UNIVERSITAT POLITÈCNICA DE VALÈNCIA

School of Civil Engineering

Basic Project of the first bridge of Zorrotzaurre Island (Bilbao)
Analysis of initial conditions, calculation of foundations, and construction and equipment design

End of Degree Project

Bachelor's Degree in Civil Engineering

AUTHOR: Jonas, Linus

Tutor: Monleón Cremades, Salvador

Cotutor: Lázaro Fernández, Carlos Manuel

External cotutor: Buchmann, Alfons

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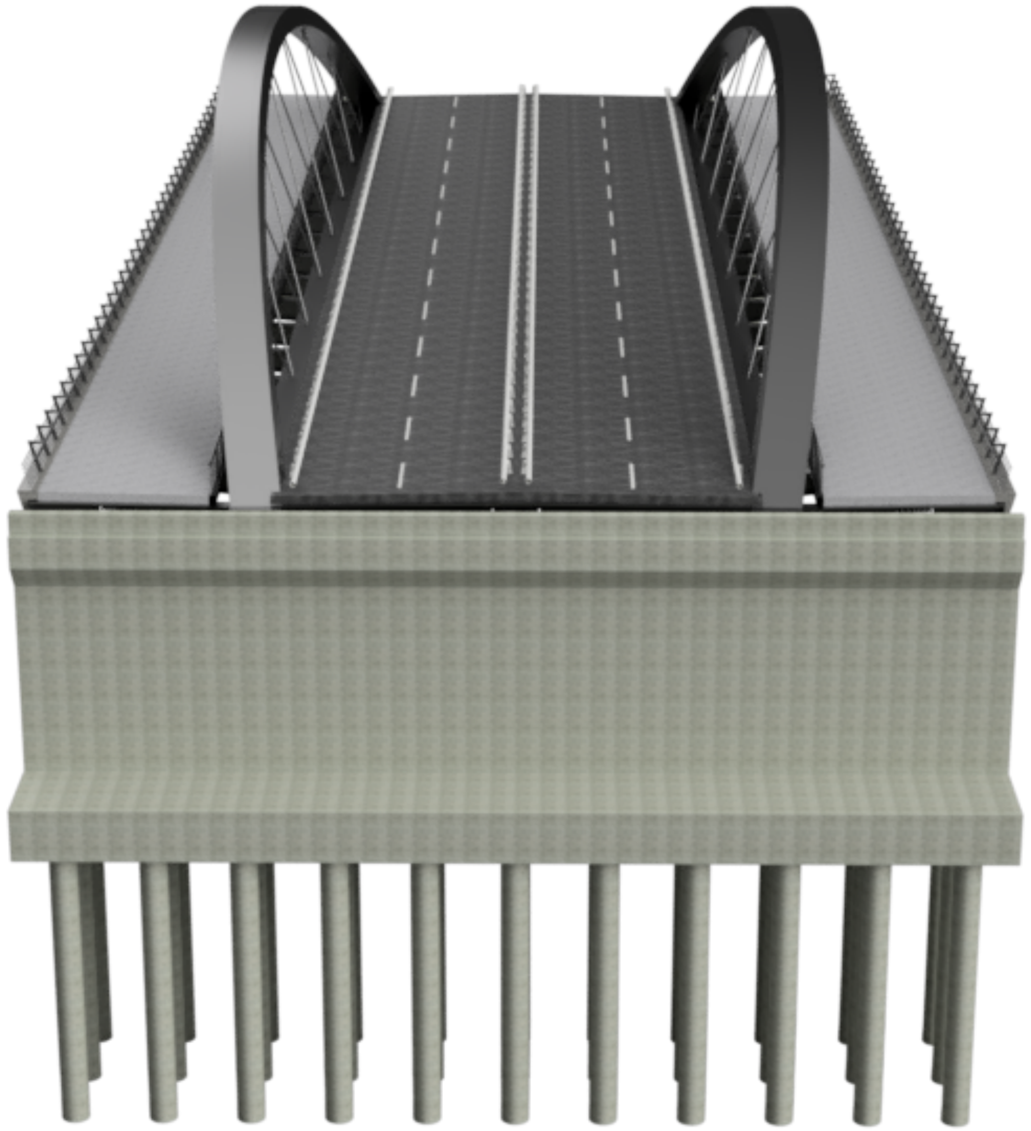
Project Report and Appendices



Authors:

Kevin Petri

Linus Jonas

Tutors:

Salvador Monleón Cremades

Carlos Manuel Lázaro Fernández

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Project Report

1. Purpose of the Basic Project

The aim of the following basic project is to develop an alternative proposal to the Frank Gehry Bridge, inaugurated in Bilbao in 2015, which serves as a link between the Deusto district and the island of Zorrotzaurre, crossing the Deusto Channel. The project will be developed according to the specifications of the tendering company Euskal Trenbide Sarea and the conditions established during the construction of the Frank Gehry Bridge.

2. Location

The project is located in Bilbao, the capital of the Spanish state País Vasco.

Figure 1: Location Bilbao [Source Apple Maps]

The bridge connects the Deusto district in the north of Bilbao with the island of Zorrotzaurre, which was created by the final opening of the Deusto Channel. The bridge crosses the Deusto Channel.

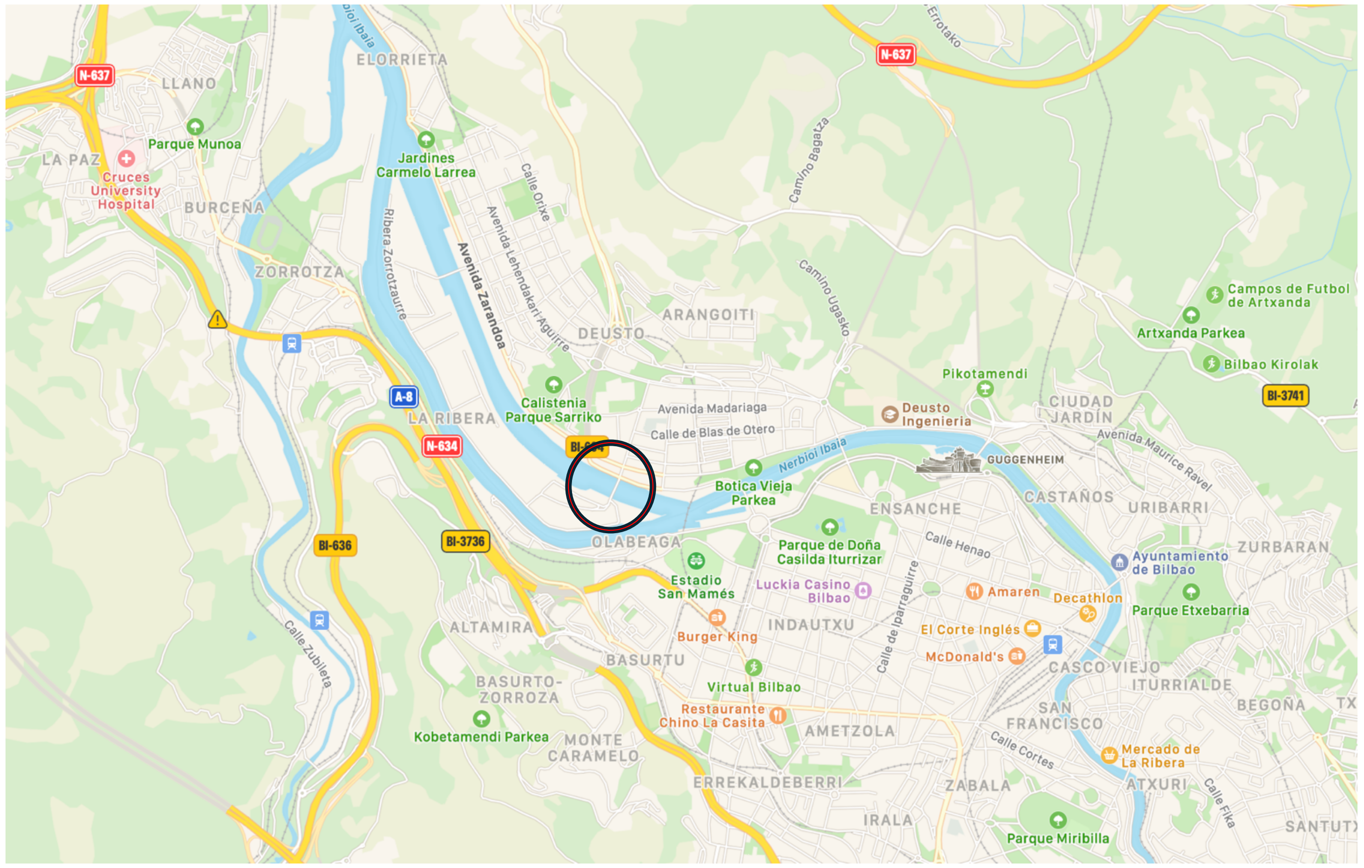

Figure 2: Location of the Bridge [Source Apple Maps]

3. Background History

The first ideas for the Deusto Channel were born in the 1930s. Due to the increasing use of the Port of Bilbao, the need was felt to make the river Nervión navigable further inland, which had previously proved difficult for larger vessels due to the Olabeaga and Elorrieta bends in the river's natural course. The channel would provide a more navigable alternative with a higher water level (an alternative that could be used by larger ships). Quays were to be built along the course of the channel. Three construction phases were completed in 1946, 1950 and 1951, during which all but the last 370 meters of the channel were built and put into operation. Over the years, due to increasing traffic and larger ships, an alternative port was sought and found in the Santurtzi area. As this established itself as Bilbao's new port, the channel and the surrounding neighborhoods became less and less important until the channel was finally closed as a port facility in 2006. In order to revitalize the island of Zorrotzaurre and make it an important part of Bilbao, a master plan designed by architect Zaha Hadid was presented in 2004. According to this plan, the island of Zorrotzaurre (at that time still a peninsula) would become a district with a mix of residential space (half of which would be social housing), commercial and office space, educational facilities, social services, and spaces to improve the quality of life (green spaces, promenades, avenues). The mobility of the island should be similar to that of the rest of the city, i.e., pedestrian and bicycle friendly, and connected to the public transportation network by a tram line that crosses the island.

The island will be connected to the surrounding neighborhoods by three bridges, one of which will be the bridge developed in the following project. It will be built in the area that is not yet open at the time of construction. The complete opening of the channel and the transformation of the Zorrotzaurre peninsula into an island is also part of the master plan.

4. Geotechnical Data

The geotechnical study is an investigation of the geotechnical conditions on which the bridge will be built. Geotechnical data is provided by the tendering party. This given data is completed and confirmed with more geotechnical data obtained over time on the island.

Due to the location of our bridge in the so-called Basque-Cantabrian Basin, which is a foreland of the Pyrenees, it can be assumed that the lower layers are calcareous siltstones from the Lower Cretaceous. The upper layers are silt and clay alluvium, since the area of the island of Zorrotzaurre is very close to the natural course of the river Nervión. Throughout the city of Bilbao, the upper soil layers are characterized by Quaternary deposits.

Since Zaha Hadid's master plan covers the entire island of Zorrotzaurre, several geotechnical studies have been carried out over the years. From these investigations, SPT's (Standard Penetration Tests) and a DPSH (Dynamic Probing Super Heavy) are used to confirm and complete the given data. Based on the given geotechnical profile and the complementary data, the assumed soil layers are confirmed and the depths of the individual layers are determined and analyzed more precisely. It can be seen that the siltstone layer begins at about 18,50 m - 19 m. The overlying silt layer is about 12 - 14 m thick. On the channel side of the Deusto district, there is a layer of clay about 3 meters thick between the upper layer, which is about 2,5 meters thick, and the silt layer. On the channel side of the island, the silt layer is directly adjacent to the top layer. Here the top layer has a thickness of about 4,5 m.

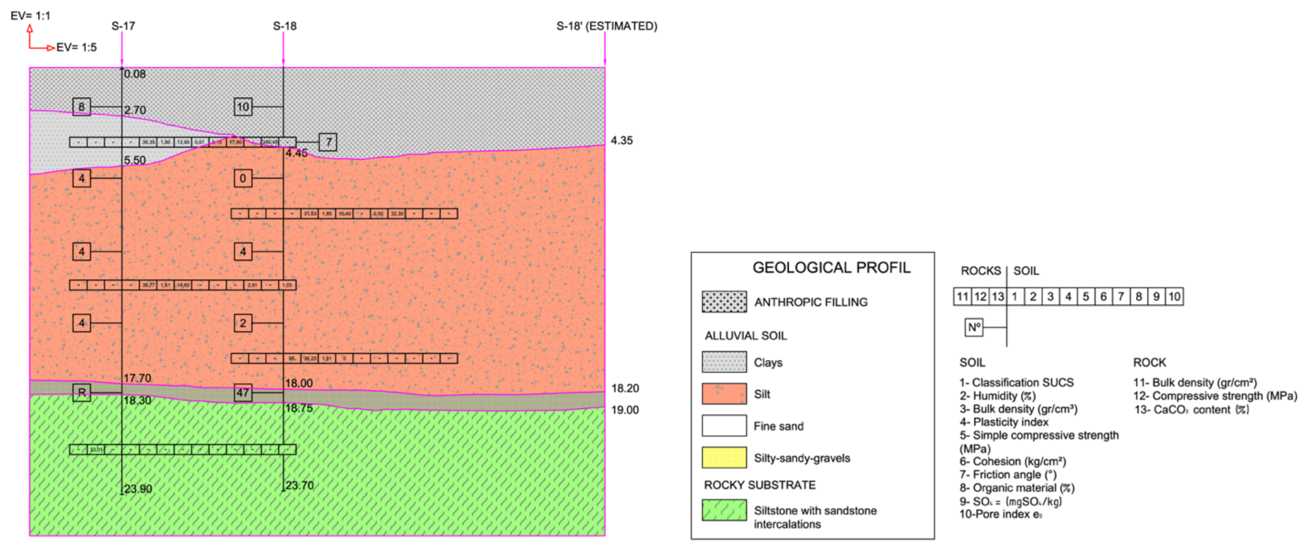

Figure 3: Ground profile provided by Euskal Trenbide Sarea

The most important soil properties such as density, compressive strength, cohesion and friction angle of the individual layers are also summarized in the appendix.

5. Hydrology

The hydrological appendix analyzes the watershed of the River Nervión, which feeds the channel. The size of the catchment area and the underlying river systems, climatology, land use and lithology are considered.

Then, the channel profile provided by the tendering company is considered, along with the required normal and flood levels and the necessary flood safety.

The channel has a width of 75 m. The central bottom of the channel is 4,60 m below sea level, at high water the water level is 4,45 m above sea level. In the central 40 meters there is a 1 meter high free zone above the water level, e.g. for floating debris during high water.

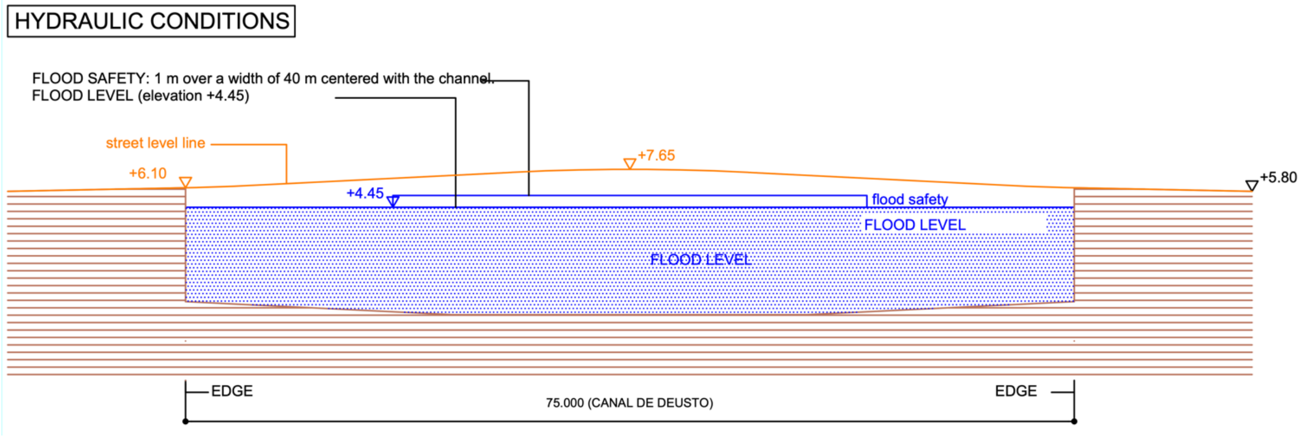

Figure 4: Cross-section of flood runoff Deusto Channel

6. Study of Alternatives

The purpose of this section is to summarize the various bridge design alternatives considered. The primary objective is to identify the most suitable bridge design that balances technical feasibility, economic viability, environmental integration, and aesthetic value. This analysis is crucial for ensuring the bridge fits the prerequisites and contributes positively to the urban development of Zorrotzaurre Island.

6.1. Prerequisites

Before analyzing the alternatives, several technical constraints were established:

- The bridge must be a single-span design due to restrictions on placing supports in the channel.
- The plan view requires a straight alignment connecting "Julio Urquijo" street in Deusto to Zorrotzaurre Island.
- The span width is approximately 76.5 meters with a total deck height limited to 1.40 meters to maintain the safeguard above flood levels.
- The cross-section must provide a usable width of at least 28 meters, including traffic lanes, shoulders, and sidewalks. (2 lanes of 3.5m in each direction with 1m shoulders to accommodate safety barriers and 6m usable sidewalks on both sides.)
- for transversal drainage, 2% slopes will be adopted

6.2. Alternative 1 - Bowstring Bridge

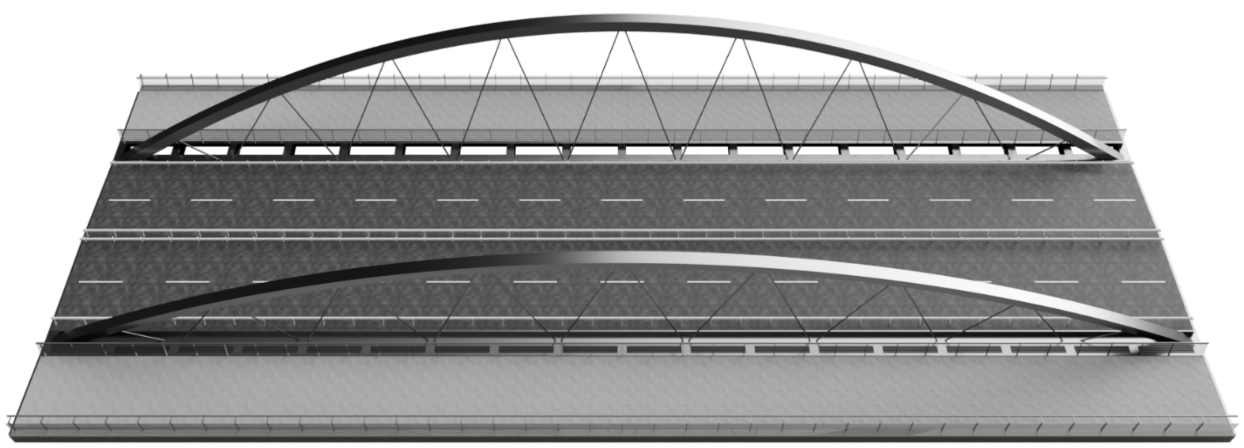

Figure 5: 3D Rendering of Alternative 1 [Own elaboration; Autodesk Fusion 360]

- Features two outwardly inclined steel arches.
- Compressive forces in the arches balanced by tensile forces in the deck.
- Aesthetic design with sidewalks offset outward, creating a gap between longitudinal beams and sidewalks, allowing pedestrians to look down into the channel.

6.3. Alternative 2 - Warren Truss Bridge

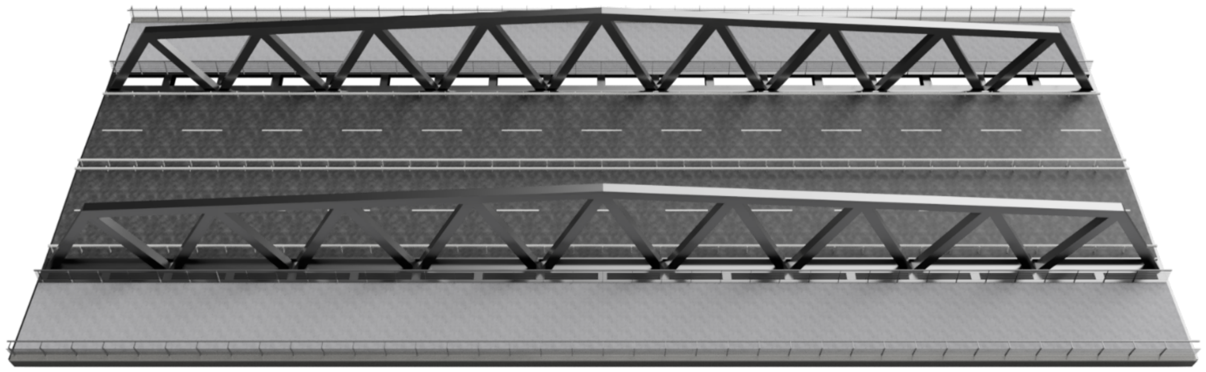

Figure 6: 3D Rendering of Alternative 2 [Own elaboration; Autodesk Fusion 360]

- Longitudinal beams with integrated trusses separating the roadway from pedestrian areas.
- Efficient load distribution but less visually appealing.

6.4. Alternative 3 - Single Tower Cable-stayed Bridge

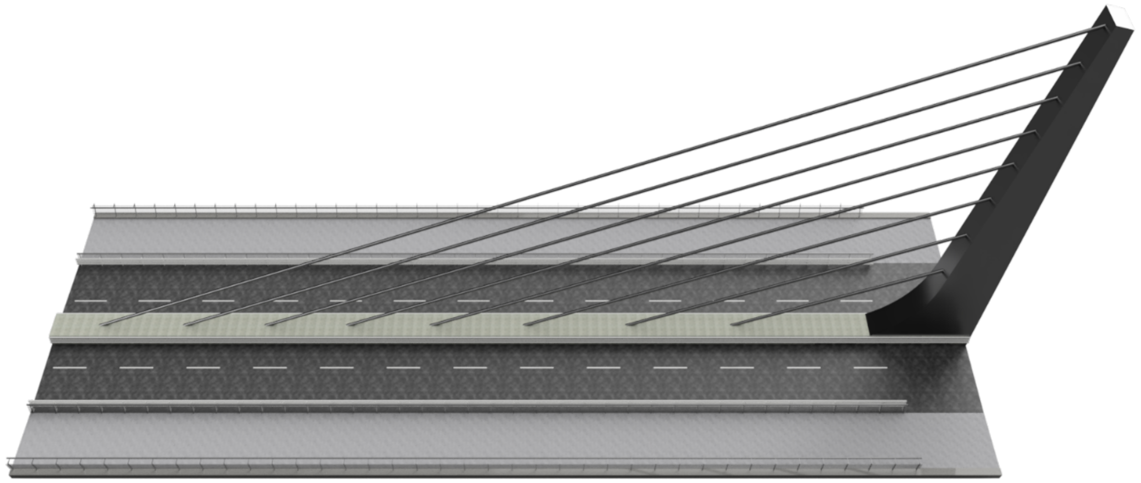

Figure 7: 3D Rendering of Alternative 3 [Own elaboration; Autodesk Fusion 360]

- Central tower with parallel cables supporting the deck.
- Prestressed concrete box girder for torsional resistance.
- Visually striking but complex and costly to construct.

6.5. Alternative 4 - Four Tower Cable-stayed Bridge

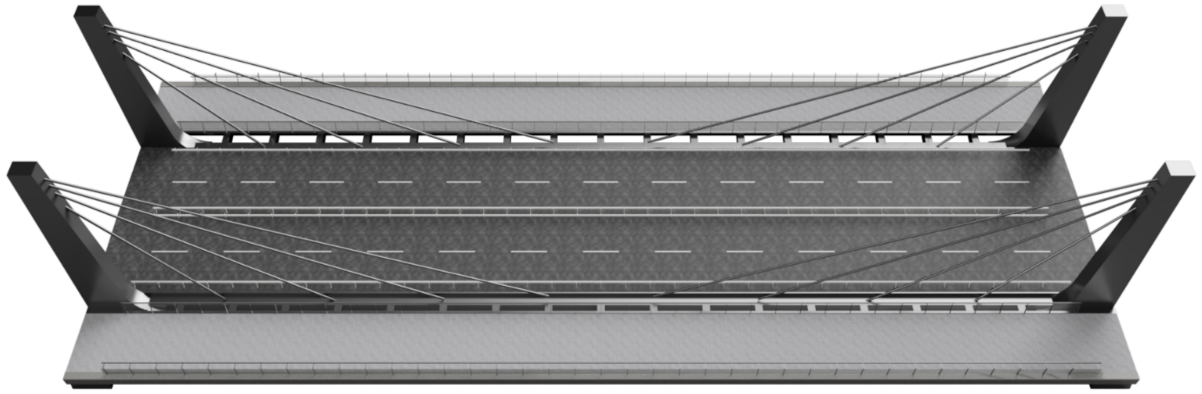

Figure 8: 3D Rendering of Alternative 4 [Own elaboration; Autodesk Fusion 360]

- Two inclined towers with cables connected to half the deck on either side.
- Offers torsional rigidity and simpler construction than a single tower design.

6.6. Evaluation and Selection

The proposed bridge design alternatives were evaluated based on several criteria: cost-effectiveness (50%), aesthetic appeal (25%), functionality (15%), and construction time and process (10%).

The Bowstring Arch Bridge (Alternative 1) scored the highest overall, effectively balancing these factors. It was chosen for its cost efficiency, visual appeal, and functional performance, along with a straightforward construction process. The arch bridge's design offers a harmonious blend of practicality and aesthetics, making it an optimal choice for contributing positively to the urban landscape of the Deusto channel area.

7. Calculation of the Structure

In the previous section and detailed in the appendix "Study of Alternatives," the bridge typology for the thesis was determined. The purpose of the appendix "Calculation of the Structure" is to verify the viability of this design.

A local model of a crossbeam and a global model of the entire metal load-bearing structure were created in the structural analysis software SAP2000. Permanent loads, including the self-weight of the supporting structure (directly considered in SAP) and dead loads, as well as variable loads such as traffic, pedestrian, wind, and temperature effects, were determined.

The arches were analyzed for buckling, revealing that the initial design, as presented in the appendix "Study of Alternatives," did not provide the necessary stability. Consequently, the cross-section of the arches was widened horizontally until sufficient stability was achieved. All load-bearing elements were then checked for axial forces, shear forces, bending moments, and their interaction, ensuring they do not exceed design resistances according to the ultimate limit state. For the serviceability limit state, vertical deflections were verified to be within allowable limits.

Additionally, the resulting vertical forces of the supports were used to select the bearing pads, and the maximum horizontal deformations were used to select the expansion joints. The following is a 3D view of the final bridge, which differs from the version shown in alternative 1 primarily due to the more massive arches:

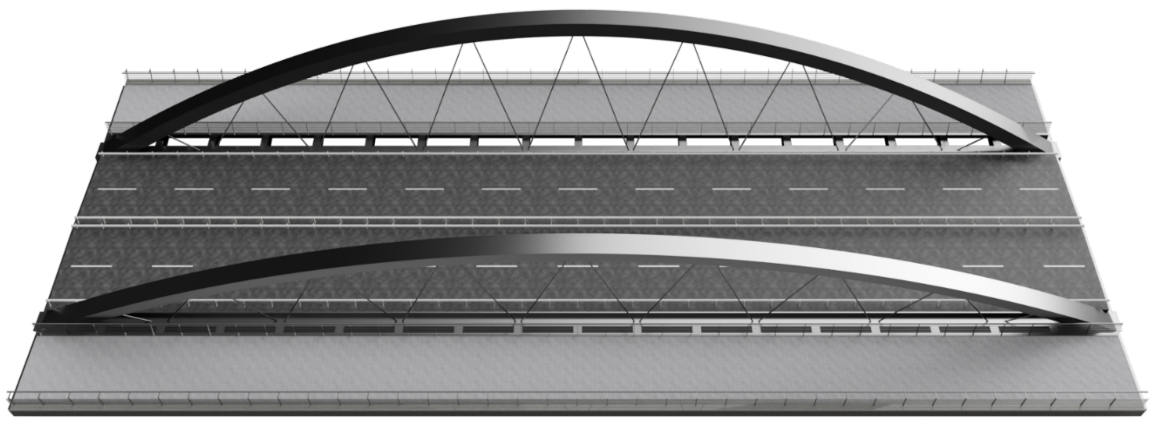

Figure 9: 3D Rendering of the Final Design [Own elaboration; Autodesk Fusion 360]

The deck consists of a system of transverse floor beams and cantilevered side girders, supporting a 26 cm thick concrete slab, which collaborates with the steel structure for load resistance. This transverse system transfers the loads to the longitudinal beams and then part of the loads are transferred through the suspension cables to the arches, which primarily handle compressive forces.

8. Calculation of Foundations

In the appendix to the foundation design, the foundations required to transfer the forces determined in the previous appendix to the superstructure design to the subsoil are dimensioned and verified.

The bridge is supported by a bridge retaining wall that functions on one side as a channel wall and on the other side as an earth retaining wall. This retaining wall is designed without further bearing capacity checks.

Since the load bearing stone layer (as determined in the geotechnical appendix) is relatively deep, bored piles are required to stabilize the bridge retaining wall and transfer forces to the load bearing soil layer. Three rows of 11 bored piles each are installed at the bottom of the bridge retaining wall. These piles are 11 meters long and 1 meter in diameter. They are tested for their load bearing capacity.

9. Bridge Fittings

In this appendix, bridge components are developed that do not serve a structural purpose but are essential to the usability of the bridge. The following bridge components are listed in the appendix:

- Pipelines: According to the tender, pipelines must also be routed across the river in the bridge structure.

- Drainage: Due to the cross slope of the roadway and sidewalk and the fact that the bridge crosses the channel, no special drainage measures are required.

- Lane distribution: The tender requires two traffic lanes, each with two 3-meter wide traffic lanes and two 6-meter wide pedestrian walkways. There must also be space for the safety barriers.

- Guardrails: Guardrails are required to secure the sidewalks, using custom-designed guardrails. The outer guardrails are different from the inner guardrails.

- Cornice: Custom-designed model for the cornice, that follows the inclination of the guardrails and arch.

- Crash barriers: Custom-designed models are also used for crash barriers.

- Pavements: The roadways are covered with asphalt, the pedestrian paths are covered with paving stones.

- Lighting: The roadway is illuminated by centrally positioned lanterns, while the pedestrian paths have lighting modules embedded in the handrails.

10. Construction Process and Work Schedule

The appendix "Construction Process and Work Schedule " details the work schedule for the construction of the bridge over the Deusto channel in Bilbao, breaking down the construction process into distinct phases and outlining the timeline for each activity.

10.1. Construction Process

- **Phase 1. Stakeout and Excavation of Work Area:** Initial Setup and preparation.
- **Phase 2. Sheet Pile Retaining Walls and Excavation**: Driving of sheet pile retaining walls and further excavation of their enclosures for foundation preparation.
- **Phase 3. Foundations and Abutments:** Construction of bored piles, pile caps, and abutments, including waterproofing and backfilling.
- **Phase 4. Manufacturing and Transport of Steel Structure:** Production of steel components in a workshop, segmented for easy transportation to the site.
- **Phase 5. Temporary Support Structure:** Installation of temporary supports to stabilize the structure during assembly.
- **Phase 6. Assembly of the Metal Structure:** On-site assembly of longitudinal and transverse beams, arches, and tension rods.
- **Phase 7. Concrete Slab and Related Tasks:** Installation of formwork, reinforcement, and pouring of the concrete slab.
- **Phase 8. Bridge Fittings, Paving, and Signage:** Final installation of fittings, paving of roadway and sidewalks, and application of traffic signs and road markings.

10.2. Work Schedule

The work schedule, presented as a Gantt chart, outlines the sequence and duration of the main activities, totaling an **estimated 48 weeks for project completion**.

Each activity's duration was calculated based on average performance per unit, quantities derived from project drawings, dependencies between activities, and a standard workweek of five 8-hour days.

11. Sustainable Development Goals

In the Appendix to the Sustainable Development Objectives, the project is linked to the Sustainable Development Goals established by the United Nations. These are 17 goals of the United Nations that aim to achieve economic growth, reduce inequalities and injustices in living standards, create equal opportunities, ensure the sustainable use and management of natural resources, and preserve ecosystems. In this context, the items: 3. good health and well-being; 8. decent work and economic growth; 9. industry, innovation and infrastructure; 10. reduced inequalities; 11. sustainable cities and communities; and 13. climate change action, will be looked at as the development of the project contributes to these goals.

12. Economic Evaluation

The economic evaluation provides a detailed analysis of the project costs, justifying the projected budget by outlining the necessary tasks, grouped into 12 main chapters, and their associated quantities and unit prices.

The unit prices include all direct costs such as materials, labor, equipment, and transportation. Overhead is considered at 13%, and the profit margin is 6%. VAT in Spain is applied at 21%.

The budget summary aggregates the total direct costs from all chapters, totaling €5,528,918.81. Adding overhead and profit margin, the base bidding budget excluding VAT is €6,579,413.39. Including VAT, the **total budget is €7,961,090.20**, with a **per square meter cost of €2,973.33**.

Valencia the 3 July 2024, signed by the authors:

L. Jonas

Jonas, Linus

K. Petri

Petri, Kevin

Bibliography

- Information about the Island of Zorrotzaurre; accessed 13.06.2024; https://www.bilbaoekintza.eus/en/project/zorrotzaurre-the-isle-of-bilbao
- History of the Deusto Channel; accessed 13.06.2024; https://www.proarquitectura.es/pdf/PM73-1.pdf