Vinnytsia National Technical University
(full name of the higher education institution)

Faculty of Construction, Civil and Environmental Engineering
(full name of the institute, name of the faculty)

Department of civil engineering, urban planning and architecture
(full name of the department)

MASTER'S QUALIFICATION THESIS

On topic:

«The method of strengthening the crossbars of bridge bearings by arranging polygonal reinforced concrete brackets»

Performed by: 2nd year student, group 2B-22m

Specialty 192 Civil Engineering and Construction

(code and name of specialty)

LI Xiaohong

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«_____»__________________2024

Vinnytsia, VNTU – 2024

Vinnytsia National Technical University
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FACULTY OF CONSTRUCTION, CIVIL AND ENVIRONMENTAL ENGINEERING
(full name of the institute, name of the faculty)

DEPARTMENT OF CIVIL ENGINEERING, URBAN PLANING AND ARCHITECTURE

Education level master

Studies direction 19 Architecture and construction
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EDUCATIONAL PROGRAM CIVIL AND INDUSTRIAL ENGINEERING

APPROVED
Head of Department CEUPA
________ Svets V.V.
«__» ______ 2024

T A S K

OF MASTERS QUALIFICATION THESIS

Li Xiaohong
(FULL NAME)

1. Master's thesis topic The method of strengthening the crossbars of bridge bearings by arranging polygonal reinforced concrete brackets

Master's thesis supervisor Popov V.O., PhD, docent of CEUPA Department,
(surname, first name, patronymic, academic degree, academic title)

approved by order of the higher educational institution from «__»_____20__ No___

2. Deadline for submission of work by a master's student June 10, 2024

3. Initial thesis data: Work by scientific direction. Current regulatory sources on bridge design and their components. Initial information on defects and damage to the crossbars of bridge piers, as well as existing methods of strengthening them. Sketches of possible variants of polygonal brackets for reinforcing the crossbars

4. Content of the settlement and explanatory note (list of issues to be developed): Introduction. which should reflect the relevance of the topic, purpose, scientific novelty, practical significance, tasks, object and subject of research. The research part, consisting of three sections: Chapter 1, in which have to be performed an analysis of the state by designing of bridge structures, structural components of reinforced concrete bridge, their support system and bearings, an analysis of normative and literary sources on the topic of MQT. Chapter 2, in which have to be performed an analytical and finite-element modeling of the stress-strain state of the crossbars of bridge bearings under the influence of climatic and technological influences and also, have to be performed the selection of a rational shape of the clamp based on the results of modeling. Chapter 3 – should be investigated technological issues related to the arrangement of effective formwork, adhesive coatings and rational concrete mixtures for the arrangement of polygonal brackets. Chapter 4 — Economic part, in which to investigate the economic effect of the offered solutions in comparison with classic ones. Conclusions in which to reflect the main scientific and practical results of the work performed

5. List of graphic material (with exact indication of mandatory drawings)

Posters that reflect: 1-3 — topic, purpose and tasks of the work, scientific novelty, practical significance; 4-7 — structural components of bridge piers, their variants, the status of the design of reinforced concrete brackets; 8 — modeling of the stress-strain state of a bridge support crossbar reinforced with the proposed polygonal bracket; 9 – scientific and technical description of the proposed design of the polygonal brackets; 10 – 11 - typical defects and damage to the crossbars of bridge piers; 12-13 — structural variants of polygonal brackets depending on the design of the bridge support (consider single-pillar, two-pillar and multi-pillar systems) and proposals for reinforcing polygonal brackets; 14 – Results of economic calculations; 15 – MQW Conclusions

6. Consultants of thesis parts

Part	Surname, initials and position of consultant	Signature and date	
		Task issued	Task accepted
Introduction, Chapter 1	Popov V.O., docent of CEUPA Department	[signature]	[signature]
Chapter 2	Popov V.O., docent of CEUPA Department	[signature]	[signature]
Chapter 3	Popov V.O., docent of CEUPA Department	[signature]	[signature]
Chapter 4. Economic part	Popov V.O., docent of CEUPA Department	[signature]	[signature]

7. Issue date of the task February 04, 2024

CALENDAR SCHEDULE

No	The name of the stages of the master's qualification work	The term of performance of work stages	Note
1	Scientific analysis of the state of the design of bridge piers, in general, and strengthening of their crossbars systems, in particular. Preparation the Chapter 1.	to be completed by March 20, 2024	Lixiaohong
2	Preparation the Introduction.	until 01.04.2024	Lixiaohong
3	Preparation the Chapter 2. Suggested construction solutions of brackets to crossbar system. Modelling	to be completed by April 10, 2024	Lixiaohong
4	Preparation the Chapter 3. Rational technology of brackets production	to be completed by April 30, 2024	Lixiaohong
5	Preparation the Chapter 4. Economic part Preparation the Conclusions.	to be completed by May 15, 2024	Lixiaohong
6	Preparation for publication and publication of MQT results. Approbation	to be completed by May 30, 2024	Lixiaohong
7	Checking work for plagiarism	10.06.2024	Lixiaohong
8	Preliminary defense of the master's qualification thesis	12.06.2024	Lixiaohong

Graduate student Lixiaohong LI Xiaohong
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Master's thesis supervisor [signature] POPOV V.O.
(signature) (surname and initials)

ABSTRACT

UDK 699.8, 624.21.09, 624.271

Li Xiaohong. The method of strengthening the crossbars of bridge bearings by arranging polygonal reinforced concrete brackets. Master's qualification thesis in the specialty 192 - "Civil Engineering and Construction", educational program - "Industrial and Civil Engineering". Vinnytsia: VNTU, 2024. 156 p.

In English. Bibliography: 73 titles; fig. 28; tabl. 7.

The master's qualification thesis investigates the stress-strain state of polygonal brackets for strengthening the crossbars of bridge bearing system under the influence of a complex of climatic and technological loads including dynamic load from rolling stock to find a rational brackets form. Have been carried out scientific researches to generalize information on typical structures of bridge piers, in general, and their crossbar systems, in particular. Have been summarized defects and damage that occur on transom systems during long-term operation, as well as modern methods of strengthening transoms. Have been developed a methodology for selecting a rational polygonal structural form of the clamp based on finite element modeling. Have been proposed the constructive varieties of polygonal reinforcement brackets are depending on the number of risers of bridge supports. Also have been proposed rational technological measures for the arrangement of polygonal brackets to strengthen defective crossbars systems. In economic part have been evaluate the effectiveness of the proposed method of reinforcement. The cost of a polygonal clip turned out to be higher than the cost of a classic rectangular clip, but its higher technical and economic parameters, such as high reliability and durability and special architectural appeal, overlap.

The master's qualification thesis contains 0 sheets of graphic part.

Key words: bridge, supports, piers, crossbar of bearing system, defects and damages, reinforcement brackets, reinforcing frame.

摘要

UDK 699.8, 624.21.09, 624.271

李晓红。通过布置多边形钢筋混凝土支架加固桥梁支座横杆的方法。硕士资格论文，专业 192 – “土木工程与建筑”，教育计划 – “工业和土木工程”。文尼察：VNTU，2024 年。156 页。

英文。参考书目：73 个标题；图 28；表 7。

本硕士论文研究了在包括车辆动态载荷在内的一系列气候和技术载荷影响下，用于加固桥梁支座系统横杆的多边形支架的应力应变状态，以找到合理的支架形状。进行了科学研究，以总结桥墩典型结构及其横杆系统的信息。总结了横梁系统在长期运行过程中出现的缺陷和损坏，以及加固横梁的现代方法。开发了一种基于有限元建模的夹具合理多边形结构形式选择方法。提出了多边形加固支架的构造变化取决于桥梁支座的立管数量。还提出了布置多边形支架以加固有缺陷的横杆系统的合理技术措施。在经济方面评估了所提出的加固方法的有效性。事实证明，多边形夹的成本高于经典矩形夹的成本，但其更高的技术和经济参数（例如高可靠性和耐用性以及特殊的建筑吸引力）是重叠的。硕士论文包含 0 张图解部分。

关键词：桥梁、支座、桥墩、支座横梁、缺陷和损伤、加固支架、加固框架。

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9	Strengthening reinforced concrete bridge support systems and bearings. Review of architectural solutions （Continued）	Poster
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INTRODUCTION

Actuality of topic. Today, in the People's Republic of China, in Europe, and throughout the world, there is a problem of improving logistics flows for the uninterrupted supply of goods and services to consumers, improving the transit capabilities of countries, increasing turnover, intensification of tourism and international travel, as well as for the normal functioning of the economy. Automobile roads are the most developed link of transport networks in the whole world. Various engineering structures, including automobile bridges, are built to overcome natural obstacles on highways. Therefore, bridges are critical components of transportation infrastructure. Bridges consist of several important structural components, among which bridge supports and span structures should be highlighted.

The supports (bridge piers) provide essential support of bridge structures. Scientific research helps in understanding the behavior of bridge supports under various conditions such as traffic loads, environmental factors, and seismic events. This understanding can lead to the development of safer designs and construction methods, ultimately enhancing the safety of highway bridges and protecting the lives of car-drivers. Bridge supports are subjected to various forms of deterioration over time, including corrosion, abrasion, and structural fatigue. Different scientific research can identify ways to improve the durability and longevity of bridge piers through the use of advanced materials, innovative construction techniques, and effective maintenance strategies. This can help in reducing the need for frequent repairs and replacements, thereby saving both time and resources. Highway bridges, including their supports and bearings, must withstand the forces exerted by natural disasters such as earthquakes, floods, and hurricanes. Scientific research enables engineers to better understand how bridge supports behave under extreme conditions and develop designs that are more resilient to such events. Enhancing the resilience of bridge supports can minimize the disruption caused by natural disasters and contribute to the overall resilience of transportation networks.

Today, issues of construction, reconstruction and capital repair of bridge structures, in general, and bridge supports and bearings, in particular, are dealt with by well-known companies, such as: Communications Construction Company, Railway Group Limited, State Construction Engineering Corporation (China), Mostobud, Autostrada, Acciona (Ukraine), VINCI Group, Bouygues Construction (France), Balfour Beatty, Costain Group (GB), Flatiron Construction, Kiewit Corporation (USA).

Investing in scientific research aimed at improving bridge supports can lead to cost savings in the long run. By identifying more efficient construction techniques, optimizing material usage, and extending the service life of bridge supports, research outcomes can help reduce overall project costs and enhance the cost-effectiveness of transportation infrastructure investments.

The scientific research devoted to bridge supports of highway bridges, in general, and methods of their strengthening, in particular, are essential for enhancing safety, durability, resilience, environmental sustainability, and cost-effectiveness. By advancing our understanding of bridge supports behavior and facilitating innovation in design and construction practices, such research contributes to the overall improvement of transportation infrastructure and the well-being of society.

Therefore, the study of methods of strengthening the crossbars of bridge bearings and bridge supports by some additional structural components as the reinforced concrete brackets, is expedient and relevant.

Connection of work with scientific programs, plans, topics. The scientific work was carried out in accordance with the research topic of the department of Construction, Urban Economy and Architecture, VNTU, Ukraine, No60-K6 “Improvement of calculation methods and technologies of automated design and installation of the building-foundation-base system, taking into account information technologies for supporting construction objects” (01.01.2024-31.12.2026).

The purpose and objectives of the study. The purpose of the master's qualification work is the modelling the stress-strain state (SSS) of bridge support structures within crossbar reinforced with reinforced concrete brackets under the action of a complex of permanent and variable loads, including temporary loads from traffic.

In this work, it is necessary to solve the following tasks of scientific research:

- to perform a thorough scientific analysis of the existing scientific and regulatory framework for the design bridges;

- to conduct a thorough scientific analysis of typical designs of bridge piers, which are most often used in road construction;

- on the basis of modern scientific research, determine the function of crossbars in bridge support systems;

- on the basis of public scientific information about the technical condition of bridge piers and their crossbar systems, determine the most typical defects and damage characteristic of these structures;

- propose a rational method of strengthening defective structures of transom systems by arranging clips of various shapes;

- to develop a highly detailed finite-element model (FEMs) of the stress-strain state of the crossbars of bridge supports, which work in conjunction with reinforcement brackets of various shapes;

- on the basis of detailed FEM of the stress-strain state of the crossbars of bridge supports, to propose a rational constructive solution and shape of reinforcement brackets;

- to develop constructive and technological proposals for the arrangement of rational reinforcement brackets.

Object of study − behavior of the structures of bridge abutments under the influence of constant and variable loads, taking into account defects and damage acquired during long-term operation, as well as reinforced structures.

Subject of study – stress-deformed state of the system “crossbar of bearing support – reinforced concrete bracket”.

Research methods. Have been used methods of classical structure mechanics, material resistance and methods of finite element modeling (FEM) on the LIRA-SAPR software complex to solve the problem of finding the optimal geometric parameters of structures of reinforced concrete brackets for strengthening the crossbars of bridge supports.

The novelty of the obtained results. In the work, the scientific direction of rational design of reinforced concrete brackets for strengthening the crossbars of bridge supports based on finite element modeling underwent further development. Have been proposed the rational constructive relations between the elements of reinforcement of crossbars and parameters of rational reinforcement of such reinforcing structures.

Personal contribution of the master's student consists in the development of highly detailed finite element models of the stress-strain state of reinforced concrete brackets of various structural forms for strengthening the crossbars of bridge supports which made it possible to determine the rational structural form of the reinforcement brackets for the cantilever sections of the crossbars as well as rational methods of their reinforcement.

Approbation of the results of the master's thesis.

The results of the work were tested on:

- "LIII All-Ukrainian Scientific and Technical Conference of the Faculty of Construction, Civil and Environmental Engineering (2024)", held on March 20-23, 2024 at VNTU, Vinnytsia, Ukraine.

- International scientific and practical Internet conference "Youth in science: research, problems, prospects (MN-2024)", held on November 15, 2023 to May 20, 2024at VNTU, Vinnytsia, Ukraine.

Publications.

1. Li Xiaohong. Overhaul of the crossbars systems of bridge supports with the installation of reinforced concrete brackets [Electronic resource] / V. Popov, D. Bayda, Xiaohong Li // Electronic scientific publications. Abstracts of the report at the LIII All-Ukrainian Scientific and Technical Conference of the Faculty of Construction, Civil and Environmental Engineering (2024) (Vinnytsia, 20-23.03.2024) – Electronic text data –

2024. P. 1350 – 1353. Link: https://press.vntu.edu.ua/index.php/vntu/catalog/view/832/1453/2726-1

2. Li Xiaohong. Strengthening the foundations of the primary ammonia reforming furnace in conditions without working free space using self-compacting concrete [Electronic resource] / V. Popov, Wenjun Sun, Xiaohong Li // Abstracts of the report at the International scientific and practical Internet conference Youth in science: research, problems, prospects (MN-2024), (VNTU) – Electronic text data – 2024. Link: https://conferences.vntu.edu.ua/index.php/mn/mn2024/paper/view/21531

CHAPTER 1 ANALYSIS OF THE CURRENT STATE OF THE THEORY AND PRACTICE OF STRENGTHENING OF BRIDGE BEARINGS

1.1 Bridge structures. Structural components of reinforced concrete bridge structures.

Reinforced concrete bridges, as an essential component of modern transportation infrastructure, play a crucial role in facilitating transportation between urban areas during the process of urbanization. Understanding the components of bridge structures is vital for devising effective reinforcement solutions. The structural components of bridge structures, particularly reinforced concrete bridges, are as follows.

1.1.1 Bridge Superstructure.

Zhou Hongfeng, Jiang Linhong, and Lu Chongjie (2024) pointed out in their study that the main structure of a bridge is a crucial component of bridge engineering, The bridge superstructure is a vital component of bridge engineering, directly influencing the safety, stability, and reliability of the bridge [1]. It encompasses the bridge deck, piers, and abutments, each serving important functions and collectively forming the fundamental support system of the bridge (Fig. 1.1).

Firstly, the bridge deck is the part of the bridge where vehicles travel, and its design and material selection are crucial. Generally, the bridge deck is composed of concrete or reinforced concrete, materials known for their excellent load-bearing capacity and durability, maintaining structural stability over prolonged periods of use.

To enhance vehicle safety, the bridge deck is often covered with non-slip materials, effectively preventing vehicles from skidding on wet or water-covered surfaces, thus reducing the occurrence of traffic accidents.

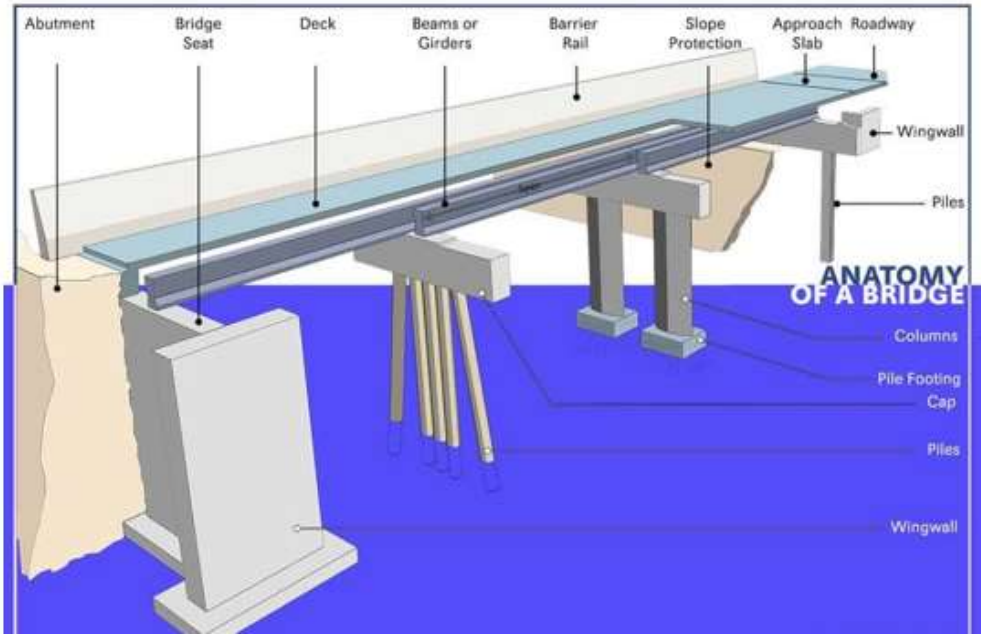

Figure 1.1 – Bridge Superstructure

Next, the piers are the vertical support elements of the bridge superstructure. Piers bear the loads from the bridge deck and transfer them to the abutments or foundations. Piers are typically constructed using poured concrete, a material with good compressive and flexural strength capable of withstanding significant loads from the bridge deck. The shape and dimensions of piers are determined by the span and loads of the bridge. Engineers design piers accordingly to ensure they can withstand anticipated loads and maintain structural stability.

Lastly, the abutments are the horizontal structures that connect the piers with the bridge deck. Abutments play a crucial role in distributing and transferring loads and are an indispensable part of the bridge superstructure. Abutments are also usually made of concrete, with design considerations for continuity and stability concerning the connected piers, ensuring the integrity and safety of the overall bridge structure.

Based on research, the bridge superstructure consists of the bridge deck, piers, and abutments, all collectively responsible for supporting bridge deck loads and transferring them to the piers and abutments. Through proper design and construction, the stability and reliability of the bridge superstructure can be ensured, providing safety for pedestrians and vehicles alike.

1.1.2 Bridge Bearings

Bridge bearings, though small in size, play a crucial role in bridge engineering. They are responsible for connecting the bridge superstructure to the substructure, bearing and transmitting various loads endured by the bridge, while allowing for corresponding displacements and deformations when subjected to external forces, ensuring the safe and stable operation of the entire bridge system[2]

Rubber bearings are a common type of bridge bearings (fig. 1.2).

Figure 1.2 – Bridge Bearings

Made from rubber material, they possess certain flexibility and elasticity, capable of absorbing and attenuating vibrations when the bridge is under load, serving as shock absorbers and cushions. The design of rubber bearings takes into account the load requirements of the bridge structure and the influence of the surrounding environment, ensuring their reliability and stability under various conditions.

Another common type of bridge bearing is the sliding bearing. It is typically composed of steel plates and sliding materials, with certain sliding properties. When the bridge is affected by external factors such as temperature changes or earthquakes, sliding bearings can generate corresponding sliding deformations, reducing stress concentration and damage to the structure, thereby safeguarding the overall safety of the bridge. The selection and design of sliding bearings need to consider the specific conditions of the bridge to ensure their normal operation under various working conditions[3].

Additionally, there are fixed bearings. Fixed bearings are usually used at the ends of bridges or in positions where no displacement is required. They securely fix the bridge superstructure, protecting it from external forces and ensuring the overall stability and safety of the bridge. The design of fixed bearings needs to consider the load characteristics of the bridge and the foundation conditions to ensure their effective load-bearing capacity and structural stability.

Bridge bearings, as important components of bridge structures, undertake crucial tasks of supporting, transmitting loads, and allowing for displacement and deformation. Different types of bearings play their unique roles in bridge engineering. Through rational selection and design, the safe and reliable operation of bridge systems can be ensured, providing solid assurance for people's travel and the circulation of goods.

The typical parameters and data of reinforced concrete bridge structural components are shown in Table 1.1.

The concrete strength used for the bridge deck is 30 MPa, which represents the compressive strength of concrete. The range of loads the bridge deck can withstand is between 20-80 kN/m^2, indicating that the bridge deck design considers various load conditions.

Table 1.1 – Typical Parameters and Data of Reinforced Concrete Bridge Structural Components

Bridge Structural Components	Typical Parameters	Data
Bridge Deck	Concrete Strength	30 MPa
	Load Range	20-80 kN/m²
Pier (support)	Dimensions	According to span and height variation
	Concrete Strength	40 MPa
Abutment	Dimensions	According to span and load variation
	Concrete Strength	35 MPa
Bearing	Type	Rubber bearing, sliding bearing, fixed bearing
	Function	Load-bearing, damping, displacement

The dimensions of the piers vary with changes in span and height, as different spans and heights require piers of different sizes for support. The concrete strength used for the piers is 40 MPa, slightly higher than that of the bridge deck concrete. The dimensions of the abutments also vary with changes in span and load to adapt to the support requirements under different conditions. The concrete strength used for the abutments is 35 MPa. The types of bearings include rubber bearings, sliding bearings, and fixed bearings, and the selection of these bearings depends on the specific design and functional requirements of the bridge. The functions of the bearings include bearing, damping, and displacement, and different types of bearings exhibit different performance in these aspects.

1.2 Reinforced concrete bridge support system and bearings. Review of constructive solutions.

1.2.1 Modern classification of bridge supports. (massive piers, column-type piers, multiple riser supports with crossbars).

In bridge engineering, bearings are crucial components that connect bridge piers (supports) and the bridge deck. Their functions include bearing the loads of the bridge and transmitting them to the piers, providing expansion and contraction movements of the bridge, and resisting external loads such as seismic forces. Reinforced concrete bridge supports, as a common type, have been widely used in engineering practice.

In bridge engineering, bearings are essential components that connect the bridge piers and the bridge superstructure. Their functions include bearing the load of the bridge and transmitting it to the piers, accommodating the bridge's thermal expansion and contraction, and resisting external loads such as earthquakes. Reinforced concrete bridge bearings, a common type, are widely used in engineering practice.

Bridge bearings can be categorized into various types based on their structural forms and functional characteristics. These include, but are not limited to, large bearings, column-type bearings, and multi-rise bearings with cross beams.

Bridge bearings can be classified into various types based on their structural forms and functional characteristics, including but not limited to large bearings, column-type bearings, and multi-rise bearings with crossbeams.

A) Large Supports

Large supports play a crucial role in bridge engineering, especially in large-span or special bridge structures. Their design not only needs to consider the specific load conditions of the bridge itself but also must meet strict requirements for the bearing structure. This type of support typically consists of multiple load-bearing units, allowing for flexible combinations according to the needs of the bridge structure to ensure overall stability and safety (fig. 1.3).

During the design and manufacturing process of large supports, engineers must consider multiple factors comprehensively. Firstly, load-bearing capacity is essential; large bearings must withstand various static and dynamic loads from the bridge itself and transportation processes.

Figure 1.3 – Large support (pier)

To ensure that the bearings do not fail or damage during long-term use, their load-bearing capacity must be accurately calculated and verified. Secondly, stability is crucial; large bearings need to maintain stability under various environmental conditions. This includes considering the stability performance of supports under extreme conditions such as earthquakes, wind forces, and temperature changes, as well as designing and reinforcing the support structure accordingly for seismic, wind, and temperature changes [4]. Additionally, adaptability is also an important consideration in the design of large supports. Due to the diverse requirements of different bridge projects, large bearings need to have a certain degree of flexibility and universality to adapt to different structural forms, load conditions, and foundation conditions.

In practical applications, the convenience of maintenance and cost-effectiveness of large bearings also need to be considered. Since large bearings are usually installed at the bottom of bridges or on support piers, maintenance and upkeep may be affected by traffic and environmental factors. Therefore, during the design phase, considerations should be given to the accessibility of bearing structures for inspection and maintenance, as well as the cost-effectiveness of maintenance, to ensure that the bearings remain in good condition throughout their service life.

B) Column-Type Supports (piers)

Column-type supports, as common and simple piers types in bridge engineering, constitute an essential part of bridge structures in terms of their structural design and functional characteristics. From the upper bearing surface to the lower columnar support body, each component of column-type supports plays a crucial role in providing necessary support and stability to the bridge structure (fig. 1.4).

Figure 1.4 – Bridge pier

In bridge design and construction, the application of column-type bearings offers numerous advantages such as simplicity in structure, low manufacturing costs, and easy installation and maintenance.

The structural features of column-type supports mainly consist of the upper support surface and the lower columnar support body. The upper bearing surface serves as the contact surface between the upper bridge structure and the bearing, with its design considering the connection method with the upper bridge structure and the load-bearing capacity of the bearing surface.

The lower columnar support body is the main part of the bearing, with its design and manufacturing considering aspects such as load-bearing capacity, stability, and seismic resistance of the bearing. This simple and practical structural design has led to widespread application of column-type bearings in bridge engineering.

The design principle of column-type supports is to ensure that the bearing plays a key role in providing stable support within the bridge structure. When designing column-type bearings, engineers need to consider factors such as the bearing's load-bearing capacity, stability, and adaptability. To ensure that the bearing can work stably and reliably throughout the bridge's service life, its design needs to undergo rigorous calculation and verification. Additionally, the design of column-type bearings also needs to consider factors such as the connection method with the upper bridge structure and the stability performance of the bearing under different environmental conditions, including seismic events, wind forces, and temperature changes.

The application scope of column-type supports also needs to be fully understood. Due to their advantages of simple structure, low manufacturing costs, and easy installation and maintenance, column-type bearings are widely used in small-span bridges or general road bridges. In these bridge projects, column-type bearings not only meet the basic requirements of bridge structures for bearings but also provide reliable support and assurance for the stable operation of the bridge.

Column-type bearings, as common and important bearing types in bridge engineering, play a crucial role in the stable operation of bridge structures in terms of their structural design and functional characteristics. With a deep understanding of the structural features, design principles, and application scope of column-type bearings, better understanding and application of this bearing type can be achieved, providing effective technical support and assurance for the design and construction of bridge engineering projects.

C) Multi-Rise Supports with Crossbars

Multi-rise supports with crossbars (crossbeams), as a type of bearing with complex structure and comprehensive functionality in bridge engineering, play an extremely important role. Their design concept and practicality are pivotal in modern bridge construction (fig. 1.5).

Figure 1.5 – Multi-layer support with beams

The distinguishing feature of multi-rise bearings with crossbars lies in their complex structure and robust functionality. Compared to traditional single-rise supports, multi-rise bearings with crossbars incorporate multiple adjustable piers units beneath the support surface, interconnected by crossbars, forming an integrated support system [5].

This structural design allows the bearings to adapt more flexibly to the expansion and contraction requirements of the bridge while also providing stronger seismic resistance.

The inclusion of crossbars not only enhances the overall stability of the bearings but also effectively distributes the loads of the bridge structure, enhancing its load-bearing capacity.

Multi-rise supports with crossbars find wide applications in bridge engineering, particularly in large-span bridges or high-speed railway bridges. These large-span bridges often face complex and variable environmental and load conditions, necessitating stringent requirements for the bearings. Multi-rise bearings with crossbeams can meet these high demands in bridge engineering, ensuring the safe and stable operation of bridge structures. High levels of technical expertise and equipment support are required during design and construction to ensure the stability and reliability of the bearing system[6].

Furthermore, multi-rise bearings with crossbeams offer several other advantages. For example, the adjustability of the bearing units allows for effective adjustment of the bridge's expansion and contraction movements, reducing structural stress and extending the bridge's service life. Additionally, the integrated design of the bearing system reduces construction difficulty and costs, thereby enhancing the project's economic efficiency.

As an important type of bearing in bridge engineering, multi-rise bearings with crossbeams possess complex structures and comprehensive functionalities. Their application in large-span bridges or high-speed railway bridges effectively enhances the stability and safety of bridge structures, making significant contributions to the development of transportation infrastructure.

In summary, reinforced concrete bridge bearings can be classified into various types based on their structural forms and functional characteristics, including large bearings, column-type bearings, and multi-rise bearings with crossbeams.

1.2.2 Modern classification of bridge bearings (elastomer bearings, cup bearings, sliding bearings, roller bearing systems).

A) Elastomer bearings

Elastomeric bearings are a common type in bridge engineering, and their design and application hold significant importance in modern bridge construction. These bearings are primarily made from rubber or other elastic materials, with their core function being to provide cushioning and damping between the bridge and its supports (fig 1.6). The following is an in-depth description of elastomeric bearings:

Figure 1.6 – Elastomer support

A.1) Characteristics of Rubber Materials. Elastomeric bearings typically use rubber materials due to their excellent elasticity and durability. Rubber materials can effectively absorb the deformation and vibrations generated under load, reducing adverse impacts on the bridge structure.

A.2) Structural Form. Elastomeric bearings usually have a circular or rectangular shape to fit the bridge's support structure. Their internal design is well-engineered to ensure stability and reliability under various loads.

A.3) Load Transfer Mechanism: The bridge load is transferred to the piers or other supporting structures through the bearings, where elastomeric bearings play a critical role. Their elastic properties allow for effective dispersion and cushioning of stresses during load transfer, thereby protecting the integrity and stability of the bridge structure.

A.4) Maintenance and Inspection: Compared to other types of bearings, elastomeric bearings have lower maintenance costs and a longer service life. Due to their simple structure and reliable performance, they are relatively easy and cost-effective to maintain and inspect regularly. Elastomeric bearings are widely used in various types of bridge engineering, including highway bridges, railway bridges, and special engineering projects [7].

Their flexibility and adaptability make them suitable for the diverse needs of different bridge projects.As a crucial component of bridge structures, elastomeric bearings play an important role in modern bridge engineering. Their excellent elastic properties, stable structural design, and low maintenance costs make them one of the preferred types in bridge bearing design.

B) Cup bearings

A pot bearing is a specially designed bridge bearing named for its shape, which resembles an inverted cup. The design of this bearing primarily focuses on supporting the bridge and providing damping effects. In bridge engineering, the choice of bearing is crucial because it directly affects the stability, reliability, and load-bearing capacity of the bridge. Pot bearings are typically made of metal or rubber and feature a precisely engineered internal structure that can withstand vertical loads from the bridge and transfer them to the piers or other supporting structures. Compared to traditional bearings, pot bearings offer superior damping and cushioning effects, effectively absorbing the vibrations and deformations generated under load, thereby protecting the bridge structure from damage (fig. 1.7).

Figure 1.7 – Cup-shaped support.

In modern bridge design, the application of pot bearings is becoming increasingly common, especially in regions where external environmental factors such as earthquakes must be considered.

Their advantages include simple structure, easy installation, and stable, reliable performance. Additionally, pot bearings have a long service life and low maintenance costs, making them one of the preferred choices in bridge engineering. As a crucial component in modern bridge engineering, pot bearings provide important assurance for the stable operation and safe passage of bridges with their unique design and excellent performance. In future bridge design and construction, pot bearings will continue to play a significant role, contributing to the development and advancement of bridge engineering.

C) Sliding bearings

A sliding bearing is a common type of bridge bearing designed to address horizontal displacement issues caused by temperature changes, earthquakes, and other factors. It is typically composed of metal plates and low-friction materials, such as polytetrafluoroethylene (PTFE), which have a low coefficient of friction to allow the bridge to slide freely in the horizontal direction [8]. The main function of sliding bearings is to permit horizontal displacement of the bridge when under load, thereby alleviating stress concentrations caused by temperature variations and seismic activity. When the bridge is subjected to horizontal forces, the sliding bearing reduces the friction generated, allowing the bridge to slide relatively freely and thus reducing the stress on the bridge structure (fig. 1.8).

Figure 1.8 – Sliding support

Sliding bearings offer numerous advantages in bridge engineering. First, they effectively reduce the stress on bridge structures, enhancing the stability and safety of the bridge. Second, sliding bearings have a long service life and low maintenance costs, making them one of the preferred choices in bridge design. Additionally, the installation and replacement of sliding bearings are relatively simple, which can be done without interrupting traffic.

However, the design and application of sliding bearings need to consider several factors. For instance, the coefficient of friction and sliding distance of the bearings must be appropriately selected based on the specific design requirements of the bridge. Moreover, during the installation and replacement of sliding bearings, it is essential to ensure their levelness and sealing to guarantee their proper functioning [9].

As a modern type of bridge bearing, sliding bearings have significant application value. By reducing stress concentrations in the bridge structure, they improve the bridge's stability and safety. In future bridge design and construction, sliding bearings will continue to play a vital role, contributing to the development and advancement of bridge engineering.

D) roller bearing systems

In the modern classification of bridge bearings, rolling bearing systems play a critical role in bridge engineering. The design principles and practical applications of rolling bearing systems are of great significance for the stability and safety of bridge structures. Rolling bearing systems are a common type of bridge bearing, characterized primarily by their use of rolling bearing devices to support and transfer the loads of the bridge. Compared to traditional fixed bearings or sliding bearings, rolling bearing systems have a more flexible structure, allowing for a wider range of displacement and rotation under load [10].

In bridge engineering, rolling bearing systems typically consist of multiple rolling bearing units distributed on the bearing surface beneath the bridge supports. Each rolling bearing unit contains rolling balls or cylindrical rollers, which are specially designed to effectively reduce friction resistance when the bridge is under load, thereby reducing stress concentrations in the bridge structure.

The application range of rolling bearing systems is broad, including various types of bridge structures such as large-span bridges, highway bridges, and railway bridges. By reasonably designing and arranging the rolling bearing units, the load-bearing capacity and seismic performance of the bridge can be significantly improved, thereby extending the service life of the bridge. Additionally, rolling bearing systems have low maintenance costs and long service life, making them an important choice in bridge design. Compared to other types of bearing systems, rolling bearing systems are relatively easy to install and maintain, reducing the difficulty and cost of bridge maintenance work.

As one of the modern classifications of bridge bearings, rolling bearing systems have significant application value in bridge engineering. Through their special design and excellent performance, rolling bearing systems can effectively enhance the stability and safety of bridge structures, contributing to the development and advancement of bridge engineering.

1.2.3 A historical tour of the design of bridge supports and bearings in China and around the world.

In the history of bridge bearings and support design in China and worldwide, bridge piers have played a crucial role as an essential component of bridge support structures. Bridge piers are vertical support structures in bridge engineering, primarily responsible for bearing the bridge's load and transferring it to the foundation. In ancient China, the design and construction of bridge piers have a long history. As early as the Shang Dynasty, over 3000 years ago, China began building stone arch bridges and wooden plank bridges, using stone piers to support the bridge structures. Over time and with advancements in technology, the design of ancient Chinese bridge piers became increasingly refined, resulting in many bridges with unique styles and artistic value.

In modern times, the design and construction of bridge piers focus more on structural stability and safety. Countries worldwide actively explore and apply innovative pier design solutions to optimize bridge structures. For example, Japan's "hollow pier" design uses hollow pier structures, which not only reduce the weight of the piers but also effectively enhance their seismic resistance. The United States' "cable-stayed pier" design employs a cable-stayed support method, enabling long-span bridge structures with excellent economic and technical performance.

Reinforced concrete bridge supports, as vital components connecting bridge piers and decks, have undergone a long developmental journey in their design and reinforcement. The designs of bridge supports and bearings in China and around the world have exhibited diverse characteristics at different historical periods, reflecting the technological levels and engineering requirements of different eras [11].

Ancient Chinese bridge engineering employed various forms of supports in design and construction (fig. 1.9), such as stone piers and stone seats, which to a certain extent met the engineering needs of the time.

Figure 1.9 – Typical support structure of ancient Chinese bridges

With the progress of science and engineering technology, reinforced concrete bridge supports gradually became mainstream. Since the 20th century, with the continuous expansion of bridge construction scale and the increase in spans, the design of bridge supports in China has undergone a transformation from simplicity to complexity, from tradition to modernity (fig. 1.10).

Especially in recent years, with the construction of large-span bridges and high-speed railways, innovations in the design of bridge bearings in China have continuously improved design levels and construction technologies, ensuring the reliability and safety of bridge engineering.

Figure 1.10 – Typical support structure of modern Chinese bridges

On a global scale, the design of bridge supports and bearings has also undergone a similar developmental trajectory. Different countries and regions have designed bridge piers and bearings with their own characteristics based on their engineering needs and technological conditions. For example, European countries emphasize the stability and seismic performance of bridge piers and bearing structures, adopting many advanced design concepts and construction technologies. The United States focuses on the economy of engineering and the convenience of construction in bridge piers and bearing design, proposing many innovative design schemes and construction methods.

Through a historical review of bridge bearing designs in China and around the world, it can be observed that technical exchanges and experience sharing in the field of bridge engineering among different countries and regions have promoted the development and progress of bridge engineering [12]. In the future, with the continuous development of technology and the changing demands of engineering, the design of bridge bearings will continue to evolve towards greater safety, economy, environmental friendliness, and intelligence, making greater contributions to the development of human society.

1.3 The main components of multi-post bridge supports (foundations, columns, crossbars, tie-rods, elastomeric bearings).

Multi-column bridge supports, as a common form of bearings, mainly consist of foundations, columns, crossbeams, tie rods, and elastomeric bearings. These components cooperate with each other to form a stable structure, providing solid support and reliable load-bearing capacity for bridges [13].

The foundation (fig. 1.11) of multi-column bridge supports is the load-bearing foundation of the piers, directly bearing the loads of the bridge structure and transferring them to the subsoil.

The design of the foundation needs to fully consider the bearing capacity of the subsoil, geological conditions, and the impact of the surrounding environment to ensure the stability and safety of the bearings.

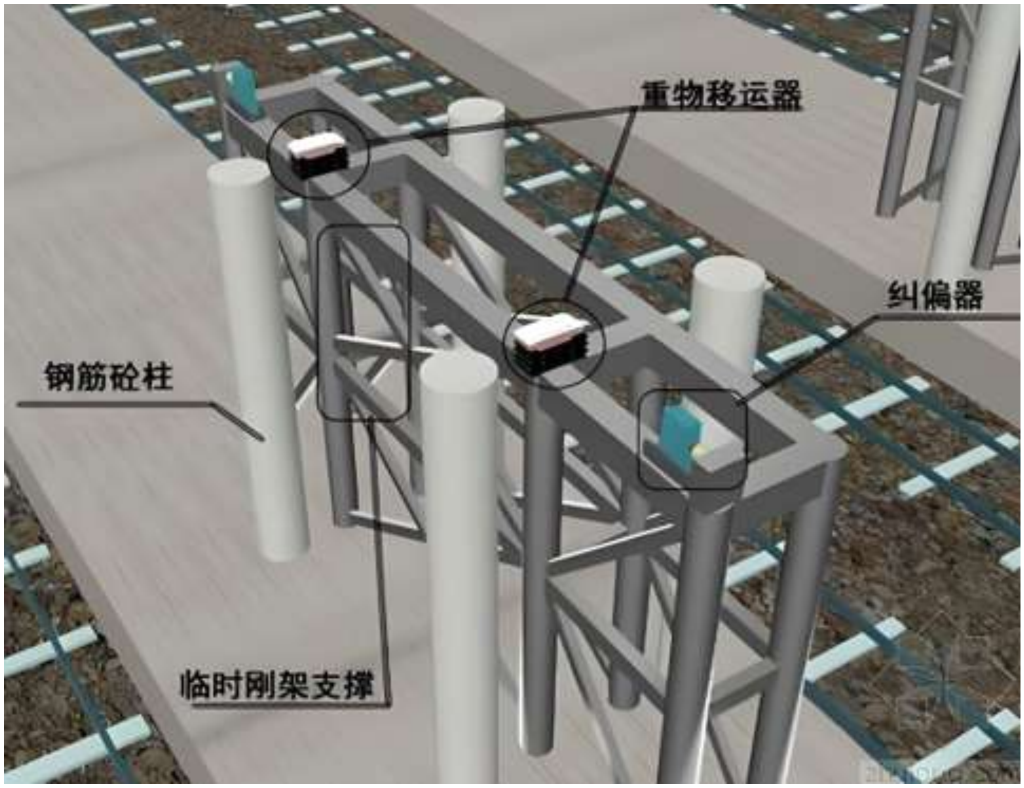

Figure 1.11 – Typical foundation for bridge support

Columns are the main load-bearing components of the supports, responsible for transferring the loads of the bridge structure to the foundation (fig. 1.12). The design of columns needs to consider the magnitude of the loads, the transfer path, and the stability of the structure. They are typically made of reinforced concrete or steel structures, providing sufficient strength and rigidity.

Crossbars (crossbeams) connect multiple columns, forming the main load-bearing framework of the bearings, and they bear the horizontal loads and moments of the bridge structure. The design of crossbeams needs to consider their stress performance and deformation characteristics under different load conditions. They are typically made of reinforced concrete or steel structures, providing sufficient stiffness and ductility.

Figure 1.12 – Typical piers supporting bridges

Tie rods are used to connect columns and crossbeams, enhancing the overall stability and load-bearing capacity of the bearings. The design of tie rods needs to consider their stress performance and connection methods. They are usually made of high-strength steel or prestressed concrete, providing sufficient strength and stiffness.

Figure 1.13 – Typical beams supported by bridges

Elastomeric bearings (fig 1.14) are located between the columns and the foundation, serving to cushion and transmit loads. The design of elastomeric bearings needs to consider their deformation characteristics and resilience under different load conditions. They are typically made of rubber, steel plates, or composite materials, providing sufficient deformation capacity and durability.

The main components of multi-column bridge supports together form a stable structure, providing reliable support and load-bearing capacity for bridges.

When reinforcing bridge bearings, it is necessary to comprehensively consider the structural characteristics and stress performance of these components and take appropriate reinforcement measures to enhance the safety and reliability of the bearings.

Figure 1.14 – Typical elastomer bearings for bridge support

1.4 Methods of strengthening existing reinforced concrete bridge supports

In the process of bridge maintenance and upkeep, reinforcing existing reinforced concrete bridge supports is one of the important means to ensure the safety and stability of bridge structures. The selection of reinforcement methods should be based on the specific condition of the bridge supports and the goals of reinforcement, employing appropriate technical solutions and measures. The following are methods for reinforcing existing reinforced concrete bridge supports:

A) Grouting is a common reinforcement method that involves injecting specific materials, such as cement grout or resin grout, into the interior of the support structure to fill voids, enhance the strength, and rigidity of the support. Grouting reinforcement can effectively repair cracks, increase the load-bearing capacity of the support, and improve its durability [14]. In practical operations, suitable grouting materials and process parameters should be selected based on the specific condition and reinforcement requirements of the support.

B) Clamping with increased section is a reinforcement method based on reinforcing steel plate clamps on the columns or beams of the support, and increasing the cross-sectional area of the clamp to enhance the load-bearing capacity and rigidity of the support. It is suitable for support structures under high stress or suffering from fatigue damage, effectively improving the bending and shear resistance of the support.

C) Impregnation with polymer composite materials is a method using lightweight and high-strength materials, whereby these materials are impregnated onto the surface or within the support structure to form a reinforcement layer, enhancing the strength, rigidity, and durability of the support. Its advantages include simple construction, low cost, and minimal impact on the structure, making it suitable for local reinforcement or repair of supports [15].

C) External reinforcement refers to attaching additional reinforcement components, such as steel plates, carbon fiber sheets, etc., to the exterior of the support structure. This is done to form a composite system with the support structure, thereby enhancing the overall load-bearing capacity and stability of the support. External reinforcement can effectively address issues such as uneven loading and fatigue cracking in the support structure, improving the support's seismic and wind resistance capabilities.

D) Adding supports and extra columns. In certain situations, to enhance the overall load-bearing capacity and stability of bridge supports, it may be considered to add supports and extra columns. This is done to increase the support points of the support and the rationality of the support layout. This reinforcement method needs to fully consider the stress characteristics of the support structure and the overall layout of the bridge, ensuring reinforcement effectiveness and construction safety [16].

For different bridge support issues and reinforcement needs, appropriate reinforcement methods can be selected. Based on scientifically effective reinforcement measures, the safety and reliability of bridge supports can be improved, extending their service life and ensuring the long-term operation of bridge structures. A comparison of reinforcement methods for existing reinforced concrete bridge supports is shown in the following Table 1.2.

Table 1.2 – Comparison of Methods for Reinforcing Existing Reinforced Concrete Bridge Bearings

Reinforcement Methods	Applicable Conditions	Advantages	Disadvantages
Grouting	Crack repair, enhancement of strength and stiffness, durability improvement	Simple construction, significant repair effect	Choice of grouting material, high construction technology requirements
Increasing the section of the clamp	The bearing structure is subjected to high forces and suffers from fatigue damage	Enhancing the load-bearing capacity and stiffness of the bearing, relatively simple construction	Requires significant space for construction, noticeable appearance after reinforcement
Impregnation with polymer composite materials	Local reinforcement or repair, improvement in durability	Lightweight, high strength, easy construction, minimal impact on structure	High material cost, need to ensure consistent impregnation quality and layer thickness
External Reinforcement	Uneven structural stress, fatigue cracks exist	Enhancing overall load-bearing capacity and	Significant impact on traffic during

		stability, relatively simple construction	construction, high material cost
Adding supports and additional columns	Improving overall load-bearing capacity and stability, rational layout	Reasonable structural layout, increased support points, improved stability	Increased construction cost and duration, significant impact on existing structure

1.5 Conclusions on chapter 1 (regarding the necessity of researching methods of strengthening bridge bearings, in general, and bearing crossbars, in particular)

Bridges are crucial transportation hubs in cities, and their safety directly impacts urban transportation and economic development. Within bridge structures, bridge supports serve as vital components connecting bridges to their foundations, making their stability and safety paramount. Based on the findings of this study, the following conclusions can be drawn:

1. Necessity of Reinforcing Bridge Supports: As the operational lifespan of bridges increases and traffic loads grow, issues such as cracking and deformation often arise in bridge supports, significantly affecting bridge safety and service life. Therefore, reinforcing bridge supports is of crucial practical significance and urgency, as it can extend the lifespan of bridges and ensure smooth and safe transportation [17].

2. Importance of Reinforcing Support Beams: Support beams, as integral components of support structures, directly influence the overall structural safety of bridges. Addressing issues such as cracking and deformation in support beams requires appropriate reinforcement measures. The method discussed in this study, which involves using polygonal reinforced concrete brackets to reinforce support beams, provides important technical support and guidance for practical engineering projects.

In summary, reinforcing bridge supports is a crucial measure to ensure the safe and stable operation of bridges. Particularly in the context of reinforcing support beams, factors such as structural safety, stability, and cost-effectiveness need to be comprehensively considered to ensure reinforcement effectiveness and long-term operational stability. Research and practice in reinforcing bridge supports will provide essential technical support and guidance for ensuring bridge safety and extending their service life.

CHAPTER 2 SUGGESTED CONSTRUCTION SOLUTIONS OF BRACKETS TO CROSSBAR SYSTEM. MODELING

2.1 Possible forms of brackets

2.1.1. Rectangular bracket.

Rectangular supports are a commonly used structural form in bridge reinforcement, offering advantages such as simple structure, clear force distribution, and ease of construction. In bridge bearing reinforcement projects, rectangular supports effectively transfer the loads from the upper part of the bridge to the lower structure, providing support and reinforcement.

When designing rectangular supports, it is necessary to determine their dimensions and reinforcement. The size design should be based on the bridge's width, length, and the loads it needs to bear. Typically, the width of the support should match the width of the bridge to ensure effective support. Regarding length, it is crucial to consider the stability and load-bearing capacity of the support, avoiding lengths that are too long, which could reduce stability, or too short, which might not meet the support requirements.

In terms of reinforcement design, the principles of reinforced concrete structure design are applied to calculate the diameter, spacing, and arrangement of the steel bars. The primary purpose of reinforcement is to enhance the load-bearing capacity and deformation performance of the support, ensuring it does not fail during use[18].

To verify the load-bearing capacity and stability of rectangular supports, finite element analysis (FEA) is conducted. By establishing a finite element model of the support and applying loads consistent with actual conditions, the stress distribution, deformation, and potential failure modes under load can be determined. These analysis results are of significant importance for optimizing the design and ensuring construction safety.

The design parameters of the rectangular bracket are shown in Table 2.1.

Table 2.1 – Design parameters of rectangular bracket

Parameter name	Symbol	Numerical value	Unit
Bracket width	B	2.0	m
Bracket height	H	1.5	m
Steel bar diameter	d	25	mm
Rebar spacing	s	150	mm

Based on the basic principles of reinforced concrete structure design, the area of steel bars required for the bracket is calculated to ensure that its load-bearing capacity meets the requirements. The specific formula is as follows:

$$As = \frac{M}{fy \cdot d \cdot (h_0 - \frac{x}{2})} \tag{2.1}$$

Among them, As is the area of the steel bar, M is the applied bending moment, fy is the yield strength of the steel bar, d is the effective height of the beam, h0 is the total height of the beam, and x is the depth from the compression surface to the neutral axis.

Through finite element analysis, the stress distribution cloud diagram and deformation diagram of the bracket under load are obtained. These graphics visually display the stress and possible failure modes of the bracket, providing a basis for optimized design.

During the construction process, the quality of concrete pouring for the supports was also strictly controlled to ensure that the concrete reached the design strength. At the same time, the processing and arrangement of steel bars are also precisely controlled to ensure the overall performance of the bracket.

As a simple and effective reinforcement structure, rectangular brackets have wide application value in bridge reinforcement projects. Through reasonable design and construction control, the safety and stability of the bridge can be effectively improved.

2.1.2. Trapezoidal bracket.

In bridge reinforcement projects, trapezoidal supports serve as an important structural form, with their unique geometric shape providing excellent stability while ensuring sufficient load-bearing capacity.

A) Design Principles of Trapezoidal Supports.

The design of trapezoidal supports is based on their geometric properties and principles of structural mechanics. The trapezoidal shape, with a wider bottom and a narrower top, allows for more effective stress distribution and reduction of stress concentration by utilizing the inclined angle of the slanted sides when subjected to vertical loads. This enhances the load-bearing capacity of the support while also improving its stability due to the wider bottom structure.

B) Design Parameters and Calculations of Trapezoidal Supports.

The design parameters of trapezoidal supports mainly include the height (H), top width (a), bottom width (b), slant angle (θ), and reinforcement. These parameters are precisely calculated based on factors such as the actual loads, span , and support dimensions of the bridge.

The dimension calculations of trapezoidal supports must meet the support requirements of the bridge while considering construction conditions and costs. The height (H) is typically determined based on the span of the bridge and the load conditions of the support. The top width (a) and bottom width (b) are determined based on the width of the bridge and the dimensions of the support. The selection of the slant angle (θ) considers the stability of the support and construction convenience.

Reinforcement design is a crucial aspect of trapezoidal support design, involving calculations based on the principles of reinforced concrete structure design and considering the dimensions and load conditions of the support. This includes determining the diameter, spacing, quantity, and arrangement of the steel bars to ensure sufficient load-bearing capacity and deformation performance of the support.

For flexural members with trapezoidal sections, their normal section flexural bearing capacity needs to satisfy the following formula:

$$Mu \leq f_c \cdot b \cdot x \cdot (h_0 - \frac{x}{2}) + f_y \cdot A_s \cdot (h_0 - \frac{x}{2}) \quad (2.2)$$

Among them, Mu is the ultimate bending moment, f_c is the compressive strength of concrete, b is the average width of the trapezoidal section, x is the height of the compression zone, h_0 is the effective height of the section, f_y is the tensile strength of the steel bar, A_s is the steel bar section in the tension zone area [19].

To more accurately assess the load-bearing capacity and stability of trapezoidal supports, finite element analysis software was used to model and simulate the supports. In the modeling process, factors such as the geometric shape, material properties, boundary conditions, and loads of the supports were considered. Through finite element analysis, the stress distribution, deformation, and potential failure modes of the supports under loading were obtained.

As an effective form of bridge reinforcement, trapezoidal supports have extensive prospects in bridge reinforcement projects. Through rational design and construction control, trapezoidal supports significantly enhance the safety and stability of bridges, providing strong guarantees for transportation. In future bridge reinforcement projects, further exploration of optimized design and construction methods for trapezoidal supports will better meet engineering requirements.

2.1.3. Polygonal shape.

In bridge reinforcement projects, selecting the appropriate form of support is crucial for ensuring the stability and safety of bridge structures. Polygonal reinforced concrete supports, as an innovative reinforcement method, have gradually gained attention in the engineering community due to their unique geometric characteristics and superior mechanical properties [20].

The design of polygonal supports should be based on the specific structure, loading characteristics, and reinforcement requirements of the bridge. The following principles should be considered during the design process:

1. The geometric shape of the support should be coordinated with the bridge structure to ensure uniform loading and reduce stress concentration.

2. The material of the support should meet the requirements for strength, stiffness, and durability, ensuring that no damage occurs during long-term use.

3. The connection between the support and the bridge should be reliable and capable of withstanding various loads transmitted by the bridge.

To evaluate the performance of polygonal supports in bridge reinforcement, finite element method (FEM) modeling analysis is adopted. The finite element method is a numerical analysis method that discretizes continuous bodies into a set of finite elements and solves parameters such as stress and strain for each element.

Firstly, a three-dimensional geometric model of the polygonal support is established based on the actual dimensions and reinforcement requirements of the bridge. Parameters such as the side length, angles, and height of the polygonal support can be adjusted according to actual conditions. the modeling process, the connection method and constraints between the support and the bridge should be fully considered.

Material properties for each element are defined based on the type and performance requirements of the support, including elastic modulus, Poisson's ratio, density, and yield strength [21]. For reinforced concrete supports, the compressive strength of concrete and the tensile strength of steel reinforcement should also be considered.

Appropriate loads are applied according to the actual loading conditions of the bridge, including static loads, dynamic loads, and temperature loads. At the same time, reasonable boundary conditions, such as fixed constraints, sliding constraints, and elastic constraints, are set to simulate the interaction between the support and the bridge.

The support model is divided into a mesh to discretize the model into finite elements. Mesh division should fully consider the geometric features of the model and the accuracy requirements of the calculations. Then, finite element software is used to solve the model and calculate such parameters as stress, strain, and displacement for each element.

Loads and boundary conditions are important factors affecting the performance of the support. During the modeling process, the actual loading conditions and constraints of the bridge should be fully considered to simulate the real working environment. By comparing the calculated results under different loads and boundary conditions , the performance of the support under different conditions can be evaluated.

Table 2.2 – Comparison of polygonal bracket parameters

Bracket shape	side length (m)	Angle (°)	High (m)	elasticity Modulus (GPa)	Poisson's ratio	density (kg/m³)	yield Strength (MPa)
rectangle	2.0	90	3.0	30	0.2	2500	350
trapezoid	2.0-3.0	90	3.0	30	0.2	2500	350
polygon	2.0-2.5-2.0	60-120	3.0	30	0.2	2500	350

From the above analysis, it can be seen that polygonal reinforced concrete supports have good application prospects in bridge reinforcement.

2.1.4. Curvilinear shape.

In bridge support reinforcement projects, curved-shaped supports, as an innovative solution, are designed not only considering the stability of the structure but also taking into account the mechanical transmission efficiency and the overall aesthetics of the bridge. , especially under complex loading conditions, relies on precise mathematical models and calculation methods to ensure their effectiveness in practical applications.

The design of curved-shaped supports is primarily based on the geometric dimensions of the bridge support and the expected loads. Common curved shapes include arcs, parabolas, ellipses, etc., each with specific applications in bridge engineering. For instance, arc supports provide uniform radial support forces, while parabolic or elliptical supports may have higher mechanical efficiency under certain load distributions.

In the design process, a parametric modeling approach is employed, adjusting parameters such as radius, center position, start and end angles of the curve to generate various possible shapes of curved supports. The selection of these parameters is based on the actual conditions of the bridge, such as span, height, load distribution, etc.

To evaluate the mechanical performance and stability of different curved-shaped supports, finite element method (FEM) modeling and analysis are adopted. The finite element model considers the geometric shape, material properties, boundary conditions, and load situations of the support [22]. In the modeling process, the support is divided into small mesh elements, and the mechanical response of each element is described by mathematical equations.

Static and dynamic analyzes are conducted separately for each type of curved-shaped support. Static analysis is used to assess the stress and deformation of the support under static loads, while dynamic analysis evaluates the response of the support under dynamic loads such as seismic events and wind loads.

In static analysis, various loads borne by the bridge support, such as dead loads, live loads, and temperature loads, are considered. Through the finite element model, stress distribution, deformation, and support reactions of the support under these loads are calculated, which are crucial for assessing the load-bearing capacity and stability of the support.

In dynamic analysis, the effects of dynamic loads such as earthquakes and wind loads on the support are considered. The finite element model is used to simulate the vibration response and dynamic characteristics of the support under these loads, which are essential for evaluating the safety and reliability of the support under extreme conditions.

Through finite element analysis, a large amount of data on the mechanical performance and stability of different curved-shaped supports are obtained, including stress distribution, deformation, support reactions, vibration response, etc. To present these data more intuitively, they are organized into tabular form (see Table 2.3).

Table 2.3 – Data on the mechanical properties and stability of stents with different curve shapes

Bracket shape	Maximum stress (MPa)	Maximum deformation (mm)	Support reaction force (kN)	First-order natural frequency (Hz)
Arc bracket 1	200	5	1000	2.5
Arc bracket 2	180	4	950	2.7
Parabolic bracket 1	190	4.5	1050	2.6
Elliptical stand 1	185	4.2	1020	2.8

By comparing the data from different curved-shaped supports, it was found that certain shapes exhibit better mechanical performance and stability under specific load conditions. For instance, in some cases, arc-shaped supports may demonstrate lower stress and deformation, while parabolic or elliptical supports might exhibit higher mechanical efficiency under certain load distributions. These findings provide crucial insights for selecting suitable curved-shaped supports in practical engineering applications.

2.2 Modeling of a polygonal bracket under load using the finite element method.

In bridge bearing reinforcement projects, polygonal reinforced concrete brackets serve as an effective means of reinforcement, and their design must fully consider the stability, mechanical performance, and actual load conditions of the structure. Therefore, the finite element method (FEM) is adopted to model and analyze the mechanical response of polygonal brackets under load, ensuring the rationality and reliability of bracket design.

The finite element method is a computational technique based on mathematical approximation used to simulate and analyze the complex behavior of physical systems. In the field of bridge engineering, the finite element method is widely applied in structural analysis, stress calculations, deformation predictions, and so on. By discretizing a continuous body into a finite number of elements and establishing mechanical equilibrium equations on each element, the finite element method can accurately simulate the response of structures under loading.

The finite element modeling process of polygonal brackets includes several key steps:

Geometric modeling: Establish a three-dimensional geometric model of the polygonal brackets according to design requirements. The shape, size, and quantity of the polygonal brackets are determined based on the actual situation of the bridge bearings and reinforcement needs.

Material property definition: Define material properties for the finite element model of the polygonal brackets, including elastic modulus, Poisson's ratio, density, etc. These properties are determined based on the actual performance of the reinforced concrete materials used.

Mesh generation: Divide the geometric model of the polygonal brackets into small mesh elements. The density and shape of the mesh have a significant impact on the accuracy and efficiency of the calculations. A denser mesh is adopted in critical areas (such as stress concentration zones) to improve calculation accuracy.

Boundary condition setting: Set boundary conditions for the model according to the actual installation of the polygonal brackets. Typically, the bottom of the bracket is fixed, while the top is connected to the bridge bearings. Additionally, the interaction between the brackets and surrounding structures needs to be considered.

Load application: Apply corresponding loads to the finite element model based on the load conditions and reinforcement requirements of the bridge bearings. These loads may include static loads (such as dead loads, live loads), dynamic loads (such as vehicle loads, wind loads), and temperature loads, etc.

Solution and post-processing: Obtain the mechanical responses such as stress, strain, displacement, etc., of the polygonal brackets under loading by solving the finite element equations. Utilize post-processing tools to visualize the calculation results for analysis and evaluation of brackets performance.

In finite element analysis, the following formulas serve as the basis for calculating the mechanical response of polygonal brackets.

$$[K] \cdot u = F \tag{2.3}$$

where $[K]$is the stiffness matrix, u is the displacement vector, and F is the load vector.

Stress-Strain Relationship: Based on material properties, establish the relationship between stress and strain. For reinforced concrete materials, elastic or elastoplastic constitutive models are typically employed.

$$\sigma = E\varepsilon \tag{2.4}$$

where σ is the stress tensor, E is the elastic modulus tensor, and ε is the strain tensor.

Displacement interpolation function: Within the grid unit, the displacement value of the node is extended to the entire unit through the displacement interpolation function. This helps to establish a continuous displacement field inside the cell.

$$u(x) = \sum_{i=1}^{n} N_i(x) u_i \tag{2.5}$$

Among them, $u(x)$ is the displacement vector of any point x inside the unit, $N_i(x)$ is the shape function used for interpolation, and u_i is the displacement vector of the i -th node. n is the number of nodes of the unit.

Through finite element analysis, the mechanical response data such as stress, strain and displacement of the polygonal bracket under load were obtained. The mechanical responses of different polygonal brackets under the same loading conditions are as follows Table 2.4.

Table 2.4 – Mechanical responses of different polygonal brackets under the same loading conditions

Bracket type	maximum stress in metal parts （MPa）	maximum strain （με）	maximum displacement （mm）
Rectangular stand	250	1500	2.5
Ladder bracket	230	1400	2.3
Hexagonal bracket	220	1350	2.2
Round (curved shape) stand	210	1300	2.1

2.2.1 Modeling of a polygonal clip

For example have been developed, a model of the stress-deformation state of a crossbar of a bridge two-strut support, which is under the influence of a combination of permanent, temporary climatic and temporary technological loads from rolling stock. The model was developed for a real bridge structure, which is affected by wheel loads, which are simulated by NK-80 and A-11 trolleys. The territory where the example bridge is located is located in the 1st climatic zone and, according to the classification of [23] and is located in the 3rd wind, 4th snow and 3rd icy areas and has the following climatic characteristics: snow load – 1,400 kN/m^2; wind pressure – 0,5 kN/m^2; the thickness of the ice wall is 19 mm.

The bridge structure, which is taken as an example, is classified as a road of international importance. That is, the bridge structure located on this road belongs to the class of consequences (responsibility) - SS-3 (significant consequences), according to [24]. According to [25], we accept the consequences class - I (bridges of great social and economic importance). According to the table 4.3 [25] for the prefabricated monolithic bridge road structure, the design life is 80 years. When performing the calculations of the main load-bearing structures (class A), the reliability coefficient according to [25] = 1.05 should be taken into account.

According to the adopted design decisions, the span structure of the bridge structure is affected by:

- dead loads (own weight of the girder structure, transition plates, weight of handrails and barriers, weight of the beams and crossbars, weight of structures of road clothing and roadway waterproofing, load from sidewalks;

- live loads adopted in accordance with [25], which consist of the load on the carriageway (NK-80 and A-11) and the temporary load on the sidewalks from the crowd of people, which is 400 kg/m2;

- temperature, ice and other climatic effects.

Live load NK-80 is a four-axle truck with a standard load on 1 axle $P_n = 196\ кН$.

Live load A-11 – a two-axle cart with a standard load on 1 axle – $P_n = 9.81 \cdot 11 = 107.91\,(kN)$ + a strip of uniformly distributed load $V_n = 0.98 \cdot 11 = 10.78\ (kN / \text{m})$.

The undercarriage of T-shaped running beams are located on the structure of the crossbars in such a way that the axis of the undercarriage coincides with the axis of the crossbar. All crossbars are beams with a rectangular section of 1800 x 3680 (h) mm, 16.50 m long. The finite elements model of the structure of the bridge piers after strengthening the crossbar with a polygonal bracket is shown in Fig. 2.1 – 2.2.

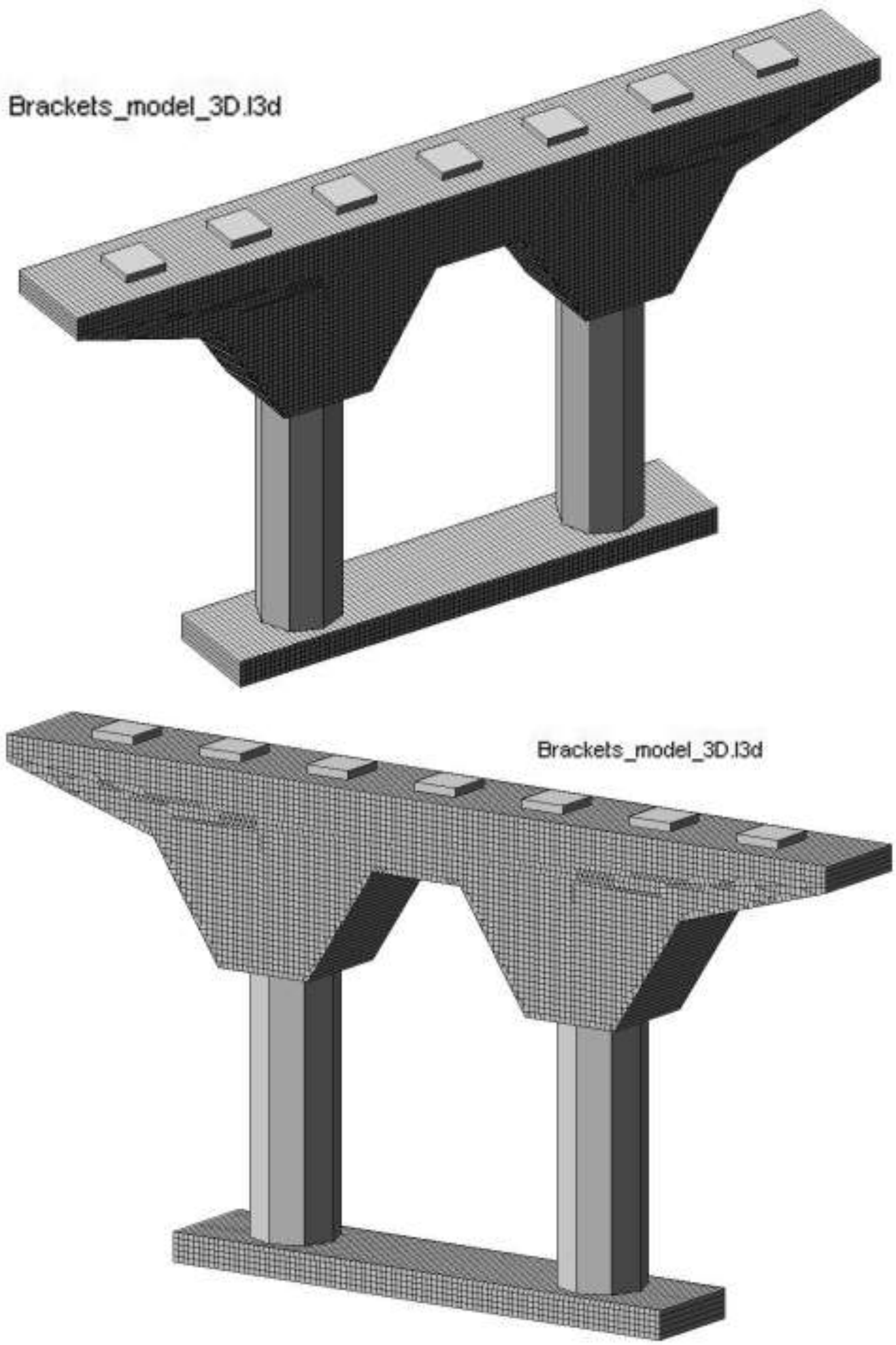

Figure 2.1 – 3D FEM model of stress strain staite of the crossbar with a polygonal bracket

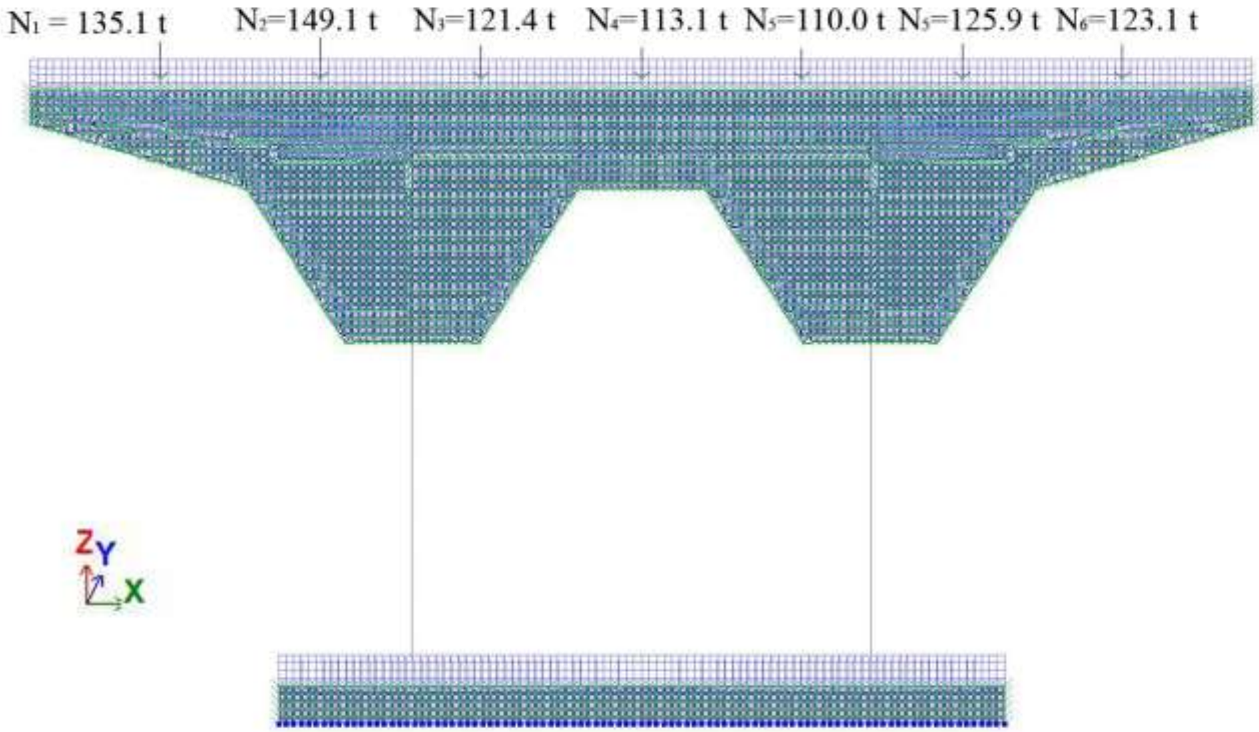

Figure 2.2 – Loads on the subfertilizers of the rod-plate model of the polygonal reinforcement bracket

The magnitude of the concentrated forces simulating the effect of span T-shaped beams (reactions in the supports) will depend on the location of the temporary moving influences (NK-80 or A-11). Two worst cases were considered (wheels of NK-80 or A-11 carts). For these two options, the vertical effects on the subfertilizers were calculated, using the influence lines, the absolute values of which, from left to right, are as follows:

For moving load NK-80: $N_1 = 1148\ kN$, $N_2 = 1424\ kN$, $N_3 = 1172\ kN$, $N_4 = 882\ kN$, $N_5 = 877\ kN$, $N_6 = 1093\ kN$, $N_7 = 1028\ kN$.

For moving load A-11: $N_1 = 1351\ kN$, $N_2 = 1491\ kN$, $N_3 = 1214\ kN$, $N_4 = 1131\ kN$, $N_5 = 1100\ kN$, $N_6 = 1259\ kN$, $N_7 = 1231\ kN$.

The most disadvantageous for the crossbar console is the combination of loads with A-11 loads + a crowd of pedestrians. We will perform the calculation for this combination (see Fig. 2.2).

The calculation of the stress-strain state of the bridge structure was performed by detailed modeling of the main elements in the form of a three-dimensional model using the "Lira-Windows" Software Complex, which is a computer system for structural analysis and design.

The theoretical basis of the used program is the finite element method (FEM). The implemented variant of FEM uses the principle of possible movements.

The model of the support of a bridge structure with a polygonal reinforcement bracket is adopted as a spatial system consisting of plate elements that simulate the operation of a crossbar, reinforcement brackets, and, also rod elements that simulate the operation of risers and tie-rods.

Physico-mechanical characteristics of shell and rod elements of the model. Poisson's ratio $\nu = 0,2$. We reduce the modulus of elasticity, towards the margin, according to the recommendations of methodological literature:

$E = 0,7 \cdot E_{cd}\left(B35\right) = 0,7 \cdot 25 \cdot 10^9 = 17,5 \cdot 10^9 \left(Pa\right)$. The density of reinforced concrete $R_0 = 2,500\ m / м^3$. The discretization step of the shell model is 100 x 100 мм.

The cross-sections of the rods are adopted in accordance with the actual cross-sections of the risers and sub-girders of the elements of the simplified geometric scheme (See Fig. 2.2).

In the calculation for the 1-st group of limit states, design loads were used, for the 2-nd group of limit states – operational loads.

2.3 Analysis of model calculation results. Definition of the dangerous areas.

In bridge bearing reinforcement projects, conducting a thorough analysis of the computed results after modeling polygonal reinforced concrete brackets using the finite element method is a crucial step. This not only helps assess the effectiveness of bracket design but also accurately identifies potential hazard zones, providing a scientific basis for subsequent reinforcement measures.

A) Stress distribution analysis. Firstly, attention is focused on the stress distribution of the brackets under loading. Stress is a critical indicator for evaluating structural strength and durability. The stress contour map obtained through finite element modeling visually displays the stress levels on different parts of the brackets. Typically, Areas with higher stress are more prone to cracking or failure, thus warranting special attention.

In rectangular brackets, stress concentration often occurs at the corners, making these areas particularly hazardous. While trapezoidal brackets improve stress distribution to some extent, stress concentration still exists near the sloping edges. Polygonal brackets, due to their numerous sides, exhibit relatively uniform stress distribution, but stress concentration may still occur at the vertices. Curved brackets, with their smooth curve characteristics, help reduce stress concentration, resulting in a more uniform stress distribution.

To assess the stress state of the brackets more accurately, stress data from key points are extracted for analysis. For instance, comparing the maximum stress values under the same load for brackets of different shapes and identifying the locations where maximum stress occurs. This data aids in identifying hazardous areas on the brackets and formulating appropriate reinforcement measures accordingly.

B) Displacement analysis. In addition to stress distribution, displacement of the brackets under loading is also an important indicator for evaluating their performance. The displacement contour map obtained through finite element modeling visually displays the displacement situation of different parts of the brackets[26]. Typically, areas with larger displacements may indicate inadequate structural stiffness or other potential issues.

In rectangular brackets, localized deformations caused by stress concentration at the corners may result in uneven displacement distribution. Trapezoidal brackets may experience larger displacements near the sloping edges, which could be related to stress concentration in that area. Polygonal brackets, due to their numerous sides , tend to exhibit relatively uniform displacement distribution. Curved brackets, with their smooth curve characteristics, help reduce displacement and improve the overall stiffness of the structure.

To assess the displacement situation of the brackets more accurately, displacement data from key points are extracted for analysis. For example, comparing the maximum displacement values under the same load for brackets of different shapes and identifying the locations where maximum displacement occurs. This data aids in identifying potentially problematic areas on the brackets and formulating appropriate reinforcement measures accordingly.

C) Modal analysis. In addition to static analysis, modal analysis of the brackets is also crucial. Modal analysis can reveal the vibration characteristics of the brackets under dynamic loads such as seismic events and wind loads, including natural frequencies, damping ratios, etc[23]. This information is vital for assessing the safety and reliability of the brackets under extreme conditions.

Through modal analysis, the natural frequencies and corresponding mode shapes of the brackets are obtained. Typically, the mode shapes corresponding to the lower natural frequencies have a significant impact on the structural dynamic response. Therefore, special attention is paid to the mode shapes corresponding to the lower natural frequencies to assess the performance of the brackets under dynamic loads.

If the natural frequency of a bracket coincides or closely matches with possible external excitation frequencies, resonance may occur at that frequency, leading to structural damage or failure. Hence, it's important to avoid such occurrences during the design process.

The maximum stress and maximum displacement values for brackets of different shapes under the same load conditions are provided in Table 2.5.

Thorough analysis of the finite element modeling results of polygonal reinforced concrete brackets enables the accurate identification of hazardous areas on the brackets, thereby facilitating the formulation of corresponding reinforcement measures.

Additionally, modal analysis provides crucial information for evaluating the performance of the brackets under dynamic loading conditions.

Table 2.5 – Maximum stress and maximum displacement values of brackets with different shapes under the same load conditions

Bracket type	Maximum stress (MPa)	Maximum stress position	Maximum displacement (mm)	Maximum displacement position
Rectangular stand	250	corner	2.5	corner
Ladder bracket	230	Near the hypotenuse	2.3	Near the hypotenuse
Hexagonal bracket	215	vertex	2.1	vertex
Round (curved shape) stand	205	Evenly distributed	1.9	Evenly distributed

These insights are vital for ensuring the safety and reliability of bridge bearing reinforcement projects. In future design and construction processes, it is imperative to fully consider these analytical results and continually optimize the design schemes of the brackets to ensure the safe operation of the bridge.

2.3.1 Analysis of the results of calculations of the example of a polygonal reinforcement bracket

As a result of finite-element calculations performed by software, have been determined the stresses in the plate elements that model the polygonal bracket of the bolt reinforcement (Fig. 2.3, 2.4).

As well as the deformation of the bracket structure (Fig. 2.5) were determined.

It follows from these figures that the greatest compressive stresses in the polygonal reinforcement bracket are concentrated in the corners of the shape fractures and and in places of adjacency to the pillars of the bridge support.

The highest tensile stresses are concentrated in the upper part of the polygonal bracket, where the working reinforcement was located near the defective crossbar.

However, the level of tensile stresses is significantly lower than before reinforcement. Therefore, the indicated system "defective bolt - polygonal clip - riser" can accept design loads.

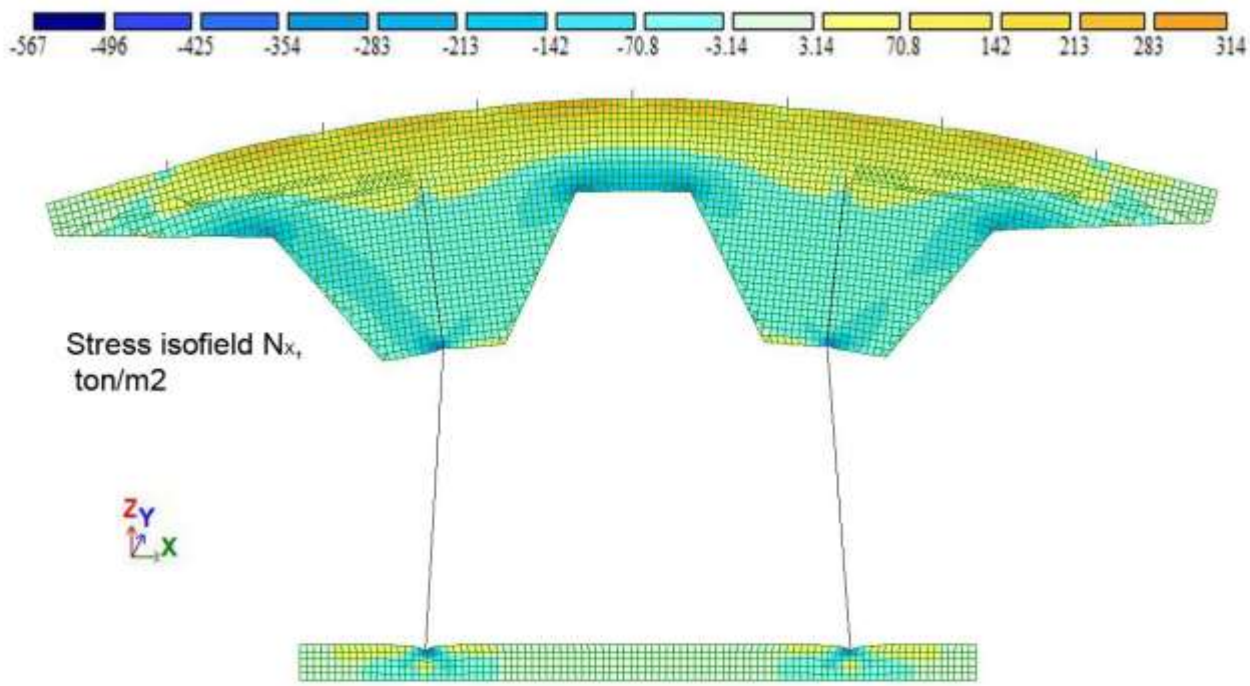

Figure 2.3 – Axial stresses in shell elements, t/m^2

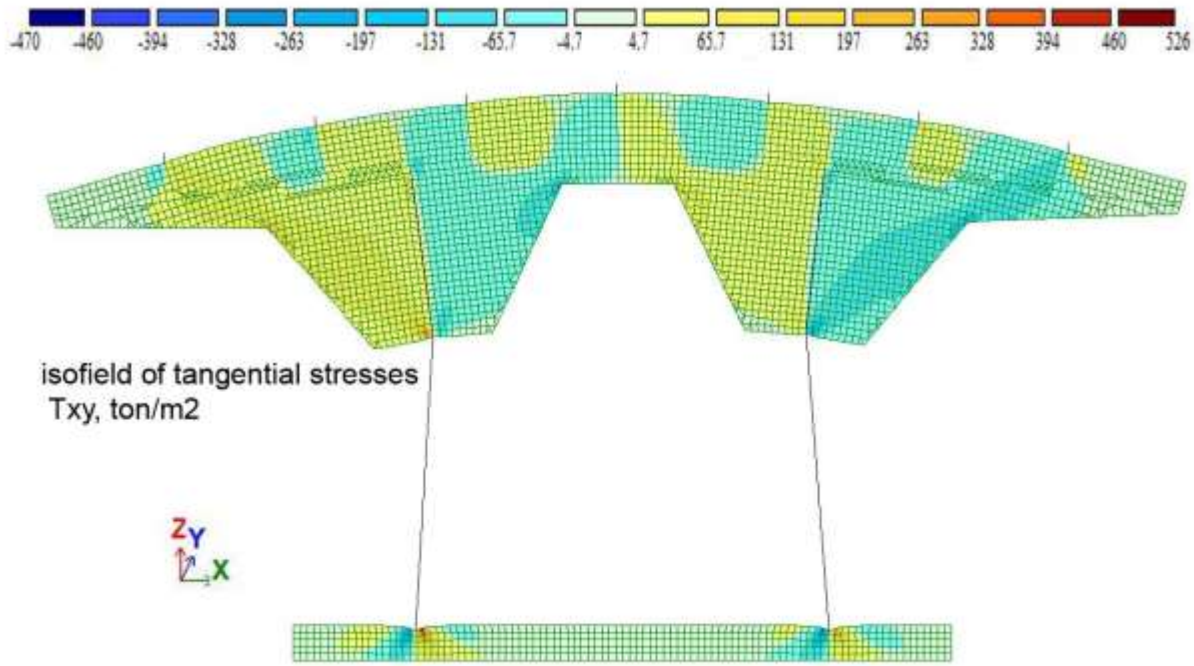

Figure 2.4 –Tangential stresses in shell elements of the model, t/m^2

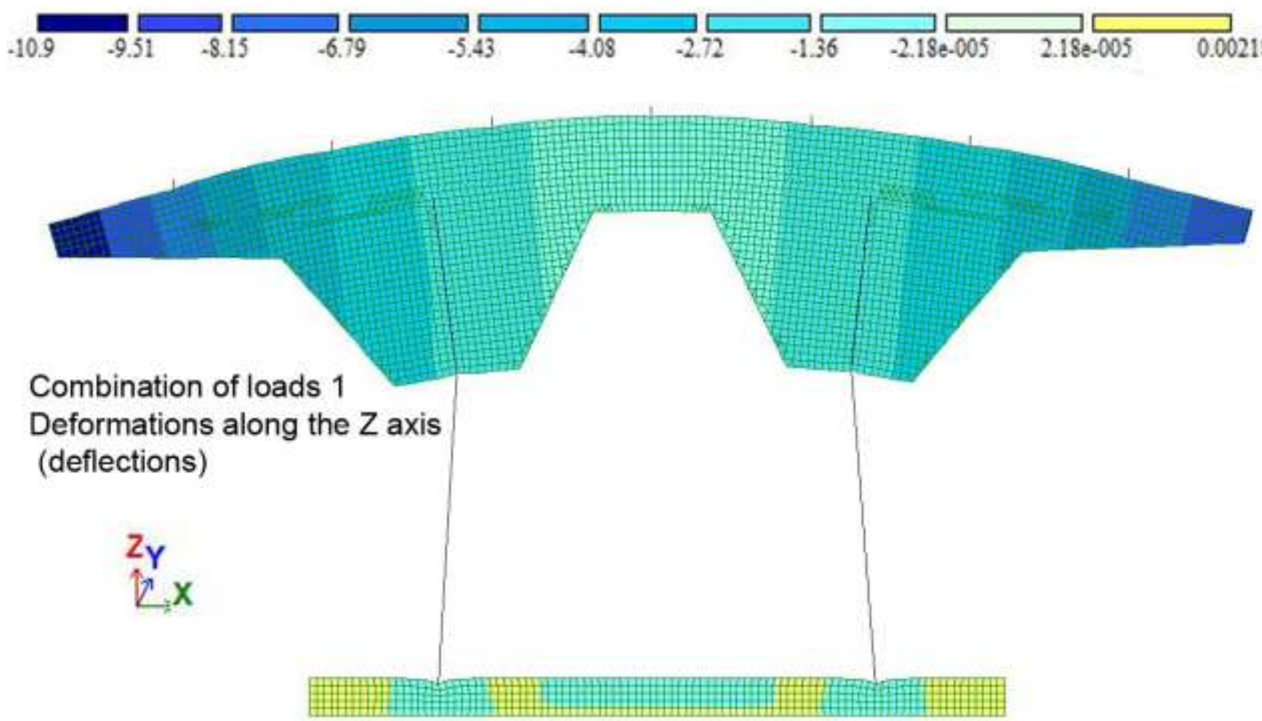

Figure 2.5 –Tangential stresses in shell elements of the model, t/m^2

The deformations of the reinforced structure are only 10.5 mm on the consoles, which is much less than the permissible deflections of the consoles (20 mm).

2.4 A rational design solution for reinforcing the bracket.

The completed finite element calculations allow you to follow the main structural dependencies in the design of rational structures of polygonal brackets.

The design of polygonal reinforced concrete in bridge reinforcement projects is undoubtedly important. But the design of auxiliary clamps connecting bridge supports and abutments is also important. And it cannot be ignored that these additional clamps must withstand the loads transmitted from the support. Even under load, it must be firmly connected to the bridge support. Therefore, in order to prevent slipping or sliding, the design of the reinforcement clamp must take into account structural strength, stability, and compatibility with the bridge support.

A) Reinforcement plan for the damaged section of the bridge.

The fig 2.6 shows a bridge section with several important parameters and dimensions marked. The bridge design consists of multiple piers and supporting structures. The spans and structures between each pier are clearly marked on the figure. Construction technology violations increase the burden of floods causing serious damage to beams. Affecting the stability and safety of the bridge. Uneven concrete pouring or irregular steel pouring. This leads to reduced structural strength due to the use of inappropriate materials or construction methods. The load shown in the bridge diagram is 122.5 kN, but the actual load is far more than the design value. This may increase the stress and deformation of the beam. The water flowing through the bridge damages the infrastructure of the bridge. Leading to steel corrosion and material deterioration. This makes the beam weaker. Beam damage includes cracking, peeling, and even breaking, which endangers the safety of the bridge. Regular inspection and maintenance of bridge structures, especially the beam part, is an important measure to ensure the long-term safe use of the bridge.

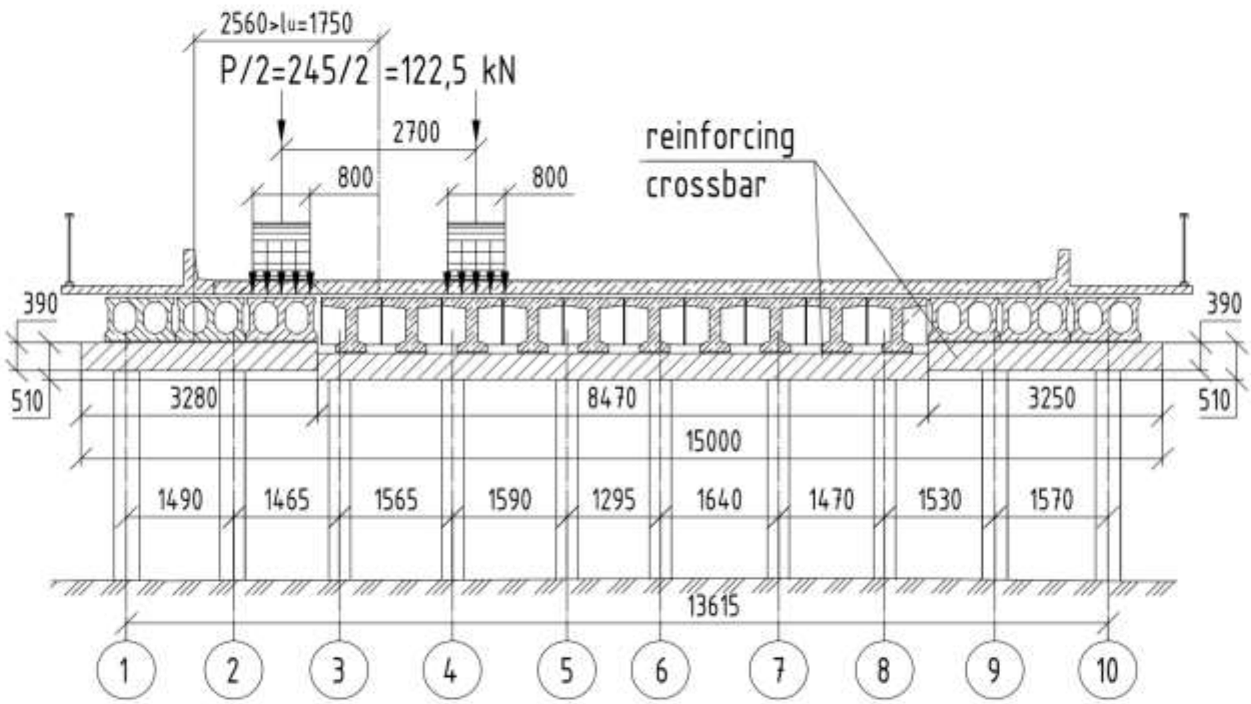

Figure 2.6 – Bridge cross section

The renovation project consists of four main components: the installation of a polygon reinforcement fence; Installation of additional anchors Preparation of additional materials for work and concrete injection To increase the load-bearing capacity Polygonal reinforcement brackets are spread along the beam. The anchors can withstand a load of 122.5 kN and a distance of 2700 mm Adhesive is used to secure the anchors to the concrete to ensure a strong connection to the beam. High grade steel is used as a reinforcing material for the job. fixed or connected to the frame by welding or tying To increase the strength of the structure

Finally, after entering all the optional parts. High strength concrete is injected to provide strength and stability. All concrete injections are done in layers. This ensures that each concrete layer is completely filled. Eliminate gaps and complete corrections.

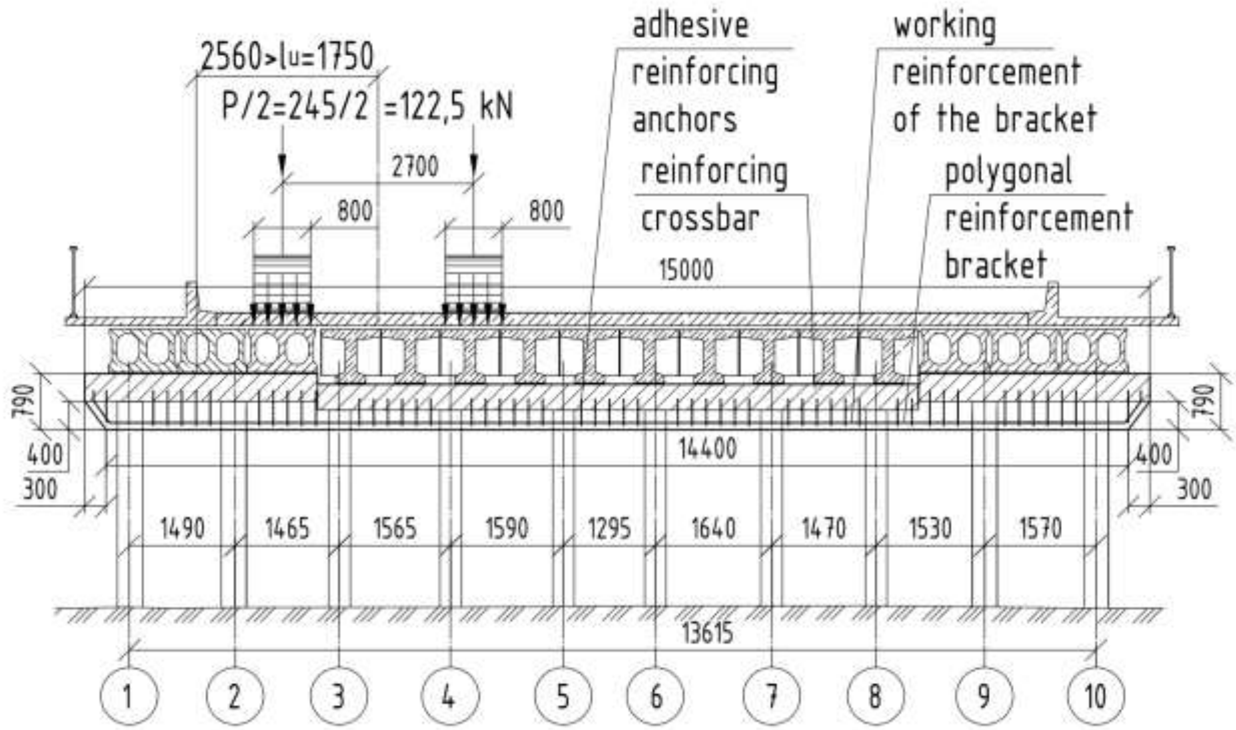

Figure 2.7 –Bridge Section Reinforcement Scheme

Calculation of relevant repair scheme:

Total bearing capacity of reinforced anchor bolts

$$F_{total} = 2 \times 122.5N = 245N$$

Total length of polygonal reinforcement bracket

$$L_{Bracket} = 15000mm$$

The number and weight of reinforcement bars

The diameter of the reinforcement bars is assumed to be 20 mm, and the weight of each meter of reinforcement bars is approximately 2.47 kg

The total length of the reinforcement bars is assumed to be the same as the length of the bracket, and a reinforcement bar is installed every 300 mm

$$N_{Rebar} = \frac{15000mm}{300mm} = 50root$$

$$W_{Rebar} = 50root \times 15m \times 2.47kg/m = 1852.5kg$$

Concrete area. Assume that the concrete pouring thickness is 100mm, covering the entire beam:

$$V_{Concrete} = 15000mm \times 2700mm \times 100mm = 405m^3$$

Conclusion. Through the above calculations and scheme design, the repair of the bridge beam will effectively enhance its bearing capacity and structural stability. In the specific implementation, adjustments need to be made according to the actual situation to ensure the construction quality and achieve the expected repair effect.

B) Being alone on the bridge.

This image shows a single deck bridge that was severely damaged in violation of construction regulations. Increasing the bridge load and water effects according to the parameters in the picture The bridge design consists of many columns and supporting structures. The dimensions and structure are as follows:

The total length of the bridge is 16,000 mm The distance between each pillar is 9,500 mm.

The T-beam of the bridge is arranged in four groups with a distance of 2,100 mm between them and each group can support a load of 122.5 kN.

The height of the bridge is 350 mm It is reinforced by a transverse reinforcement with a width of 700 mm.

The thickness of the top of the terminal is 900 mm, the height of the column is 8,100 mm (adjustable), the height from the top of the column to the ground is 8,900 mm.

The deck width is 2,300 mm, with one deck on each side of the bridge. The floor slab is supported by T-shaped steel.

The use of non-compliant materials or methods during construction, such as uneven concrete pouring and irregular steel bar laying, has led to a decrease in the strength of the bridge structure. The design load is 122.5 kN, but the load in actual use may far exceed the design value, increasing the stress and deformation of the beam. Water erodes the bridge foundation structure, causing steel corrosion and material degradation, further weakening the strength of the beam. Ultimately, the damage to the beam manifests as cracks, spalling, and even fractures, seriously threatening the stability and safety of the bridge. Regular inspection and maintenance of the bridge structure, especially the beam part, is an important measure to ensure the long-term safe operation of the bridge.

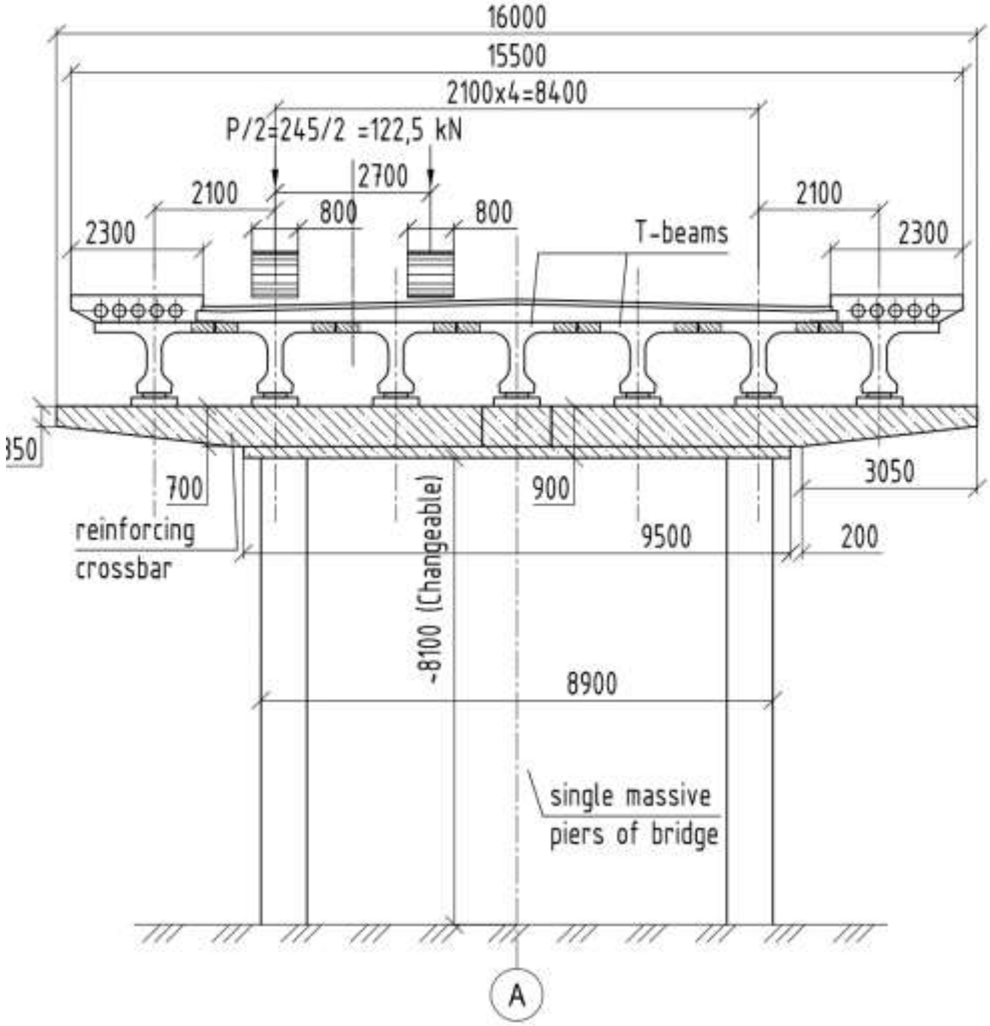

Figure 2.8 –Single squat bridge

To calculate the repair solution for adhesives, reinforcement anchors, and polygonal reinforcement brackets, you first need to know the specific information of each parameter. Here is the calculation process:

Total bearing capacity of reinforcement anchors

Assume that the individual bearing capacity of each reinforcement anchor is known as F KN. Based on the number of anchors shown in the drawing, we can calculate the total bearing capacity.

Assume that n anchors are used for each beam.

$$Total\ bearing\ capacity = n \times F$$

Assuming that the bearing capacity of each anchor is 100 kN and 10 anchors are used per beam:

$$Total\ bearing\ capacity = 10 \times 100 = 1000kn$$

The dimensions of the reinforcement bracket are shown on the drawing. Assume that the horizontal length of the bracket is$L_1 mm$, The length of the slope is$L_2 mm$, Overall length of bracket$L$ It is the sum of these two parts.

$$L = L_1 + L_2$$

$$L_1 = 3550mm \qquad L_2 = 2000mm$$

$$L = 3550 + 2000 = 5550mm$$

The number and weight of reinforcement depends on the size and spacing of the reinforcement used. Assume that the diameter of the reinforcement is dmm and the weight of each reinforcement is ωkg/m. Assume that the number of reinforcements used per meter is n.

Assuming a 20 mm diameter steel bar is used, unit weightω ≈ 2.47, Use 5 bars per meter.

$$\text{Weight per meter} = \text{n} \times \omega = 5 \times 2.47 = 12.35\text{kg/m}$$

The total length of the bracket is 5.55 meters, so the total weight is:

$$\text{gross weight} = 12.35 \times 5.55 = 68.93\text{kg}$$

4. Concrete area

The area of concrete depends on the geometry of the supports and beams. Assume that the total width of the concrete covered area is Bmm and the total height is Hmm.

as the picture shows

$$\text{B} = 900\text{mm} \qquad \text{H} = 3300\text{mm}$$

The area A of concrete is:

$$A = B \times H = 900 \times 3300 = 2.97 m^2$$

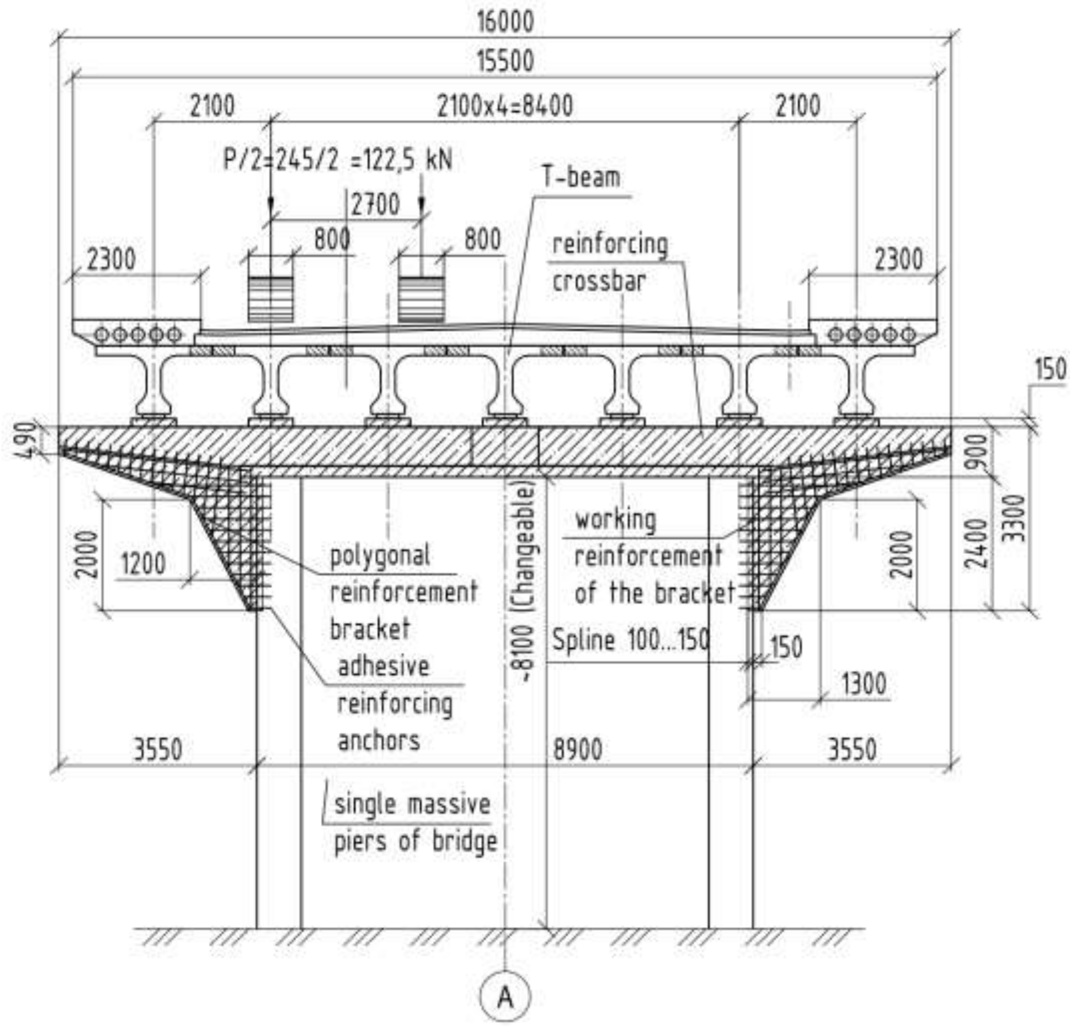

Figure 2.9 – Single squat bridge reinforcement plan

C) Double-pier bridge

Figure 2.10 shows a typical double-pier bridge. Due to technical violations in construction, increased bridge loads, and the damaging effects of water, the bridge beams were severely damaged, affecting the stability and safety of the bridge.

The bridge design includes multiple piers and supporting structures, and the spans and structures between each pier are marked in detail on the drawings. The main parameters of the bridge are as follows:

The total length of the bridge is 16000 mm, of which the effective span is 15500 mm.

The length of each T-beam is 2100 mm, and the total length of the four beams is 8400 mm.

The design load on the beam is 245 kN, distributed in two locations, with a load of 122.5 kN at each location and a spacing of 2700 mm.

The total height of the beam is 350 mm, and the height of the reinforcement beam under the beam is 700 mm.

The double-pier design of the bridge has a spacing of 6000 mm between the piers, a width of 1500 mm for each pier, and a height of about 7000 mm (variable).

The crossbeams of the bridge are supported by multiple T-beams and reinforced crossbeams. However, due to the use of non-compliant materials or methods during construction, such as uneven concrete pouring and non-standard steel bar laying, the structural strength is reduced. The bridge load marked in the figure is 122.5 kN, but the actual load may far exceed the design value, increasing the stress and deformation of the crossbeam. Water erodes the bridge foundation structure, causing steel corrosion and material deterioration, further weakening the strength of the crossbeam.

Damage to the crossbeam includes cracks, spalling and even breakage, threatening the safety of the bridge. Regular inspection and maintenance of the bridge structure, especially the crossbeam part, is an important measure to ensure the long-term safe operation of the bridge. Through reasonable repair schemes, including the use of adhesives, reinforced anchor bolts, polygonal reinforcement brackets and working reinforcement, the load-bearing capacity and overall structural strength of the crossbeam can be effectively enhanced, thereby ensuring the long-term stability and safety of the bridge.

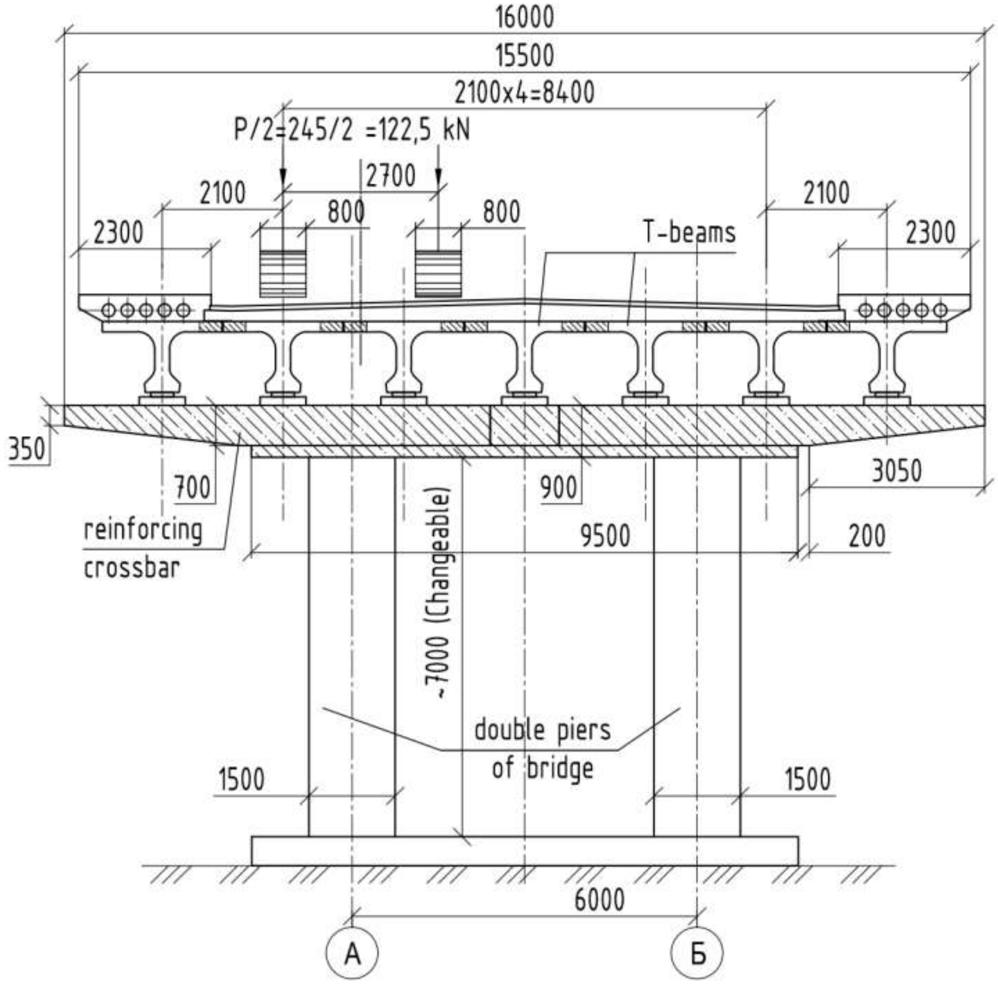

Figure 2.10 –Double Squat Bridge

Calculation of adhesive, reinforcement anchor bolts, and polygonal reinforcement brackets in the Shuangdun Bridge reinforcement scheme:

Total bearing capacity of the reinforcement anchor bolts

As shown in the figure, the bearing capacity of each anchor bolt is 245 kN, and the total bearing capacity of the two anchor bolts is 490 kN.

Total length of the polygonal reinforcement bracket

Transverse (horizontal distance between beams):

Length of each span: $2100mm + 800mm + 800mm + 2100mm = 5800mm$

Add the two end extensions: $2300\text{mm} + 2300\text{mm} = 4600\text{mm}$

Total horizontal length: $5800\text{mm} + 4600\text{mm} = 10400\text{mm}$

Longitudinal (vertical distance from beam to bottom of support column):

Length of each vertical segment: $2000\text{mm} + 1300\text{mm} = 3300\text{mm}$

The length of the hypotenuse at each end (assuming a 45 degree angle):

$$3300\text{mm} \times \sqrt{2} = 4667\text{mm}$$

Total vertical length: $3300\text{mm} + 4667\text{mm} = 7967\text{mm}$

Total length (horizontal + vertical): $10400\text{mm} + 7967\text{mm} = 18367\text{mm}$

Reinforcement quantity and weight

Calculate the length and weight of each rebar:

Length of each steel bar: $18367\text{mm} = 18.367\text{m}$

Cross-sectional area of steel bars:: $\pi \times (8\text{mm})^2 = 201.06\text{mm}^2$

Steel bar weight per meter: $201.06\text{mm}^2 \times 7.85g/cm^3 = 1.5783kg/m$

Total weight of each steel bar: $18.367\text{m} \times 1.5783\text{kg/m} = 28.96\text{kg}$

Total number and weight of reinforcement bars:

Assuming 10 reinforcement bars are required per meter, the number of reinforcement bars is:

Number of steel bars required per meter length: 10root/m

Total reinforcement quantity: $18.367 \times 10\text{root/m} = 183.67\text{root}$

gross weight: $18.367\text{root} \times 28.96\text{kg} = 5316.87\text{kg}$

Concrete area

Calculate the concrete pouring area:

Bottom area of the support:

Bottom area: $6000\text{mm} \times 200\text{mm} = 1.2\text{m}^2$

Bracket side area:

Area of left and right sides: $6000\text{mm} \times 1300\text{mm} = 7.8\text{m}^2$

Area of the front and back sides (considering the extended part of the polygon): $2850\text{mm} \times 1300\text{mm} = 3.705\text{m}^2$

Total concrete area:

The total area: $1.2\text{m}^2 + 7.8\text{m}^2 \times 2 + 3.705\text{m}^2 \times 2 = 24.21\text{m}^2$

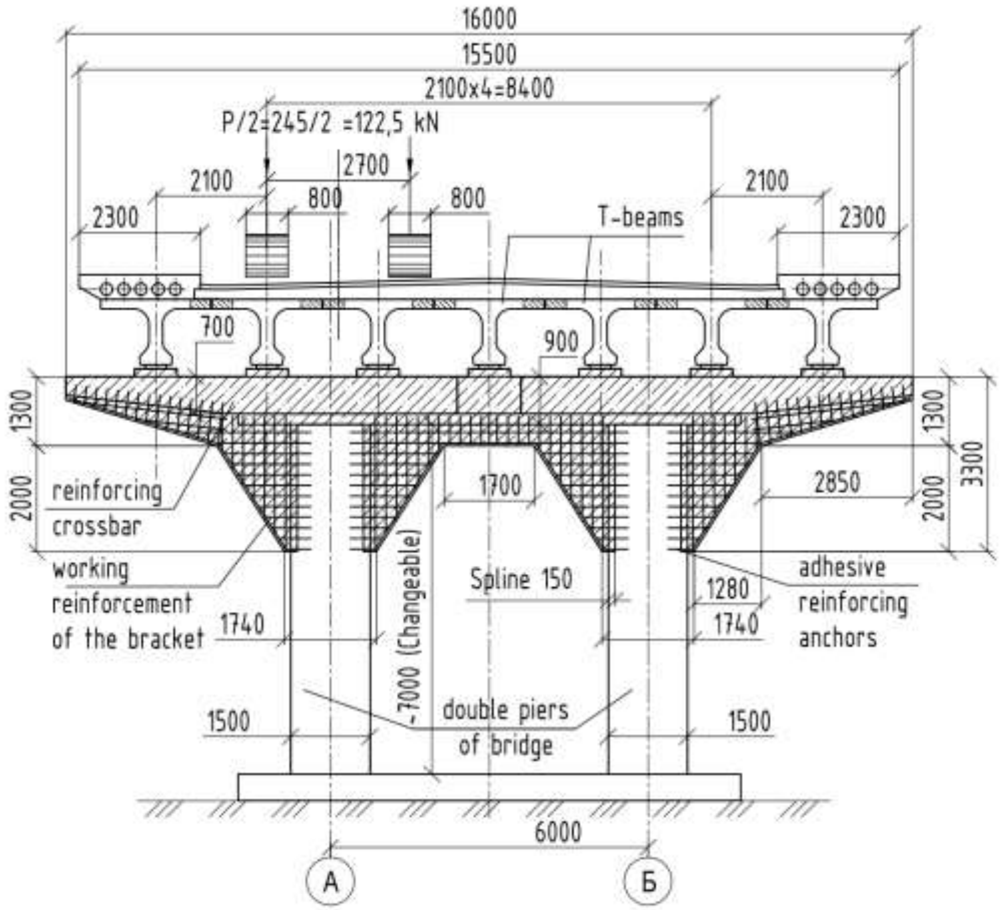

Figure 2.11 – Double Squat Bridge Reinforcement Solution

2.5 Conclusions on chapter 2.

A) After an in-depth discussion on the potential application of polygonal reinforced concrete brackets in bridge bearing reinforcement engineering, and modeling and analysis of their performance under load through the finite element method, the following conclusions are drawn:

B) Bracket form selection. When considering different shapes of brackets, we found that each shape has its own unique advantages and applicable scenarios. Rectangular stands are a reliable choice in many situations due to their simplicity and stability. Ladder brackets may perform better under certain special angles or diagonal supports. By increasing the number of sides, polygonal-shaped brackets can provide more uniform stress distribution and higher structural strength, and are suitable for scenes with higher requirements for load distribution. Curved brackets, on the other hand, have unique advantages in reducing stress concentration and increasing structural flexibility due to their smooth transition characteristics.

C) The Importance of Finite Element Modeling. Finite element modeling technology provides a powerful tool for evaluating the performance of differently shaped brackets under load. By simulating actual load conditions and boundary conditions, the stress distribution, displacement and dynamic response of the bracket can be accurately predicted, providing a scientific basis for bracket design and optimization [27]. The application of this technology not only improves design efficiency, but also reduces test costs and ensures the feasibility and safety of the reinforcement project.

D) The rationality of reinforced clip design. Reinforcement clips are a key component connecting brackets and bridge supports, and their reasonable design is directly related to the success or failure of the reinforcement project. By considering factors such as structural strength, stability, compatibility, and constructability, reinforcement clips can be designed that both meet mechanical requirements and are easy to install. In addition, the performance and service life of reinforced clips can be further improved by optimizing material selection, structural improvements, and anti-slip treatments.

E) Comprehensive consideration of construction solutions. Aspects such as bracket form, finite element modeling results, and reinforcement clip design were considered when formulating a construction solution. By comparing and analyzing the advantages, disadvantages and applicable scenarios of different solutions, we can choose the solution that best suits the current engineering needs. At the same time, attention should also be paid to quality control and safety management issues during the construction process to ensure the smooth implementation and completion quality of the reinforcement project.

CHAPTER 3 RATIONAL TECHNOLOGY OF BRACKETS PRODUCTION

3.1 Effective formwork systems

Considering the method of strengthening bridge supports on polygonal reinforced concrete supports, There is no doubt that the design of the formwork system is an important part in all production processes. It is not the construction system that determines the accuracy and efficiency of the frame construction. But it affects the overall quality and cost of the rehabilitation program. In this section we describe the design and operation of an effective manufacturing system. It focuses on the two-step structural integration process shown in Fig 3.1 and 3.2.

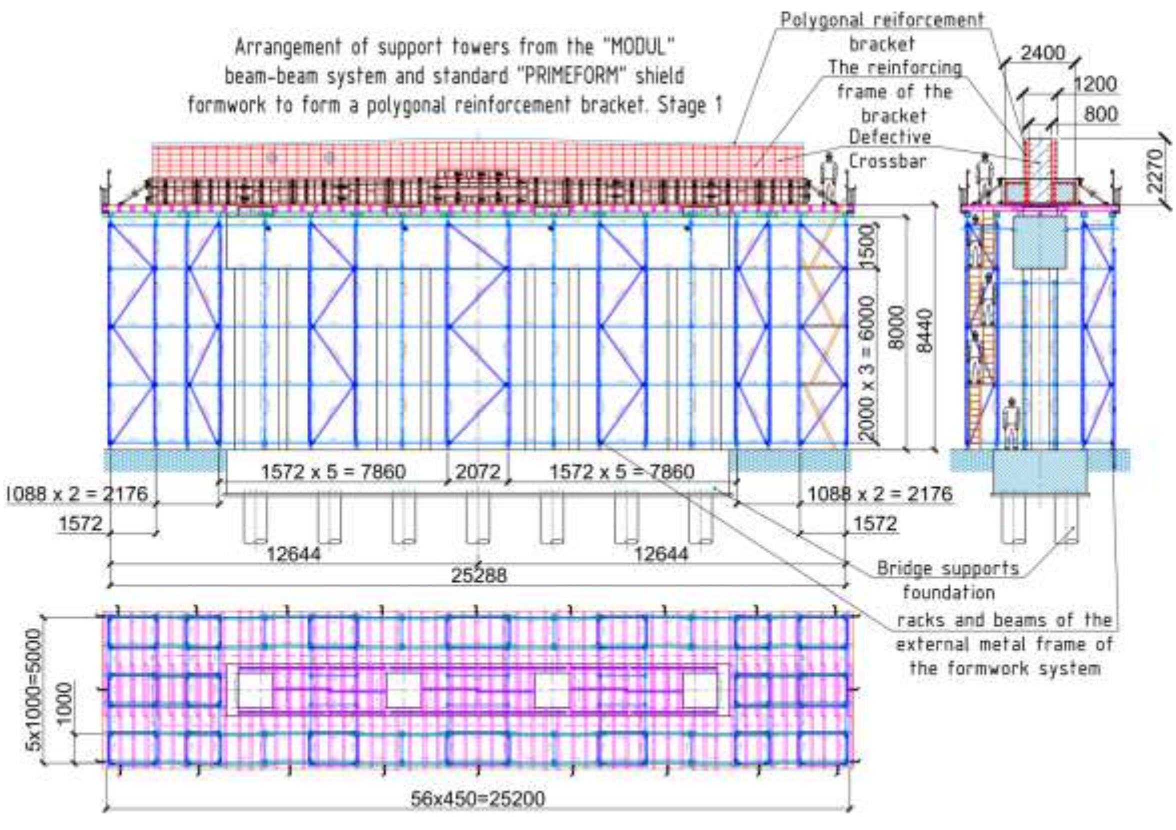

Figure 3.1 – The first step in template system installation

The first thing to consider when designing a construction system for polygonal reinforced concrete support is the shape and size of the support. Because bridge posts are heavy, they are easy to change. Therefore, the columns must have strength and stability to respond to diverse and adverse operating conditions. Accordingly, we have chosen a polygonal structure as the basic shape of the support base. The length and angle of each side were carefully calculated so that the base would sit comfortably on the bridge posts and be properly supported.

In Fig 3.1 it can be seen that the first step in installing the structural system is to build the outer shell of the supports. The key to this step is choosing the right materials for the columns and beams. and proper connection point design The materials of the columns and beams must be strong and rigid enough to withstand the pressure and vibration of the concrete being poured. The connection points help stabilize the structure and avoid deformation or collapse of the slab due to undue stress. In actual practice high grade steel plates are used as material for columns and beams. By joining different parts together by glueing or crossing.

Next, Fig 3.2 shows the second step of installing the form system. the installation and repair of the internal structure The main function of the internal structure is to create space in the support base for pouring concrete. This is to evenly fill the concrete and fill all the spaces. Create and position the inner workbook correctly. during construction Accurate measuring tools are used to check and correct the position and size of the form. Make sure the structure and the outer shell of the support fit together without gaps or movement.

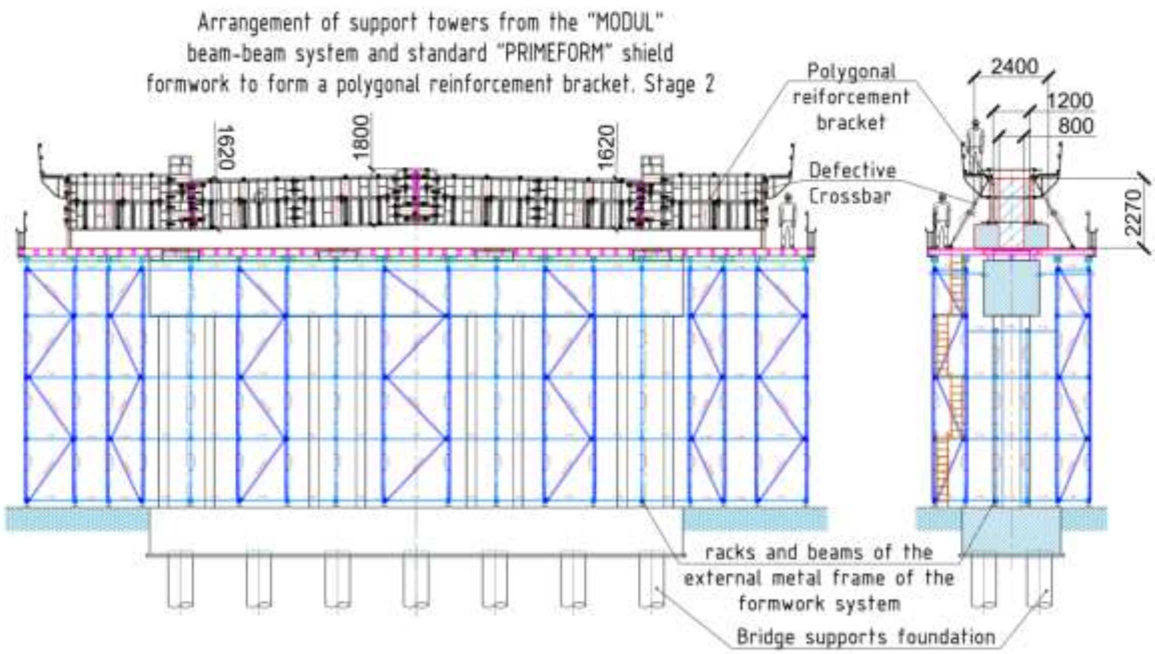

Figure 3.2 – The second step of template system installation

In addition to the construction and installation of the correct workbook, The choice of concrete mix is also important in relation to the quality of the support. From the environment and requirements for strengthening bridge supports. We have selected concrete mixes that are high strength, long lasting and water efficient. This mixture reduces the risk of breakage and changes in support due to heavy loads. As a result, production and quality will improve.

In addition to the design of formwork systems and concrete mixtures, the strength of the adhesion of the newly injected concrete to the existing steel structure is also considered. For this purpose a new additive mixture has been developed which has excellent adhesion and durability. can adapt to a variety of complex environments and construction situations. From tests on the use of real mechanical work, this adhesive mixture was found to increase the bond strength between the support and the existing structure. It gets stronger

The method of strengthening bridge decks using polygonal reinforced concrete units has many advantages and strengths. Bridges can be properly and efficiently reinforced using the correct structural system. The selection of high quality concrete mixes and the development of effective adhesives In addition to increasing the safety and durability of the bridge, It also reduces costs and risks to strengthen projects. There is reason to believe that this method will contribute more to the maintenance and strengthening of bridges in the future.

For the economic benefit analysis By comparing the construction cost per meter of the polygon abutment abutment reinforcement material with the traditional reinforcement method. This method was found to have a cost advantage and in addition, the economic benefits resulting from the use of this support structure solution were calculated, such as the longevity of the bridge. Reducing the number of repairs and reducing maintenance costs The results of this analysis show that the method of strengthening bridge decks using polygonal reinforced concrete slabs is not only technical. But it also makes economic sense. And it's good to use real events.

3.2 Effective concrete mixes for brackets

In a bridge strengthening project the selection of the appropriate concrete mix is very important to ensure the quality and performance of polygonal reinforced concrete supports. The concrete mixture should be strong and durable. It should run smoothly and work. To be able to distribute equally and all in the formwork system. and thick concrete structures can be made Here, some types of concrete aggregates are described. Each type has different characteristics and the necessary conditions.

Consider using high performance concrete. (High-Performance Concrete: HPC) is the main material for support. High performance concrete has improved with significantly improved compressive strength, durability and workability. By adjusting the ingredients of raw materials Adding high performance drainage and mixing mineral mixtures In the case of polygonal reinforced concrete supports, HPC allows the supports to withstand heavy loads no cracks or deviations. It also has water resistance properties and better resistance to freezing and thawing [28]. Drilling and screwing in the formwork system is easy. and help to build thick concrete structures.

However, high performance concrete is very expensive. This may not be suitable for projects with limited budget. For this reason, consider using Ordinary Portland Cement (OPC) with some additives to simulate the performance of HPC. For example, improvements can be achieved by adding a lot of mineral ingredients such as silica fume, fly ash At the same time, the use of high-water-reducing equipment can also reduce the water-cement ratio of OPC and increase more than flow and action. Although this concrete mix is less efficient than HPC, it is less expensive and can meet the needs of most bridge strengthening projects.

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3.3 Effective adhesive mixtures to accessins to existing reinforced structures

For the bridge strengthening project a polygonal reinforced concrete structure must be connected to the original level steel structure. The selection and use of welding agents is very important. This directly affects the strength of the reinforcement and the safety of the structure [29]. So, it is very important to develop an effective and reliable connection to connect strong and strong polygonal reinforced concrete structures to basic level steel structures.

Application of Sika MonoTop®-1010 for polygonal reinforced concrete structures.

A) Product recommendations. Sika MonoTop®-1010 is a cream-based concrete with an anti-corrosion coating. Mainly used for the repair and maintenance of reinforced concrete structures, this product not only provides good bonding properties but also. but also provides long-term protection. In general Sika MonoTop®-1010 Sika MonoTop®-1010 is widely used in the repair and maintenance of many types of buildings such as bridges, tunnels, buildings and other reinforced concrete structures. A special connection. It provides a good connection between the fixing material and the original structure. and excellent resistance to corrosion of structural steel as an additive [30], Sika MonoTop®-1010 also has a strong bond strength, can be applied to steel surfaces by quick and precise spraying or brush application.

B) Manufacturing process. Surface Treatment. Make sure the surface of the steel is clean and free of oil or rust. Use a steel brush or sandpaper to clean the surface to make it stronger. Mixing and coating. Mix Sika MonoTop®-1010. Mix according to the instructions in the product manual. And then use a brush or spray tool to match the iron surface. Drying and drying. After the coating is finished, wait until it is completely dry and hard. During this process, moisture and other contaminants must be avoided.

C) Use it in real cases. During the bridge repair project the polygonal concrete structure of the road surface is constantly reacting to the environment of moisture and corrosion. These tough conditions make steel more prone to corrosion. This affects the reliability and service life of the bridge structure. To solve the problem, Sika MonoTop®-1010 can be used to strengthen and protect structural steel structures [31].

At the first stage of the bridge repair, the details are inspected and evaluated before the work is done. The level of cleanliness and corrosion of the structural steel is assessed. Based on the results of the inspection, a repair plan will be developed after which the construction workers must thoroughly clean the steel to remove rust and contamination. Generally, a small emery cloth, sandpaper, or sandpaper is used to clean the steel surface. and avoiding the residual effects of the welder's work in the next section.

After cleaning, the user should apply Sika MonoTop®-1010. Get it all together This product can be applied with a brush or sprayed onto metal surfaces. Brushes are great for smaller, harder-looking areas. while spraying is good for larger areas. When applying the coating You should apply an even coating and continue coating each iron so that the coating is as uniform as possible.

With Sika MonoTop®-1010 Coated with steel surface. It creates a strong connection base with an anti-corrosion layer. This protective layer prevents the ingress of moisture and oxygen. With the ability to prevent the corrosion of steel. Meanwhile, this protective layer enhances the bonding of the fixing material to the original structure of Sika MonoTop®-1010. such as breaking concrete or using various repair tools. After this product there are some coatings and still strength (fig. 3.3, fig. 3.4). Using Sika MonoTop®-1010 in bridge repair does not prevent corrosion of steel. But also improves the efficiency of connecting repair materials to the original structure. This method of repair can be efficient and reliable.

Figure 3.3–Practical Application

Figure 3.4 – Practical Application

3.4 Conclusions from the technological proposals for the arrangement of brackets

After studying and conducting technical research on technical solutions for strengthening bridge structures and polygonal concrete steel regions, We have written a detailed summary of technical solutions for planning steel reinforcement. This conclusion came from the analysis of various design aspects, construction activities. Selection of properties and detailed analysis of value for money. Its purpose is to provide useful resources for similar bridge strengthening projects.

Let's start from the perspective of design elements. The design of the steel span structure of the concrete polygon bridge should carefully consider the dynamic characteristics of the return of the bridge structure and the structural strengthening requirements. By accurate calculation and analysis of simulation results The bridge structure is planned to distribute the load to each steel area and prevent damage or damage. In addition, the design of the structure takes into account the ease of operation of the construction process and good maintenance, so that the structural strengthening program is efficient and reliable.

Consider the construction process It uses a high floor system and influences the best choice of concrete to ensure the accuracy and high quality of the installation and construction of the steel border bridge. The use of this platform system increases the efficiency of the construction process and provides the accuracy of the section and the stability of the steel area. This is because of the strength of concrete that is properly made. The strength and durability of the steel area is guaranteed and can withstand harsh conditions and adverse environmental conditions.

When considering the choice of materials Concrete and high concrete materials are used and mixed with single additives to create a strong connection between

After careful study and technical research on the strengthening of the bridge structure with polygonal concrete steel regions, We have calculated the cost per meter. By comparing different prices like different materials. Alternative manufacturing methods

And what is value for money? From the results of this analysis, it was found that the technology for strengthening the structure with polygonal concrete steel regions is very cost effective.

For example, when it comes to material costs, you may find that the cost of steel and concrete is slightly higher than normal materials. But because it works well and the cost of regular maintenance is less. All prices are at a reasonable level. When manufacturing costs are considered Investment in technology and increased skilled labor may be significant. But by strengthening the structure, the quality and stability of the construction system will improve. With this investment All construction costs will be reduced.

In addition, the cost index of classic reinforcement methods such as steel zone placement was evaluated and their costs were compared. working time and the effects of the addition The results of this study confirm Technology for the strengthening of the structure and areas of reinforced concrete.

CHAPTER 4 ECONOMIC PART

4.1 Calculation of the estimated cost (cost) of 1 linear meter of the construction of the reinforcement of the crossbar system of the bridge support using a polygonal clip.

In the bridge strengthening project, a heavy beam system was used for the strengthening work. Cost analysis is an important reference point for engineering decision making. Below is an approximate linear construction cost per meter to use a temporary beam system to strengthen the bridge.

A) Cost of materials

A.1) Rebar steel price. Assume that the rebar project uses HRB400 rebar with a diameter of 25 mm, and the market price is ¥5/kg. According to the design, about 20 kg of reinforcing steel is required for each linear meter of reinforcement, and therefore reinforcing steel. price 20kg/m × ¥5/kg = ¥100/m。

A.2) Concrete cost. C30 strength grade concrete is used, and its market unit price is about ¥400/ m^3. According to the design, 0.3 m^3 of concrete needs to be poured for each meter of linear reinforcement. Based on this, the concrete cost is 0.3 m^3 × ¥400/ m^3= ¥120/m.

A.3) Formwork system cost. The formwork system is a one-time investment, but considering its reusability, the cost is allocated to each meter of linear reinforcement. Assuming the total cost of the formwork system is ¥50,000 and it is expected to be reused 1000 times, the formwork system cost per meter of linear reinforcement is ¥50,000 / 1000 times = ¥50/m.

A.4) Adhesive cost. High-performance epoxy adhesive is used, and its market unit price is ¥100/kg. Each meter of linear reinforcement requires about 0.2kg of adhesive, based on this, the adhesive cost is 0.2kg/m × ¥100/kg = ¥20/m.

B) Labor cost.

Based on the scale and complexity of the project, it is estimated that 2 workers will work for 1 day for each meter of linear reinforcement. The labor cost is calculated at ¥300 per person per day. Based on this, the labor cost is 2 people/m × ¥300/person/day = ¥600/m.

C) Equipment cost

Equipment cost mainly covers the operating costs of construction machinery, such as cranes, concrete mixers, etc. Taking into account the depreciation and maintenance costs of the equipment, the estimated equipment cost per meter of linear reinforcement is ¥100/m.

D) Other costs

Other costs include construction management fees, safety measures fees, taxes, etc., and are expected to account for 10% of the total cost. Based on this, the other costs per meter of linear reinforcement are (rebar cost + concrete cost + formwork system cost + adhesive cost + labor cost + equipment cost) × 10%.

E) Total cost calculation

The total cost per meter of linear construction = steel bar cost + concrete cost + formwork system cost + adhesive cost + labor cost + equipment cost + other costs

= ¥100/m + ¥120/m + ¥50/m + ¥20/m + ¥600/m + ¥100/m + （¥100/m + ¥120/m + ¥50/m + ¥20/m + ¥600/m + ¥100/m）× 10%

= ¥100/m + ¥120/m + ¥50/m + ¥20/m + ¥600/m + ¥100/m + ¥99/m= ¥1089/m

F) Cost analysis

It can be seen from the above calculation that the linear construction cost per meter of using the polygonal clamp pier beam system to strengthen the bridge is approximately ¥1089. This cost covers everything from materials, labor to equipment and other aspects, providing a more comprehensive cost reference for engineering decisions.

Compared with traditional reinforcement methods, the polygonal clamped pier and beam system may have a slightly higher initial investment, but considering its long-term reinforcement effect and improvement in the overall performance of the bridge, its long-term benefits are significant. In addition, the system also has the advantages of short construction period and small impact on traffic, which further enhances its economic and social benefits.

Based on this, in bridge reinforcement projects, the use of polygonal clamped pier beam systems as a reinforcement solution is a choice worth considering.

4.2 Determination of generalized cost indicators of the classical method of reinforcement (by arranging supports)

In bridge reinforcement projects, classic reinforcement methods usually involve arranging supports to enhance the bearing capacity and stability of bridge structures. This series of methods has been verified in practice for many years and has been widely used in the maintenance and reinforcement of various types of bridges. In order to evaluate the comprehensive cost indicators of this series of classic reinforcement methods, it is necessary to conduct an in-depth cost analysis of each link involved.

A) Material cost

In the classic reinforcement method, material cost is an important component of the total cost. This series of materials mainly includes steel, connectors, prestressed steel bars, concrete, etc. of the supporting structure. Depending on the specific reinforcement design and the actual condition of the bridge, the selection and amount of materials will vary.

Taking steel as an example, assuming that Q345B grade steel is used as the main material of the supporting structure, its market price is about ¥5000/ton. According to the design calculation, about 0.2 tons of steel are required for each meter of reinforcement length. Based on this, the steel cost is 0.2 tons/m × ¥5000/ton = ¥1000/m.

Similarly, the cost of materials such as connectors and prestressed steel bars also needs to be calculated based on the design quantity and market price. For example, the cost of connectors may include bolts, nuts, washers, etc., and their unit price and quantity will vary depending on the connection method and bridge size. The cost of prestressed steel bars depends on the diameter, length and unit price of the steel bars.

As an important part of the reinforced structure, the cost of concrete also needs to be taken into consideration. According to the design of the reinforcement plan, a certain amount of concrete may need to be poured to enhance the overall performance of the structure. The cost of concrete includes material costs, transportation costs, pouring costs, etc., and the specific amount will vary depending on the strength grade of the concrete, the pouring method and the amount of work.

B) Labor cost

In the classic reinforcement method, labor cost is another important cost component. This series of costs covers the wages, social security, welfare and other expenses of the construction workers. Depending on the scale and complexity of the reinforcement project, the number of workers required and the salary level will also vary.

Assume that the reinforcement project requires 10 workers to carry out the construction, each worker is paid ¥300 per day, and the construction period is 30 days. Then, the total labor cost is 10 workers × ¥300/person/day × 30 days = ¥90,000. If overtime, holidays and other factors are taken into account, the actual labor cost may be higher.

C) Equipment cost

In the classic reinforcement method, equipment cost is also a part that cannot be ignored. This series of costs includes the purchase or rental costs of construction machinery, maintenance costs, fuel costs, etc. According to the needs of the reinforcement project, the construction machinery required includes cranes, excavators, concrete mixers, etc.

Assume that the reinforcement project requires the rental of a crane and an excavator for construction, with daily rental costs of ¥5,000 and ¥3,000 respectively, and a construction period of 30 days. Then, the total equipment cost is (¥5,000/day + ¥3,000/day)

× 30 days = ¥240,000. In addition, additional costs such as equipment maintenance costs and fuel costs need to be considered.

D) Other costs

In addition to the above-mentioned material costs, labor costs and equipment costs, the classic reinforcement method may also involve some other costs. This series of costs includes construction management costs, safety measures costs, taxes, etc. The specific amount of this series of costs will vary depending on the actual situation of the project.

Assume that construction management costs account for 10% of the total cost, safety measures costs account for 5% of the total cost, and taxes account for 3% of the total cost. Then, other costs can be estimated based on the total cost.

E) Comprehensive cost index

By combining the above costs, the comprehensive cost index of the classic reinforcement method can be calculated. This index not only covers the direct material, labor and equipment costs, but also takes into account other related costs. The comprehensive cost index based on comparing different reinforcement schemes can provide strong support for engineering decision-making.

4.3 Calculation of the economic effect from the implementation of the proposed structural solution of the bracket (comparison with typical analogues)

When evaluating the economic benefits of bridge reinforcement projects, it is necessary to compare the costs and performance of different reinforcement schemes. The following is a comparative analysis of the economic benefits of the reinforcement scheme based on polygonal reinforced concrete supports and typical analogs (such as traditional steel support reinforcement and concrete enlarged foundation reinforcement).

A) Cost comparison

A.1) Polygonal reinforced concrete support reinforcement solution.

Material cost. The cost of high-performance concrete, steel bars, adhesives, etc. per meter of reinforcement length is about ¥1500/m. Labor cost: Considering the convenience of modular construction and prefabricated components, the labor cost per meter of reinforcement length is about ¥800/m (covering installation, fixing and inspection, etc.). Equipment cost: Covering the cost of using equipment such as formwork system construction, concrete pouring and adhesive coating, the cost per meter of reinforcement length is about ¥200/m. Indirect costs (such as design, management, taxes, etc.): The indirect cost per meter of reinforcement length is about ¥300/m.

A.2) Traditional steel support reinforcement scheme:

Material cost. The material cost of steel, connectors, etc. per meter of reinforcement length is about ¥1200/m. Labor cost: The construction complexity is relatively high, and the labor cost per meter of reinforcement length is about ¥1200/m. Equipment cost: The operating cost of equipment such as hoisting and welding is about ¥150/m per meter. Indirect cost: The indirect cost per meter of reinforcement length is about ¥250/m.

B) Concrete expansion foundation reinforcement scheme:

Material cost: The material cost of concrete, formwork, etc. per meter of reinforcement length is about ¥1300/m. Labor cost: The construction period is long, and the labor cost per meter of reinforcement length is about ¥1000/m. Equipment cost: The operating cost of equipment such as concrete mixing and pouring is about ¥180/m per meter. Indirect cost: The indirect cost per meter of reinforcement length is about ¥270/m.

C) Performance benefit analysis

Polygonal reinforced concrete support reinforcement solutions have significant advantages in performance, such as higher load-bearing capacity, better stability and durability. This series of advantages will bring the following economic benefits:

Extending the service life of the bridge: Assuming the extension by 5 years, the annual maintenance cost savings is ¥100,000, and the total income is ¥500,000. Reduced maintenance frequency: Due to improved durability, maintenance frequency is reduced. Each meter of reinforcement length can reduce maintenance costs by approximately

¥2,000 in 10 years. Improved traffic flow and safety: The indirect economic benefits are difficult to quantify directly, but can be regarded as part of the long-term benefits.

D) Comprehensive economic benefit assessment

Polygonal reinforced concrete support reinforcement scheme:

Total cost (per meter): ¥1500 (material) + ¥800 (labor) + ¥200 (equipment) + ¥300 (overhead) = ¥2800/m.

Total income (taking into account performance and life extension): Each meter can save ¥2,000 in maintenance costs within 10 years, plus the income from extended service life of ¥500/m (calculated based on the total income of 500,000 yuan per meter), totaling ¥2,500 /m.

E) Typical analogues. The traditional reinforcement scheme and the concrete expanded foundation reinforcement scheme are inferior to the polygonal reinforced concrete bracket reinforcement scheme in terms of cost and performance. Based on this, their comprehensive economic benefits are relatively low.

In summary, the polygonal reinforced concrete bracket reinforcement scheme has significant advantages in economic benefits. Although its initial investment cost is slightly higher, considering its superior performance and long-term economic benefits, this solution is a recommended choice in bridge strengthening projects.

4.4 Conclusions on chapter 4.

In the field of bridge reinforcement, finding an economical and efficient reinforcement method has always been the goal pursued by engineers. This study is based on a method of strengthening bridge supports based on polygonal reinforced concrete brackets. After in-depth technical analysis and economic evaluation, it shows its significant advantages and potential. The following is a comprehensive summary of the methods described in this study:

From a technical perspective, the polygonal reinforced concrete support reinforcement scheme is based on an innovative formwork system design, achieving rapid and efficient construction of the reinforced structure. The formwork system consists of an external frame of pillars and beams. Based on the installation steps shown in Figure 3.0a and Figure 3.0b, a reinforced bracket that is stable and adaptable to various bridge shapes can be quickly built. This formwork system not only improves construction efficiency, but also ensures the accuracy and reliability of the reinforced structure.

Regarding the concrete mixture, special requirements for bridge reinforcement were proposed and high-performance concrete patches were selected. This kind of concrete patch has good fluidity and crack resistance, can effectively fill the gap between the bridge bearing and the reinforcement bracket, and improve the overall performance of the reinforcement structure. In addition, based on reasonable concrete proportions and maintenance measures, the durability and service life of the reinforced structure can be further improved.

In terms of adhesive mixtures, adhesives for existing steel structures were explored. This adhesive has excellent bonding performance and durability, and can tightly connect the reinforcement bracket and the original structure of the bridge to form a whole. The use of adhesives can significantly improve the stability and load-bearing capacity of the reinforced structure, thereby extending the service life of the bridge.

In addition to the technical advantages, the polygonal reinforced concrete support reinforcement scheme was evaluated from an economic perspective. First, based on calculating the estimated cost per meter of linear construction, it was found that this option may be slightly higher in initial investment than traditional reinforcement methods. However, when factors such as the performance of the reinforced structure, construction period, long-term maintenance costs, and extension of the service life of the bridge are comprehensively considered, the economic benefits of the polygonal reinforced concrete bracket reinforcement scheme gradually become apparent.

Specifically, this solution is based on improving the load-bearing capacity and stability of the bridge, reducing the frequency of repairs and replacements, thereby reducing long-term maintenance costs. In addition, the service life of the bridge is also extended because the durability and stability of the reinforced structure are significantly improved. The cumulative effect of this series of economic benefits makes the polygonal reinforced concrete support reinforcement solution have a higher return on investment in the long term.

In the comparison with typical analogues, two methods, traditional steel support reinforcement and concrete expanded foundation reinforcement, were selected as comparison objects. Based on comparative analysis, it is found that the polygonal reinforced concrete bracket reinforcement scheme shows significant advantages in terms of cost, performance, construction period, etc. First, in terms of cost, although the initial investment is slightly higher, the long-term maintenance cost is lower and the service life is longer; secondly, in terms of performance, this solution achieves higher load-bearing capacity and stability based on optimized structural design and material selection; Finally, in terms of construction period, due to the adoption of modular construction and prefabricated component technology, the construction period has been greatly shortened.

The bridge reinforcement method based on polygonal reinforced concrete supports is a technologically advanced, cost-effective and new reinforcement technology. It not only has significant technical advantages and economic benefits, but also can adapt to various bridge shapes and reinforcement needs. In future bridge reinforcement projects, this solution is expected to become a mainstream reinforcement method, providing a strong guarantee for the safe operation and long-term use of bridges. At the same time, it is also expected that this solution can be continuously improved and optimized in practice to make greater contributions to the development of the bridge reinforcement field.

CONCLUSIONS

In this scientific research have been offered the method of strengthening the crossbars of bridge bearings by arranging polygonal reinforced concrete brackets to solve the important scientific and technical problem of strengthening the existing building structures of bridge structures, in general, and their crossbar of piers systems, in particular, for ensure the perception of increased traffic disturbances, as well as for further trouble-free operation. This method increases the reliability of bridge supports, makes them architecturally expressive and strong compared to the classic method of strengthening bridge supports by arranging rectangular reinforcement brackets.

1. Have been summarized the scientific and technical information of modern sources on the design of bridge structures. Have been described the constructions of bridge piers are summarized and their main structural parts (piles, piles cup, support stand (pier), piers cap, crossbar, bearing system)) and their functions. Have been determine the function of crossbars in bridge support systems.

2. Have been performed scientific analysis of literature sources on the technical condition of bridge constructions. Have been summarized defects and damage to bridge support systems. Have been founded that one of the most worn structural elements of the bridge is their crossbars systems of bridge supports.

3. The most dangerous defects of the crossbars of bridge piers include:

- the destruction of the protective layer of concrete,
- corrosion of the working reinforcement,
- carbonization of the surface layers of concrete,
- violation of the integrity and continuity of the span structure, which leads to permanent locking of the crossbar systems,
- stress cracks in the concrete,
- damage and bends of the reinforcement, as well as, reduction of the bearing capacity of the structure due to the specified defects and damage.

4. Existing rational options for strengthening bridge crossbars are considered (injection of cracks with epoxy mixtures, installation of steel brackets and unloading structures, installation of additional supports, installation of reinforced concrete brackets of rectangular shape). Have been offered a more rational way of strengthening the supports crossbars by arranging a polygonal-shaped bracket, which is architecturally expressive and constructively effective.

5. For a typical two-pillar bridge support system with a crossbar in the form of a precast reinforced concrete long beam, have been developed the rational reinforcement bracket of a polygonal shape, which repeats the shape of the curve of bending moments.

6. Have been developed the highly detailed finite-element model (FEM) of the stress-strain state of the system: defective crossbar – reinforcement clip – bridge supports – foundation – foundation under the action of a complex of permanent and variable loads, including temporary loads from traffic. During the modeling, have been taken into account in the margin of safety that the defective structures of the crossbar and the elements of the reinforcement bracket are connected at key points in accordance with the step of the reinforcing anchors, which are glued into the crossbar structure.

7. Have been considered several variants of the structural polygonal shape of the brackets, from which the most rational one was chosen on the basis of detailed FEM of the stress-strain state of the crossbars of bridge supports. Some of the most important design recommendations are listed below

7.1. Established rational proportions of brackets parts:

- the height of the reinforcement clips in the span should be 1.5 - 2 times the height of the existing defective crossbars;

- the height of the bracket in the support area should be 2 to 4 times larger than the height of the bracket in the span;

- the polygonal form of the formwork of the crossbar brackets should repeat the shape of the bending moments;

- if the form or structural crossbars does not allow creating a polygonal shape of the brackets in the support plane, a polygonal cross-section of the brackets should be designed.

7.2. Recommendations regarding the arrangement of reinforcement of the brackets:

- reinforce the polygonal bracket with spatial reinforcing frames of a complex shape, which completely cover the structures of the defective bolt, if possible.

- the working, structural and forming reinforcement of the brackets must be connected to the structures of the support piers and crossbars with chemical anchors;

- the working reinforcement of the brackets must pierce the support columns of the bridge piers. If this is not possible, the reinforcement must be inserted into the body of the support with chemical anchors for the anchoring length determined by the calculation.

8. Have been developed rational technological recommendations for the production of reinforcement clips in the conditions of the construction site:

- have been offered the use of an effective formwork system with the use of a strut-and-beam external support frame to create a complex polygonal shape of the reinforcement brackets;

- for the arrangement of an adhesive coating on defective bolt structures and reinforcement fittings based on materials from the Swiss company Sika (as SikaMonotop 1010);

- the use of self-compacting quick-hardening concrete mixtures is proposed for concreting constructions of polygonal reinforcement brackets.

9. Have been calculated the cost indicators of the offered constructive solutions of the polygonal bracket, which turned out to be higher than the cost of strengthening the crossbar of bridges support systems by classical methods. However, the strength resource, reliability and durability of the structures of bridge piers strengthened by the proposed method is much higher, which, in the final case, will lead to a quick payback of over expenditures.

10. The conducted scientific researches and their main results, which consist of the developed design methods, the proposed constructive forms of reinforcement crossbars brackets and the principle constructive solutions of their reinforcement, can be recommended for use in the implementation of real bridge strengthening projects in China, Ukraine and other parts of the world.

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ANNEXES

Annex A（审批表）

Annex B

ВІННИЦЬКИЙ НАЦІОНАЛЬНИЙ
ТЕХНІЧНИЙ УНІВЕРСИТЕТ

СЕРТИФІКАТ

засвідчує, що

Сяохун ЛІ

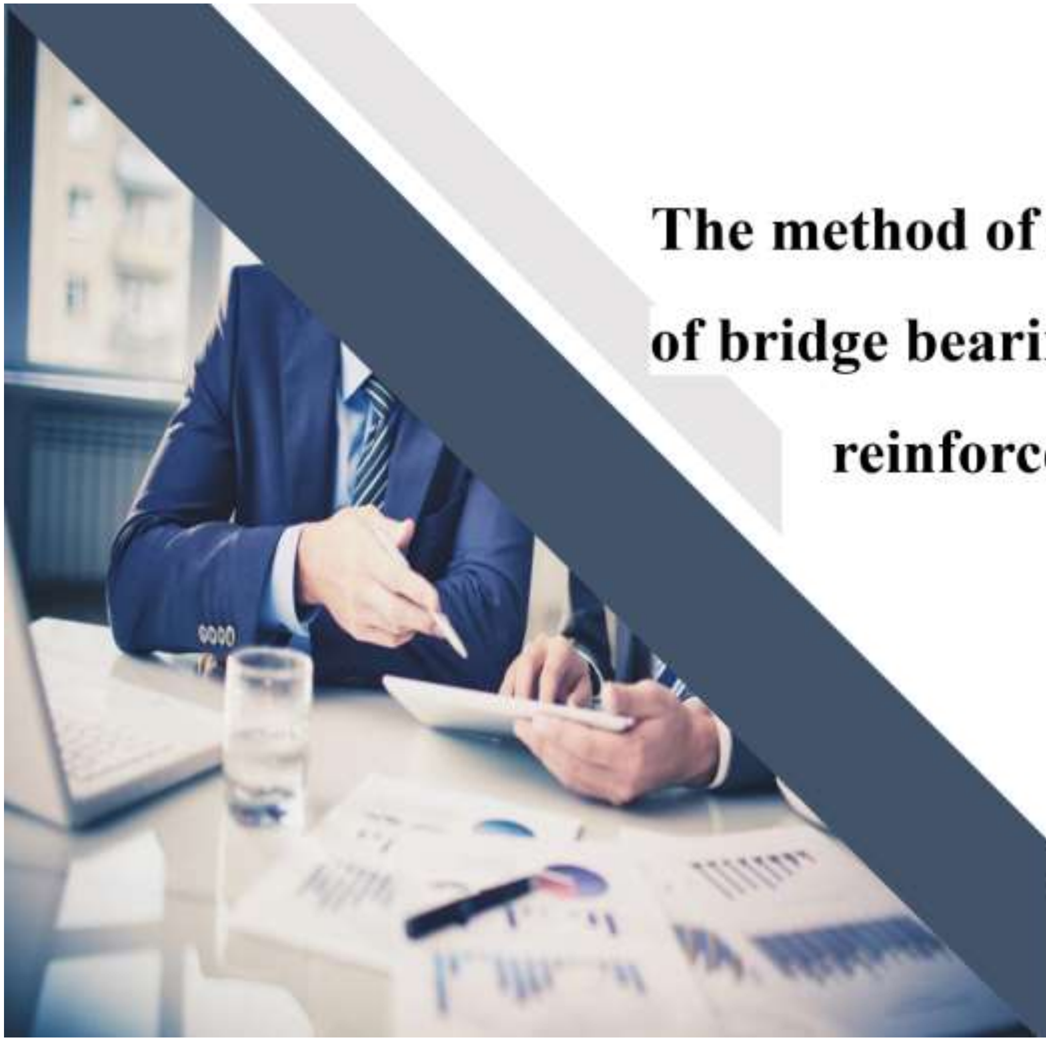
взяв участь у роботі

LIII Всеукраїнської науково-технічної конференції
підрозділів ВНТУ

20 — 22 березня 2024 р.

Тривалість 15 годин (0,5 кредиту ЄКТС)

Проректор з наукової роботи ВНТУ Ірина ЄПІФАНОВА



The method of strengthening the crossbars of bridge bearings by arranging polygonal reinforced concrete brackets

Master students Presenter：Li Xiaohong (China)

Supervisor: Assoc. prof. Volodymyr Popov (VNTU, Ukraine)

Contents

01 Introduction

Research on Reinforcement Methods for Bridge Bearings and Load-bearing Beams

Relevance of the Topic:

1. Issues related to improving global logistics flows
2. Enhancing national transit capacity and trade
3. Importance of transportation infrastructure for road and bridge operations

Importance of bearings:

1. Provide necessary support for bridge structures
2. Scientifically study how to improve the design and construction of bridge bearings under various conditions

Links between work and scientific plans, programs, themes

The scientific work is carried out on the basis of the research theme of the Faculty of Architecture, Urban Economy and Construction of Vinnitsa National Technical University (VNTU), Ukraine, No. 60-K6 “Improvement of computational methods and technologies of automated design-installation of building foundation systems taking into account IoT technologies supported by buildings” (January 1, 2024 - December 31, 2026).

Purpose and tasks of the study

1. Research objectives

Simulate the strain state of a load-bearing beam reinforced with reinforced concrete brackets under fixed and varying loads.

2. Research tasks

Research Mission

Conduct a detailed scientific analysis of the existing scientific and regulatory framework for bridge design

↓

Detailed scientific analysis of typical bridge pier designs most commonly used in road construction

↓

Determine the function of beams in bridge pier systems based on modern scientific research

↓

Identification of the most typical defects and damages of these structures based on public scientific information on the technical condition of piers and their beam systems

↓

Propose a reasonable method to strengthen defective structures by setting fixtures of various shapes

↓

Development of highly detailed finite element models (FEM) of stress and strain states of bridge pier beams working with various shapes of reinforcement brackets

↓

Based on the detailed FEM of the stress-strain state of the pier beam, a reasonable structural solution and shape of the reinforcement bracket are proposed

↓

Propose reasonable structural and technical suggestions for strengthening the support

01 Introduction

project	content
Study subjects	The behavior of the pier structure under constant and variable loads during long-term operation, taking into account defects, damage and reinforcement.
Research Topics	The stress-deformation state of the load-bearing support beam-reinforced concrete support system.
Research methods	Structural mechanics methods, material resistance methods and finite element modeling (FEM) methods are used to optimize geometric parameters in the LIRA-SAPR software system.
Innovation	1. The direction of rationally designing reinforced concrete supports to strengthen bridge load-bearing beams has been further developed. 2. The rational structural relationship between the reinforced components has been proposed.
Personal Contribution	1. Developed high-precision finite element models of reinforced concrete brackets of various structural forms. 2. Determined the reasonable structural form and reinforcement method of the cantilever beam segment reinforcement bracket.

Large support (pier)

01 Introduction

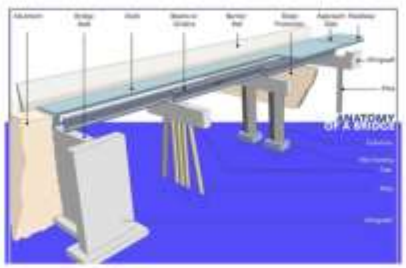
The work was tested on the following occasions:

- The test was conducted at the "3rd All-Ukrainian Scientific and Technical Conference of Faculties of Architecture, Civil and Environmental Engineering" held at Vinnitsa National Technical University (VNTU) on March 20-23, 2024.
- The test was conducted at the International Scientific and Practical Internet Conference "Youth in Science: Research, Problems, Prospects (MN-2024)" held at Vinnitsa National Technical University (VNTU) on November 15, 2023 - May 20, 2024.

1.1 Bridge structure (components of reinforced concrete bridge structure)

Main structure of bridge (bridge deck, piers, abutments)

The bridge superstructure consists of the bridge deck, piers and abutments, which are jointly responsible for supporting the load of the bridge deck and transferring it to the piers and abutments. Through reasonable design and construction, the stability and reliability of the bridge superstructure can be ensured, providing safety for pedestrians and vehicles.



Bridge Superstructure

Bridge bearings: bearing types and parameters

Although small in size, bridge bearings play a vital role in bridge engineering. They are responsible for connecting the bridge superstructure and substructure, bearing and transmitting various loads borne by the bridge, and allowing corresponding displacement and deformation when subjected to external forces, ensuring the safe and stable operation of the entire bridge system.

Bridge Bearings

02 CHAPTER 1

1.2 Strengthening reinforced concrete bridge support systems and bearings. Review of architectural solutions

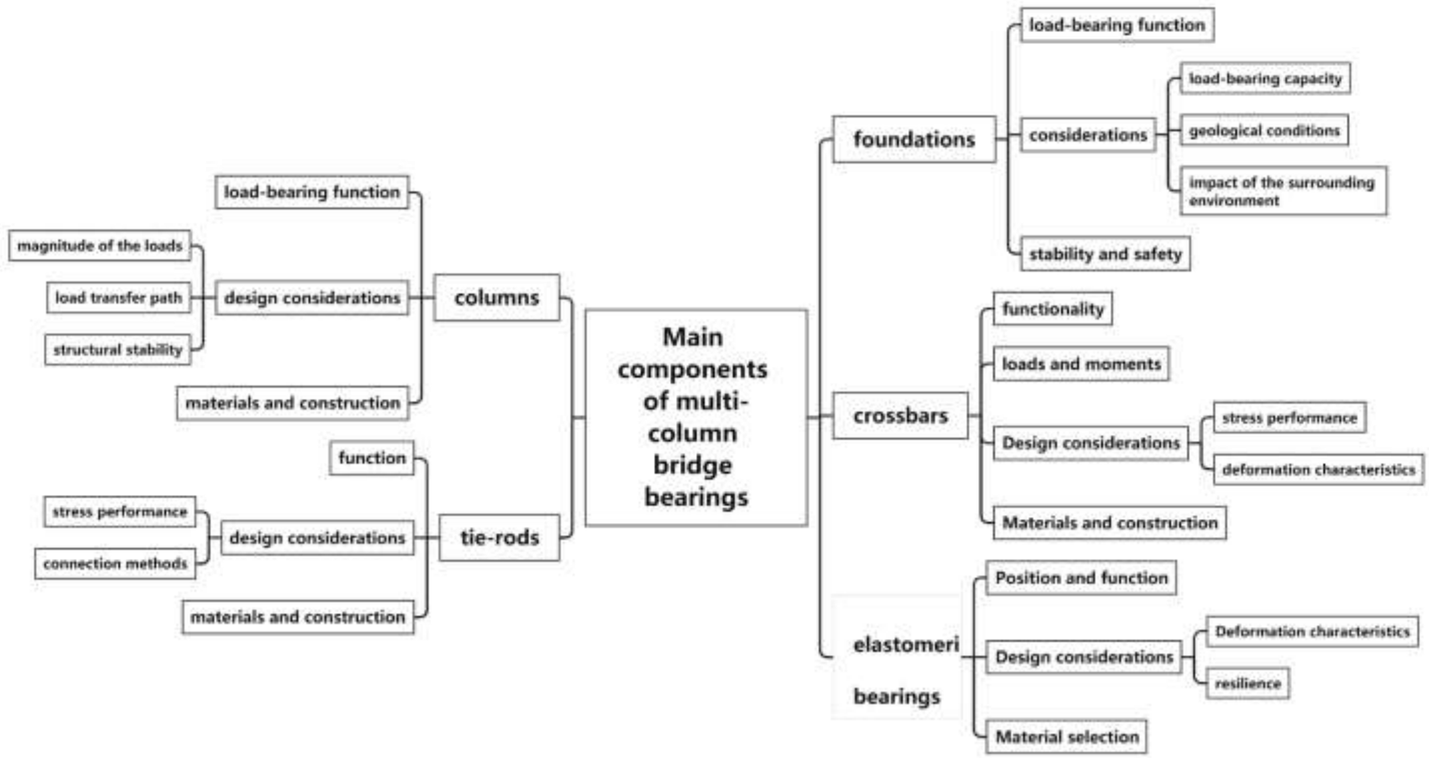
chapter	Classification	Key points
1.2.1 Modern classification of bridge supports	Large support	Importance and role, design points, design and manufacturing considerations (load capacity, stability, adaptability), maintenance and cost-effectiveness
	Column support (bridge pier)	Importance and function, structural characteristics, design principles, application advantages, application scope, technical support
	Multi-lift support with crossbeam	Importance and role, structural characteristics, application scope, design and construction requirements, application advantages, contributions, summary
1.2.2 Modern classification of bridge bearings	Elastomer support	Importance and role, material properties, structural characteristics, load transfer mechanism, maintenance and repair, scope of application, summary
	Cup type support	Importance and role, materials and structure, functions, advantages, design and application considerations, contributions
	Sliding bearing	Importance and role, materials and structure, functions, advantages, design and application considerations, contributions
	Rolling bearing system	Importance and function, design principle, structural characteristics, application scope, advantages, installation and maintenance, application value
1.2.3 Historical review of bridge bearing and support design in China and the world	The evolution of bridge piers	
	Development of reinforced concrete bearings	
	Design trends across Europe	
	Technical exchange and experience sharing	
	Future trends	

1.2 Strengthening reinforced concrete bridge support systems and bearings. Review of architectural solutions

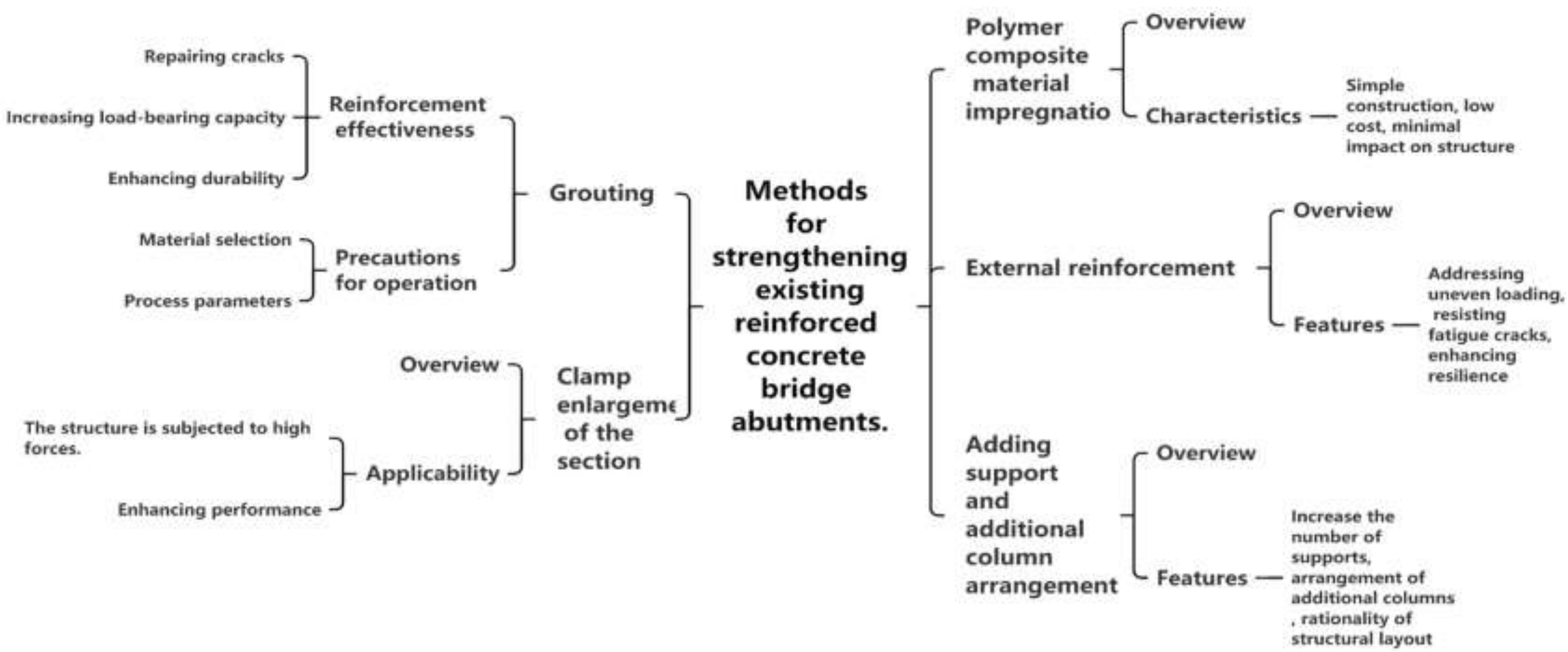
Figure2.3 – Typical support structure of ancient Chinese bridges

Figure 2.4– Typical support structure of modern Chinese bridges

1.3 Main components of multi-column bridge bearings



1.4 Methods for strengthening existing reinforced concrete bridge bearings



1.5 Summarize

Strengthening bridge piers is a key measure to ensure the safe and stable operation of bridges. Especially in the context of strengthening supporting beams, it is necessary to fully consider factors such as structural safety, stability and economy to ensure the reinforcement effect and long-term operational stability. The research and practice of strengthening bridge piers will provide the necessary technical support and guidance to ensure bridge safety and extend its service life.

2.1 Possible forms of brackets (rectangular brackets)

1、 Rectangular Bracket Introduction

- The role of rectangular brackets in bridge reinforcement
- Advantages: simple structure, clear force analysis, convenient construction

2、 Rectangular bracket design

Dimension design:

- Matching of bracket width with bridge width
- Consideration of bracket length for stability and load-bearing capacity

Reinforcement design

- Calculation of steel bar diameter, spacing, and arrangement
- Measures to improve support bearing capacity and deformation performance

Design parameters of rectangular bracket

Parameter name	Symbol	Numerical value	Unit
Bracket width	B	2.0	m
Bracket height	H	1.5	m
Steel bar diameter	d	25	mm
Rebar spacing	s	150	mm

2.1 Possible forms of brackets (rectangular bracket continued)

3. Analysis and verification of rectangular bracket

Finite element analysis method

Establish finite element model

Apply actual load

Determine stress distribution,

deformation, possible failure mode

4. Calculation formula

$$s = \frac{M}{fy \cdot d \cdot (h_0 - \frac{x}{2})}$$

As is the reinforcement area, M is the applied bending moment, fy is the yield strength of the reinforcement, d is the effective height of the beam, h0 is the total height of the beam, and x is the depth from the compression surface to the neutral axis.

5. Quality control during construction

Concrete pouring quality control

Precise control of steel bar

processing and layout

6 Conclusion

The application value of rectangular brackets in

bridge reinforcement projects

The importance of reasonable design and

construction control

2.1 Possible forms of brackets (trapezoidal brackets)

1 Ladder bracket introduction

- The role of trapezoidal bearings in bridge reinforcement.
- Advantages of the unique geometry: good stability and sufficient load-bearing capacity

2 Design principle of trapezoidal support

- Utilize geometric characteristics and structural mechanics principles.
- The design of wider bottom and narrower top distributes stress, reduces stress concentration, and improves load-bearing capacity and stability.

3 Design parameters and calculations

- Main parameters: height (H), top width (a), bottom width (b), inclination angle (θ), reinforcement.
- Parameter determination basis: actual bridge load, span, support size, construction conditions and cost.
- Reinforcement design: According to the design principles of reinforced concrete structure, calculate the diameter, spacing, quantity and arrangement of steel bars .

4 formula

$$Mu \leq f_c \cdot b \cdot x \cdot \left(h_0 - \frac{x}{2}\right) + f_y \cdot A_s \cdot \left(h_0 - \frac{x}{2}\right)$$

5 Finite Element Analysis

- Modeling and simulation: Considering geometry, material properties, boundary conditions, loads, etc.
- Analysis results: Stress distribution, deformations, and potential failure modes.

6 in conclusion

- Application prospects of trapezoidal bearings in bridge reinforcement projects.
- Improve bridge safety and stability through reasonable design and construction control.
- Exploration of future optimization design and construction methods.

2.1 Possible forms of brackets (polygonal brackets)

Introduction to Polygonal Support

- The role of polygonal reinforced concrete supports in bridge reinforcement.
- Unique geometric features and superior mechanical properties.

Design Principles

- The geometry is coordinated with the bridge structure, the load is evenly distributed, and stress concentration is reduced.
- The support material meets the strength, stiffness and durability requirements.
- The reliable connection between the support and the bridge can withstand the various loads transmitted by the bridge.

Finite element analysis

- Build 3D geometric models: adjust parameters such as side length, angle, height, etc.
- Define material properties: elastic modulus, Poisson's ratio, density, yield strength, etc.
- Apply loads and set boundary conditions: static loads, dynamic loads, temperature loads, fixed constraints, sliding constraints, elastic constraints, etc.

Modeling and solving

- Meshing: Consider geometric features and calculation accuracy.
- Calculate stress, strain, displacement and other parameters of each unit.
- Compare the calculation results under different loads and boundary conditions to evaluate the performance of the bracket.

in conclusion

- The application prospects of polygonal reinforced concrete bearings in bridge reinforcement.
- Improve bridge safety and stability through reasonable design and construction control

Bracket shape	side length (m)	Angle (°)	High (m)	elasticity Modulus (GPa)	Poisson's ratio	density (kg/m³)	yield Strength (MPa)
rectangle	2.0	90	3.0	30	0.2	2500	350
trapezoid	2.0-3.0	90	3.0	30	0.2	2500	350
polygon	2.0-2.5-2.0	60-120	3.0	30	0.2	2500	350

Comparison of polygonal bracket parameters

2.1 Possible forms of the bracket (curved shapes)

Introduction to Curved Support

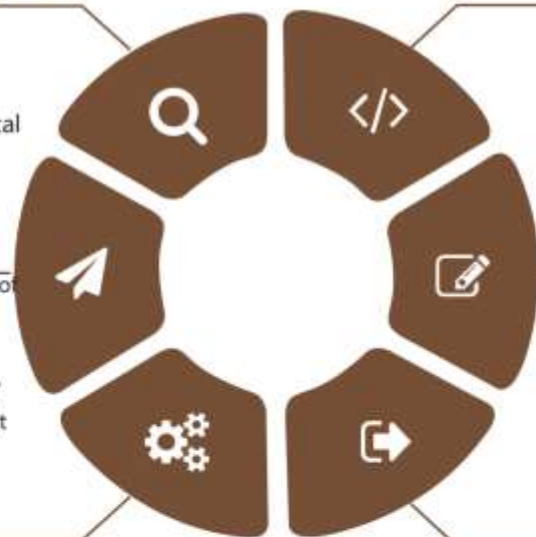
Innovative application in bridge support reinforcement.
Taking into account structural stability, mechanical transmission efficiency and aesthetics

Design Principle

Based on the geometric dimensions and expected loads of bridge bearings.
Common curve shapes: arc, parabola, ellipse, etc.
Parametric modeling: Generate different curve shapes by adjusting parameters such as radius, center position, start and end angles.

Finite element analysis

Build a finite element model: consider geometry, material properties, boundary conditions, and loading scenarios.
Static analysis: evaluate stresses and deformations under static loads.
Dynamic analysis: evaluate response under dynamic loads such as earthquakes and wind loads.



Static analysis

Evaluate stress distribution, deformations, support reactions under dead loads, live loads, temperature loads, etc.

Power Analysis

Simulate vibration response and dynamic characteristics under dynamic loads such as earthquakes and wind loads.
Evaluate the safety and reliability of bearings under extreme conditions.

in conclusion

Comparison of mechanical properties and stability of different curved brackets under specific load conditions.
Selecting appropriate curved brackets provides important reference for practical engineering applications.

2.2 Finite element method for modeling polygonal supports under load

Introduction to polygonal reinforced concrete supports

Definition and application background

Importance of polygonal reinforced concrete supports in bridge bearing reinforcement.

Emphasize the importance of structural stability, mechanical properties and actual loading conditions.

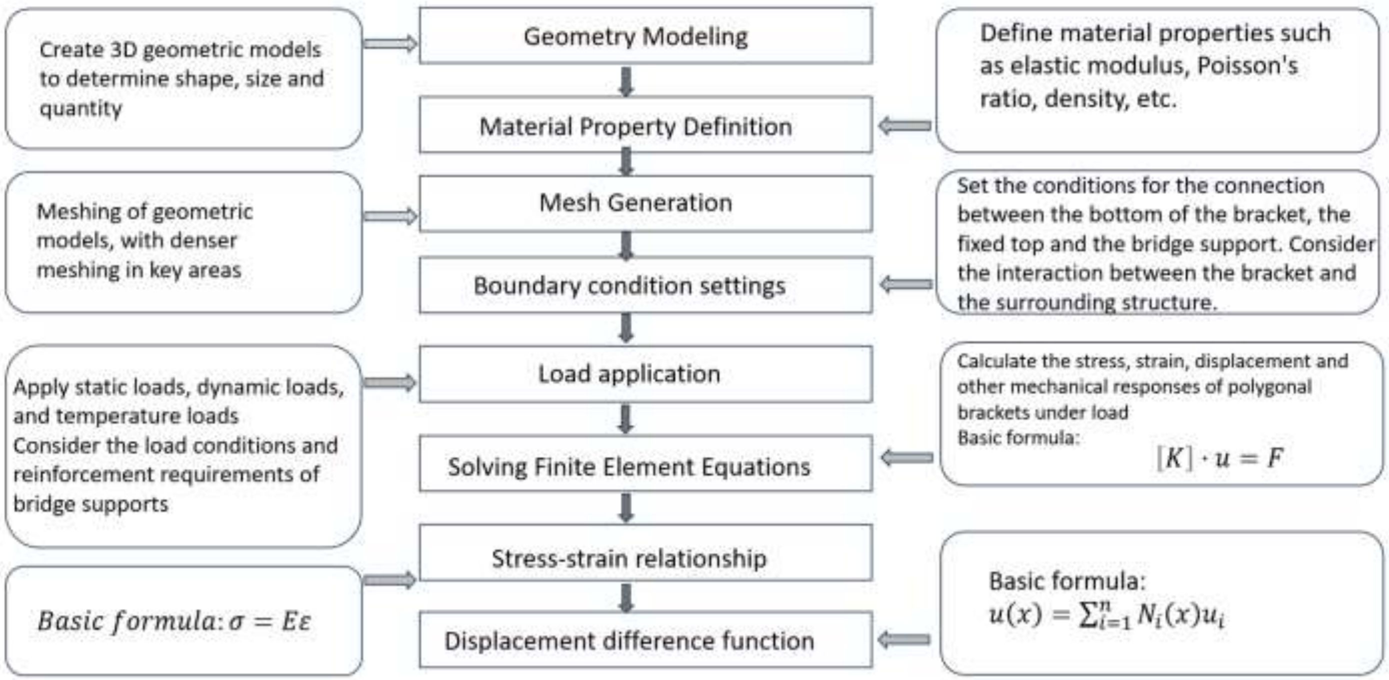
Finite Element Method (FEM)

FEM is a computational technique based on mathematical approximation.

Widely used in bridge engineering: structural analysis, stress calculation, deformation prediction, etc.

2.2 Finite element method modeling of polygonal bracket under load

Finite element modeling process of polygonal bracket



2.2 Finite element modeling of a polygonal bracket under load

comparison of mechanical response data

Mechanical responses of different polygonal brackets under the same loading conditions

Bracket type	maximum stress in metal parts（MPa）	maximum strain（με）	maximum displacement（mm）
Rectangular stand	250	1500	2.5
Ladder bracket	230	1400	2.3
Hexagonal bracket	220	1350	2.2
Round (curved shape) stand	210	1300	2.1

2.2 Finite element method for modeling polygonal supports under load

Beam stress-deformation model VS **Model influencing factors**

Model development

- The model considers permanent, temporary climatic and technical loads.
- The example bridge is located in climate zone 1, wind zone 3, snow zone 4 and ice zone 3.

Structure

- The bridge is of international importance and has a design life of 80 years.
- The reliability factor must be considered in the calculation of the main load-bearing structure

Dead load and live load

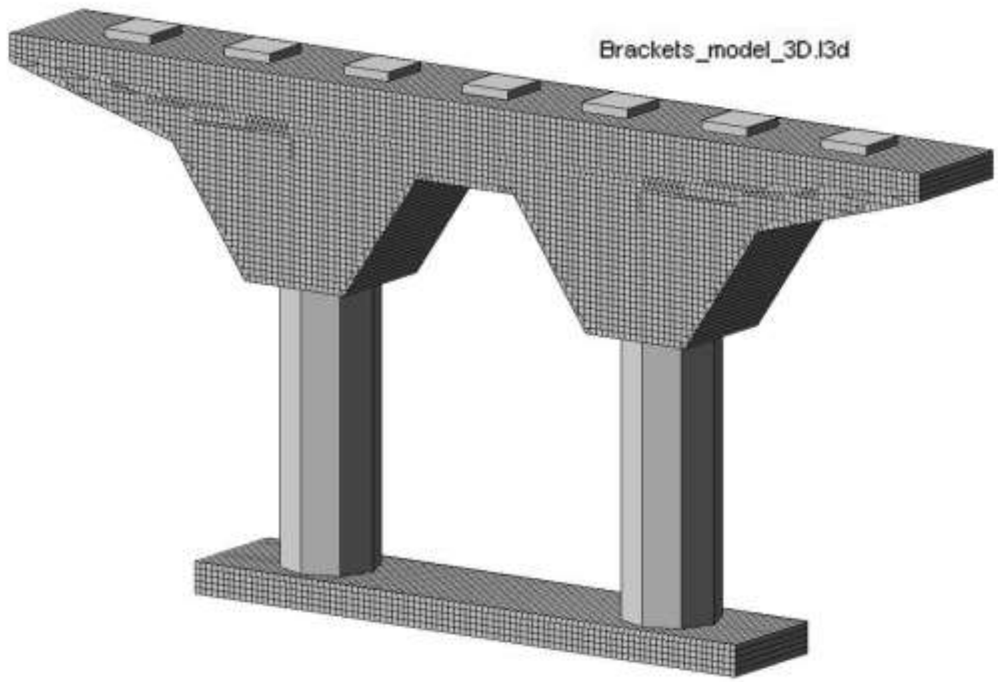
- Dead load: dead weight of beam structure, transition plate, handrail and guardrail weight, etc.
- Live load: NK-80 and A-11 trolley load, crowd load.

Temperature and climate impacts

Temperature load, ice load, etc.

2.2 Finite element method modeling of a polygonal support under load

bridge finite element model



3D FEM model of stress strain staite of the crossbar with a polygonal bracket

2.2 Finite element method modeling of a polygonal support under load

bridge finite element model

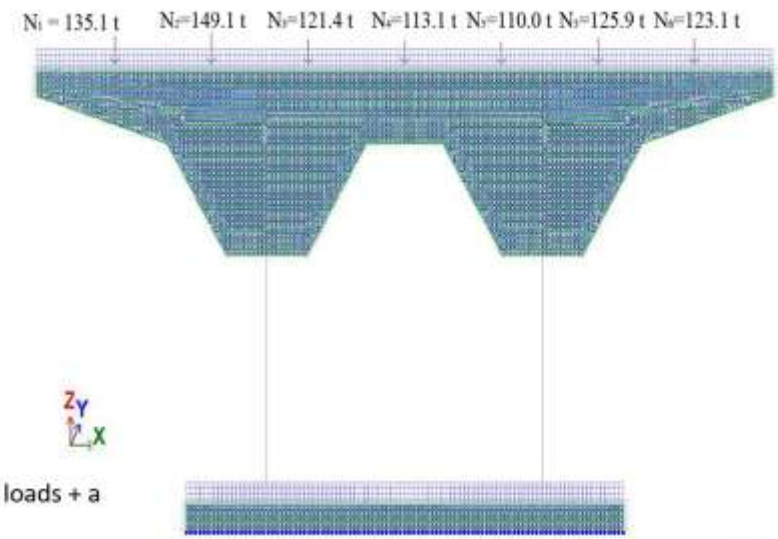
The magnitude of the concentrated forces simulating the effect of span T-shaped beams (reactions in the supports) will depend on the location of the temporary moving influences (NK-80 or A-11). Two worst cases were considered (wheels of NK-80 or A-11 carts). For these two options, the vertical effects on the subfertilizers were calculated, using the influence lines, the absolute values of which, from left to right, are as follows:

For moving load NK-80:

$N_1 = 1148\ kN$
$N_2 = 1424\ kN$
$N_3 = 1172\ kN$
$N_4 = 882\ kN$
$N_5 = 877\ kN$
$N_6 = 1093\ kN$
$N_7 = 1028\ kN$

For moving load A-11:

$N_1 = 1351\ kN$
$N_2 = 1491\ kN$
$N_3 = 1214 kN$
$N_4 = 1131\ kN$
$N_5 = 1100\ kN$
$N_6 = 1259\ kN$
$N_7 = 1231\ kN$



The most disadvantageous for the crossbar console is the combination of loads with A-11 loads + a crowd of pedestrians. We will perform the calculation for this combination

2.2 Finite element method modeling of polygonal bracket under load

modeling using Lira-Windows software

软件简介 (Software Overview)

Lira-Windows软件用于结构分析和设计。
实施的FEM变体使用可能运动原理。

建模细节 (Modeling Details)

作为空间系统的桥梁结构支撑模型。
物理机械特性、弹性模量和泊松比的定义

将弹性模量降低到极限:

$$E = 0{,}7 \cdot E_{cd}\left(B35\right) = 0{,}7 \cdot 25 \cdot 10^{9} = 17{,}5 \cdot 10^{9}\ \left(Pa\right)$$

钢筋混凝土的密度 $R_0 = 2{,}500\ m / м^3$

壳模型的离散化步长为100 x 100mm。杆件截面按简化几何方案构件立管和副梁的实际截面确定。
第 1 组极限状态计算采用设计荷载，第 2 组极限状态计算采用工作荷载。

2.3 Analysis of model calculation results (definition of dangerous areas)

In the bridge support reinforcement project, the polygonal reinforced concrete support is analyzed through finite element modeling to determine its mechanical response under different load conditions, identify potential danger areas, and provide a scientific basis for subsequent reinforcement.

Stress distribution analysis

- Stress contour map: intuitively display the stress level of different parts of the bracket.
- Dangerous area: areas with greater stress are more likely to crack or break.
- Rectangular bracket: stress concentration at the corners.
- Trapezoidal bracket: stress concentration at the inclined edge.
- Polygonal bracket: stress is relatively uniform, but concentrated at the vertex.
- Arc bracket: stress distribution is uniform, reducing stress concentration.
- Key point data extraction: compare the maximum stress value and position of brackets of different shapes

Displacement analysis

- Displacement contour map: Displays the displacement of each part of the bracket.
- Displacement distribution and structural stiffness:
- Rectangular bracket: Large local deformation at the corners and uneven displacement.
- Trapezoidal bracket: Large displacement near the hypotenuse.
- Polygonal bracket: Relatively uniform displacement.
- Arc bracket: Minimum displacement and high overall stiffness.
- Key point data extraction: Compare the maximum displacement value and position of brackets of different shapes

Modal Analysis

- Vibration characteristics: Evaluate the natural frequency and vibration mode of the bracket under dynamic loads such as earthquakes and wind loads.
- Resonance risk: Avoid the natural frequency of the bracket being consistent or close to the external excitation frequency to prevent structural damage.
- Design optimization: Optimize the bracket design based on the modal analysis results to ensure safety and reliability under dynamic conditions.

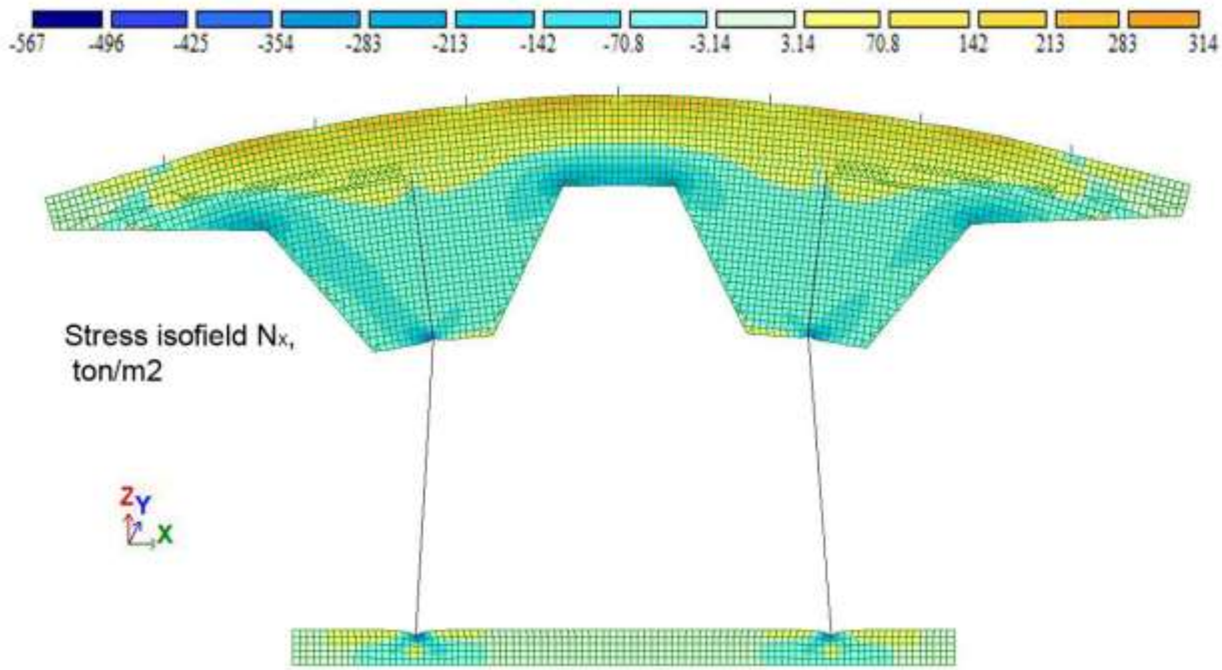
2.3 Analysis of model calculation results (definition of dangerous areas)

Maximum stress and maximum displacement values of brackets with different shapes under the same load conditions

Bracket type	Maximum stress (MPa)	Maximum stress position	Maximum displacement (mm)	Maximum displacement position
Rectangular stand	250	corner	2.5	corner
Ladder bracket	230	Near the hypotenuse	2.3	Near the hypotenuse
Hexagonal bracket	215	vertex	2.1	vertex
Round (curved shape) stand	205	Evenly distributed	1.9	Evenly distributed

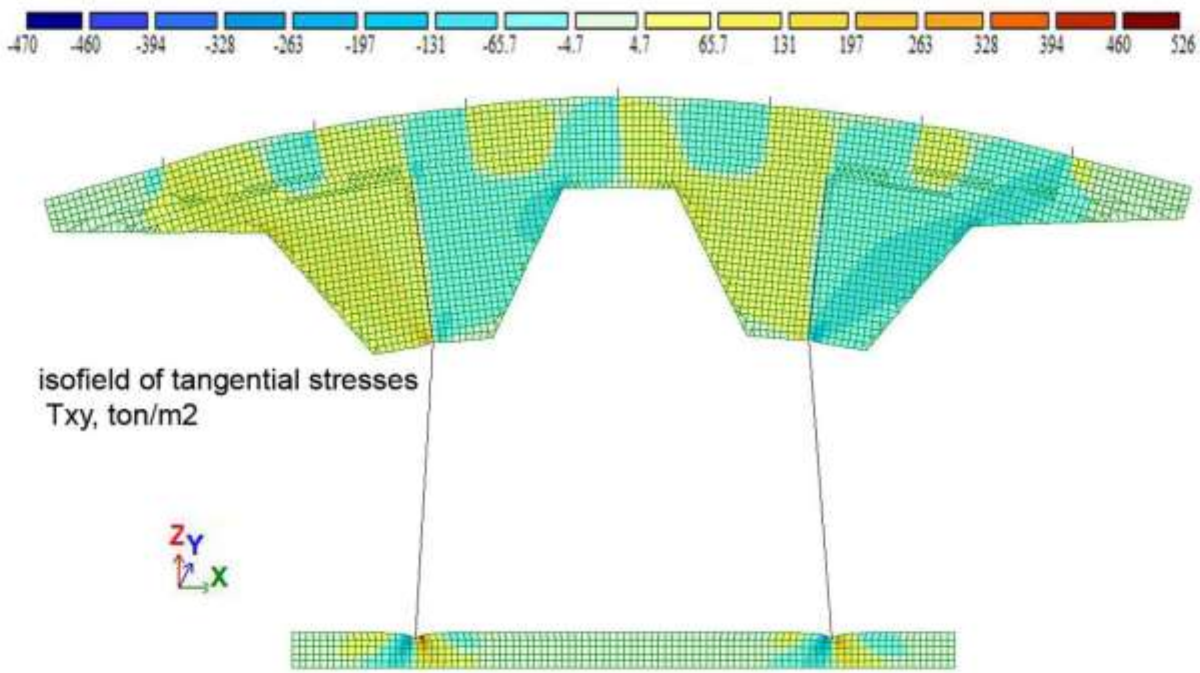
2.3 Analysis of model calculation results

analysis of calculation results of polygonal reinforcement bracket example



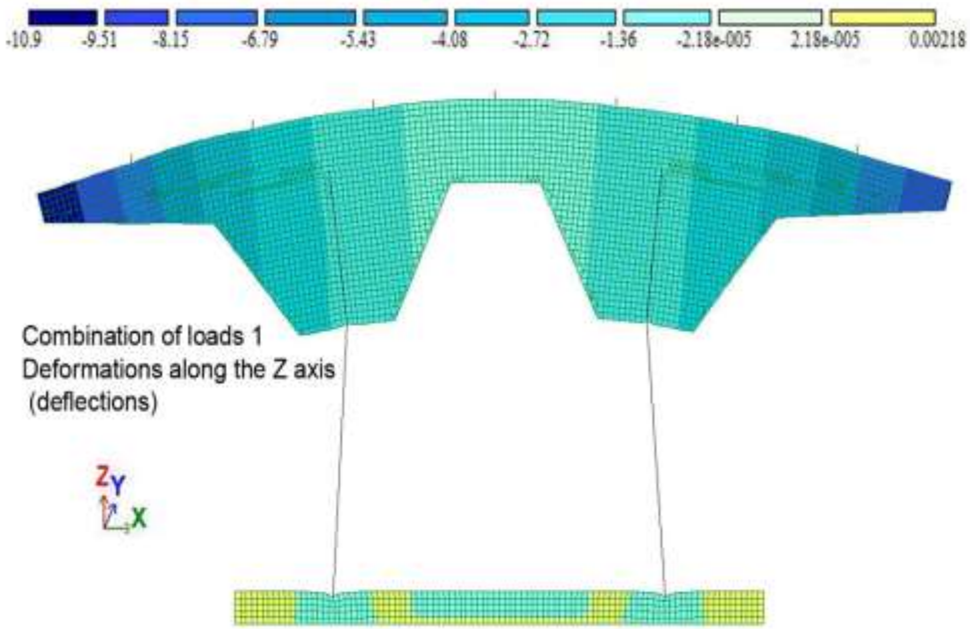
2.3 Analysis of model calculation results

analysis of calculation results of polygonal reinforcement bracket example)



2.3 Analysis of model calculation results

analysis of calculation results of polygonal reinforcement bracket example)



As can be seen from these figures, the highest compressive stresses in the polygonal reinforcement bracket are concentrated in the corners of the shape cracks and close to the bridge support columns. The highest tensile stress is concentrated in the upper part of the polygonal bracket, where the working reinforcement is located near the defective beam. However, the tensile stress level is significantly lower than before reinforcement. Therefore, the system "defective bolt-polygonal clamp-riser" shown can withstand the design load.

03 CHAPTER 2

2.4 Reasonable support reinforcement design scheme

reinforcement scheme for damaged bridge sections

Causes of damage to the bridge structure:

Illegal construction techniques lead to increased flood burden

Uneven concrete pouring and irregular steel pouring

Use of inappropriate materials or construction methods

Actual load exceeds design value, leading to increased stress and deformation of beams

Water flow damages foundation structure, leading to steel corrosion and material deterioration

Beam damage manifestations: cracking, spalling, fracture

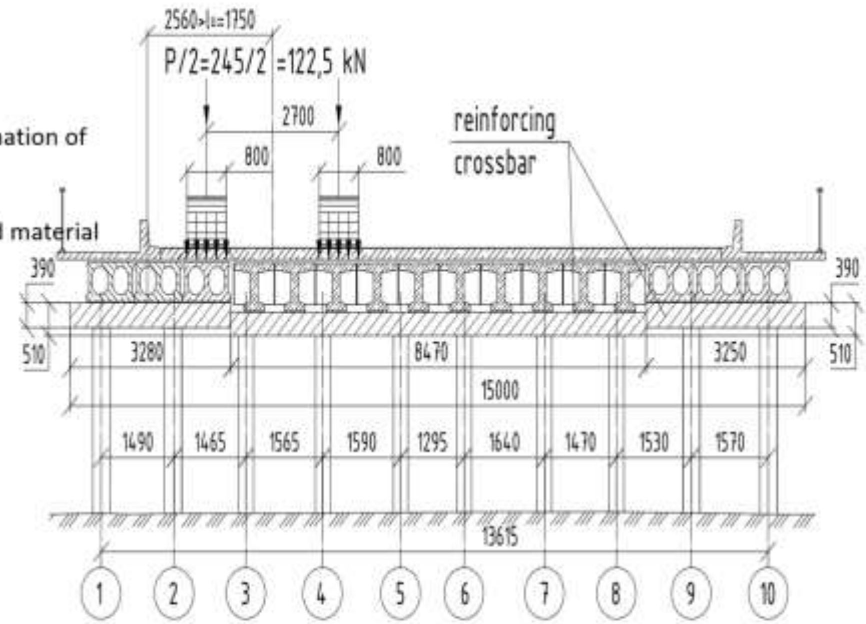
Reinforcement Solution：

Installation of polygonal reinforcement fences

Installation of additional anchor bolts

Preparation of additional working materials and concrete injection

Increase of load-bearing capacity



Bridge cross section

2.4 Reasonable support reinforcement design scheme

reinforcement scheme for damaged bridge sections

Total bearing capacity of reinforced anchor bolts

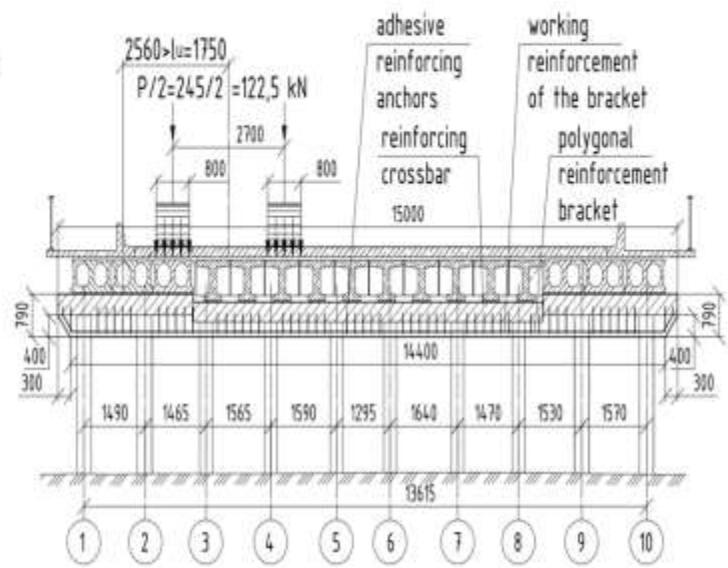
$$F_{total} = 2 \times 122.5\,\mathrm{N} = 245\,\mathrm{N}$$

Total length of polygonal reinforcement bracket:

$$L_{Bracket} = 15000\,\mathrm{mm}$$

Steel bar quantity and weight

- Rebar diameter: assumed to be 20 mm, weight per meter approximately 2.47 kg
- Total length of rebars: assumed to match the bracket length, installed every 300 mm
- Number of rebars: $N_{Rebar} = \frac{15000\,\mathrm{mm}}{300\,\mathrm{mm}} = 50\,\mathrm{pieces}$
- Total weight of rebars: $W_{Rebar} = 50\,\mathrm{pieces} \times 15\,\mathrm{m} \times 2.47\,\mathrm{kg/m} = 1852.5\,\mathrm{kg}$



Conclusion

The above calculations and design plan will effectively enhance the load-bearing capacity and structural stability of the bridge beam.
Adjustments based on actual conditions are required during implementation to ensure construction quality and achieve the desired repair results.

2.4 Reasonable support reinforcement design scheme

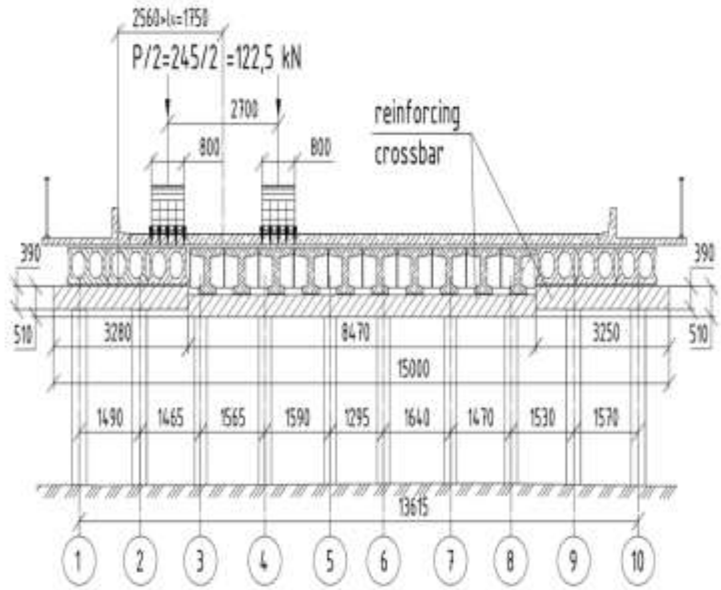
single-layer bridge damage and reinforcement

- Bridge structure and dimensions (as shown in the figure)
- Cause of damage

  Construction non-compliant
  Load exceeded design value: 122.5 kN
  Water erosion

- Damage Effect

  Reduced structural strength
  Increased stress and deformation
  Cracks, spalling and fractures
  Compromised bridge stability and safety



Single squat bridge

2.4 Reasonable support reinforcement design scheme

damage and reinforcement of single-layer bridges

Total Bearing Capacity of Reinforcement Bolts

- **Assumption**: Each bolt has a bearing capacity of 100 kN, and each beam uses 10 bolts
- **Total Bearing Capacity**: 10 × 100 = 1000 kN

Total Length of Polygonal Reinforcement Bracket

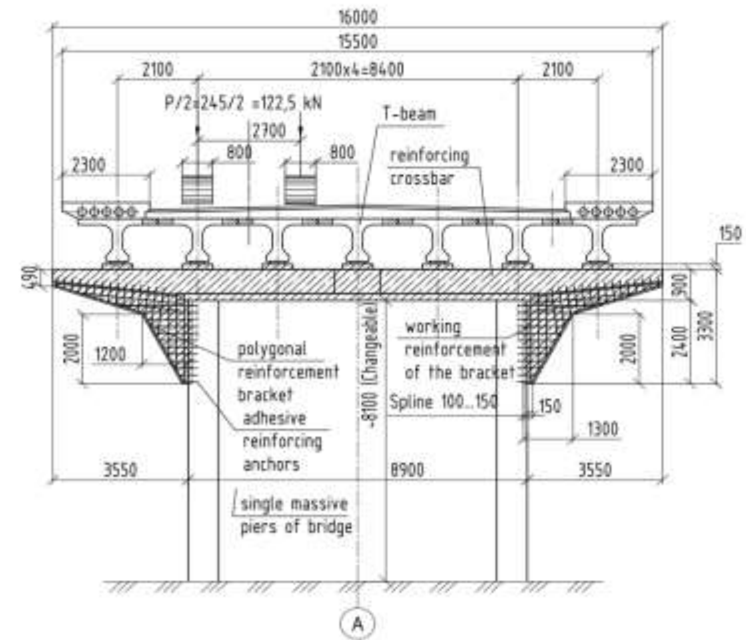
- **Horizontal Length (L1)**: 3550 mm
- **Inclined Length (L2)**: 2000 mm
- **Total Length**: L = L1 + L2 = 5550 mm

Quantity and Weight of Rebar

- **Diameter of Rebar**: 20 mm
- **Unit Weight**: ω ≈ 2.47 kg/m
- **Quantity per Meter**: 5 pieces
- **Weight per Meter**: 5 × 2.47 = 12.35 kg/m
- **Total Weight**: 12.35 × 5.55 = 68.93 kg

Concrete Cover Area

- **Total Width (B)**: 900 mm
- **Total Height (H)**: 3300 mm
- **Concrete Area**: A = B × H = 2.97 m²



Single squat bridge reinforcement plan

2.4 Reasonable support reinforcement design scheme

Damage and reinforcement of double-deck bridge

Current Issues

- Construction Violations: Use of non-compliant materials and methods, resulting in uneven concrete pouring and irregular rebar placement.
- Overloading: Design load is 122.5 kN, but actual load may far exceed this value.
- Water Damage: Erosion of the bridge's foundation structure by water leads to rebar corrosion and material degradation.

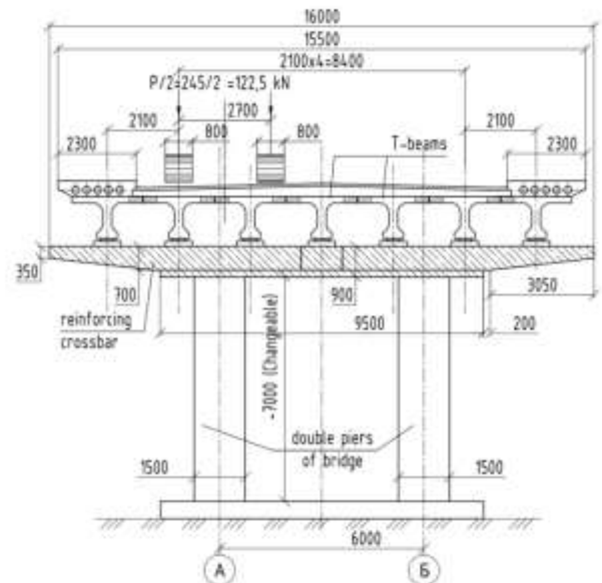
Bridge Parameters (see figure)

Bridge Damage

- Cracks and Peeling: Beams exhibit cracks, peeling, and even breakage.
- Safety Threat: Increases the instability and safety risks of the bridge.

Reinforcement Measures

- Adhesive: Improve structural bonding strength.
- Reinforcement Bolts: Increase bearing capacity.
- Polygonal Reinforcement Bracket: Enhance overall structural rigidity.
- Working Rebar: Strengthen beam bearing capacity.



Double Squat Bridge

2.4 Reasonable support reinforcement design scheme

Damage and reinforcement of double-deck bridges

Reinforcement Anchor Total Bearing Capacity:
Bearing capacity per anchor: 245kN
Total bearing capacity for two anchors: 490kN

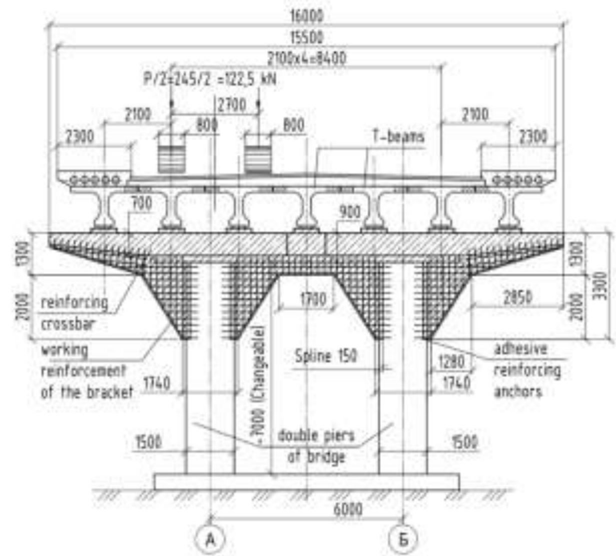
Total Length of Polygonal Reinforcement Brackets:
Length per span: 5800mm
Additional end extension: 4600mm
Total horizontal length: 10400mm
Vertical (Vertical Distance from Beam to Support Column Base):
Length of each vertical segment: 3300mm
Length of each diagonal end (assuming a 45-degree angle): 4667mm
Total vertical length: 7967mm
Total Length (Horizontal + Vertical): 18367mm

Quantity and Weight of Reinforcement:

Calculation of length and weight per steel bar:
Length per steel bar: 18.367m
Cross-sectional area of the steel bar: 201.06mm^2
Weight per meter of steel: 1.5783kg/m
Total weight per steel bar: 28.96kg
Total number and weight of steel bars:
Assuming 10 bars per meter, the total number of bars: 183.67 bars
Total weight: 5316.87kg

Concrete Area:

Calculation of concrete pouring area:
Support base area: 1.2m²
Bracket side area:
Area on both left and right sides: 7.8m²
Front and back area (considering the extension of the polygon): 3.705 m²
Total concrete area: 24.21 m²



Double Squat Bridge Reinforcement Solution

2.5 in conclusion

Bracket type selection:

Each bracket type has its own unique advantages and application scenarios.Rectangular brackets are simple, stable and generally reliable.Stepped brackets perform well at specific angles or diagonal supports.Polygonal brackets provide more uniform stress distribution and higher strength, especially for demanding load situations.Curved brackets reduce stress concentration and enhance structural flexibility

Rational Reinforcement Clamp Design:

Crucial for project success, clamps must balance strength, stability, and ease of installation.Material optimization and structural improvements enhance clamp performance and lifespan.

Importance of finite element modeling:

Finite element modeling accurately predicts stress distribution and helps in bracket design and optimization.Improve design efficiency, reduce testing costs, and ensure engineering feasibility and safety.

Comprehensive Construction Planning:

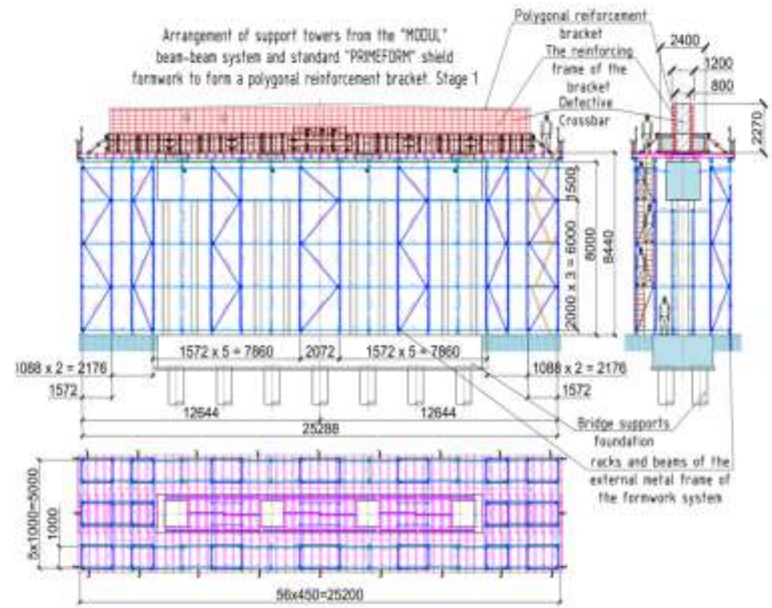
Plans should consider support structure, finite element modeling, and clamp design.Selection of the most suitable plan based on comparative analysis of advantages, disadvantages, and applicability.Emphasis on quality control and safety management ensures smooth project implementation and high-quality completion.

3.1 Rational technology for scaffold production

effective formwork system

Design bracket shape and size:

- The polygonal bracket was chosen as the basic shape to meet strength and stability needs.
- The length and angle of each side was carefully calculated to ensure a comfortable fit and proper support.



The first step in template system installation

3.1 Rational technology for scaffold production

effective formwork system

Design bracket shape and size:

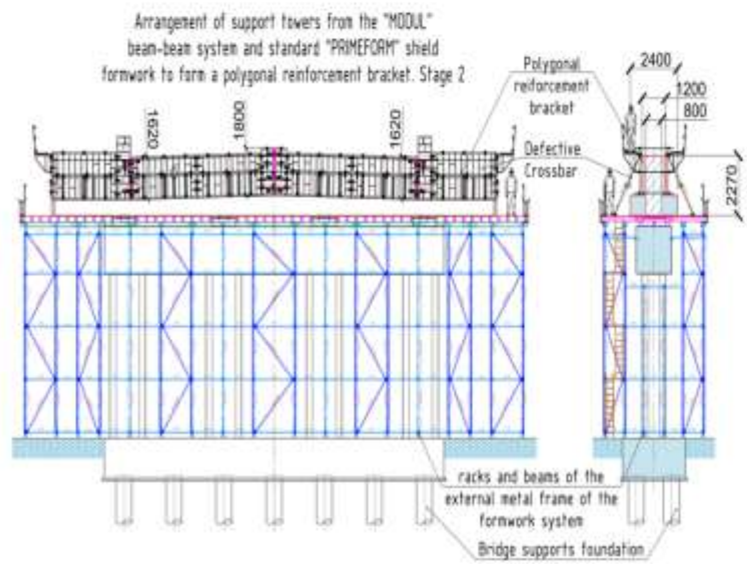
- The polygonal bracket was chosen as the basic shape to meet strength and stability needs.
- The length and angle of each side was carefully calculated to ensure a comfortable fit and proper support.

Concrete Selection and Adhesion:

- Select concrete mixes with high strength, durability and water conservation to reduce the risk of fractures and support changes.
- Develop new additive mixes with excellent adhesion and durability to increase the bond strength between the support and the existing structure.

Economic Benefit Analysis:

- Compared with traditional reinforcement methods, polygonal brackets have cost advantages.
- Using this bracket structure can reduce the number of repairs and maintenance costs, extending the life of the bridge.



The second step of template system installation

3.2 Proper technology for support production

effective support concrete mixture

High Performance Concrete (HPC):

- High compressive strength, good durability and strong processability.
- By adjusting the composition and adding substances, the bracket can withstand heavy loads without cracks or deviations.
- It has excellent waterproof performance and freeze-thaw resistance.

Ordinary Portland Cement (OPC) with additives:

- Simulate HPC performance by adding mineral ingredients (such as silica fume, fly ash).
- Use high water reduction equipment to reduce water-cement ratio and increase fluidity.
- Although less efficient, the cost is more suitable for projects with limited budgets.

3.3 Effective adhesive mixtures for joining existing reinforced structures

Importance of welding agent selection:

Directly affects the strength of steel bars and structural safety.

Sika MonoTop®-1010的应用

- Product recommendation: Cream-based concrete with an anti-corrosion coating for the repair and maintenance of reinforced concrete structures. Provides long-term protection and good bonding properties.
- Manufacturing process: Surface preparation: Ensure that the steel surface is clean and free of oil or rust. Mixing and application: Mix and apply to the steel surface according to the product manual instructions.
- Drying and baking: Wait for the coating to dry and harden completely, avoiding moisture and other contaminants.
- Use in actual cases: In bridge repair projects, it is used to strengthen and protect structural steel structures, improve their reliability and service life. Conduct detailed inspections and assessments before repairs, clean the steel surface, remove rust and pollution, and ensure construction quality.

Practical Application

Practical Application

3.4 Conclusion of the support layout technical solution

Design elements to consider:

Comprehensive consideration of the rotational dynamic characteristics of the bridge structure and the reinforcement requirements.

The structural design focuses on construction operability and maintainability to ensure that the solution is efficient and reliable.

Construction process using high floor system

Ensure accuracy and high-quality construction.

Improve construction efficiency and ensure structural stability and section accuracy.

material selection

Use concrete and high concrete materials and mix with a single additive to create a strong connection.

Cost-benefit analysis

By comparing the costs of different materials and manufacturing methods, it was found that the polygonal concrete steel zone reinforced structure is cost-effective.
Investing in technology and increasing skilled labor may be larger, but by strengthening the structure, the quality and stability of the building system will be improved, thereby reducing overall construction costs.

Comparison of Classic Reinforcement Methods

The cost index of classical strengthening methods such as reinforcement zone placement is evaluated and compared with strengthening techniques for reinforced concrete structures and zones.

4.1 Calculation of the linear construction cost per meter of the bridge pier system reinforcement beam structure

project name	**Amount**
Material costs	Steel bar cost: ¥100/m Concrete cost: ¥120/m Formwork system cost: ¥50/m Adhesive cost: ¥20/m
Labor cost	¥600/m
Equipment cost	¥100/m
Other costs	¥99/m
Total cost calculation	¥1089/m

Compared with traditional reinforcement methods, the initial investment of the polygonal clamp pier-beam system is slightly higher, but the long-term benefits are significant. Its long-term reinforcement effect and improvement of the overall performance of the bridge are obvious. In addition, the system has a short construction period and little impact on traffic, further improving its economic and social benefits. Therefore, adopting this system in bridge strengthening projects is an option worth considering.

4.2 Comprehensive cost index of classic reinforcement methods

Material costs

Steel cost: ¥1000/m

Connectors, prestressed steel bars,

Concrete costs need to be calculated based on specific design

Labor cost

Assuming the construction requires 10 workers

Total labor cost: ¥90,000

Equipment cost

Assuming rental of crane and excavator

Total equipment cost: ¥240,000

Other costs

Construction management fee: 10% of total cost

Safety measures fee: 5% of total cost

Taxes: 3% of total cost

Comprehensive cost indicators

Consider direct costs and other related costs to compare the cost-effectiveness of different reinforcement solutions

4.3 Comparison of economic benefits of bridge reinforcement schemes

Cost Comparison

Polygonal reinforced concrete support reinforcement solution:

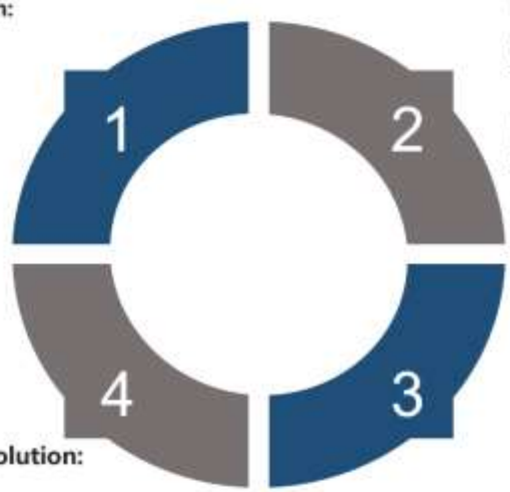
Total cost: ¥2800/m

Traditional steel support reinforcement solution:

Total cost: ¥2750/m

Concrete expansion foundation reinforcement solution:

Total cost: ¥2750/m



Performance Benefit Analysis

Polygonal reinforced concrete support reinforcement solution:
Higher bearing capacity, stability and durability
Traditional reinforcement solution and concrete foundation expansion reinforcement solution:
Performance and durability are inferior to polygonal reinforced concrete support reinforcement solution

Comprehensive economic benefit evaluation

Polygonal reinforced concrete support reinforcement scheme:
Total income: ¥2500/m (considering performance and life extension)
Traditional reinforcement scheme and concrete enlarged foundation reinforcement scheme:
The overall economic benefits are relatively low

in conclusion

The polygonal reinforced concrete support reinforcement solution has significant advantages in economic benefits. Although the initial investment is high, the long-term performance and benefits are significant.

4.4 Conclusion

Study on Economic Benefits of Bridge Reinforcement

Economic Benefit Evaluation

VS

Study on Economic Benefits of Bridge Reinforcement

- Initial investment is higher: but long-term maintenance costs are low and the service life of the bridge is extended
- Long-term return on investment is high.

Comparison with typical solutions

Traditional steel support reinforcement
Concrete expansion foundation reinforcement

Cost: Low initial investment but high long-term maintenance cost
Performance: Bearing capacity and stability are inferior to polygonal reinforced concrete support solutions
Construction period: Longer.

Summary

Reinforcement scheme of polygonal reinforced concrete support

Advanced technology, high cost-effectiveness and strong adaptability
It is expected to become the mainstream reinforcement method, providing guarantee for safe operation and long-term use of bridges
It needs to be continuously improved and optimized in practice

Technical advantages:

1. Innovative formwork system design: improving construction efficiency and strengthening structural accuracy
2. High-performance concrete patches: good fluidity, crack resistance, and enhanced overall performance
3. High-quality adhesives: Improve structural stability and load-bearing capacity

Annex C

ПРОТОКОЛ
ПЕРЕВІРКИ КВАЛІФІКАЦІЙНОЇ РОБОТИ НА НАЯВНІСТЬ ТЕКСТОВИХ ЗАПОЗИЧЕНЬ

Назва роботи: Метод підсилення ригелів мостових опор влаштуванням полігональних залізобетонних обойм

Тип роботи: Магістерська кваліфікаційна робота
(БДР, МКР)

Підрозділ кафедра БМГА, ФБЦЕІ
(кафедра, факультет)

Показники звіту подібності Unicheck

Оригінальність 95,63 % Схожість 4,37 %

Аналіз звіту подібності (відмітити потрібне):

- [x] 1. Запозичення, виявлені у роботі, оформлені коректно і не містять ознак плагіату.
- [ ] 2. Виявлені у роботі запозичення не мають ознак плагіату, але їх надмірна кількість викликає сумніви щодо цінності роботи і відсутності самостійності її виконання автором. Роботу направити на розгляд експертної комісії кафедри.
- [ ] 3. Виявлені у роботі запозичення є недобросовісними і мають ознаки плагіату та/або в ній містяться навмисні спотворення тексту, що вказують на спроби приховування недобросовісних запозичень.

Особа, відповідальна за перевірку ________ (підпис) Блащук Н.В. (прізвище, ініціали)

Ознайомлені з повним звітом подібності, який був згенерований системою Unicheck щодо роботи.

Автор роботи ________ (підпис) Лі Сяохун (прізвище, ініціали)

Керівник роботи ________ (підпис) Попов В.О. (прізвище, ініціали)

RESPONSE
of master's qualification thesis supervisor

student LI Xiaohong
(full name)

on the topic The method of strengthening the crossbars of bridge bearings by arranging polygonal reinforced concrete brackets

The master's qualification thesis investigates the stress-strain state of bridge support structures within crossbar reinforced with reinforced concrete polygonal brackets under the action of a complex of dead and live loads by finite elements method. This made it possible to determine the most heavily loaded sections of the reinforcement structures.

The author proposed a method of selecting a rational polygonal shape of the crossbar reinforcement bracket depending on the number of supporting columns of the bridge support (for single-column, double-columns and multi-columns constructions) and the technology of arranging polygonal brackets.

The master's qualification thesis corresponds to the issued task. The relevance of the master's thesis is justified by the need to find rational constructive form of reinforcement structures to ensure high strength, reliability and further long-term operation of bridge structures, as an important component of the state transport system.

The mentioned scientific researches were carried out by the author on the basis of a deep and modern understanding of the state of the issue of bridge construction, their constituent parts and reinforcement construction.

For today have been known that the crossbar of the bridge support keeps the movable and immovable bearing parts of the bridge. Therefore, in order to correctly take into account this interaction and understand the issues related to the joint operation of the crossbar system, the reinforcement bracket, the bearings and the columns of the bridge support, the author conducted a thorough scientific generalization of standards and scientific research information in this field.

Have been outlined by author the advantages and disadvantages of polygonal brackets system of reinforcing in comparison with standard methods of reinforcement, such as epoxy injection, concreting, etc. In addition, have been offered a rational method of reinforcement for the polygonal constructions of brackets of bridges crossbars specified in the topic of the master's qualification work.

The scientific research carried out by the author of the master's thesis was done independently at a high level. The master's student is erudite, knows how all materials on the rational design of polygonal reinforcing brackets of crossbars, knows how to analyze and summarize scientific material. As a result, have been published two scientific publications based on the material of the master's thesis. The main results of the work have been reported on LIII All-Ukrainian Scientific and Technical Conference of the Faculty of Construction, Civil and Environmental Engineering (2024) and also on International scientific and practical Internet conference "Youth in science: research, problems, prospects (MN-2024) held on 2022 at VNTU, Vinnytsia, Ukraine.

The research carried out by the author was finished in time, in accordance with the approved calendar schedule. The master's student's level of training meets the requirements of the educational program in the specialty 192 Construction and civil engineering and deserves an "A" grade and the award of a "Master's" degree in civil engineering.

Master's thesis supervisor

PhD, Docent of CEUPA Department		POPOV Volodymyr O.
(position, academic degree, academic rank))	(signature)	(surname and initials)

RESPONSE OF OPPONENT
on master's qualification thesis

student LI Xiaohong
(full name)

on the topic The method of strengthening the crossbars of bridge bearings by arranging polygonal reinforced concrete brackets

In the master's qualification thesis (MQT) have been investigated rational methods of calculation and design the polygonal reinforcement brackets for defective crossbars of bridge piers. The content of the MQT corresponds to the task. The relevance of the master's thesis is confirmed by the need to create effective and architecturally expressive constructions of reinforcement of existing bridges to increase their strength, reliability and durability, in conditions of increased traffic load.

MQT of scientific direction consists of four main chapters, introduction and conclusions. The first chapter of masters thesis is devoted in general to the analysis of the state of the design bridges, in general, and bridge piers, in particular. The author of the work provided information on bridge construction in China and reviewed the structural components of typical bridge support systems. Have been described problematic issues in the design of constructions of reinforcement of bridge piers.

In the second chapter of the MQT, the author describes the methodology of detailed finite-element model of the structure of polygonal brackets, which are arranged around crossbar systems that have suffered damage due to long-term use. Issues related to determining the location of the most stressed sections of the brackets were studied. Localized areas with tensile stresses in which reinforcement must be installed. Also, in this part of the work, the author proposed a rational construction of reinforcement of polygonal clips, which should be connected to the struts of bridge piers and metal crossbars by gluing anchors.

The third section of the master's qualification work is devoted to technological proposals for the arrangement of polygonal brackets systems with difficult construction using modern formwork systems with an external rack-and-beam frame. The author of the scientific work proposed effective concrete compositions for concreting polygonal brackets and effective adhesive mixtures to joining to existing reinforced structures.

The fourth chapter (economic part) allowed the author to evaluate the feasibility of the provided proposals according to the integral value criterion. The main components of the cost for the installation of the reinforcement brackets were determined, which include the cost of materials and labor costs. The calculations determined that the cost of the proposed method of amplification is higher than the standard method. But regarding to reason that the strength resource, reliability and durability of the structures of bridge piers strengthened by the proposed method is much higher, which, in the final case, will lead to a quick payback of over expenditures.

The main results of the MQT were published in two scientific papers and tested at two scientific conferences.

The following shortcomings can be noted in the work. From the MQT, it is not entirely clear what the crossbar of the bridge support looked like before the reinforcement. Before modeling, two schemes should have been shown – before amplification and after amplification. The author should have described in detail the process of collecting loads on the bridge crossbar. The specified shortcomings don't reduce the overall positive impression of the work and do not have a fundamental meaning.

Scientific studies in the direction of optimization of methods of rational design and modeling stress-strain state of polygonal brackets of reinforcement of bridge pier systems, outlined in the MQT, allow us to conclude that the master's student meets the requirements of the educational program in the specialty 192 "Construction and civil engineering" and, with appropriate protection, deserves an "A" grade and awarding her a "Master's" degree.

Master's thesis opponent
PhD, Docent of thermal power engineering Department
(position, academic degree, academic rank))

(signature)

Nataliia REZYDENT
(surname and initials)