina Källhage

Notations

Regulations

TDOK 2013:0267	Document from the Transport Administration *(Trafikverksdokument)*
TRVINFRA-00331	Document from the Transport Administration. Current regulation *(Trafikverksdokument)*
VV Publication 1998:78	Document from the Transport Administration *(Trafikverksdokument)*
2009 load models	Document from the Transport Administration *(Trafikverksdokument)*

Abbreviations

A/B-value	Describes the design or permitted axle load (A) and bogie load (B) according to the bridge classification
BATMAN	Database for constructions owned by the Transport Administration
BK	Load-bearing capacity class *(Bärighetsklass)*
BKR	Boverkets Construction Guidelines *(Boverkets Konstruktions Regler)*
FEM	Finite Element Method
PDF	Probability Density Function
ULS	Ultimate Limit State

Roman lower case letters

M_E	Bending moment
M_R	Moment capacity
W_b	Bending moment resistance
V_E	Shear force
V_R	Shear capacity
h	Height
b	Width

Greek letters

λ	Slenderness

1 Introduction

The increasing traffic loads and volumes on today's road network place higher demands on the capacity of existing bridges (Vägverket, 2000). Bridges built today are dimensioned for higher loads than today's road system allows, with the purpose to meet future demands (Trafikverket, 2025a). This concept has been applied in the past, which is one reason why many older structures remain in use today. However, bridges built previously were designed according to earlier regulations and traffic load models, while current demands and standards have changed significantly.

The Swedish Transport Administration *(Trafikverket)* owns and manages the state-owned bridges in Sweden. The administration is responsible for all phases in the process, from bridge planning to maintenance and demolition. In total, the Administration manages approximately 17000 road bridges (Trafikverket, 2025a). Some of these are becoming relatively old and the requirements for permitted total weights are rising on the road network (Vägverket, 2000). In 2019, the Transport Administration officially received a commission from the government with the task to increase the load-bearing classification on the Swedish road network (Natanaelsson and Eriksson, 2020). As a result of this, many bridges require inspection and analysis in order to ensure the capacity and meet the requirements. Some results did not lead to any further measures, but in some cases actions such as reinforcements or even replacements are needed. Numerous structures remain to be thoroughly investigated and analyzed for the Transport Administration to complete the task.

This thesis aims to support the Swedish Transport Administration in the evaluation of bridges whose load-bearing capacity has been determined using standardized values. This chapter presents an overview of the study, including background, followed by the purpose of the study, and concludes with the limitations and sources of uncertainty.

1.1 Background

Methods for classifying bridge constructions related to load-bearing capacity have developed over time. For old bridges, the demands and loads acting on the structures were different from today. This means that the old regulations and standards used in bridge construction must be adapted to current traffic load regulations. This will require individual load-bearing capacity analysis for all constructions falling under this criteria. The administration initiated another method for load-bearing assessment. A simplified method called standard classification *(schablon-klassning)*.

The process started by performing load-bearing capacity calculations for approximately 150 bridges, calculated according to the VV Publication 1998:78 (Vägverket, 1998). They represented a set of structures within each type of construction and they were individually analyzed to ensure that variations within the respective categories were captured (C. Warg, personal communication, February 5, 2026). The results from this analysis were used as supporting documentation when assessing the values of the non-classified bridges.

Based on the calculations, all bridges were assigned A/B values, corresponding to the maximum load accepted on the bridge. These values formed the basis for the standardized classification, and the calculated values were assessed against similar bridges that did not have any supporting material regarding load-bearing capacity. The method for how the bridges were analyzed and assessed a value based on the calculated bridges are not documented in detail. Some different criteria have been noted to make room for some variations within the structures.

The Swedish Transport Administration has about 200 bridges that were previously given a standard classification, but which now have their own load-bearing capacity calculations. The distribution of bridge structures is shown in Figure 1.1. When these were carried out, the load-bearing capacity turned out different compared to the earlier classification, in several cases. This is what to assume from a standard classification, since the objective of the method is to effectively and relatively rapidly find similarities in order to assess values. Although this leaves the Swedish Transport Administration with an okay understanding of the capacity of some bridges, but when the requirements and demands are increasing, so must the knowledge.

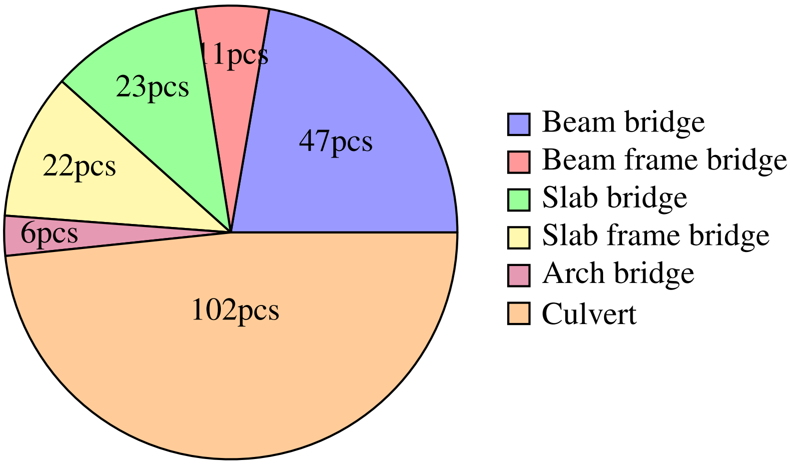


Figure 1.1: The distribution of bridges that initially had standard values but were later assigned newly calculated values.

Therefore, it is of interest to investigate bridges that still have a standard classification. The Swedish Transport Administration has identified just over 3000 bridges classified with this method. Assessing bridges by this process causes uncertainty in the process of planning the maintenance and the routes of heavy load vehicles.

1.2 Purpose

The aim of the project is to develop a supporting material for the process to categorize and prioritize approximately 3000 standard classified bridges. This work will be a support to the Transport Administration and their future work with bridge asset management.

The project should answer the following questions:

- Which bridge structure should be prioritized for further analysis?
- Where do refined analyzes provide the greatest added value?
- What aspects of the standard classification might affect the load-bearing capacity?

1.3 Method

The methodology of the project includes several steps. The first part of the process was to familiarize ourselves with and gain knowledge of how the bridges initially were assigned their standard values. To make this possible, the old standards were reviewed and interviews with experts from the Swedish Transport Administration were conducted.

BATMAN research was performed to identify the types of bridge constructions relevant to the scope of the project. All bridges with standard value were compiled and summarized in excel and categorized according to different criteria.

To achieve the objective of categorizing the 3000 bridges that currently have a standard classification, the main focus of this work was on bridges that initially had been assessed according to the standard classification and also received an individual load-bearing capacity calculation.

About 200 such bridges were gathered in excel and summarized with relevant categorization. The difference was observed between the standard classification value and the calculation of the load-bearing capacity. To analyze the calculated A/B values for each bridge, the design capacity, the direction of load, and the location of the governing section were extracted from the calculations. The dimensions of the relevant construction parts were manually gathered from the BATMAN database, based on the bridge structure. The relevance of the construction part is based on the way of actions for the constructions.

The data were handled in Excel and Matlab and to enable analysis of the bridges, diagrams and plots were created. The analysis has focused on the differences between the standard values and the calculated load-bearing capacity values in relation to data received in BATMAN, such as construction year, regulations, calculations and bridge dimensions.

1.4 Limitations

The work in this project will not deal with the actual state of the bridge. There will be no analysis on the physical condition since the scope of the project handles the methods behind the classification and capacity calculations. The scope of the project is also restricted to the bridge structure, excluding the foundation. Movable bridges are not considered in this study, due to their complexity with multiple bridge structures. Due to confidentiality, some data handled in this project will not be published in detail but the method and result will be generally presented.

1.5 Sources of uncertainties

For bridges with varying dimensions of load-bearing structures, such as the beams and slabs, the extracted dimensions have, in some cases, been based on an average dimension. This causes some variation and uncertainty in the dimensions of the bridges although it is giving a fair representation. In addition, the geometric dimensions have been manually extracted from blueprints with varying quality and readability, which may also have affected the values.

Some load-bearing calculations have been performed for the purpose of changing the construction or widening the bridge, which has resulted in a variation in the execution of the load-bearing capacity calculations.

2 Theory

In this chapter, a deeper insight into the background and the facts on which the work is based, are provided.

2.1 Classification

The load-bearing capacity is classified using BK-classes to indicate how much a bridge or road can be loaded (Trafikverket, 2025c). It describes how heavy vehicles are allowed to drive on the roads or bridges in the public road network. There are four different BK-classes, BK1-BK4. The load classes BK1–BK3 have long been established, with BK1 allowing the highest loads. In 2015, an investigation into a heavier load capacity class (BK4) was started and on 1 July 2018 BK4 was introduced (Natanaelsson and Eriksson, 2020). In Table 2.1 the vehicle weights allowed for the different load-bearing capacity classes are represented. By allowing roads and bridges to withstand heavier vehicles, transport efficiency is improved, which is beneficial both economically and environmentally.

Table 2.1: Load-bearing capacity classes (BK) and permissible vehicle weights (Trafikverket, 2025c).

BK	Maximum gross weight [ton]
BK4	74
BK1	64
BK2	51.4
BK3	37.5

The load-bearing classes also have different A/B values that are presented in Table 2.2. The A-value corresponds to the axle load, and the B value represents the bogie load. The bridges are dimensioned using standard vehicles, with A-and B-values describing its load-bearing capacity, and on the basis of these, the BK-class of the bridge is determined. Both A-and B-values, according to Table 2.2, must at least be satisfied to achieve the BK-class. Therefore, a bridge can have the same BK-class but different A/B values. Higher A and B values allow heavier vehicles, improving accessibility. For the general public, the BK-class is the relevant measure, but in specific cases, it is necessary to know the A/B values in order to permit exempted transports. For new bridges, A/B values of 18/30 tons are used when dimensioning to provide a margin for future traffic demands (Transportstyrelsen, 2018).

Table 2.2: BK-classes and A/B values.

BK	A/B values [ton]
BK4	12/21
BK1	12/18
BK2	10/16
BK3	8/12

2.2 History of bridge classification

The work regarding the Swedish load-bearing system of bridges began in 1986 when a so called "bearing capacity package" was introduced. During the years, new rules for load capacity calculations and new standard vehicles were developed.

The Swedish Transport Administration has five different methods to determine the load-bearing capacity of a bridge.

- **Capacity calculation:** The load-bearing capacity is determined by evaluating the structural capacity of the existing structure in each relevant cross-section (Trafikverket, 2025b). For all structural members and longitudinal systems, a load-bearing calculation must be carried out and in all limit states. This can be applied to both newly designed bridges and existing structures.
- **Load effect comparison:** This is a simplified method that can only be applied to newly designed bridges (Trafikverket, 2025b). The load-bearing capacity is determined by comparing the ultimate limit state (ULS) load effects resulting from traffic loads on the bridge, as specified in the 2009 traffic load regulations, with the corresponding effects produced by the standard vehicle.
- **Standard classification:** Accurate calculations of different bridge constructions form the basis for the standard values. Therefore, the load-bearing capacity is determined based on statistically verified knowledge of the expected capacity for a given bridge type. This method is used for already existing bridges.
- **General value:** This is based on the traffic load allowed on the connected roads and is mainly used as a temporary measure until the bridge can be assessed using other methods (BATMAN, 2026). This method is used for already existing bridges.
- **Estimated value:** The load-bearing capacity is assessed based on whether the bridge has been in service at the specified load level for an extended period without showing any damage that would affect its capacity (BATMAN, 2026). This method is only applied to stone arch bridges, as well as slab bridges, slab frame bridges, and other arch bridges with a maximum span of 6.0 meters.

To determine the exact load-bearing capacity of a bridge, a capacity calculation is required, this needs significant time and resources, and therefore the other methods can be used sometimes, except load effect comparison. If bridges instead are classified using standard classification, it is assigned a standard A/B value, which may differ from its actual load-bearing capacity. This can be problematic due to the actual load-bearing capacity can be either higher and lower.

2.2.1 Standard classification process

Bridges with standard values are designed according to the traffic load regulations of 1947, 1950, 1955, or 1960. To establish the standard classification, individual load-bearing calculations were performed on bridges with different structures and geometries to form the basis of the A/B values. At this stage, a document is used in which the bridge type, and in some cases the geometry and material determine a given A/B value. In Tables 2.3-2.6 the values of the document for traffic in the own lane are presented. Additional requirements and conditions may result in different values and these are presented in the column "Alternative A/B values (ton)". In these cases, several more specific factors determine the capacity. Additional requirements are, for example, the type of reinforcement used in the construction or if the bridge is constructed based on regulations from specific time periods. For some cases, individual assessment is required, and these are assigned the current standard classification value of 14/18 tons.

Table 2.3: Standard A/B values for beam bridges.

Beam bridge	**Material**	**Geometry**	**A/B value(ton)**	**Alternative A/B value(ton)**
Single-span & continuous	Concrete	$h > b$*	14/24	-/21 & -/18
Single-span & continuous	Concrete	$h \leq b$	14/20	-
Single-span & continuous	Steel	-	14/19	12/- & -/18
Box beam	-	-	14/23	-/18

* h = beam height, b = beam width

Table 2.4: Standard A/B values for beam frame bridges.

Beam frame bridge	**Material**	**Geometry**	**A/B value(ton)**	**Alternative A/B value(ton)**
Non-prestressed	-	-	14/24	-/21

Table 2.5: Standard A/B values for slab bridges.

Slab bridge	**Material**	**Geometry**	**A/B value(ton)**	**Alternative A/B value(ton)**
Continuous & non-prestressed	-	$L \leq 8\,\mathrm{m}$	16/-	-/24 & -/23 & -/20 & -/18
Continuous & non-prestressed	-	$L > 8, \mathrm{m}$	18/-	-/24 & -/23 & -/20 & -/18
Continuous & prestressed	-	$L \leq 8\,\mathrm{m}$	16/23	-/20
Continuous & prestressed	-	$L > 8, \mathrm{m}$	18/23	-/20

Table 2.6: Standard A/B values for slab frame bridges.

Slab frame bridge	**Material**	**Geometry**	**A/B value(ton)**	**Alternative A/B value(ton)**
Single-span	-	$L \leq 8\,\mathrm{m}$	16/24	-
Single-span	-	$8\,\mathrm{m} < L \leq 16\,\mathrm{m}$	14/24	-
Continuous	-	$L \leq 8\,\mathrm{m}$	16/-	-/24 & -/23 & -/20 & -/18
Continuous		$L > 8, \mathrm{m}$	18/-	-/24 & -/23 & -/20 & -/18

The Swedish Transport Administration has identified slightly more than 3000 bridges classified according to this method. In Figure 2.1 the distribution of different bridge structures that still have a standard classification is shown.

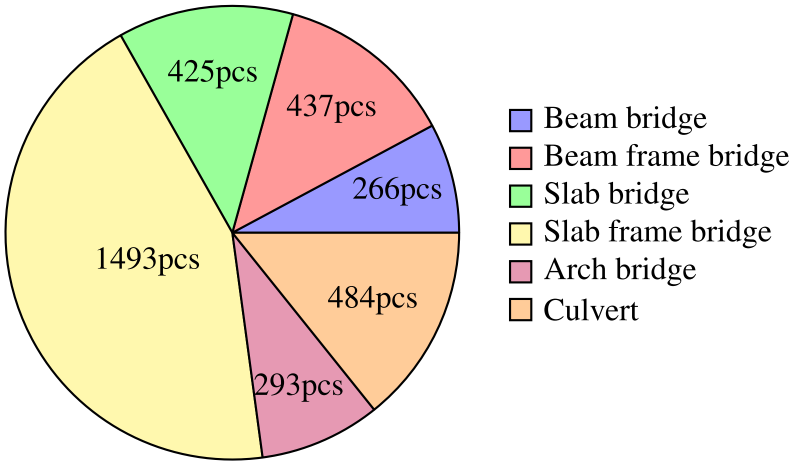


Figure 2.1: Distribution of bridge structures among the standard classified bridges.

2.2.2 Previous research

Knowledge from previous work has shown that it is difficult and complicated to use new regulations for capacity control when there has been a classification according to another regulation in the past (Gustavsson, 1998). The impact of the bending reinforcement on the shear capacity and punching shear failure of the concrete slab are for instance two verifications that are complicated to perform with changed regulations. Another experience gained during the previous bridge classification project was that most bridges load-bearing capacity can be increased when the load is described more precisely for each individual bridge. In VV publication 1998:78, the load in the transverse direction should be applied in the most unfavorable position and requirements regarding the loads are specified in the publication (Vägverket, 1998). Improved knowledge of the actual traffic load on individual bridges can result in modifications of the analytical model, and previous results indicate that more refined analyzes often yield more favorable outcomes for the structure. Another factor is that the loads used in the construction phase differ from the loads used in the classification calculations. Calculations regarding the tension capacity of concrete are also a known problem, this will for instance affect the shear capacity calculations in continuous concrete beams and decks.

2.3 Standard vehicles and traffic load models

Standard vehicles are simplified representations of road vehicles used in bridge design and assessment to model traffic load (Gustavsson, 1998). These standard vehicles are defined by specified axle- and bogie-loads and spacings and are intended to represent critical loading scenarios rather than actual individual vehicles. The purpose of standard vehicles is to ensure a uniform basis for calculating load effects on bridge structures, enabling comparable and reproducible assessments across different bridge types. The load regulations define how these standard vehicles are applied in structural analyzes (Trafikverket, 2025b). This includes guides regarding load positioning, load combinations, lane distribution and dynamic impacts.

The load models and standard vehicles have developed with time and due to the variety in construction year of the bridges in this project, different standard vehicles have formed the basis when constructed. Studies have shown that previous traffic load models tend to be conservative due to the uncertainties of load placements and the actual load effects on the structures are less than the models used in the past (Getachew, 2003).

The construction year of a bridge will impact the design and it can be difficult to implement new standards for old constructions built by other regulations (Gustavsson, 1998). The standard load models used in VV Publication 1998:78 are cases a)-l) while today's new regulations in TRVINFRA-00331 have three more load models, m, n and o (See Appendix A). These models represent cases with increased loads and with smaller distances between the position of the loads.

In 2011, Eurocode became mandatory to use when dimensioning bridges in Sweden and Boverkets Construction guidelines (BKR) were replaced. Due to changes in the characteristic strength values and methods for calculating the shear strength of concrete and steel, studies have shown that the shear capacity of reinforced concrete is slightly higher in the Eurocode compared to the earlier Boverket guidelines, resulting in a minor difference in the spacing of shear reinforcement (Hammar, 2011). Minimum shear reinforcement is a factor that changed more significant when comparing Eurocode to the BKR. Minimum shear reinforcement in concrete beams is a requirement in Eurocode and must be used in the design even if the strength of the beam will not need it.

TDOK 2013:0267 introduces updated requirements aligned with the Eurocode framework (Trafikverket, 2013). The regulation was separated in two different sections. Section 25 m defines standard vehicles with a maximum length of 25 meters, corresponding to conventional heavy vehicle combinations. Section 45 m addresses long and heavy vehicle combinations, such as those permitted under specific regulations. The standard vehicles defined in this section have significantly greater lengths and more complex axle configurations compared to previous regulations. TRVINFRA-00331 is an updated version of the earlier document TDOK 2013:0267, incorporating changes corresponding to the latest updates in the Eurocodes. All new structures, as well as reconstructions carried out on the state-owned road network, must comply with the requirements specified in TRVINFRA-00331.

2.4 Design principles

For structure analysis, the distribution of force effects is determined across its various components (Bakht and Mufti, 2015). Structural responses, such as deflection and bending moments, are referred to as load effects. When designing load-bearing structures, several requirements must be met. Resistance, stability, and durability are fundamental requirements that a structure must satisfy (Al-Emrani et al., 2013). Resistance refers to the ability of a structure to withstand loads. The resistance requirements of a bridge must be satisfied not only during its service life but also throughout the construction phase. With regard to stability, the performance of the bridge should ensure that, under normal use, deformation, vibration, and damage do not significantly affect its functionality. With regard to durability, the deterioration a bridge is exposed to due to its environment should occur in a controlled manner, ensuring that the structure maintains its functionality throughout its planned service life.

To express what a structure can withstand, a common approach is to compare resistance with action effect (Al-Emrani et al., 2013). The dimensions of different components are adjusted so that the resistance capacity is greater than or equal to the loads acting on the structure. For example, this is done by comparing the moment capacity M_{R} of a beam cross section with the applied bending moment M_{E}. To clearly assess whether dimensions can be adjusted, it is common to examine the utilization ratio, i.e., $\frac{M_{\mathrm{E}}}{M_{\mathrm{R}}}$. The same principle applies for the shear capacity, V_{R} must be greater than or equal to the applied shear force V_{E} of external loads. To fulfill this and receive optimal utilization ratios for the structure, the dimensions of the components are crucial.

Today, all bridge calculations are performed using computer programs, but manual analysis remains important. Manual analysis is still necessary for an intuitive understanding of how load effects are distributed in a bridge and to verify that the results of computer programs are reasonable (Bakht and Mufti, 2015). However, bridges had been built long before the advent of computer programs. The finite element method (FEM) as a numerical modeling approach began to take shape in the early 1940s (Liu et al., 2022). At that time, computer programs were not yet used, instead most calculations were performed manually while the technology for computer based methods was still being developed. It was not until the late 1960s and early 1970s that the finite element method (FEM) came into practical use for numerical calculations and structural analysis (Das et al., 2019).

The history of bridge design stretches far back, and the design criteria have developed and changed over time. Due to the lack of design criteria in previous regulations and design traditions, variations in bridge designs and their probability of failure are likely to differ (Bakht and Mufti, 2015).

2.4.1 Slenderness

The beam height can be assumed to depend on the span length, longer span requires larger dimensions of the beams (Al-Emrani et al., 2013). The resistance of the elastic bending moment (W) for a rectangular cross section can be expressed as $W_b = \frac{bh^2}{6}$. Meaning the elastic bending moment resistance is more dependent on the height *(h)* of the beam compared to the width *(b)*. The span length is relevant due to maximum moment effect and the height is an important factor in the moment resistance. Comparing the two factors give a measure slenderness which can be expressed as λ = *(L/h)* which provides a measure of the structural proportions and influences bending behavior and stability.

2.4.2 Steel instability

The resistance of a structural steel member is not determined solely by the strength of its cross-section, but also by whether the member remains stable under loading (Al-Emrani et al., 2013). Although a steel beam may theoretically be able to reach its full yield or plastic moment capacity, this is only possible if instability does not develop beforehand. In practice, compressed parts of the section, such as flanges or webs, may buckle before the full moment resistance is mobilized, particularly in slender sections. In addition, entire members may be affected by global instability modes, such as lateral-torsional buckling, which can further reduce the attainable capacity. This means that the theoretical strength of a section cannot always be fully utilized unless stability is ensured. For this reason, dimensioning must account for both strength and instability effects in order to prevent premature failure and enable efficient use of the structural element's capacity.

Cross section slenderness is a relevant factor for the load bearing capacity (Al-Emrani et al., 2013). An I-beam with a more slender web is more exposed to buckling compared to a thicker web sections of the same height. Also, an I-beam is at greater risk for instability problems where the ends are free to rotate compared to box beams where the flange is supported by the web.

2.4.3 Structural behavior

Different types of bridge structures transfer and resist loads through distinct structural mechanisms, depending on their geometry, materials, and overall system behavior (Vägverket, 1996).

In slab bridges, the structural behavior is based on plate action, where loads are carried and distributed through the deck in one or two dimensions before being transferred to the supports (Vägverket, 1996). Unlike beam action, where loads are resisted primarily in one direction through longitudinal bending, plate action allows concentrated loads, such as wheel loads, to spread over a larger area of the bridge deck, reducing local stress concentrations and improving load distribution. This enables the entire bridge width to contribute to the load-carrying response, which can increase structural efficiency and allow relatively shallow construction depths. The resistance is developed through a combination of bending moments, shear forces, and transverse load distribution within the slab, and the structural response is influenced by factors such as support conditions, span arrangement, and whether the slab behaves as a one-way or two-way spanning system.

Beam bridges rely on longitudinal beams to resist bending moments, with loads transferred from the deck into the beams and further to the supports. Composite bridges utilize interaction between different materials, commonly steel and concrete, where each material resists the forces it is best suited for, such as steel in tension and concrete in compression, resulting in efficient load distribution and high structural performance. Arch bridges carry loads mainly through compression, where the curved form redirects vertical loads into compressive forces and transfers them toward the supports.

The structural behavior of a culvert bridge differs from conventional bridge types, as its load-carrying capacity is based on interaction between the culvert and the surrounding soil (Sandford, n.d.). Loads from traffic are transferred through the soil cover, where part of the load is distributed and reduced before reaching the culvert. The culvert resists loads through soil-structure interaction, ring compression, and support from the surrounding soil. A key aspect of its behavior is soil-structure interaction, where the surrounding soil provides confinement and support, contributing significantly to the overall resistance. Proper dimensioning of both the culvert and the surrounding backfill is therefore essential.

Frame action is where the deck and supporting members act together as an integrated system to resist loads through a combination of bending moments, shear forces, and axial forces. Unlike simply supported systems, where moments are primarily carried within individual members, frame action allows forces and moments to be redistributed through rigid connections between the deck and supports. This interaction reduces peak bending moments in the span and transfers part of the loading into axial compression and bending in the supporting members. The load-carrying response depends on the stiffness of the connected members, boundary conditions, and the geometry of the frame, all of which influence how internal forces are distributed.

3 Results

In the following chapter, the results are presented first from an overview perspective of the load-bearing capacity. Thereafter, the focus shifts to different categories for four of the bridges, followed by a deeper analysis of their technical results. The results are based on the initial set of bridges shown in Figure 1.1 and the A- and B-values are handled separately. The arch and culvert bridges are presented in Section 3.1, but have not been further analyzed.

The results are presented in pie charts, bar charts and scatter plots. The results presented in bar charts are divided into four groups based on load-bearing calculations compared to the previous standard values. For each comparison, four figures are presented, one for each group. The four figures together summarizes to 100% in each category.

The groups:

- Decreased load-bearing capacity after calculations compared to the standard value.
- Same load-bearing capacity after calculations compared to the standard value.
- Increased load-bearing capacity to a maximum of 30% after calculations compared to the standard value.
- Increased load-bearing capacity of more than 30% after calculations compared to the standard value.

For the scatter plots, the y-axis show the load-bearing capacity [ton] for A- and B-values and the x-axis represents the slenderness, span length and construction year in different figures. The standard values are represented as small squares, while the decreased values are presented as larger black circles around the data points. Different categories for the bridges are shown by colors of the scattered data points.

3.1 Overview of load-bearing capacity

In this section, the results of the calculated values in relation to the standard values are presented, as well as the normal distribution of the bridges capacity. All bridges in Figure 1.1 are included in the results, which are the 200 bridges that initially had a standard value and were later individually calculated. In Figure 3.1 the number of bridges included in each group for the bar chart is presented. This shows that a large proportion of the bridges have obtained more than 30% higher calculated A- and B-values compared to the standard values.

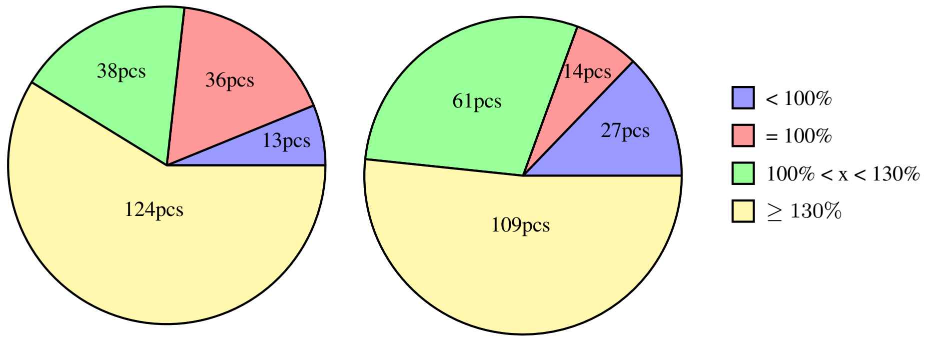


Figure 3.1: Number of bridges included in each load-bearing capacity groups, to left: A-values, and to right: B-values.

In Figures 3.2 and 3.3 the calculated load-bearing capacity is presented in relation to the given standard value and for each bridge structure. For bridges with decreased load bearing capacity, the B-value for beam frame and slab frame bridges is notably higher. Among bridges with the same load-bearing capacity, arch bridges deviate. All arch bridges have received the same A- and B-value before and after calculation. For beam and slab bridges, most B-values have an increased capacity of maximum 30%, and many bridges fall into this group. A substantial part of the A-values for the slab bridges have increased by more than 30% compared to the standard value. For culvert bridges the results show that a majority of the calculated values are much higher compared to the earlier standard values.

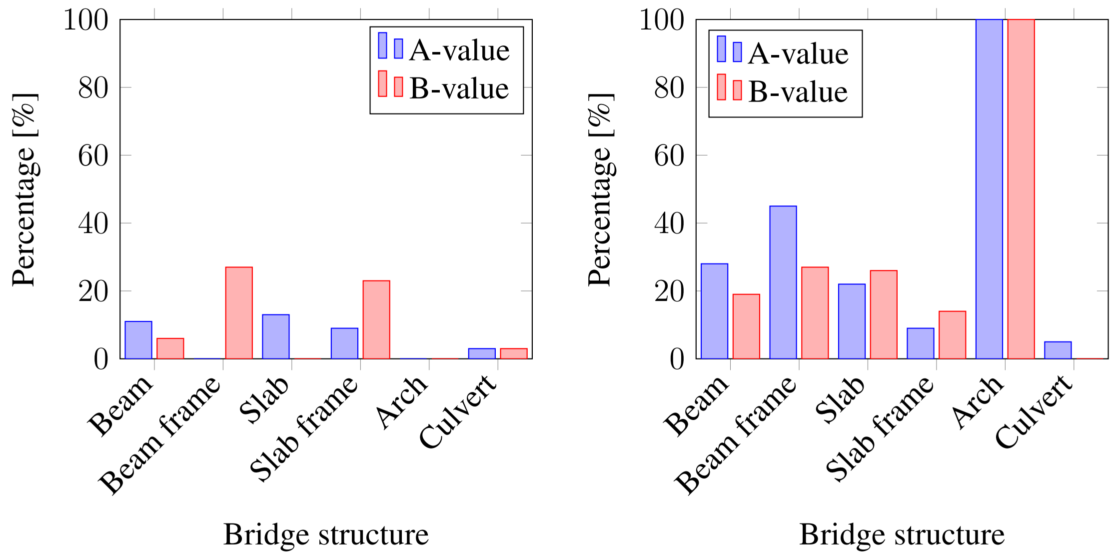
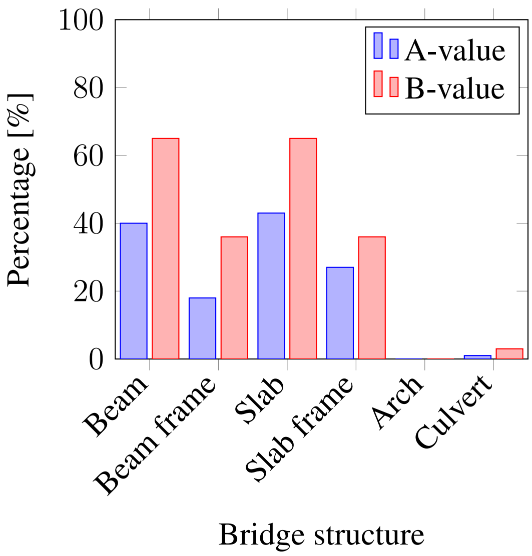


Figure 3.2: Load-bearing capacity calculations compared to the standard value, to left: decreased, and to right: same.



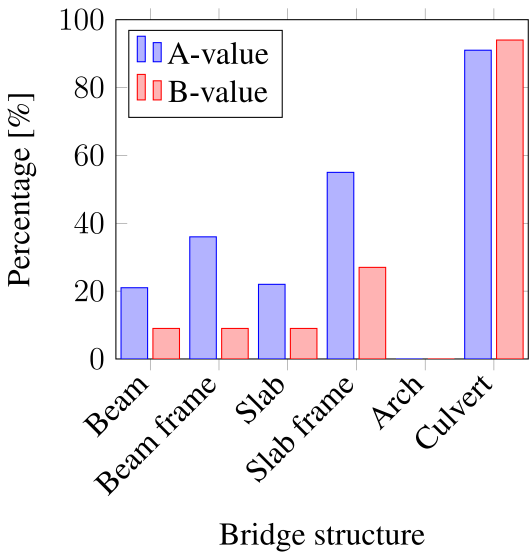


Figure 3.3: Load-bearing capacity calculations compared to the standard value, to left: increased to a maximum of 30%, and to right: increased more than 30%.

When assessing a bridge's load-bearing capacity, a detailed analysis of the structure is performed and the capacity is calculated in terms of A- and B-values. After the process, the Transport Administration investigates the results and determines the final capacity based on the analysis. In some cases, the calculations are supplemented, or a decision is made to deviate from the calculated values. In Figure 3.2 above, bridges that received the same load-bearing capacity after calculations are presented. Some of these bridges have received higher or lower calculated values, but it has been determined to retain the standard value for various reasons. In some cases, when the calculated capacity was lower than the standard value but no visible damage was observed, the standard value was retained. However, it must be reevaluated within a specified period of time. The percentage of each bridge structure that has retained their standard value instead of another load capacity retained from the calculations is presented below in Table 3.1.

Table 3.1: The percentage and number of bridge structures that have retained their previous values although the calculated values have differed in relation to the once assigned the same A-and B-values.

Bridge structure	**A-value %**	**B-value %**
Beam bridge	38 (5/13)	56 (5/9)
Beam frame bridge	20 (1/5)	33 (1/3)
Slab bridge	60 (3/5)	83 (5/6)
Slab frame bridge	100 (2/2)	67 (2/3)
Arch bridge	100 (6/6)*	100 (6/6)*
Culvert bridge	-*	0

*not evaluated

Figure 3.4 shows the distribution of the percentage difference between the standard values and the new calculated A- and B-values for the different bridge structures. The curves illustrate the central tendency and variability of the data, where the mean represents the average percentage difference, and the standard deviation reflects the spread of the difference. A narrow curve suggests low variation, whereas a wider curve indicates greater variability. The shape of the curves provides insight into how the load-bearing capacity difference varies within each group. The A-values are presented with continuous lines and the B-values are presented in dashed lines. As shown previously, the arch bridges have the same capacity in standard values as after the calculations, there is no difference and no curve appears in the figure. The culvert bridges have the largest difference in the standard values and calculated A- and B-values of all bridge structures. That is shown by the wide curvatures and the low peak. Culvert bridges also have the largest mean percent difference for both A- and B-values. In general, the B-values for all structures, seem to have a higher concentration of values closer to one. Meaning there is less variation in the differences in standard and calculated capacity for the B-values compared to the A-values.

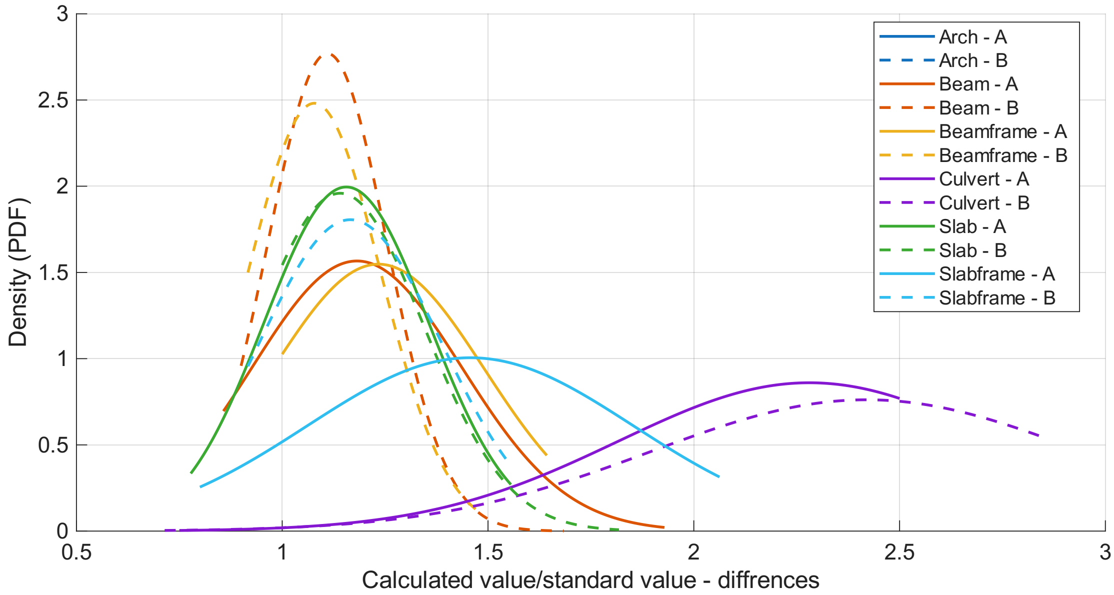


Figure 3.4: Normal distribution for A- and B-values, probability is the area under the curvature.

The normal distributions of A- and B-values are presented in Figures 3.5 and 3.6. The calculated distribution of the load bearing capacity is visualized by continuous lines, while the lines representing the normal distribution of the old standard values are dashed. The standard values have higher peaks in their distribution curvature, showing less variation and a higher concentration of data in those areas compared to the calculated values, which have a much flatter curvature in the two figures. The calculated A- and B-values for slab frame and slab bridges have a greater variation compared to the beam frame and beam bridges.

Figures 3.4, 3.5 and 3.6 are Probability Density Functions (PDF). A PDF describes the relative possibility of a continuous random variable taking on different values (Abhishek, 2024). The function itself does not give the probability at a specific point. Instead, probabilities are obtained by calculating the area under the curve over a given interval. The total area under the PDF is equal to 1, representing the certainty that the variable takes a value within the defined range. For example, according to Figure 3.5, the probability that a beam bridge has a standard value below 14 tons is approximately equal to $\frac{(14-11.4)\cdot 0.39}{2} = 50\%$. Which is correct since the curve is symmetric.

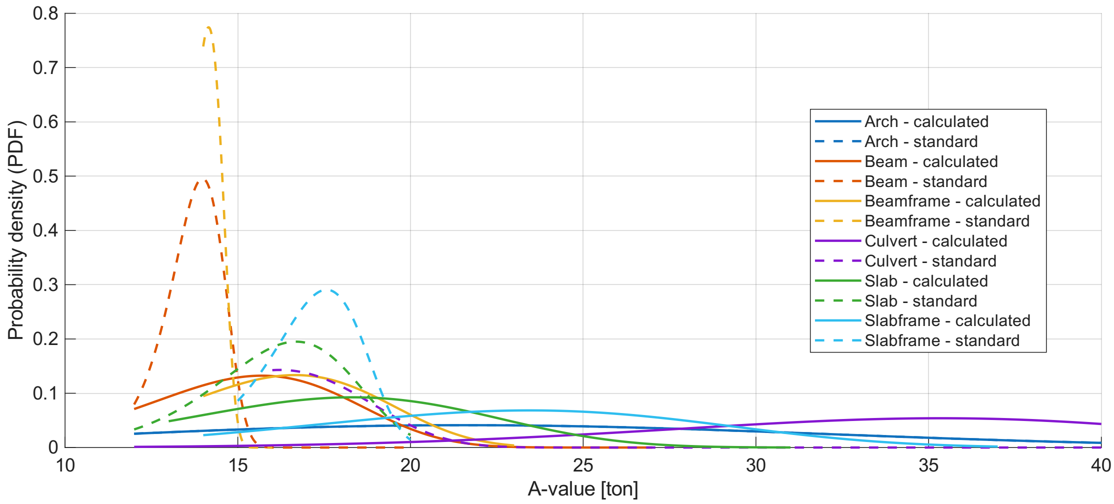


Figure 3.5: Normal distribution of calculated and standard A-values.

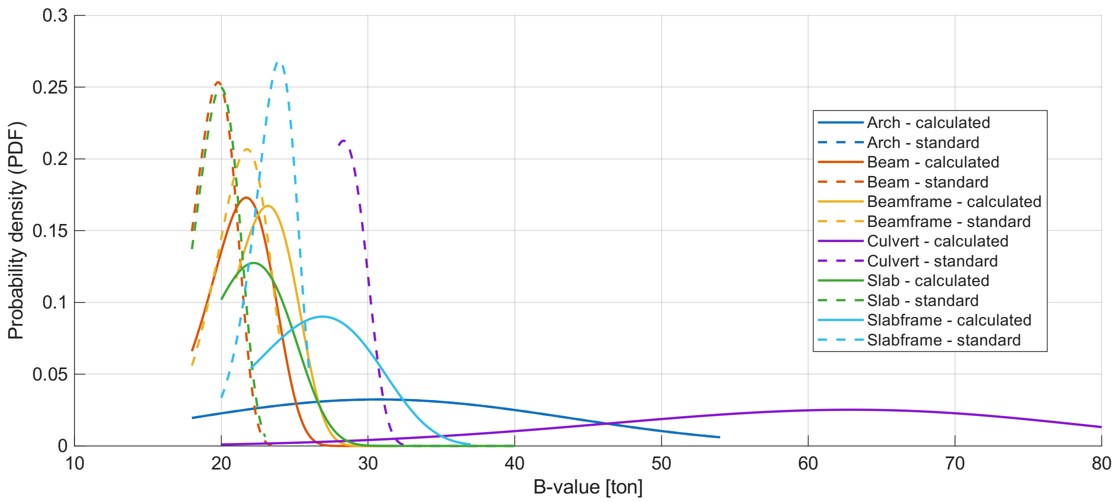


Figure 3.6: Normal distribution of calculated and standard B-values.

The culvert bridges have, in most cases, received significantly higher capacities compared to the initial standard value and the main governing factor of the capacity is related to the spread of the traffic load meaning the capacity of the surrounding soil and the thickness of the covering layer above the structure are significant factors. The arch bridges have received the exact same capacity as the standard values and the supporting documentation for the bridges are limited. As a result of this, the culvert and arch bridges have not been further analyzed and will be extracted from the following data set to ensure a more accurate comparison for the remaining bridge structures.

3.1.1 Regulations used in the calculations

In this section, the regulation used for calculation is compared with changes in A- and B-values. Due to the fact that two bridge structures are not included in this analysis (arch bridges and culvert bridges), the number of bridges included in the different groups for the bar chart changes and this is shown in Figure 3.7.

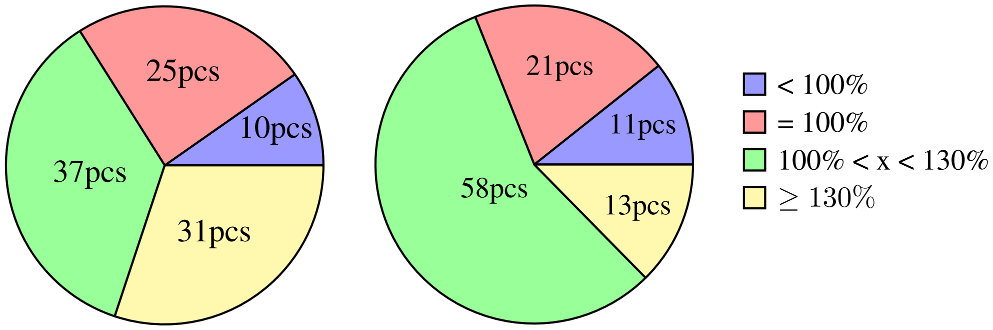


Figure 3.7: The number of bridges that has been analyzed in each load-bearing capacity group, to left: A-values, and to right: B-values.

An overview of the number of bridges in each regulation is presented in Figure 3.8. This shows that most of the calculation is based on TDOK 2013:0267. In Figures 3.9 and 3.10 the calculated load-bearing capacity is presented in relation to the standard value given for each regulation. For bridges that have received a lower calculated value, the A-value for bridges that has been calculated with TDOK 2013:0067 is notable. For B-values all regulations are more evenly distributed. Among bridges with same load-bearing capacity VV Publication 1998:78 is most common. Many bridges are in the group with an increased capacity to a maximum of 30% and here no regulation used stands out. Calculations performed according to TRVINFRA-0033 do not show any bridge with an increase in capacity of more than 30% for B-value. However, there are several bridges with an increased A-value calculated according to the considered regulation.

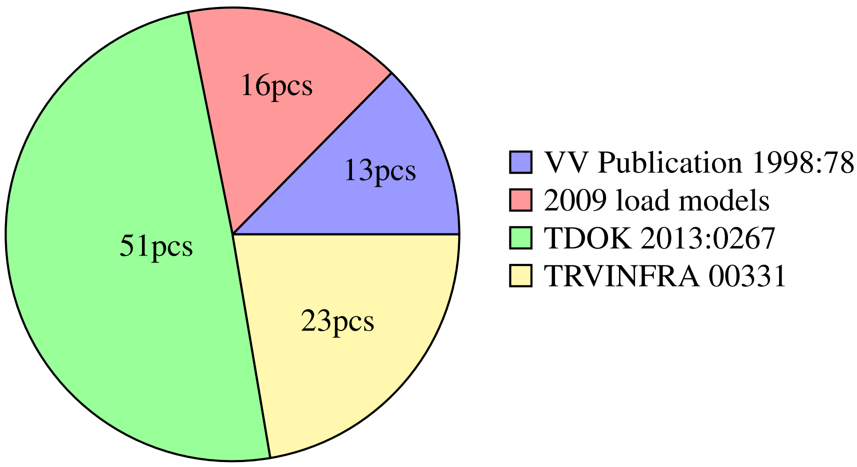


Figure 3.8: Overview of the regulations used in the bridge calculations.

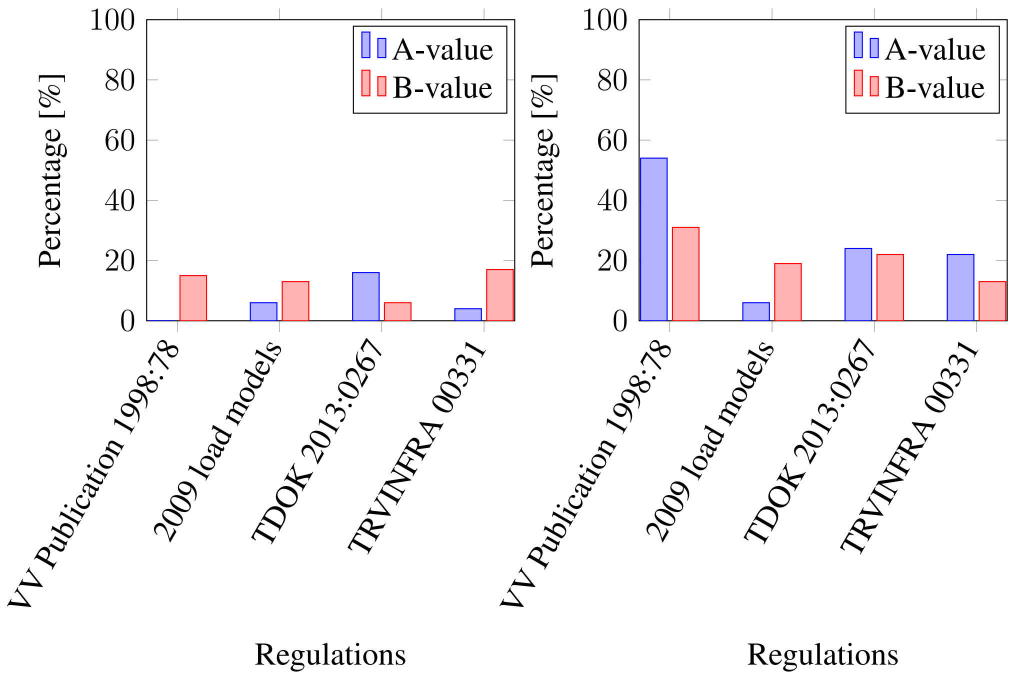


Figure 3.9: Load-bearing capacity in relation to regulation framework, to left: decreased, and to right: same.

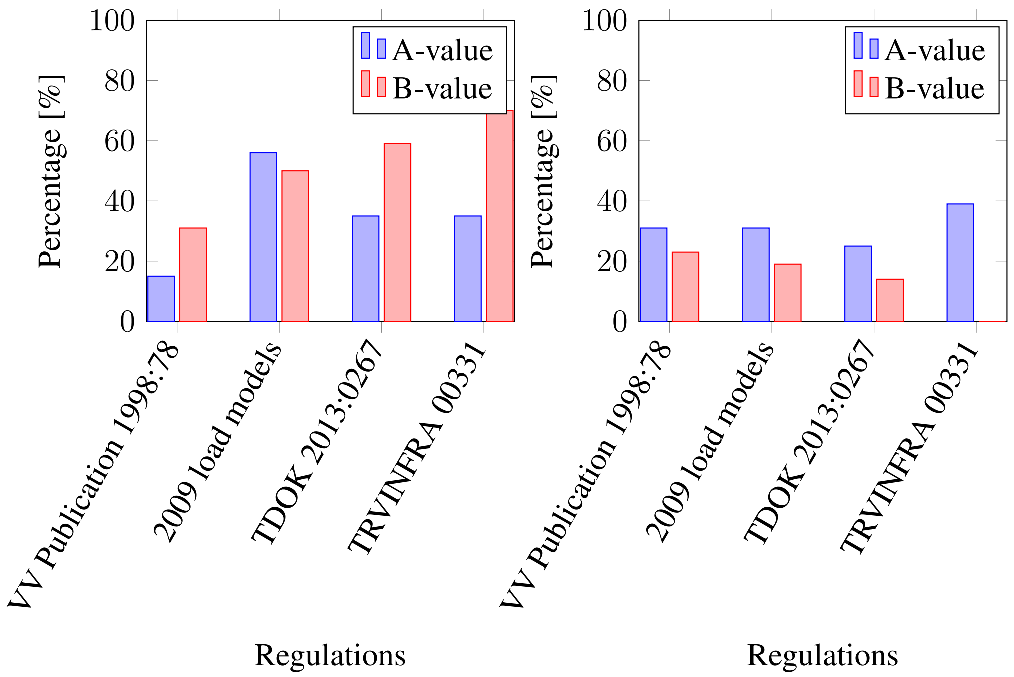


Figure 3.10: Load-bearing capacity in relation to regulations framework, to left: increased to a maximum of 30%, and to right: increased more than 30%.

3.1.2 Calculations compared to construction year

In this section, the year of construction is compared with changes in A- and B-values. The number of bridges included in each load-bearing capacity group is presented in

Figure 3.7. An overview of the number of bridges that were constructed in which period of time is presented in Figure 3.11. The data indicate that many bridges were constructed during 1960-1979. In Figures 3.12 and 3.13 the calculated load-bearing capacity is presented in relation to the standard value given for each period of time. For bridges with decreased load-bearing capacity, no decade is notable. Among bridges with same load-bearing capacity the A-values for 1900-1949 and 1950-1959 is the most pronounced. Many bridges are in the group of increased capacity to maximum 30% and here B-values for the decades stand out. For bridges that have an increase capacity of more than 30%, the A-values is dominant.

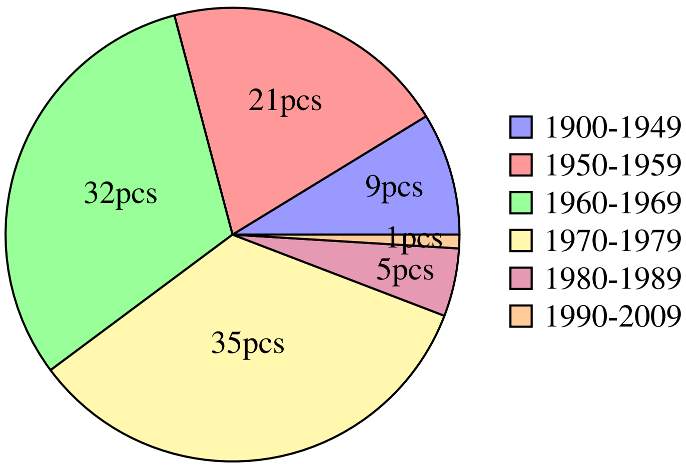


Figure 3.11: Overview of construction year for all the bridges.

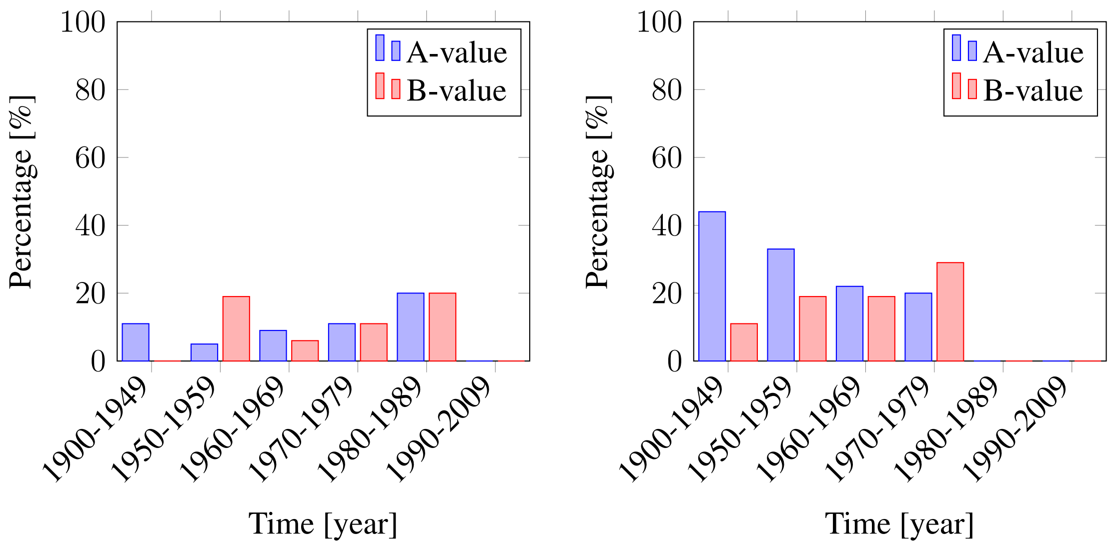


Figure 3.12: Load-bearing capacity in relation to construction year, to left: decreased, and to right: same.

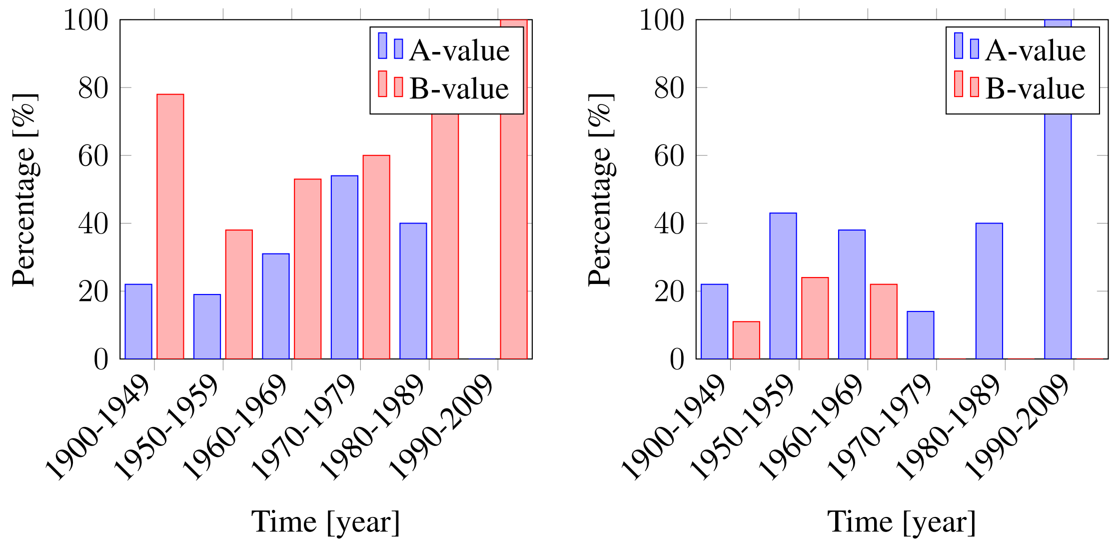


Figure 3.13: Load-bearing capacity in relation to construction year, to left: increased to a maximum of 30%, and to right: increased more than 30%.

3.2 Deeper analysis

Figures presented in the following chapter are A- and B-values in relation to span length, slab and beam slenderness, and also construction year and regulation used. The slab slenderness of the structures has been considered both longitudinal and transverse, while the beam slenderness is considered only in the longitudinal direction. For beam and beam frame bridges, the transverse slenderness in the slab accounts for the number of beams in the structure by dividing the total width of the bridge by the number of beams.

For frame actions, the thicknesses in the slab and beams are noted both in the mid span but also at the corner of the frame since the corners are subjected to high moment actions. For beam and beam frame bridges the cantilever thickness and length were documented together with the beam height.

3.2.1 Beam bridge

The A- and B-values for different construction materials in relation to the maximum span length of the bridges are shown in Figures 3.14 and 3.15. Among the beam bridges analyzed, only three cases exhibit standard A-values that differ from 14 tons. In total, five bridges show a reduced A-value after calculations. These include three steel bridges without composite action with the concrete slab and two prestressed concrete bridges.

The standard values for the beam bridges B-values are varying between 18-24 tons. A larger variation compared to the A-values for the beam bridges. The beam bridges have received B-values between 18 and 32 tons after calculations with a majority between 21 and 24 tons. Three bridges have received decreased B-values, two of them are constructions in reinforced concrete and one is a construction in steel without united action.

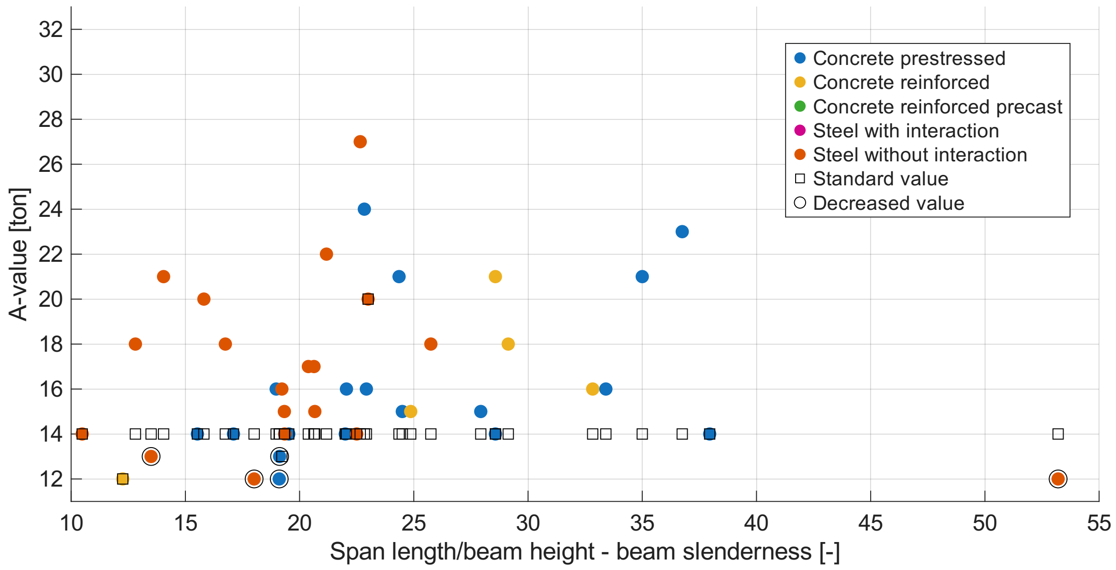


Figure 3.14: A-values and construction material for beam bridges.

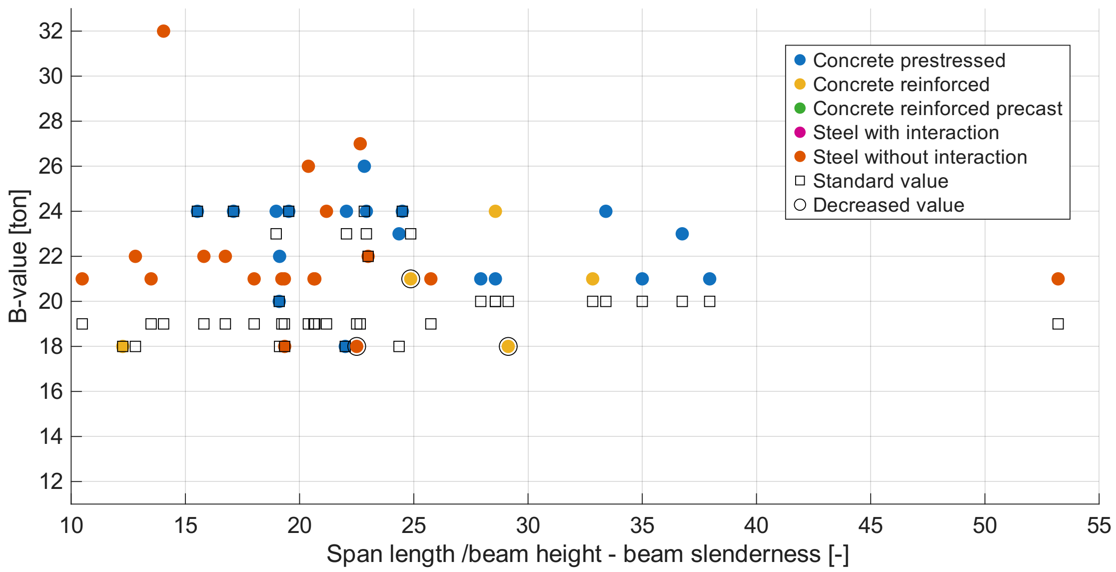


Figure 3.15: B-values and construction material for beam bridges.

Figure 3.16 and 3.17 represent the A- and B-values based on the construction year of the bridge superstructure and the colors show the regulation used for calculations when assessing the load-bearing capacity. All decreased A-values are calculated according to TDOK 2013:0267 where four out of five are based on the earlier version (TDOK 2013:0267 ver. 1-5). Three of the decreased bridges were constructed between 1968-1972. For the B-values, there are three decreased cases, calculated with three different regulations (two different versions of TDOK 2013:0267) and they are constructed between 1955-1970.

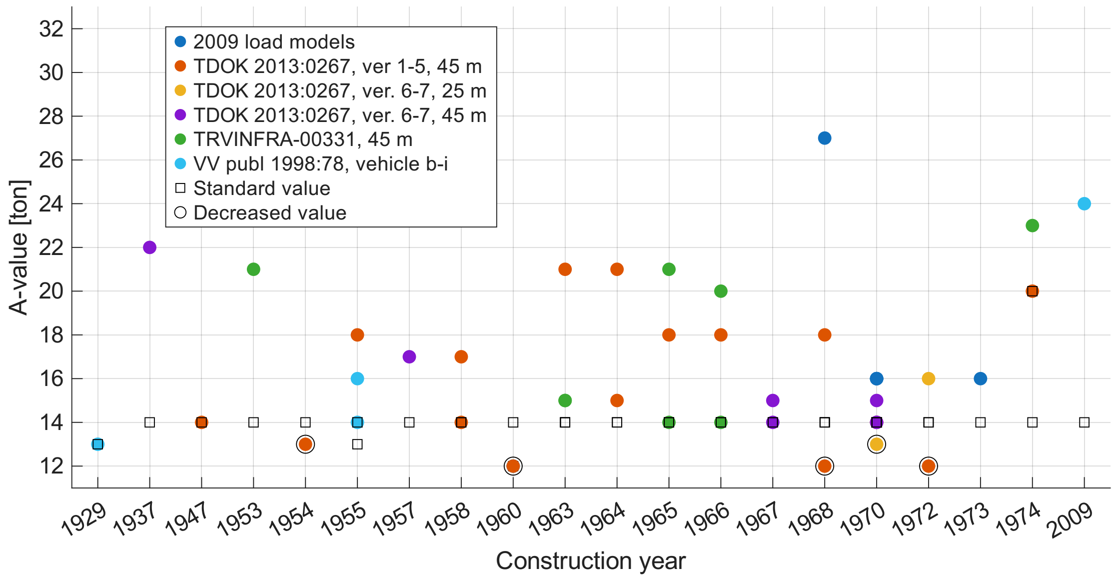


Figure 3.16: A-values in relation to construction year and regulation for beam bridges.

Figure 3.17: B-values in relation to construction year and regulation for beam bridges.

The governed construction part and the span length are visualized in Figures 3.18 and 3.19. The majority of A-values are governed by the slab and B-values are mostly governed by the beam.

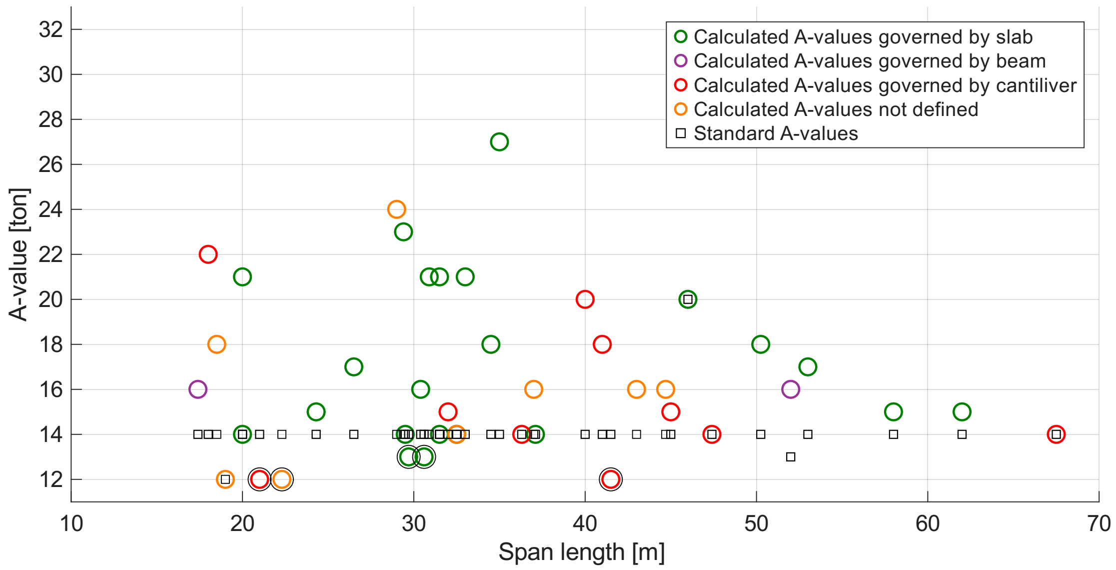


Figure 3.18: A-values in relation to the span length and governing part of the beam bridge.

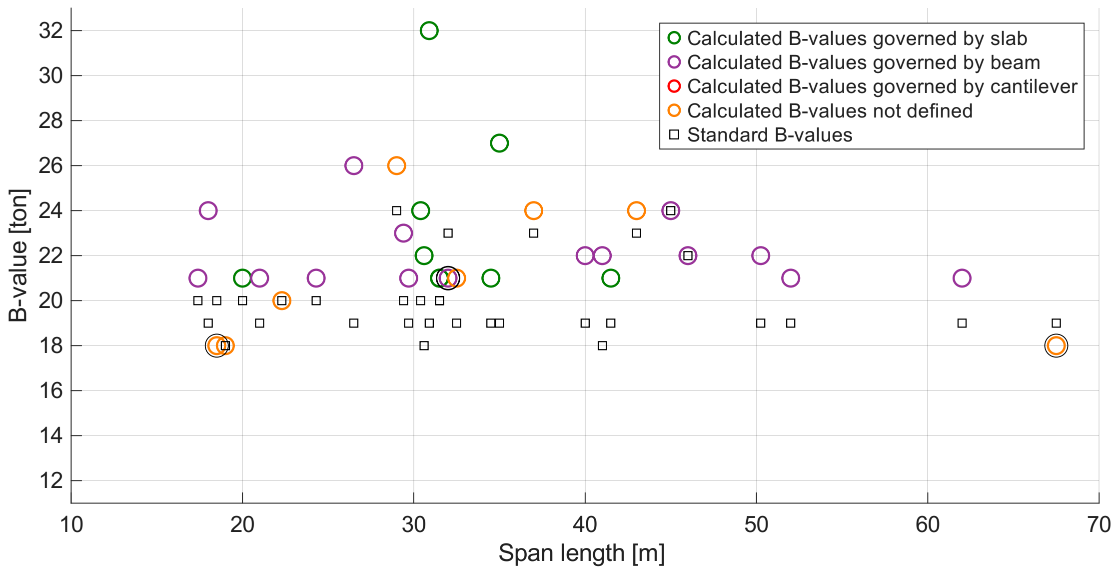


Figure 3.19: B-values in relation to the span length and governing part of the beam bridges.

For beam bridges governed longitudinal, the governing capacity for A- and B-values is presented in relation to the slenderness of the beam in Figures 3.20 and 3.21 and in relation to the slab slenderness in Figures 3.22 and 3.23.

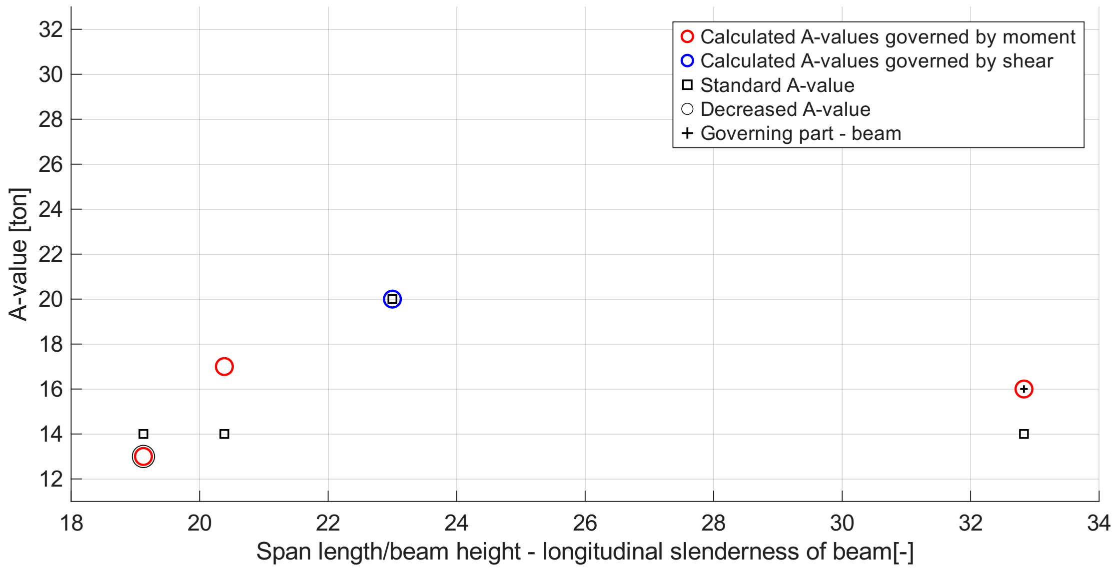


Figure 3.20: A-values governed by longitudinal analysis, governing capacity and construction part in relation to the beam slenderness for beam bridges.

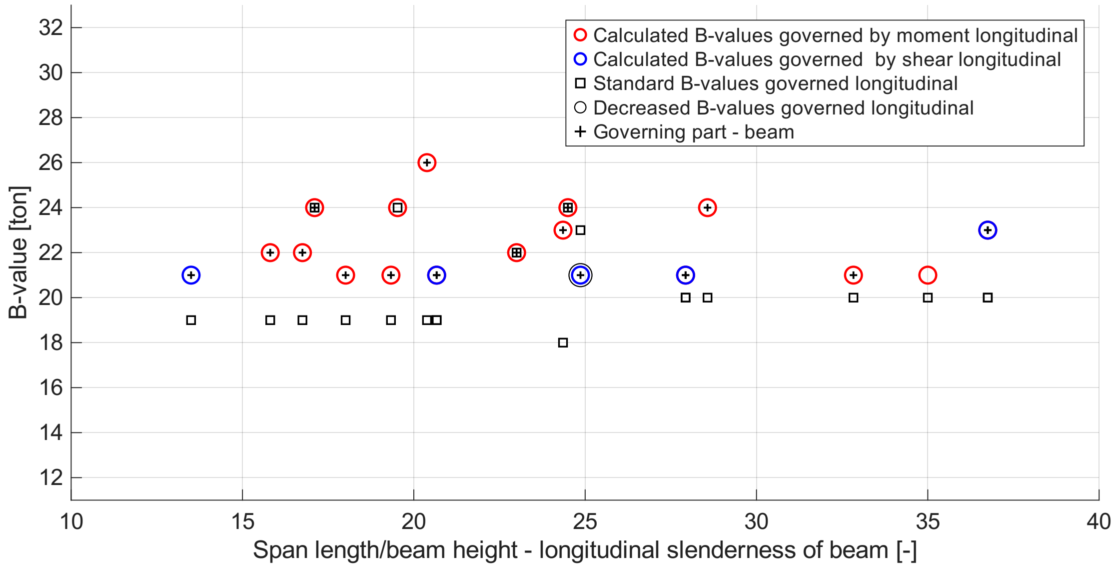


Figure 3.21: B-values governed by longitudinal analysis, governing capacity and construction part in relation to the beam slenderness for beam bridges.

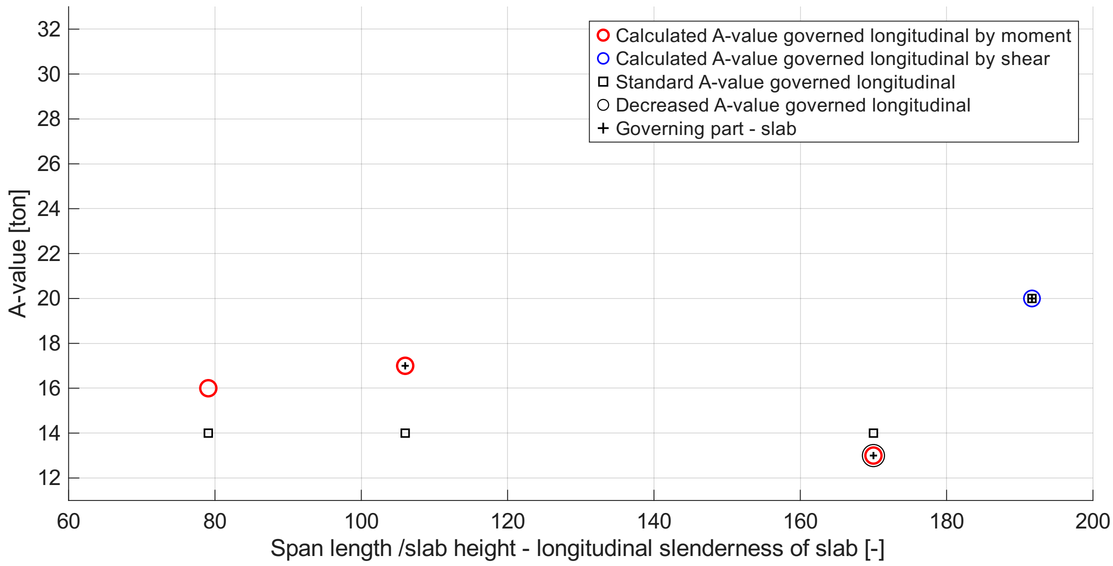


Figure 3.22: A-values governed by longitudinal analysis, governing capacity and construction part in relation to the slab slenderness for beam bridges.

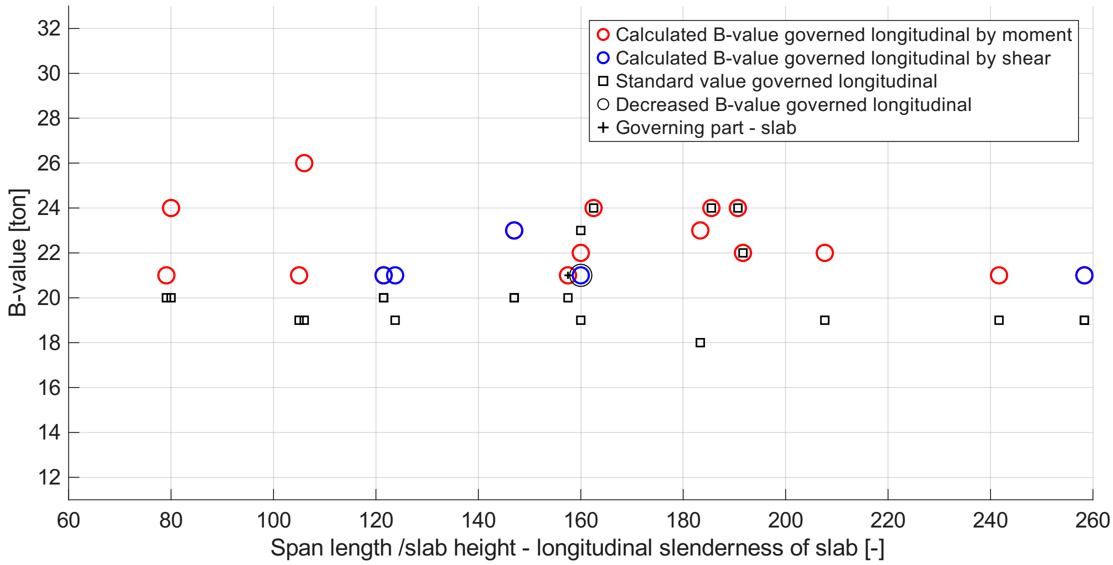


Figure 3.23: B-values governed by longitudinal analysis, governing capacity and construction part in relation to the slab slenderness for beam bridges.

The transverse slenderness of the slab is visualized in Figure 3.24 and 3.25 together with load-bearing capacity, the governing part and the capacity. Two bridges with decreased A-values are governed in the cantilever, one by moment and one by shear. The third bridge with a decreased value is governed by shear in the slab. Four out of five B-values governed in the transverse direction by the slab have moment as the governing capacity.

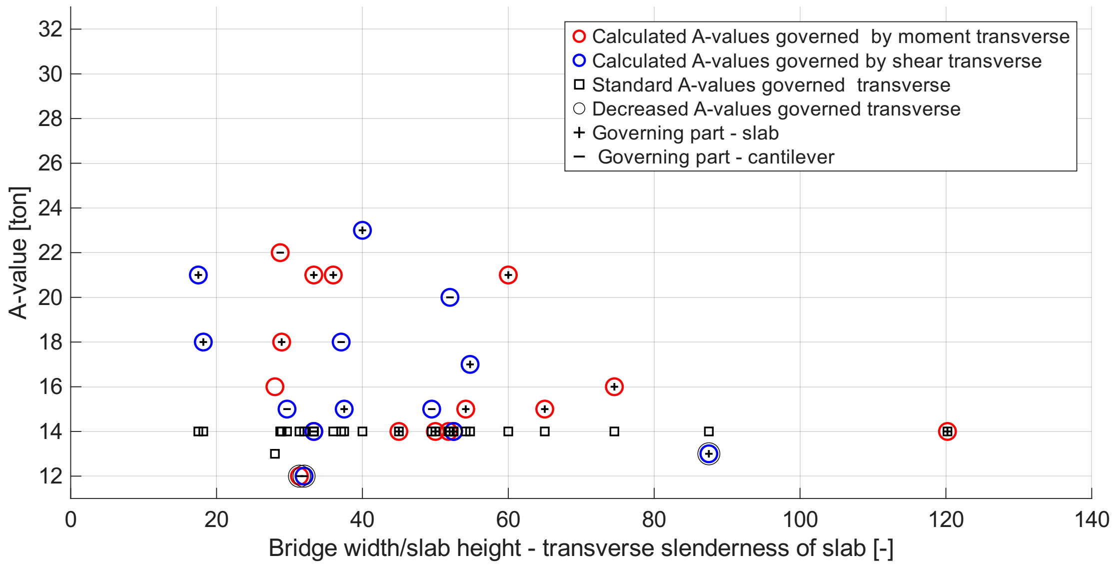


Figure 3.24: A-values governed by transverse analysis, governing capacity and construction part in relation to the slab slenderness for beam bridges.

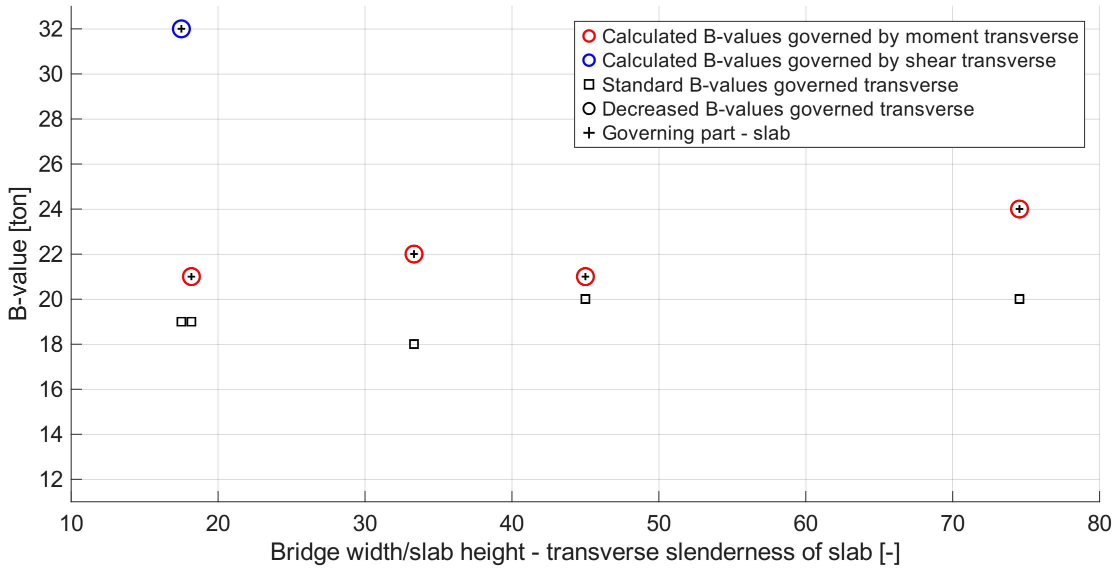


Figure 3.25: B-values governed by transverse analysis, governing capacity and construction part in relation to the slab slenderness for beam bridges.

3.2.2 Beam frame bridge

The governing parts of the A-and B values are presented in Figure 3.26 and 3.27. The standard A-values for load bearing capacity are set to 14 tons with one exception at 16 tons. The B-values are within a range of 18-24 tons. The Figures show that the main governing construction part is the slab, which is governing all the decreased cases for the beam frame bridges. Figure 3.28 shows that the three decreased bridges have B-values governed transverse by the moment in the slab. The load-bearing capacity has decreased by 1-2 tons from 24 to 22 and 23 tons. The transverse span between the beams of the bridge is the governing part for a majority the beam frame bridges with decreased B-values.

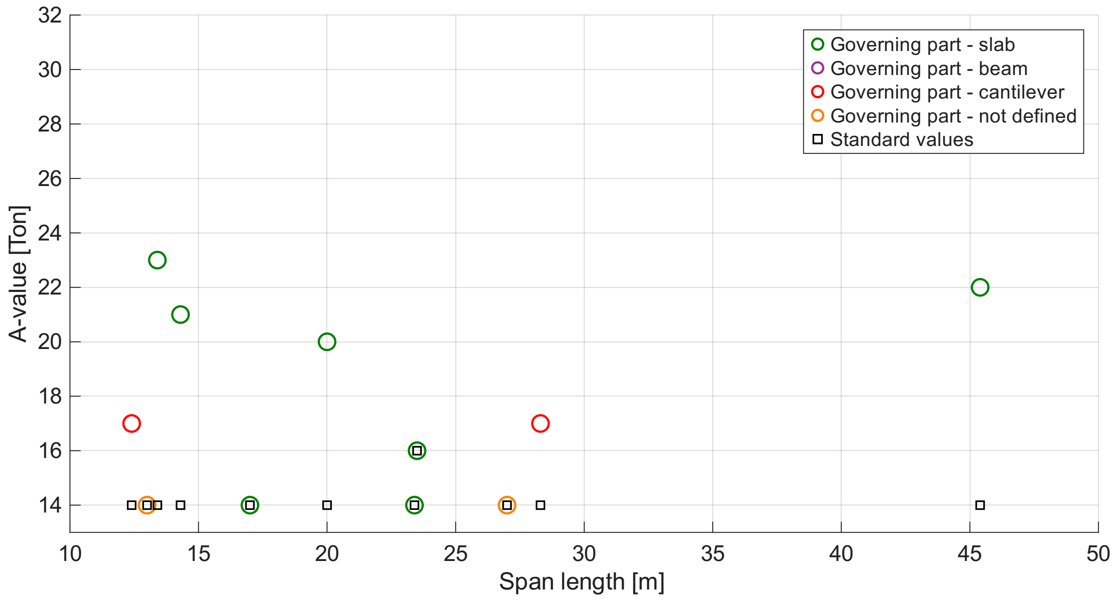


Figure 3.26: A-values in relation to the span length and governing part of the beam frame bridge.

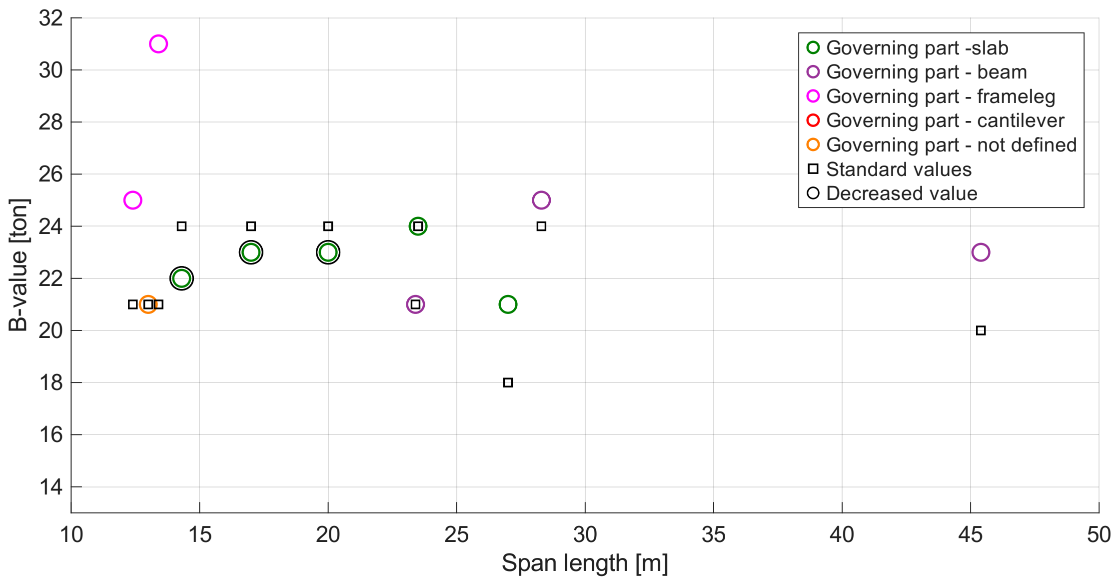


Figure 3.27: B-values in relation to the span length and governing part of the beam frame bridge.

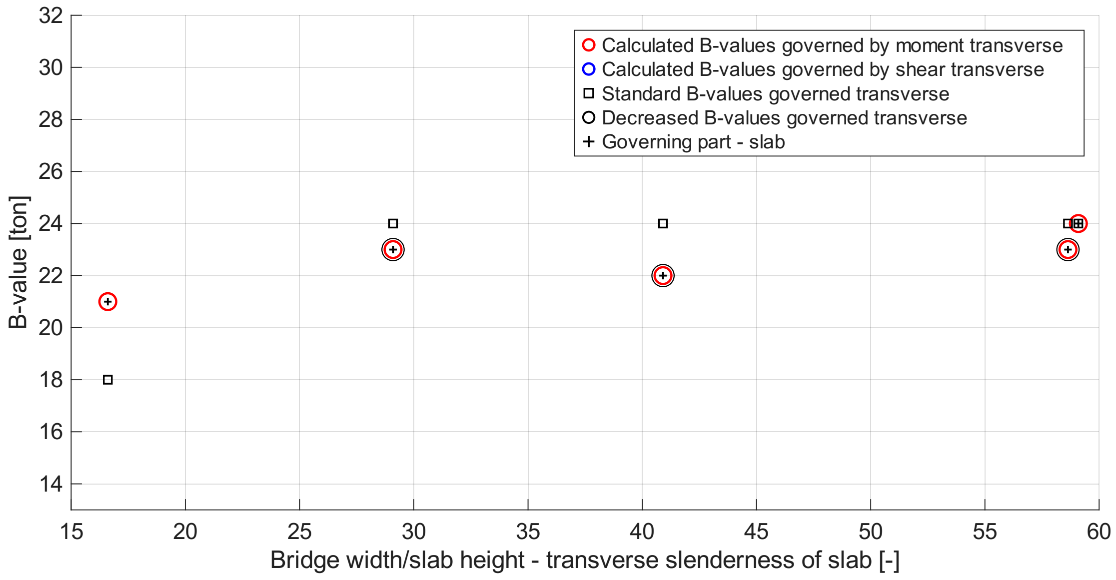


Figure 3.28: B-values governed by transverse analysis, governing capacity and construction part in relation to the slab slenderness for beam frame bridges.

Figures 3.29 and 3.30 visualize the regulations used when recalculating and the construction year for the beam frame bridges. None of the A-values for the beam frame bridges has been decreased. Two out of three bridges with decreased B-values were constructed in 1959.

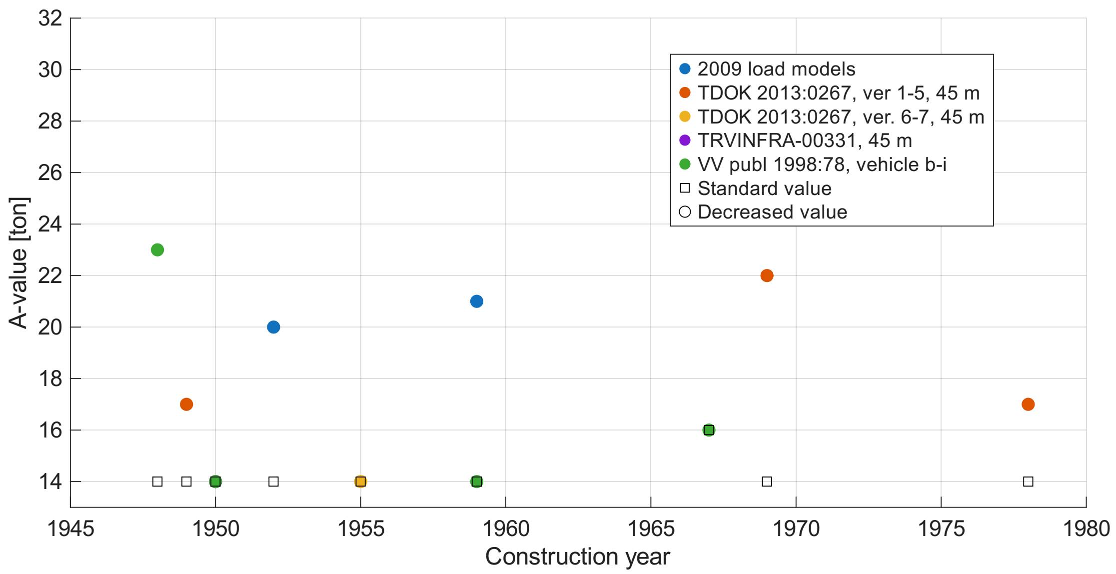


Figure 3.29: A-values in relation to construction year and regulation for beam frame bridges.

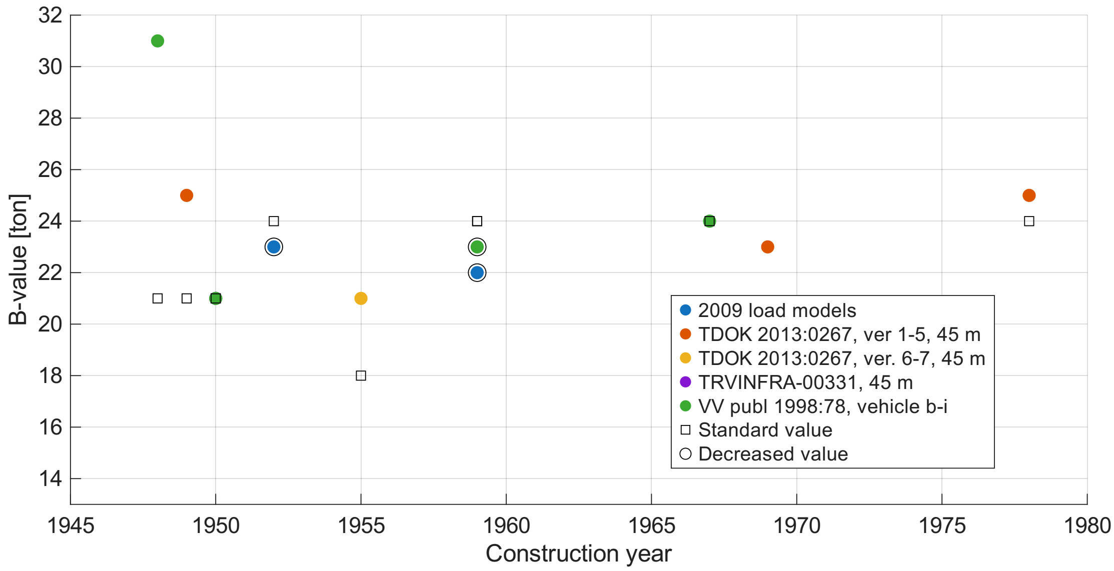


Figure 3.30: B-values in relation to construction year and regulation for beam frame bridges.

3.2.3 Slab bridge

The slab bridges are all made out of reinforced concrete and one of the bridges is pre-cast, which has received the highest values in load-bearing capacity for both A and B. This is shown in Figures 3.31 and 3.32, the A- and B-values are presented in relation to the type of construction. Two of the decreased A-values are continuous slab bridges. Continuous hollow concrete slabs indicate a more slender construction and about the same capacity as the simply supported slab bridges. The simply supported bridges indicate lower standard A-values compared to the other structures.

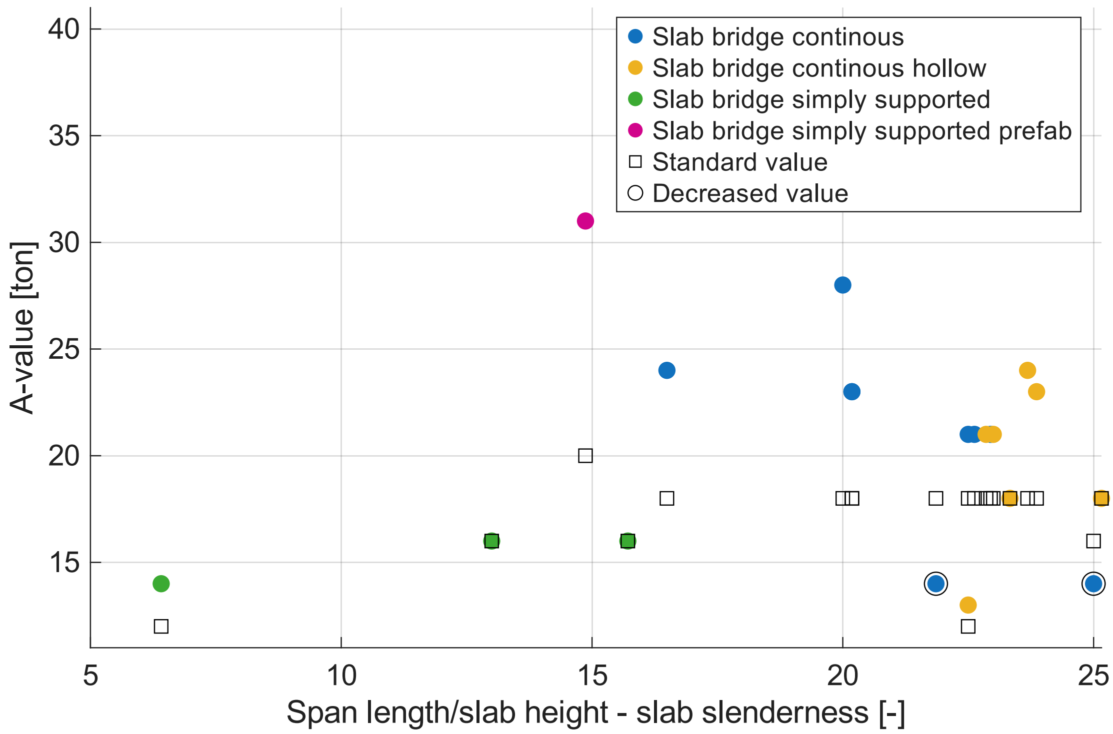


Figure 3.31: A-values in relation to the longitudinal slab slenderness and type of construction for slab bridges.

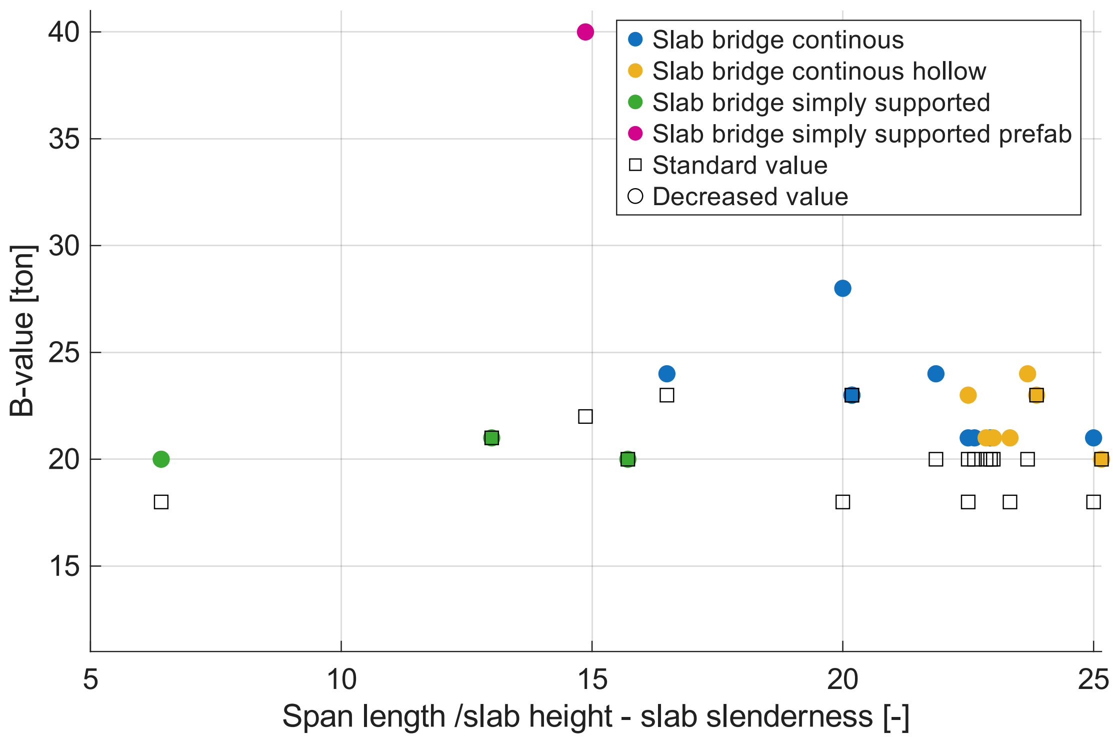


Figure 3.32: B-values in relation to the longitudinal slab slenderness and type of construction for slab bridges.

The slab bridges have received standard A-values between 12-20 tons and for B-value between 18-23 tons. Figures 3.33 and 3.34 show that most slab bridges are governed by the slab.

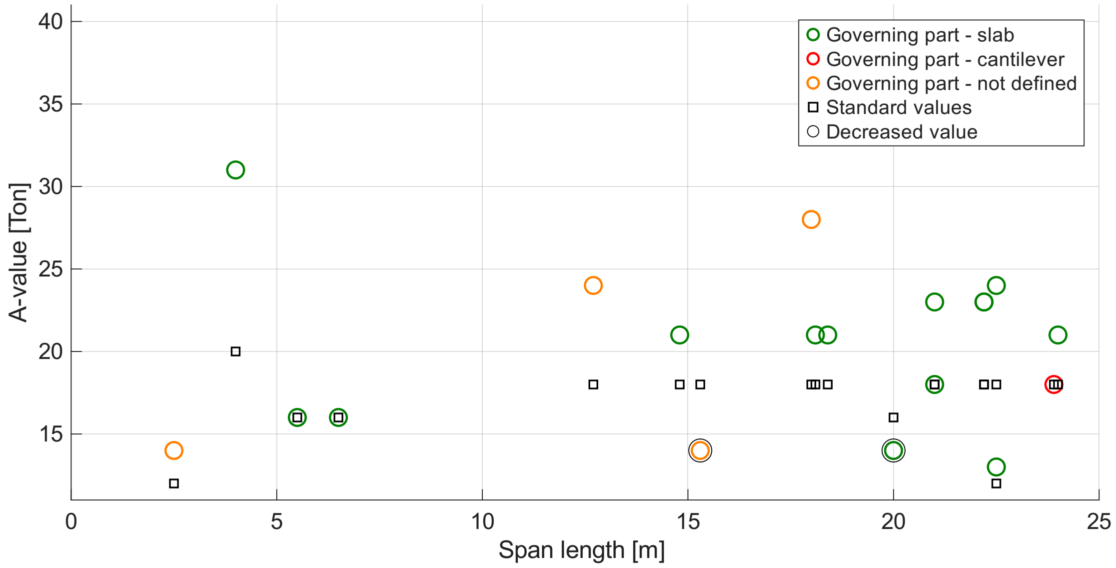


Figure 3.33: A-values in relation to the span length and governing part of the slab bridge.

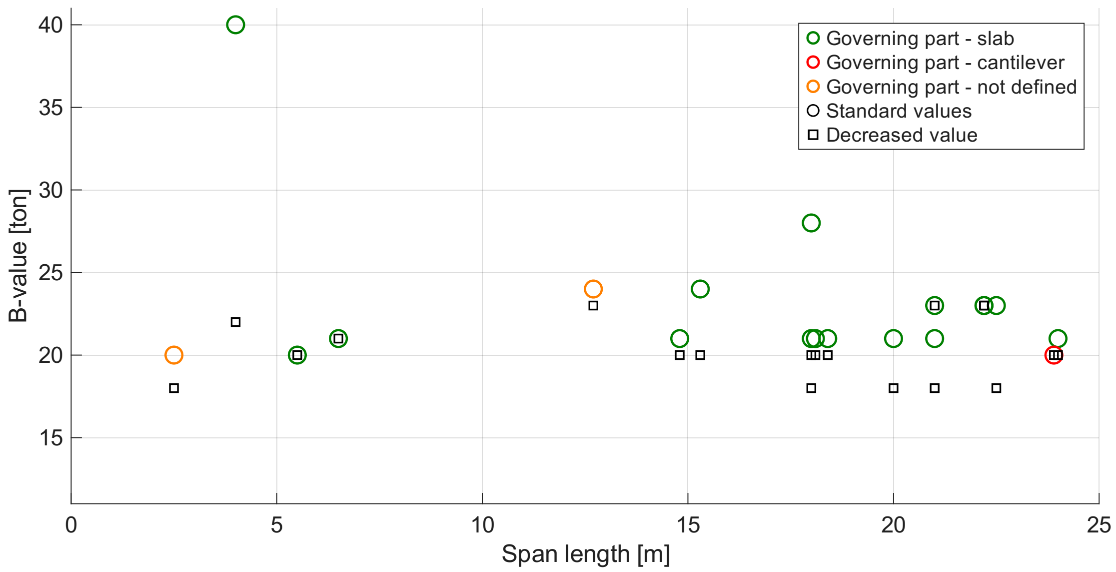


Figure 3.34: B-values in relation to the span length and governing part of the slab bridge.

Figures 3.29 and 3.30 show the construction year and the regulations used to calculate the load-bearing capacity. The decreased A-values were constructed in 1970 and 1972. A large majority of the analyzes slab bridges are constructed between 1964 and 1978.

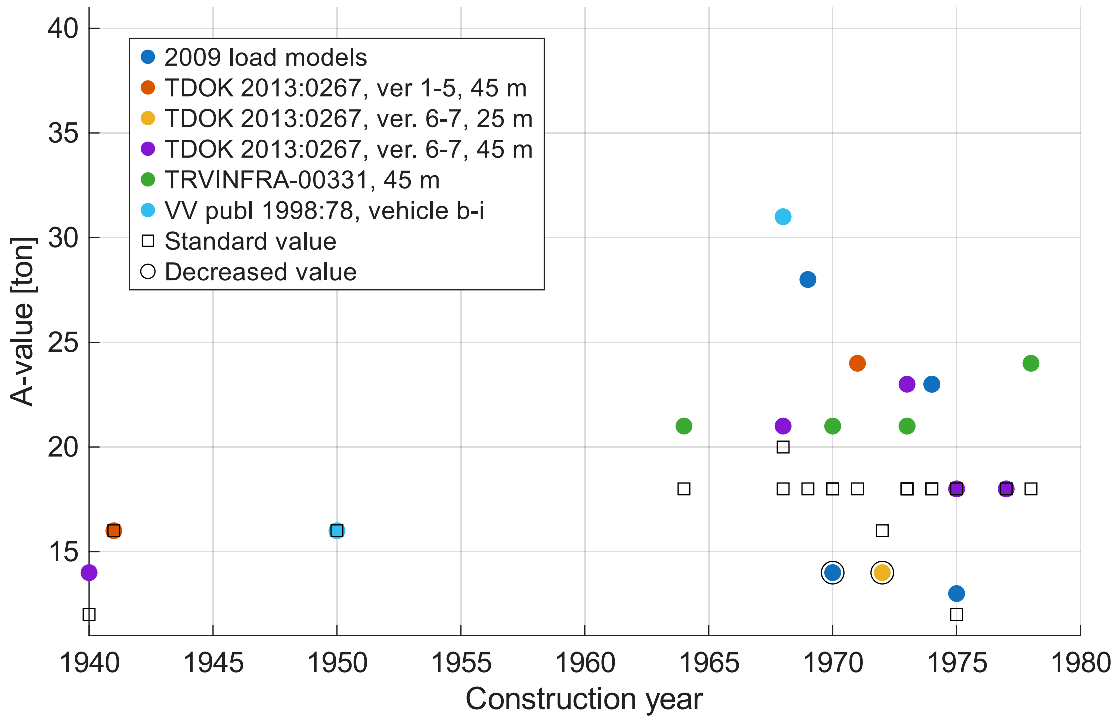


Figure 3.35: A-values in relation to construction year and regulation for slab bridges.

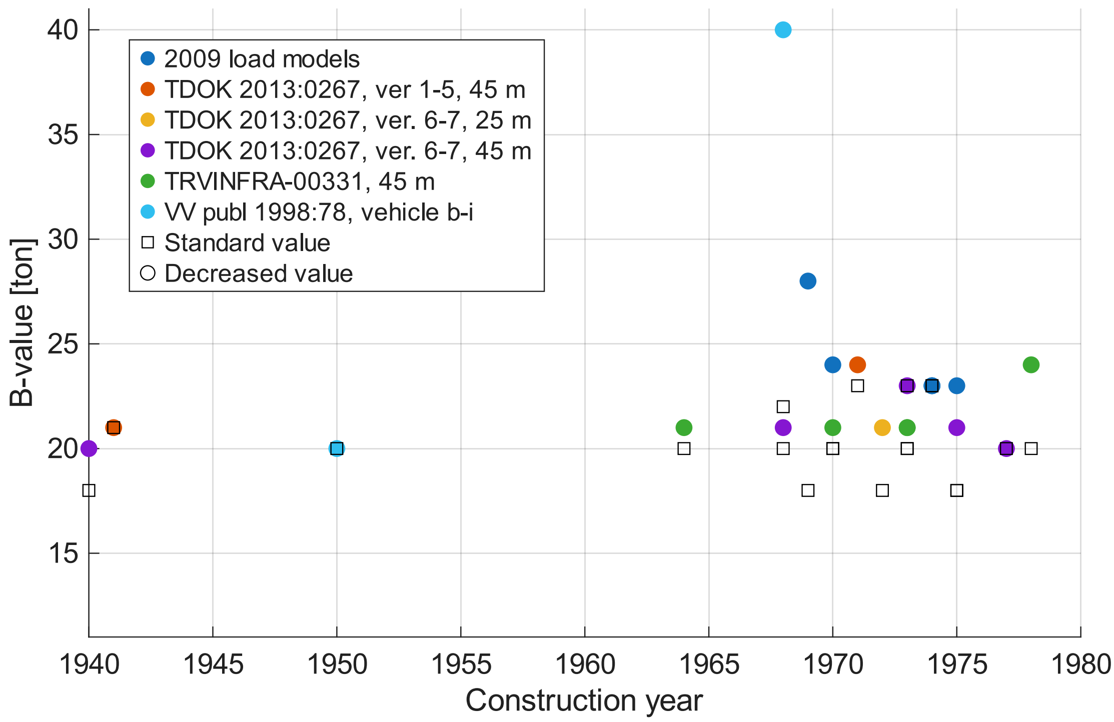


Figure 3.36: B-values in relation to construction year and regulation for slab bridges.

The A-values governed longitudinal by moment and shear in relation to the slenderness of the slab, are shown in Figure 3.37

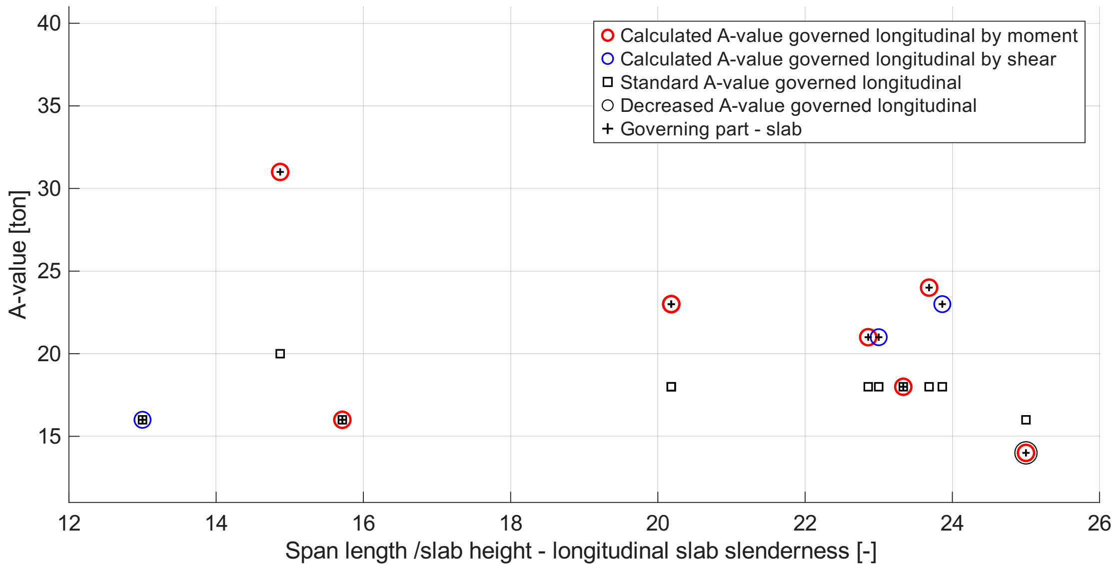


Figure 3.37: A-values governed longitudinal by capacity and construction part for slab bridges.

3.2.4 Slab frame bridge

The slab frame bridges has received standard A-values between 15-20 tons and B-values between 20-26 tons, with a majority of 18 tons and 24 tons. After calculations the variations of load bearing capacity have increased for the A-values to capacities from 14-37 tons. In B, the values reach 20-37 tons. The slab frame bridges are mostly governed in the slab for both A-and B-values. In some cases the governing part is the frame leg of the bridge, as seen in Figures 3.38 and 3.39. Three of the bridges with the largest span have been decreased together with two bridges with shorter span lengths. One of the smaller bridges has decreased in both A- and B-values. Figures 3.40 and 3.41 present the construction year and regulation used for the calculations. Slab frame bridges constructed before 1970 have received higher load-bearing capacity compared to slab frame bridges constructed around 1970 and later. Most of the decreased bridges have been calculated in accordance with TRVINFRA regulations and were constructed after 1967.

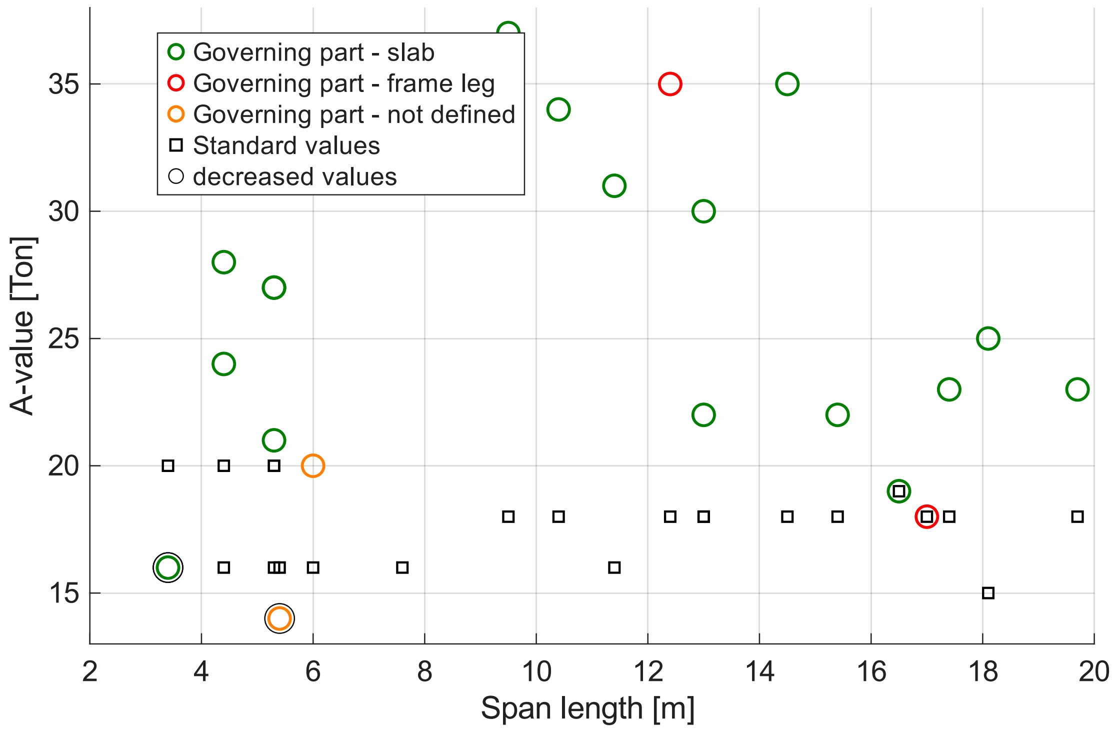


Figure 3.38: A-values in relation to the span length and governing part of the slab frame bridge.

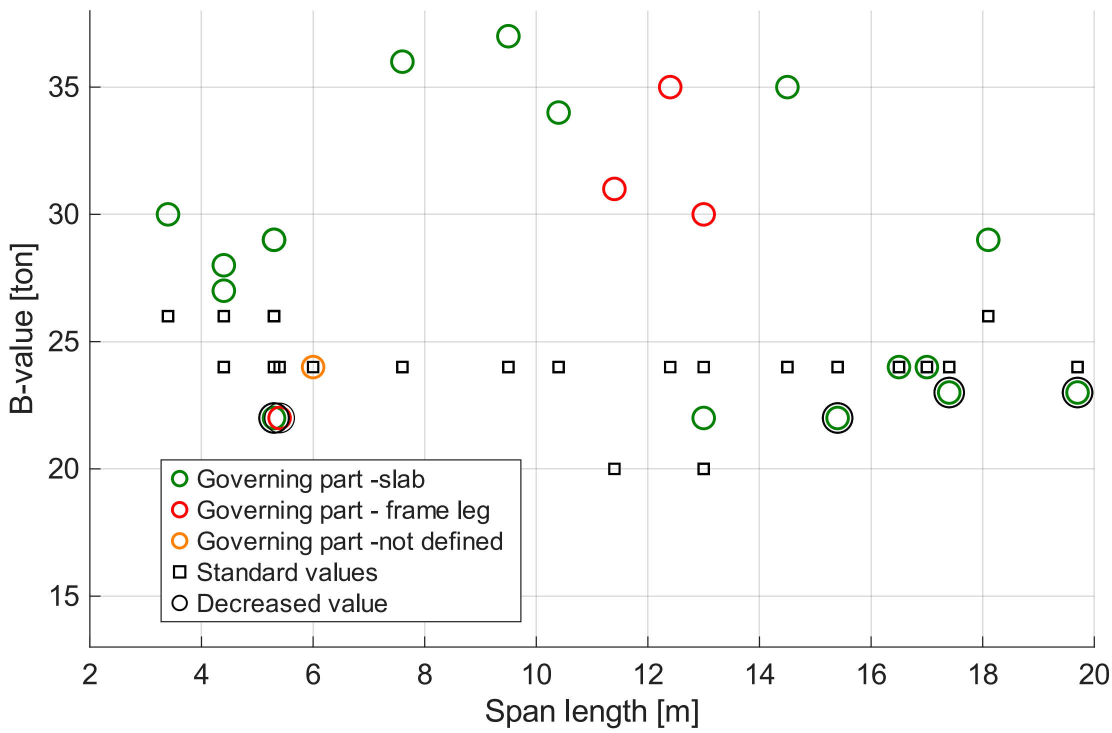


Figure 3.39: B-values in relation to the span length and governing part of the slab frame bridge.

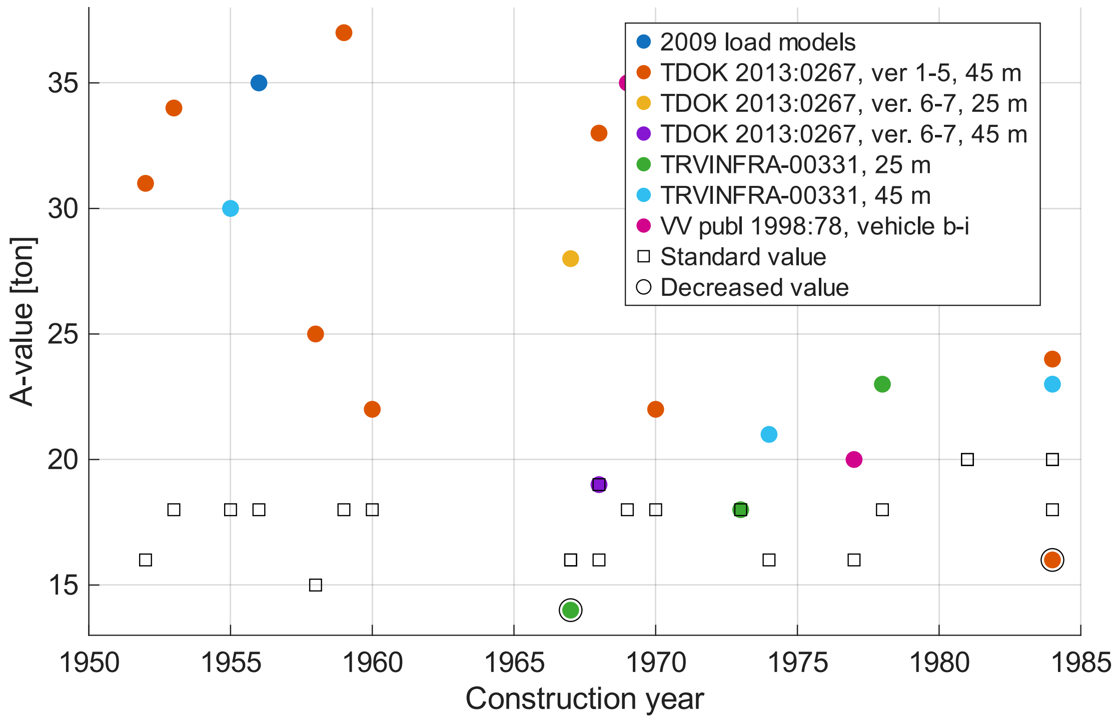


Figure 3.40: A-values in relation to construction year and regulation for slab frame bridges.

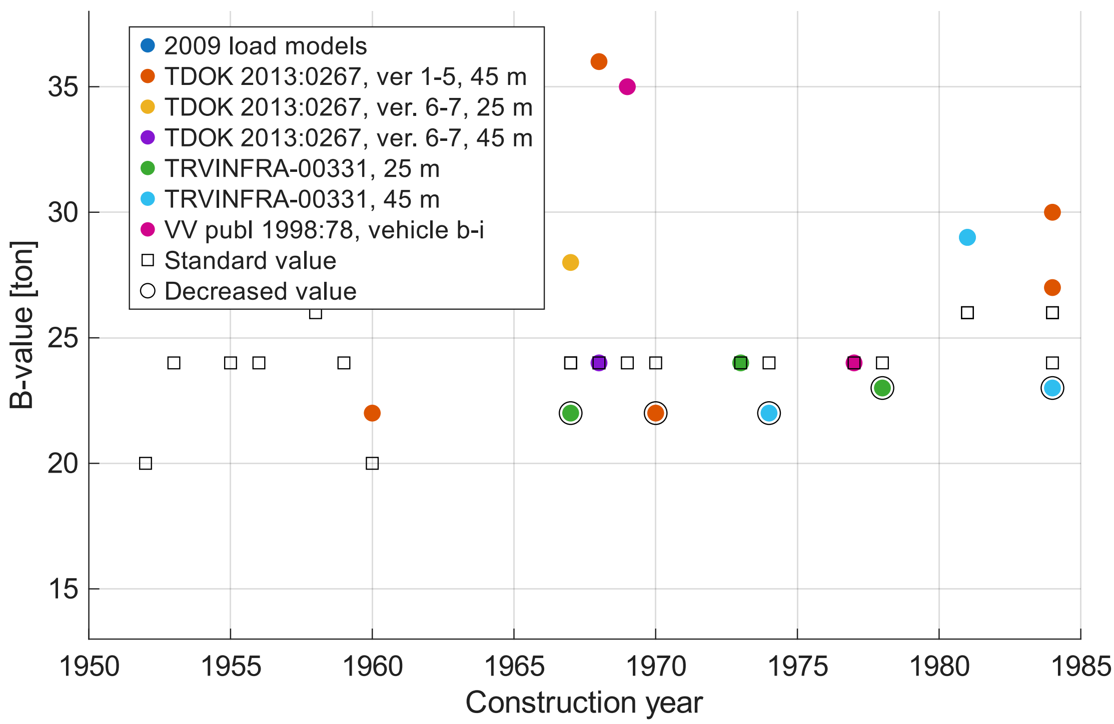


Figure 3.41: B-values in relation to construction year and regulation for slab frame bridges.

The majority slab frame bridges are governed longitudinally in both A- and B-values. The ratio between shear and moment, as well as the governing part of the structure, is presented in Figures 3.42 and 3.43. For B-values with decreased capacity, those governed by shear tend to be more slender than those governed by moment.

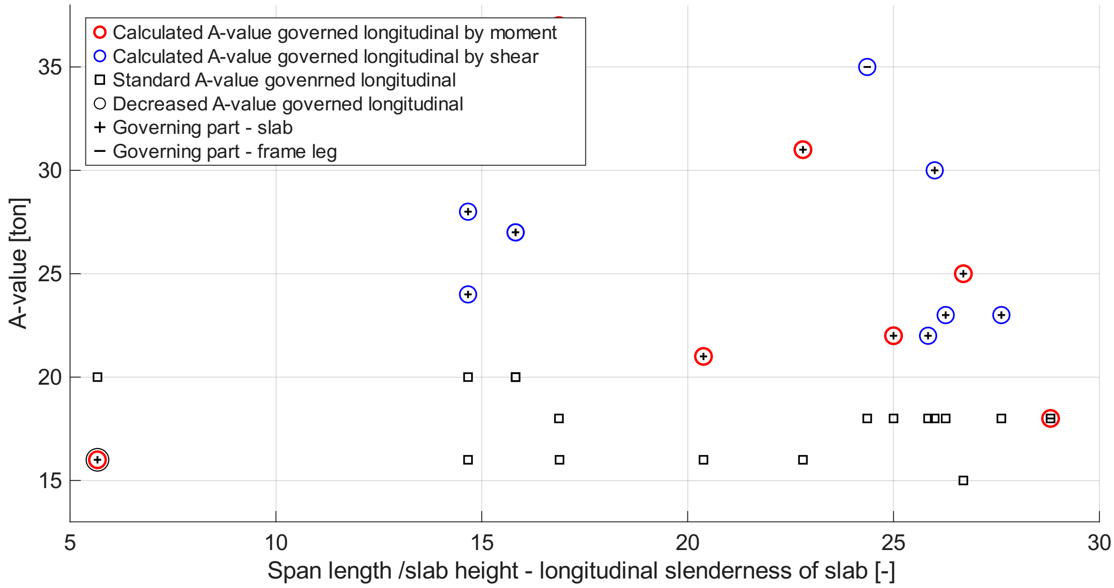


Figure 3.42: A-values governed longitudinal by capacity and construction part for slab frame bridges.

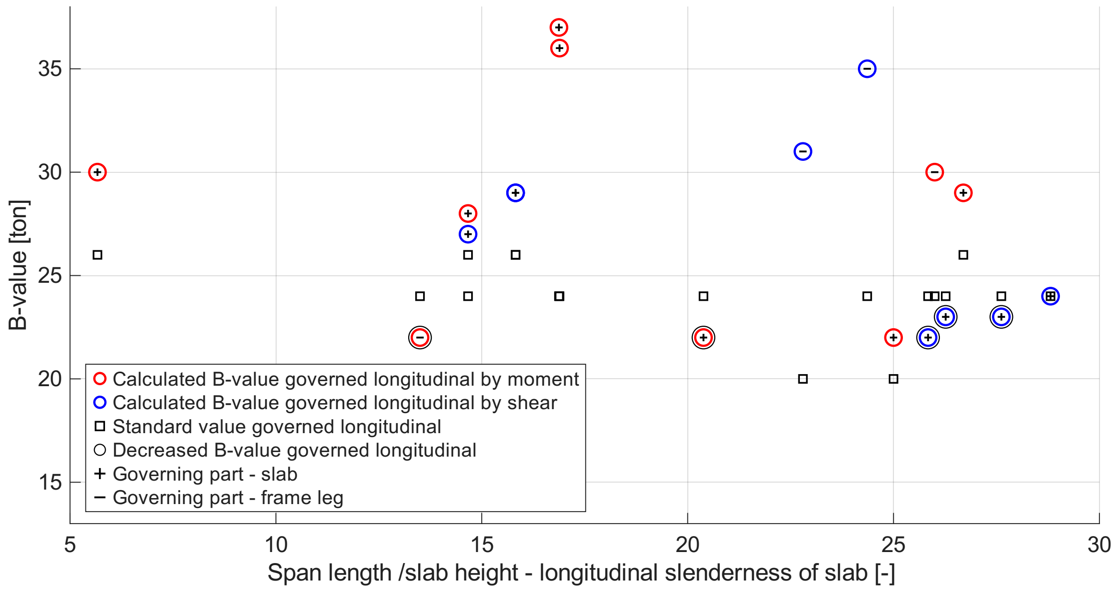


Figure 3.43: B-values governed longitudinal by capacity and construction part for slab frame bridges.

4 Discussion

This chapter discusses the results of the work and the methods used throughout the process. It also addresses how the work may contribute to future analyzes of bridge structures, as well as possible improvements and future developments.

4.1 Method considerations

In the early stages of this project, the method for achieving the purpose was not clearly defined. The Transport Administration recognized the need to structure and categorize bridges with a load-bearing capacity assessed according to a standardized classification system. How to accomplish the task was a challenge that was worked out throughout much of the initial phase of the project. When it was discovered that some bridges had previously been assigned a standard classification capacity and were later given their own load-bearing capacity calculations, a deeper analysis of those bridges was identified as a method and the most suitable path forward in order to achieve the purpose of the project.

At first, it was discussed to study what constructions should be prioritized based on the most economical and beneficial for the society in terms of large road paths and yearly traffic load. In order to fulfill the technical aspects of this work, that method was set aside. Instead, the focus shifted towards the structures and the load-bearing capacities given by the standard classification process.

During the process, we have investigated many different aspects about the approximately 200 bridges. At times, we have questioned whether this analysis will support the assessment to categorize the list with 3000 bridges that still have standard values. It has been necessary to study these 200 bridges in depth to better understand the factors that cause calculated load-bearing capacities to differ from standard values. Even if some findings are not directly applicable to the 3000 bridges, this is done to get a deeper understanding of bridge behavior. One such aspect is the comparison between calculated and standard values in relation to bridge slenderness. It was time consuming to extract all the dimensions of the relevant parts of the bridges, and doing so for all 3000 bridges is not feasible within the available time. However, this approach could be a potential path forward in the future.

The method is based on the comparison of standard values and calculated values for the given bridge structures. These differences have been compared with the categories that we have assumed might have a possible impact on the load-bearing capacity. These categories have been discussed and found in collaboration with Chalmers University supervisor and experts in the Transport Administration, and further research of the categories has been carried out based on this. There are many aspects to handle and variations of categories and combinations that have not been handled since the amount of variations is huge and would require another type of analysis.

As mentioned earlier in the report, the standard classification values are based on a set of structures within each construction group. Those bridges are supposed to cover a large set of variations, but those bridges have not been investigated in this work. In order to understand what forms the basis for the values , this is something to look at for the future.

4.2 Discussion of the standard classification process

The basis for the standard classification process involves beam, beam frame, slab and slab frame bridges. For these bridge structures, different criteria presented in Section 2.2.1 constitute the A/B value a bridge should receive as standard value. The alternative A/B values presented have more specific criteria which the bridge must fulfill, these have not been presented in detail. The impression gained from this work is that, despite the complexity and extent of bridge calculations and structural systems, only a limited number of criteria appear to determine the assigned A/B value. That means that all the variations are hard to include in the standard classification process. During the work, we did not examine how well the assigned A/B value matches the criteria that form the basis for it. For a deeper understanding and analysis of how effective the standard classification process is, this would have been of interest to investigate.

By analyzing the normal distribution presented in Figures 3.5 and 3.6, it is clear that the curves between the standard values and the calculated values differ. The curves for the standard values have higher peaks in their distribution curve which indicates that the bridges have received approximately equal A/B value in most cases, meanwhile the curvature for the calculated values shows larger variations. The curves for the calculated values are shifted to the right in most cases, indicating higher calculated values in general. This suggests that the standard values are generally on the conservative side. This is also evident in Figure 3.3, where a large proportion of cases are represented. This represents the general aspect of the classification and does not deal with individual cases. Although the normal distribution is shifted to the right, there are parts of the curve where the probability of higher a standard value compared to the actual capacity is possible, seen by the interaction of the curves.

The calculated A/B values show that the load-bearing capacity for bridges varies, both between different bridge structures and also within the same structure. According to Gustavsson (1998) it is hard to make a new calculation on existing bridges and this can affect the results. When reviewing the bridge calculations, it was noted that the extent of the checks varied depending on which company performed the analysis. As mentioned in Section 2.4, the utilization ratio is used to determine the dimensions of bridge components, and depending on the constructor, this ratio may be set differently, some allowing greater margins than others. Since this is not fully standardized, the calculated values may be based on different assumptions and objectives underlying the calculations.

4.3 Influence of construction year and regulations

When analyzing bridges with regard to the construction years, some things stand out. For bridges with decreased load-bearing capacity in Figure 3.12 no specific trends are observed. However, by examining the figures that show construction years for the different bridge constructions, it can be seen that the majority of bridges with lower values were constructed in the 1960s and 1970s. This is not as clear in Figure 3.12 because many bridges have been built during this period and the percentage is based on each decade. As reported by Das et al. (2019), the introduction of computer programs began in this decade. The finite element method (FEM) enabled more accurate calculations, making it easier for engineers to analyze how bridge components interact. This may explain the observed decrease in load-bearing capacity.

The regulations have changed and been updated over the years, and to determine whether any specific regulation stands out, the bridge results were compared based on the regulations used in the calculations. However, it is difficult to estimate how it would turn out if the bridges calculated according to the older regulations, VV publication 1998:78 and 2009 load models, were calculated according to the newer regulations. There are many factors that determine the load-bearing capacity. Minimum shear reinforcement is a requirement today, and the traffic load models have increased with longer vehicle lengths and shorter distances between the load points, causing larger load actions. Although other factors in the old regulations might have considered the uncertainties in a more restricted way. No prominent trends are observed when comparing the regulations and whether the capacity has been decreased or increased, but there is a tendency that calculations according to VV publication 1998:78 might result in the same capacity as the standard value to a greater extent compared to the other regulations, seen in Figure 3.9. Among the bridges calculated according to VV publication 1998:78, the amount bridges who received the same capacity is 54% in A-value and 31% in B-value.

4.4 Analysis of results for different bridge structures

In theory, this study was expected to yield clear results from certain comparisons. However, during the work, the results did not align with the theoretical hypothesis to the extent anticipated. Consequently, we consider the results to be difficult to analyze. Given that only a relatively small number of bridges were examined, it is also challenging to draw firm conclusions. Nevertheless, in the following section, we present the aspects in which a slight trend can be observed.

4.4.1 Beam bridges

Figure 3.2 shows that 11% of the beam bridges have a decreased capacity in A-values. This might not seem like much, but since many beam bridges are included in the analysis, there will still be quite a few of them. In theory, the span to beam height ratio is important, more slender bridges are often more critical in aspects of bending behavior and stability. In Figure 3.14 it can be seen that the most slender beam bridge has a calculated reduced capacity. However, this does not hold in general, as bridges that are not particularly slender have also been assigned lower calculated values. A closer look at the reduced capacity bridges shows that they are governed by either the slab or the cantilever, as illustrated in Figure 3.18. This may explain why the beam slenderness theory is not fulfilled. By examining Figure 3.22, which shows the bridges governed in the longitudinal direction, the A-values are related to the slenderness of the slab. Among bridges with a standard value of 14 tons and governed by moment, the most slender slab has a reduced capacity. To evaluate the remaining cases, Figure 3.24 illustrates the bridges governed in the transverse direction. Among the beam bridges with a high slenderness in the slab, one shows a reduction in A-value and is governed by the slab. However, the others with reduced capacity are not particularly slender, but they are governed by the cantilever, making them more difficult to analyze. This is because the response depends on how close the vehicle is positioned and whether there is a footpath or a cycle path on the bridge. So in theory we thought that the dimensions of the beam would be decisive, but since the majority of bridges are dimensioned in the slab, these dimensions are more critical.

The majority of all beam bridges had 14 tons as standard A-value, as seen in Figure

3.18. However, there are exceptions, and in Figure 3.14 it shows that one bridge has received 12 tons in the standard value and is made of concrete. Another has received 13 tons in standard value and is made of steel. According to Table 2.3 there are no alternative A-values for concrete beam bridges only for steel beam bridges, but then the A-value can be decreased to 12 tons and not 13 tons. This complicates the interpretation of the standard classification process.

From the results, it is evident that many bridges have achieved an increased load-bearing capacity of up to 30% compared to the standard value. This trend is illustrated in Figure 3.7, and is particularly pronounced for the B-values. Furthermore, Figure 3.3 shows that 65% of B-values for the beam bridges are in this category. In Figure 3.15, it can be seen that steel bridges have a standard value of 19 tons, as shown in Table 2.3. After calculation, the majority of these bridges exhibit an increased load-bearing capacity in the range of 21 to 22 tons. Among the bridges that still have a standard classification, the Swedish Transport Administration has 22 steel beam bridges with a standard value of 19 tons. For concrete bridges, it is clear that the majority bridges with a standard value of 20 tons have received an increased load-bearing capacity. Among the bridges that still have a standard classification, the Swedish Transport Administration has 26 concrete beam bridges with a standard value of 20 tons. With this in mind, larger increases might be possible to achieve for steel beam bridges, which increase with 2-3 tons in most cases compared to the concrete beam bridges, which generally receive an increase of 1 ton.

We noted that one of the continuous beam bridges has been assessed with values of 14/23 tons. According to the standard criteria, these values are used for box beam bridges. When further analysis of the bridge structure was performed, it was found that the bridge has a unique shape, as Figure 4.1 shows. This is an example of the complexity of the process and an indication of the variations that can be found in the set of bridges.

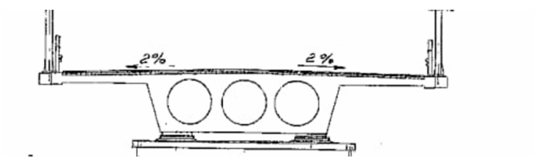


Figure 4.1: Section of bridge.

TDOK 2013:0267 ver 1-5 is an earlier version of TDOK and was meant to cover both short and long span bridges. This means that more conservative values are used in the regulation to represent the worst case. For later versions, different vehicle lengths are used to provide a more accurate load distribution and will not be as conservative for shorter span bridges. Four out of five beam bridges with a reduced A-value are calculated with TDOK 2013:0267 ver 1-5. Most of the bridges with decreased A-values are with smaller construction lengths, which supports the theory considering the conservative values when calculating according to the earlier version of TDOK 2013:0267.

Among the beam bridges with decreased A-values, three of them were constructed around 1970. This might be an indication of the use of computer programs.

4.4.2 Beam frame bridges

Beam frame bridges are the only type of bridge that does not have any bridge with a reduced A-value. Figure 3.2 shows that 45% of bridges have the same calculated A-value as the standard value. To analyze this, Table 3.1 must also be taken into consideration. This table shows that only 20% (1/5) of the beam frame bridges should have another load-bearing capacity according to the calculations, but have retained their previous value. In Table 2.3 it is presented that the normal standard value is 14 tons for beam frame bridges and in Figure 3.26 it can be seen that four of the five bridges have received this value. Due to this, it can be suggested that the standard A-value for beam frame bridges is the most representative, however, since a large proportion have also received calculated values exceeding 30% of the standard value, as seen in Figure 3.3, this conclusion cannot be firmly established. The fifth bridge, having the same capacity, is assigned a standard A-value of 16 tons. However, this value is not included in Table 2.4, which complicates the standard classification process. It is notable that according to the standard classification process, the A-value must be set to 14 since it is the only option seen in Table 2.4, and this indicates the inadequate variation of standard values for this structure, especially since the calculated values differ moderately.

When examining Figure 3.2, the B-values for the beam frame bridges are notable. The calculated load-bearing capacity has decreased with 27% of the beam frame bridges compared to the standard value. In Figure 3.27, the three bridges with reduced capacity are governed by the slab. An interesting observation is that these bridges have a standard value of 24 tons, which is the normal value used in the standard classification process when no additional requirements or conditions are applied (see Table 2.3). One of the bridges with a standard value of 24 tons has retained the same calculated value. This bridge has received a reduced calculated capacity, but the original standard value has been retained anyway, due to no visible damage. Based on this, four out of five bridges with a standard value of 24 tons have received a lower calculated value. All four bridges are also governed transversely in the slab by moment, as illustrated in Figure 3.28. The load-bearing capacity of these bridges has decreased by 1-2 tons, which means they remain in BK4 and can still withstand high loads. Among the bridges that still have a standard classification, the Swedish Transport Administration has 338 beam frame bridges with a standard value of 24 tons. Figure 3.30 shows that two of the three bridges with decreased capacity were calculated according to the 2009 load models, while the third was assessed using VV Publication 1998:78. These are the oldest regulations considered, raising the question whether recalculating these bridges using current regulation would result in other values.

4.4.3 Slab bridges

Figure 3.31 shows that two bridges were assigned a standard A-value of 12 tons, although this A-value does not exist for the slab bridges in Table 2.5. It is found that one of these bridges has been given assessed based on some calculations together with a standard values, which is the reason why it is not a value in the supporting criteria. The calculated A-values for these two bridges are 14 and 13 tons. These values are lower compared to the rest of the set. However, since the A-value of 12 tons does not exist in the standard classification system, this complicates the process. And whether there are more cases subject to this type of problem. This causes uncertainties in the data on which the analysis is based.

The precast simply supported slab bridge, was assigned a standard A-value of 20 tons, this value does not exist in Table 2.5 either. However, this may be based on knowledge about the precast elements. This bridge has received much higher load-bearing capacity compared to the rest of the slab bridges, both in A- and B-value. When analyzing this further, the slab elements have a special geometry, which makes it hard to compare to the rest of the bridges.

In Figure 3.2 it is illustrated that slab bridges are the only structure without any decreased calculated B-value. On the other hand, the figure also shows that 26% of the calculated B-values are the same as the assigned standard values, corresponding to a total of six bridges. Table 3.1 further shows that, for five of these six bridges, the calculated B-values differ from the assigned standard values, but the standard value was retained. Among these five bridges, three received lower calculated values, but their original standard values were maintained based on proven experience.

We can note from Figure 3.31 that the hollow core slab bridges and the continuous slab bridges have received approximately the same standard value and also approximately the same calculated load-bearing capacity. Both structures have some variations in their calculated load-bearing capacity, although the hollow core slab bridges seem to have smaller differences according to Figures 3.31 and 3.32. The slab slenderness may impact this as well and the analyzed hollow core structures have smaller variety of the slenderness compared to the continuous slab bridges.

The one span slab bridges (simply supported) do not have a given standard value (criteria) based on the supporting material given. There are three single span slab bridges in the supporting material, none of them has received lower values although two of them have received the exact same capacity for both A- and B- values. These two super structures have received higher capacities, but the understructure does not fulfill the criteria which govern the capacity of the bridge.

4.4.4 Slab frame bridges

For the A-values, it is notable that 55% of the calculated values have an increased capacity of more than 30%, as seen in Figure 3.3. In Figure 3.35, we can see a trend among the oldest slab frame constructions that the load-bearing capacity has increased mainly by much more than the later constructed frame bridges. The reason for this might be based on the hand calculation method that was used during this time. The knowledge and ability to analyze a structure through computer programs did not exist, and larger safety factors were applied. The industries and regulations for construction materials might also have a greater variation in the process, which can contribute to why they receive higher capacity today. The same trend can be seen for the B-values in Figure 3.36. Among the 3000 bridges that still have standard classification, slab frame bridges are the most common, with 473 of them built before 1960.

For slab frame bridges, the trend that the calculated load-bearing capacity has decreased since 1960 is most evident. This can be seen in Figures 3.40 and 3.41. This trend is more evident for the B-values, where a larger number of bridges show decreasing values. The use of computer programs in the calculations also makes it possible to analyze structures in multiple directions. This might have caused less conservative assumptions compared to earlier calculation methods, which may have contributed to the shift towards lower load-bearing capacities after 1960 for the slab frame bridges.

When examining Figure 3.2, the B-values for slab frame bridges are notable. The calculated B-value has decreased by 23% compared to the standard value. In Figure 3.39 it shows that all bridges with a reduced load-bearing capacity had 24 tons as the standard B-value. However, in contrast to beam frame bridges, a larger number of slab frame bridges had this standard value and also obtained a higher calculated capacity. All five bridges with a decreased B-value for load-bearing capacity are governed longitudinally as seen in Figure 3.43, four are governed in the slab and one in the frame leg.

4.4.5 Arch and culvert bridges

For arch and culvert bridges, the standard classification does not provide A- and B-values. Instead, several criteria are used, which for culvert bridges mainly concern the thickness of the overlying soil layer. In discussion with the Transport Administration, these two bridge structures were removed from the analysis due to the complexity of arch bridges, the supporting material and the known fact that the thickness of the overlaying soil is mainly the governing factor for the culvert bridges. Although the analysis did not include arch and culvert bridges, it can be of importance to further investigate the arch bridges since the list of 3000 bridges include 291 arches with a span of A values between 12-40 tons and B-values between 18-60 tons.

5 Conclusion

This thesis has focused on bridges that were previously assigned standard classifications but later had their load-bearing capacities determined through individual calculations. This has been challenging, as several factors influence the final decision of the capacity. In most cases, the calculated load-bearing capacity forms the basis for the decision, but in some cases other factors are decisive. These may include foundation conditions, changes in traffic loads, the condition of the bridge, and available knowledge. Since each bridge is assessed on a case-by-case basis, it has been difficult to handle them in a uniform manner.

The results indicate that the standard classification system has generally been representative and useful for simplified and rapid assessments of load-bearing capacity. However, the standard values are not always sufficient to represent the wide variation that exists between individual bridge structures. As a result, both increased and decreased calculated capacities were observed. Although all investigated bridge types contained one or more reduced values, no bridge was downgraded by an entire load-bearing class, and all bridges remained within BK4 or BK1.

Since the results are based on a limited number of bridges, it is difficult to establish clear general trends, making it challenging to prioritize the approximately 3000 standard-classified bridges on a general basis. Some patterns and aspects were identified for the different bridge structures. These are presented below and are suggested for further evaluation by the Swedish Transport Administration.

- For steel beam bridges, a trend can be observed in which bridges with a standard B-value of 19 tons have calculated load-bearing capacities ranging from 21 to 22 tons. The Swedish Transport Administration has 22 steel beam bridges with a standard value of 19 tons.
- For beam frame bridges, four out of five bridges with a standard value of 24 tons have received a lower calculated value. The Swedish Transport Administration has 338 beam frame bridges with a standard value of 24 tons.
- For slab frame bridges, a significant increase in the A-values is observed for bridges constructed before 1960. The Swedish Transport Administration has 473 slab frame bridges built before 1960.
- For slab frame bridges, the B-values indicate a slight trend toward decreasing load-bearing capacity for bridges constructed after 1960. The Swedish Transport Administration has 998 slab frame bridges built after 1960.

The results show that the calculated values are most widely distributed for slab frame bridges. This is also the bridge type with the largest number of bridges that still have a standard classification, making them valuable candidates for further investigation.

6 References

Abhishek, J. (2024, January). Understanding Probability Density Functions (PDF), Probability mass function (PMF) and Cumulative Distribution Functions (CDF).

Al-Emrani, M., Engström, B., Johansson, M., & Johansson, P. (2013). *Bärande konstruktioner - del 1*. Chalmers tekniska högskola.

Bakht, B., & Mufti, A. (2015). *Bridges: Analysis, Design, Structural Health Monitoring, and Rehabilitation* (Second edition). Springer.

BATMAN. (2026, March). Genomförande - Bärighet.

Das, B., Barbhuiya, S., Gupta, R., & Purnachandra, P. (2019). *Recent Developments in Sustainable Infrastructure*. Springer. `http://www.springer.com/series/15087`

Getachew, A. (2003, February). *Traffic Load Effects On Bridges* (tech. rep.). Royal Institute of Thechnology. Stockholm.

Gustavsson, E. (1998, December). *Utvärdering av tillåten trafiklast* (tech. rep.). Vägverket. Borlänge.

Hammar, H. (2011). *En jämförelse av Eurokod och Boverkets konstruktionsregler* (tech. rep.). LTH School of Engineering. Lund.

Liu, W. K., Li, S., & Park, H. S. (2022, October). Eighty Years of the Finite Element Method: Birth, Evolution, and Future. `https://doi.org/10.1007/s11831-022-09740-9`

Natanaelsson, K., & Eriksson, T. (2020, April). *Implementering av bärighetsklass 4* (tech. rep.). Trafikverket. Borlänge.

Sandford, T. C. (n.d.). *Soil-Structure Interaction of Buried Structures* (tech. rep.).

Trafikverket. (2013). *TDOK 2013:0267 Bärighetsberäkning av broar* (tech. rep.). Trafikverket. Borlänge.

Trafikverket. (2025a, May). Så sköter vi broar och tunnlar.

Trafikverket. (2025b, July). *KRAV TRVINFRA-00331 Bro och broliknande konstruktion Bärighetsberäkning Trafikverkets infrastrukturregelverk* (tech. rep.). Trafikverket. Borlänge.

Trafikverket. (2025c, November). Bärighetsklasser (BK) på vägar och broar. `https://bransch.trafikverket.se/for-dig-i-branschen/vag/bk--barighetsklasser-pa-vagar-och-broar/`

Transportstyrelsen. (2018, August). *Transportstyrelsens föreskrifter och allmänna råd om tillämpning av eurokoder* (tech. rep.). Transportstyrelsen (TSFS 2018:57). Norrköping.

Vägverket. (1996, November). *Broprojektering - en handbok* (tech. rep.). Vägverket. Borlänge.

Vägverket. (1998, November). *Allmän teknisk beskrivning för* (tech. rep.). Vägverket. Borlänge.

Vägverket. (2000). *Förbättring av befintliga broar* (tech. rep.). Vägverket. Borlänge.

A Standard vehicles

Bilaga 1 Typfordon - vägbroar

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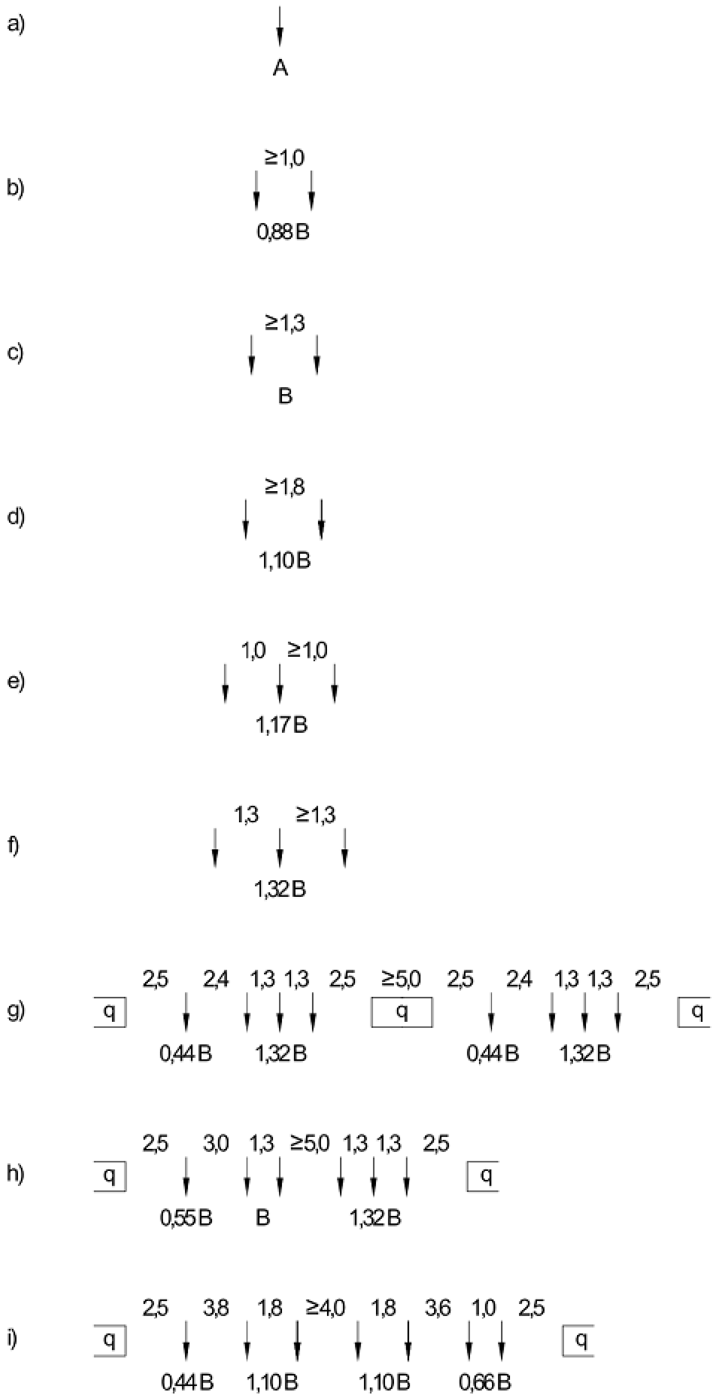

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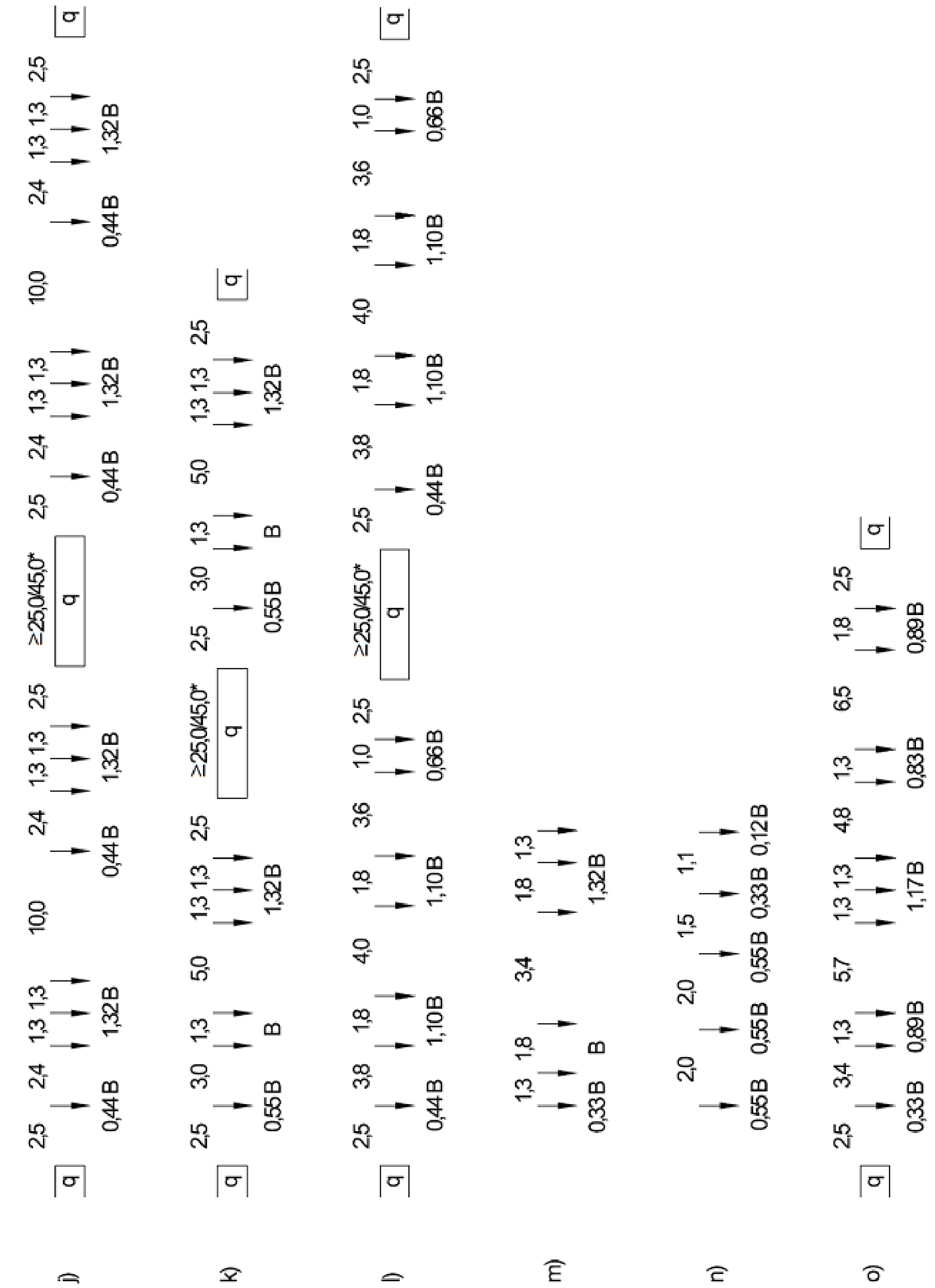

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