GEOMETRICAL ANALYSIS OF BRIDGE FORMS AND THEIR FEASIBILITY IN STRUCTURAL DESIGN

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ABSTRACT

GEOMETRICAL ANALYSIS OF BRIDGE FORMS AND THEIR FEASIBILITY IN STRUCTURAL DESIGN

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Bridges are structures that have both engineering and architectural value. The importance bridges have in society is not only due to their function but their form and posture. Bridges are structures that pass longer spans among all other structures. This passageway includes not only the quantitative values, but the quality also. The perfect harmony between its form and function is reflected in its overall structure.

Footbridges are the most intimate type of bridges for people. Usually of smaller dimensions and lighter weight, the design for these types is done with more aesthetic care.

In this study, bridges are briefly analyzed from both architectural and engineering points of view. The differences and importance of footbridges in daily life are studied. Some of the existing footbridges in Ankara are observed and models, inspired by them, are made.

With necessary adaptations, new cases are obtained and comparisons in their dimensions and structural system are realized.

Keywords: Bridges, Footbridges, Bridge Aesthetics, Structural Capacity

ÖZ

KÖPRÜ FORMLARININ GEOMETRİK ANALİZİ VE STRÜKTÜREL TASARIMLARINDAKİ YAPILABİLİRLİĞİ

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Köprüler hem mühendislik hem de mimarlık açısından değerleri olan yapılardır. Toplum içindeki önemleri sadece fonksiyonlarından dolayı değil, biçim ve duruşlarından da kaynaklanmaktadır. Diğer yapılarla kıyasla daha uzun açıklıkları geçerler. Bu uzun geçişin önemi sadece nitel değil aynı zamanda niceldir. Şekil ile işlev arasındaki anlamlı uyum bütün yapıya yansımaktadır.

Yaya köprüleri diğer köprü türleri içinde insanlara daha yakın olan bir cinstir. Daha küçük boyutlara sahip ve hafif oldukları için, bu köprülerin tasarımında estetik unsurlara daha çok önem verilebilinir.

Bu çalışmada, köprüler hem mimarlık ve hem de mühendislik açısından basitçe incelenmiştir. Yaya köprülerinin günlük hayattaki önemleri ve farklılıkları araştırılmıştır. Ankara'da mevcut olan bazı yaya köprüleri incelenmiş ve bunlardan esinlenerek analitik modeller yapılmıştır.

Bazı düzenlemeler sonucunda, yeni köprü örnekleri elde edilmiş, boyutları ve taşıma sistemleri göz önünde tutularak kıyaslamalar yapılmıştır.

Anahtar Kelimeler: Köprü, Yaya Köprüsü, Köprü Estetiği, Taşıma Kapasitesi

To Orçun GÜL

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σ	Stress
N	Axial force
A	Area of the cross section
M	Bending moment
c	Distance from the neutral axis to the surface
I	Moment of inertia

CHAPTER 1

INTRODUCTION

1.1 Argument

Human kind has made discoveries and inventions in order to survive. They discovered places to live, found things to eat, invented tools for different purposes, mainly for hunting, and constructed structures for shelter. Bridges are one of these simple inventions designed to span a gap or pass over an obstacle.

At the beginning bridges were invented as simple functional systems. As spans increased and technology improved, the idea about the structure became more complex. The complexity and vastness of the structure highlighted its visual properties and made the bridge an important part of social life. Not only the function but the way they stand has become noteworthy. Bridges started to be defined not only as structural but also as social objects.

People were once said to be both engineers and architects when these two disciplines were not accepted as two separate professions. The structures were designed with consideration of both disciplines at the same time. However, technology changed and developed significantly in time and these two fields expanded and became too heavy to be handled under a single discipline. The two branches were then separated, one taking care of imagination and design of functional space with the convenient forms and the other undertaking structural safety and constructional effectiveness of the operation [21]. Although these are mentioned as two separate disciplines, in practical life they are too complementary subjects in which one can not be existed without the other. In structural design especially special ones such as bridges, the separation of these two disciplines is impossible.

Although it's hard to draw a line between the interests of these two closely related disciplines, it is also stated that creating a structure concerning both of them at the same time is also challenging. The combination of structural requirements and the necessity of an appropriate form bring about a competition between these two fields. The success of the structure can be obtained with the harmony between these two different ideas of engineering and architecture. A good harmony between these two concepts can only be made possible during the design stage.

1.2 Objectives

Bridges are structures that should be both functional and elegant at the same time. Due to their large dimensions, they are in the same scale as the landscape of the city. Hence there is a close relationship between the environment and the structure, both in the design stage and during its lifetime. One essential point to consider in any bridge is the environmental harmony. Bridges become a part of the environment in time. Therefore, a very careful and precise study should be carried out during the design stage.

Both engineering and architectural masterpieces, bridges have held a crucial place in the civilization of mankind and in modern life. One must be well aware of the fact that bridges are structures that affect people more than any structure. The design and maintenance should include these concerns.

The alliance of a bridge is not only affected by environmental harmony but by the proportions of the elements and the detailing. The way the bridge is detailed and how the details are constructed are important. A delicate workmanship is very essential. Bridges are structures constructed for enabling movement from one side of a gap to the other. However, visual satisfaction is compulsory in order to make users feel comfortable. And these visual parameters are not only the main elements. They are the small pieces of a bridge which can make up the structure when they come together.

In this study, the developments in bridge structure and the parameters constituting the structure are observed. The alliance of bridges is investigated from the point of dimensions and their structural capacity enduring the maximum loading. Structural analysis shows the percentage use of the capacity of structures. The aim of the study is to show that the restrictions on dimensioning and geometry are not only due to the engineering parameters and the capacity but also visual perception. The significance of every parameter in the design of bridges, especially footbridges is emphasized with the overall interpretations of the results of the analyses.

Case studies on footbridges are chosen in order to delimit the study. The dimensions of footbridges are smaller than other types since the structure is only designed for passenger traffic. As the structure is smaller, the live loads acting on it are smaller too. Small dimensions allow room for flexibility in the design stage, yielding a structure that is in better agreement with structural and architectural restrictions. Smaller sections become an advantage when the structure has to span a gap and dominate the landscape of the city. The intimacy and slenderness can be regarded as the most distinctive properties of footbridges.

1.3 Methodology

Some models have to be generated in order to understand the behavior of bridges and make some comparisons. During the study, footbridges are used for case studies as they are the best examples for structures that have alliance and harmony both with the environment and people.

The analytical models in this study are inspired by some real footbridges in Ankara. However, some differences are made during the modeling stage of the structures in order to obtain a model that would be used solely in this study. The aim here is not to produce an analysis of existing bridges and evaluating them is not the issue.

The aim of the study is to observe the outcomes of these analytical models, especially from the point of their geometry and load capacity. Efficiency in the structure is attained by these analyses. Some of the dimensions are changed without tampering with the cross sections of the material. The issues that are explored are whether it is better to design a footbridge in the optimum range and what kinds of effects result from over-designing.

CHAPTER 2

STRUCTURE OF BRIDGES IN ENGINEERING

2.1 Definition of Bridge

According to Encyclopedia Americana, a bridge is a structure providing passage over a waterway, a valley, a road or other obstruction, without closing the way beneath [9].

In Encyclopedia Britannica, another definition is provided for the word “bridge,” as a structure surmounting an obstacle such as a river, road or railway and used as a passageway for pedestrian, motor or rail traffic [10].

In other words, bridge is a structure that connects two sides between which there is an obstacle to passage, such as a valley, a river or another functional structure that was built before. Moreover, sometimes none of these factors are needed to justify the existence of a bridge, such as when having a bridge is just more economical or feasible. Old waterway arches or modern highway bridges are common examples to such cases.

2.1.1 Bridges from an Architectural Point of View:

Several definitions are produced for the concept of architecture in different studies. The profession of architecture is generally considered as designing building and environments with consideration for their aesthetic effect [43]. If any structure needs to be studied solely from the architectural point of view, the ways the structure stands, appears and functions become more important than the structural mechanism and the constructional effectiveness.

The main objective of a bridge is to establish ‘connection’ between two sides which is not accepted as the major function of any structure. Generally, providing shelter is the key role that is attributed to a structure. This difference in the function of bridges from other types of structures constitutes the first reason for being called “special structures”.

The dimensions of bridges are larger than dimensions of usual structures. Passing large spans require the structure to carry substantial amounts of load, which, in turn, augments the dimensions of elements, giving way to difficulties both in design and construction. Elements in bigger than the usual size divert all the attention to the bridge. This also causes the need of the advanced technology for the construction. This special techniques used in the construction can be the reason to be called as “special”.

Another point which makes the bridge a “special structure” is the visual properties and aesthetic impact of the structure on people and on environment. They are structures standing in the middle of the environment and they have to be harmonious with their social surrounding.

Bridges are elements of architecture, but architecture of a very special kind. Although they are invented to answer the very basic need of passing a gap, bridges have already reached beyond the limits of this purpose and are now one of the most important and unique structures in the construction world [28].

Bridges are intended to pass large spans, making them mostly a challenge against nature, calling for an intelligent engineering mind at work. However, bridges are praised more for their architectural standing and artistic value than their engineering success. The reason for that is probably the social importance of bridges coming along with its history and impact on people who view them.

Bridges are the most intimate structures to people. Any kind of shelter or road or industrial structure may be serving without making themselves noticeable or they can make them noticeable with the dynamic structure of the space created below that shelter. However, bridges exist with their simpler function and their special form. When one passes a bridge, the feeling created by the structure is readily perceptible to the individual; even many of them do not have a close surrounding.

These are the reasons why bridges stand out as special structures among other structures and have a distinctive place in architecture.

2.1.2 Bridges from a Structural Point of View

The structural system is the first element of any technical discussion on bridges. Buildings and similar structures are based on a fundamental understanding of substructure and the designs are done according to these fundamental facts and codes. With bridges, the situation is somewhat different. On one hand, the idea of bridges carrying the load is very basic, since it is very similar to beams which are among the basic elements of construction. The way the system of any building works should be the same with bridge structure. On the other hand, bridges can be the most challenging structures in nature, having to cross large spans and carry heavy loads.

The structure of the bridge can be displayed obviously and the load carrying system can be basically understandable to the naked eye. On the other hand, some prefer to hide the technical properties of the bridge behind the form and put the emphasis on the visual perception of the structure. There are designers showing their ideas by artistic movements and fascinating combinations, then again there are ones telling it in a polite and modest way. These alternatives results in different outcomes, despite the fact that they are all based on the same structural fact in principle. Even the load that is carried is relatively large quantity; the way these loads should be carried is handled perfectly in the correct structural system.

In the assembling of the structural system, there are a few points which make the design challenging, one of them being the load and its distribution. In the design of bridges, live loads can not be predicted. Differing from other structures, the critical loading on a bridge is the “live load”. Live load stands for loads that are not stable and show fluctuations in time, whereas, with bridges, that is not the exact situation. The live load on a bridge is a dynamic concept. The load acting on the structure is always in movement, and not fixed at certain points.

The self weight of the structure is another important point challenging the design process. A structure has to carry its own weight before any other load. Therefore, on the top of the unapparent moving load, there is a great amount of permanent load, which can be minimized with selection of proper construction materials and structural system.

Another critic point is lateral loads, which are basically due to earthquake and wind actions. When self weight is higher, the impact of an earthquake on the structure is deeper, as it is often the case in bridge structures.

Designing a bridge with structural concerns is not a simple procedure. There are lots of parameters to be considered and the most proper solution must be chosen, but the appreciation that comes afterwards is worth the effort.

2.1.3 Bridges from a Social Point of View

Bridges are unusual and important structural systems from engineering and architectural points of vies. Moreover, they exhibit a particular significance from the social and intellectual perspective. What the word “bridge” first reminds to most people is not its incredible structural formation or its importance in the history of civilization. It is a reminder of the places that are famous with their bridges or of a specific experience.

Bridges have more significance than merely serving as a path for crossing an obstacle. Inherent in them are some symbols that are consciously planned in the design stage and some that are adopted later on regardless of their existence for purposes of linkage.

Bridges, first of all, play a very important part in the landscape of a city or region. They may even define the entire view as the dominating structure in the whole ambience of the area. Throughout the history, bridges stayed as monuments that symbolize their community.

In some cases, bridges were not only the symbol but also acted as the founder of an area or a region. Regions that are newly created need to be nourished by those that precede them. This nourishment was sometimes provided by bridges, which would bring civilization to the new and not yet developed areas, transforming them into developing and finally developed areas. The most famous example for this in history is the Brooklyn Bridge in New York City, connecting Brooklyn to Manhattan (Figure 2.1). Before the bridge, Brooklyn was a place no one wanted to inhabit and living there offered no charm at all. After the construction of Brooklyn Bridge, crowds flocked to the district invigorated by this architectural masterpiece, making Brooklyn one of the popular neighborhoods in New York.

Figure 2.1 - Brooklyn Bridge in New York, 1883 [17]

In old times, bridges were the symbol of power and superiority over other empires. To the Romans, bridges were psychological as well as physical tools to extend the emperor’s control. Their message was, “I, the Emperor Trajan, by the power of Rome, have built this massive bridge; realize the impossibility of revolution”. In medieval times, specialized orders of monks built bridges for the benefit of the community and the greater glory of God. Their message was, “We, *les freres du pont*, by the grace of our Lord, have built this bridge for you; join us in our pilgrimages to his holy shrines” [14].

The bridge has also spiritual meaning. The Islamic belief dictates that a person goes to another world after the life in this world has ended. These two worlds are connected by the bridge “*sirat*”. This suggests that bridges are not existed in the daily life terminology but they also do have an importance and place in the spiritual world.

Also in Christianity, bridges are thought to be holy places used for spiritual worship with the same implication as in Islam, i.e. bridges represent the link between heaven and earth. In evidence to this belief, old masonry bridges bear ornaments of saints on their sides. There were times in history when chapels were constructed on bridges where people would go to pray. Although this habit has been abandoned, statues of saints can still be seen in old bridges (Figure 2.2) [11].

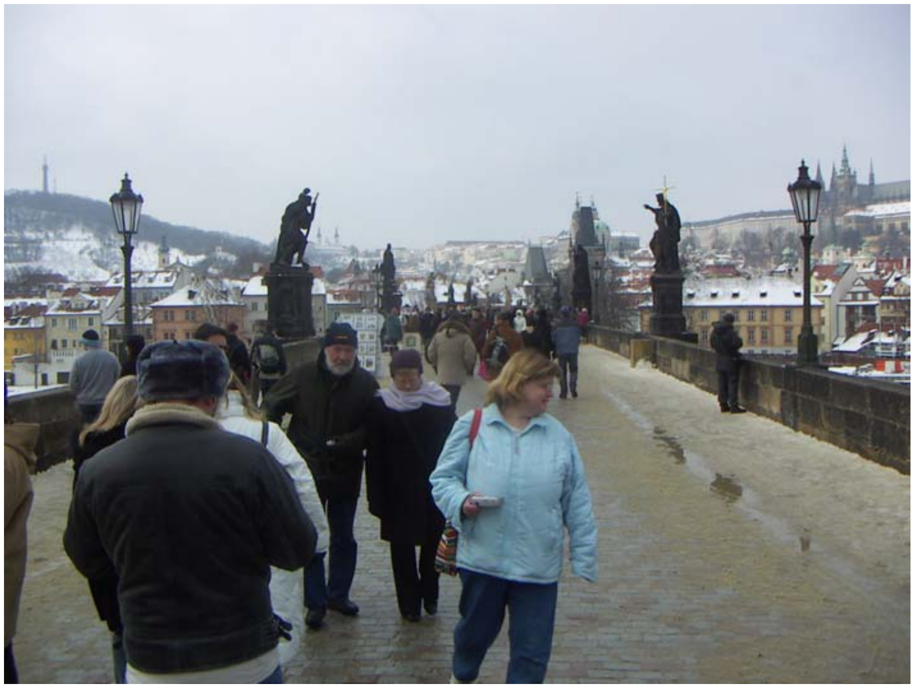

Figure 2.2 - Charles Bridge in Prague, 1357 [By courtesy of M.Pakkan]

Another myth states that when God gave the world over to manhood as a gift, the devil was so jealous that he made scratches on the earth, tearing the land into pieces and making it impossible to use by humankind [6]. According to the myth the angels decided to help and created bridges for mankind to pass these gaps when they were so desperate and since then it has been believed that constructing bridges is a blessed act.

After humans started to use bridges as places of worship, bridges became a part of daily life. Financial considerations led to the exploitation of bridges as early as 12th century. Ancient management strategies resulted from the need to pay for the running costs of the bridge as well as the periodically repair and/or renewal of the bridge. The first reported commercial use was shops that exploited the privileged position of the bridge, gradually turning them into permanent markets. These were called inhabited bridges. As there was no traffic phenomenon in that time, bridges evolved into social areas people would go to do their shopping and share the common place at the same time they were using the bridge to cross the river. This phenomenon was observed mostly in France, Italy, Germany and England as well as in some eastern countries. One of the most successful examples of these inhabited bridges that remained from these old times is the Rialto Bridge (Figure 2.3) in Venice. Some other good examples exist in such historic cities such as Firenze, Ispahan. The decline of the inhabited bridge began with the expansion of cities, as new areas outside the town became cheaper to develop than the relatively expensive places on bridges. Increasing traffic eventually killed the idea of inhabited bridges [11].

Figure 2.3 - Rialto Bridge used as an inhabited bridge, 1591 [38]

The idea of inhabited bridge is hard to adapt to today's urban life. Combined with the vehicular traffic on the bridge, the noise and the exhaust pollution can not work with the human habitat. Yet there remains a potential to exploit footbridges. Rethinking the commercial use of bridges includes spaces under bridges as well, an example of which is the old Galata Bridge in Istanbul. (Figure 2.4) [11].

Figure 2.4 - Galata Bridge in İstanbul [19]

Bridges of different functions serving different purposes in our life have differentiated the terminology of "the bridge." The function of connectivity in different professions has led to a direct correlation with the word "bridge", such as in deontology or in politics and many other different areas.

2.2 Chronological Developments of Bridges

Bridges have been used since the first civilization movements, as it was primarily a need for human kind to pass a gap which they could not otherwise. The idea of the first bridge had come out from this basic need. They used wood pieces in order to create a mechanism for passage, made a half a tree trunk, narrow lofty tree trunk or thick timber beams. (Figure 2.5) These were very primitive and easy ideas and they were working; until the day had come that these basic structures were not adequate [24].

Figure 2.5 - First examples of footbridges [24]

This inadequacy was a result of several factors, such as the progresses in civilization, which led to an augment in the loads carried or the increase in utilities and number of people using it. The structural system needed to be stronger in order to be sufficient.

Another reason why the bridges were short of meeting the needs was the development of humankind, who was trying to spread to different and larger areas and to discover new locations to settle down. The search confronted them with obstacles harder to pass than they were used to, calling for larger spans in bridges, which meant new solutions should be developed. The improvements in bridge construction technology enabled these structures to extend to larger and more civilized areas. Despite these achievements, new obstacles started to appear that were more challenging than before and rendered previous inventions ineffectual, giving way to new ideas and solutions.

The first construction material that was used in historical bridges was natural stone, which was easily attainable, shapeable and treatable. With stone, the bridges constructed were durable, beautiful and had a relatively large span in that time's standards. The stone blocks had been jointed together with nothing at first but only with the friction force among the units. By means of the structurally suitable geometry, the stones had been placed in a position that did not need any plaster. The architects and engineers at that time were getting to the correct answer only by trial and error. As the stone was strong in compression, the truth of arch bridges working only in compression was discovered. Therefore, the typical old bridges were all made up of stones in an arch form. One of the remaining examples of these old Roman arch bridge is Angel's Bridge in Rome. (Figure 2.6) [24].

Figure 2.6 - Angel's Bridge in Rome, 136 A.C. [24]

Stone has an importance far beyond its limited use today, for it was in stone that the building of bridges first became a conscious art, and it is therefore stone that, for better or worse, has determined many of today's attitudes towards the aesthetics of bridge design [28].

After using the natural stones they found, humans invented and began to use artificial materials such as clinker or hard-burned brick. One of the reasons why they preferred these materials was the color, which, unlike natural stone and later on concrete, had warm tones that created a better harmony with the environment. Also, when these materials were resources specific to the particular region, they would be preferred as they were easier and cheaper to obtain [24].

Timber was another natural material used almost exclusively in the early days. It was one of the easiest materials to handle at that time and it was more available to a young civilization. Although timber was a very early invention of man kind, the conscious use of it started long after its invention. [37]

At that time when a new material started to be used, the usual tendency was to handle it in the same manner as more familiar materials before realizing its peculiar parameters. Therefore, first arch form was used. Then trial and errors led to the realization that timber was strong both in tension and compression. This knowledge ruled out the necessity to use the geometry of the arch. Beam bridges started to be designed, constructed and used. In the process of learning the use of timber in construction, different triangle shapes appeared, which are accepted as the roots of the concept of truss system. Invention of truss system is said to be the most significant contribution of Renaissance to the structural world. [37]

However, there were problems of timber use. One is the danger of fire. Another is the need for protection against climatic conditions, inherent with the use of wood, especially humidity, which could have a very damaging effect on the substance. Therefore, covered bridges were mostly preferred when wood was the underlying material (Figure 2.7) [24, 28].

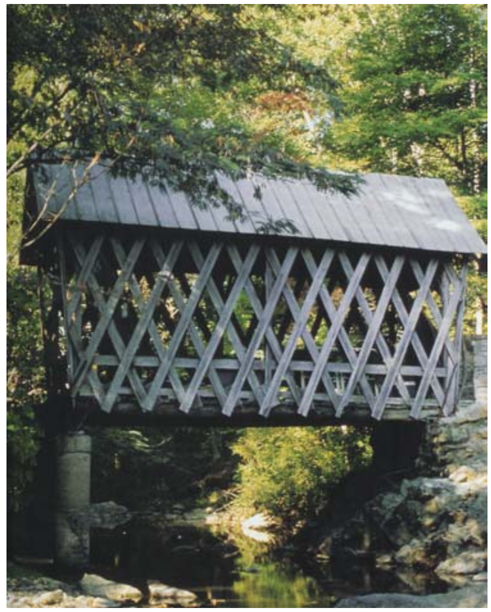

Figure 2.7 - Bodenheimer Covered Bridge, USA [42]

Technological developments and advancements in material science brought about iron in the world of construction. This need occurred after the invention of steam. With this invention, new types of machinery were used in the construction with this new technology and also new transportation ways were invented which brought the need of new bridges.

Similar to timber, iron was not a new material. However, the technology to use it properly was not known. With the necessary technology, iron started to be used in many ways. The first examples of iron bridges were designed in arch form till the original properties of the material were experienced and understood. With the perception of the properties of iron, great examples of suspension bridges and many railroad bridges were constructed. [37]

In the succeeding era, the most favored item turned out to be steel, which has a very high strength both in tension and compression. Iron was used in Europe for building cannons and machinery in the sixteenth century, but it was not until the late eighteenth century, that iron was started to be used for structures. Although Industrial Revolution introduced an era to iron bridges, this was also a necessary period of apprenticeship that was brought to an end by steel. In the second half of the nineteenth century, steel was developed and started replacing cast-iron as a structural material [5, 37]

The strength of steel can roughly be said to be ten times of compression strength and hundred times of tensile strength of medium concrete. Furthermore the ductility of the material is very advantageous. A full understanding of the capacity and properties of the material was not immediate. In the design process, the models specific to wood and even to stone were tried with iron at first and the reward was a great success both structurally and economically. The arch system was copied from the masonry examples and also used [24, 28].

In time and with the developments in technology and material science, it was discovered that a better way existed to use steel; i.e. the truss system which was first applied on timber. Truss was a complex structure made up of steel elements, coming in either two or three dimensions (space trusses) (Figure 2.8). It was an efficient solution to the deck of the bridge. The truss system could also be pre-fabrication, which made it safer and preferable. The truss system was used as the carrying system of the main beam and the deck. The deck and the truss would sometimes carry themselves and while at times they would be hung by cables, the latter of which eventually gave way to the suspension bridges. In order to lengthen the span, the deck needed to be lighter and thus the truss deck was changed into advanced technologies of concrete [28].

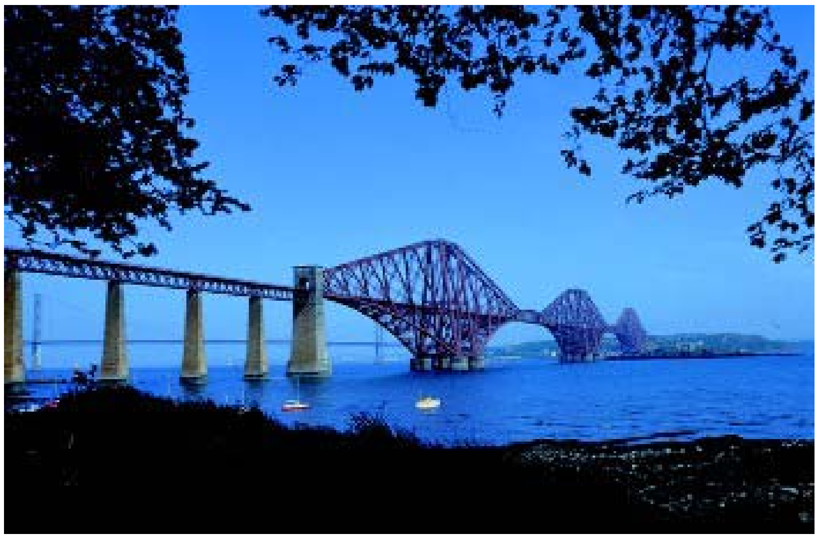

Figure 2.8 - Forth Rail Bridge, 1889 [16]

Concrete was another successful invention that dominated the materials of construction at the time it was invented and it still does. As it was found in Europe, the first examples of concrete structures were seen there. As a start, arch forms were preferred as it was the mechanism that had been proved to be working. Additionally, concrete is a material that is strong in compression and weak in tension, which is why concrete was mainly used in arch bridges. It was reasonable and efficient, as arch mostly works in compression. The idea of using concrete in compression areas was a good but temporary solution. There was a need for a material that had strength in tension as some parts of bridges had to work in tension; hence a new solution had to be found. This was how a new material that could also work in tension was invented.

Steel bars are materials to carry the tensile strength through the structure. Steel was a material that could work in both tension and compression. The system works perfectly well when they are placed in concrete blocks in tension zones. That sums up the invention of the system that is called ‘reinforced concrete.’ Reinforced concrete bridges are one of the biggest steps in the bridge history. The bridges became thinner and economical with the usage of this technology. (Figure 2.9) [24].

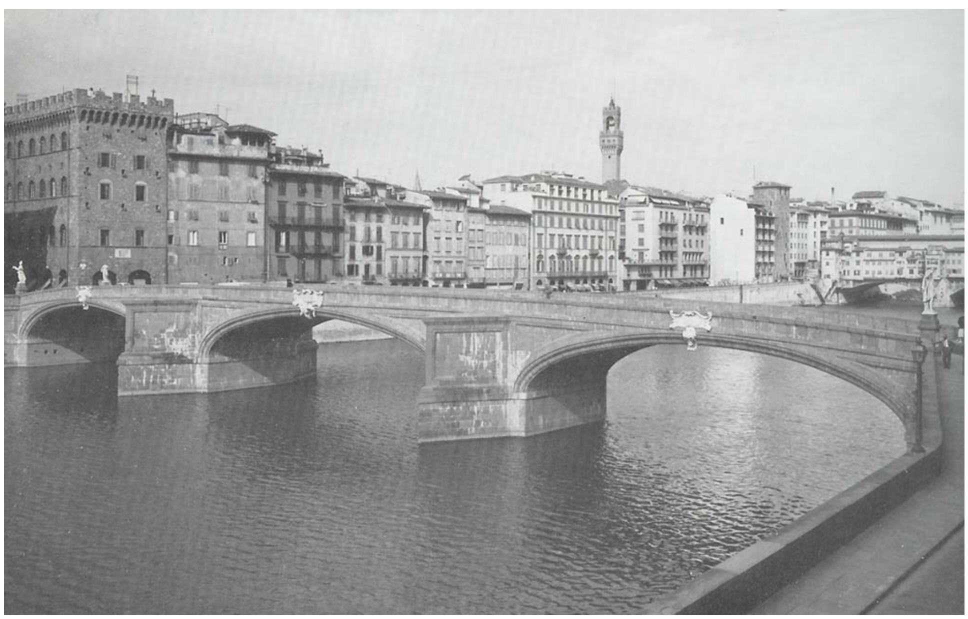

Figure 2.9 - Ponte Santa Trinita in Florence, 1567 [24]

The idea of reinforcing concrete with steel led to different inventions and to advanced technologies whereby they could be applied. The so-called ‘prestressed concrete,’ which was a resulting invention, had two types; i.e. pre-tensioning and post-tensioning. The idea behind these systems is to decrease or terminate the tensile forces occurring in the concrete volume. This required extra compressive forces, which is provided with these cables.

The theoretical idea of pre-tensioning is as follows: the steel cables are placed straight in the empty formwork at the necessary locations determined from the expected behavior form and stretched and attached firmly. After that concrete is poured into the formworks and left to dry. When concrete becomes solid, the cables are set free. The cables which were subject to tension want to return to their natural form as springs do and therefore apply compressive force to the mass of the concrete. This compressive force will equalize the tensile strength created within the structure because of its gravity load.

In post-tensioning, however, initially empty pipes or plastic tubes are placed in the formwork with a certain shape. The concrete is poured and left to harden. Then the cables are placed in the previously placed tubes and pulled. When enough drawing is provided, the ends of these cables are fixed to the end of the concrete sample. With that connection the cable which wants to go back to its natural position applies a compressive force on the block.

With prestressed concrete, dimensions are smaller and the span that a bridge can pass is longer. The best examples of these thinner prestressed bridges are designed by the Swedish architect, Robert Maillart (Figure 2.10). This kind of constructions are said to be using at least 70% less steel than ordinary reinforced concrete, which provides financial benefit and 30% to 40% less concrete, which provides economy of aesthetic importance. The popular use of prestressed concrete made it possible to construct more slender bridges than previously available in reinforced concrete [23, 24].

Figure 2.10 - Inn River Bridge, Zuoz [2]

As technology and science progress in the construction sector and especially in bridge technology, the main concern becomes not how the system will work but how it will suit the environment, how it will appear and whether it will have a prestigious place in society.

2.3 Types of Bridges

There are various parameters which can be considered in the classification of bridges. In this study, the structural formation and the load transfer mechanism are considered when classifying the bridges.

In the classification of bridges according to structural mechanism, the properties that are considered are not visual. The important parameter is not what is seen from outside but how the load is transferred within the structure. These structures are designed to transfer the load to the necessary and proper points. There are different methods for these transfer mechanisms and they are grouped in four categories.

According to structural types, the following groups can be mentioned. With regard to deck carrying mechanism, straight beam and arched system should be referred first. Cable supported systems constitute another large group which is the third system to be mentioned.

2.3.1 Beam Bridges

They are the simplest types which are made up of horizontal elements. They can be mentioned as the simplest and the oldest among the other types. When the need of a bridge first arose in history, beam type solutions were the first to be formed across the creeks. Primitive solutions such as placing woods across the gap were put into effect. There was no complex design or an extraordinary idea of transfer of load.

The applied forces are transferred through the structure in a very simple way in beam bridges. The loads are transferred vertically to the supports. The structure is designed to carry both tension and compression; because in this configuration, the upper part works in compression and the lower part works in tension. Therefore, during the history of bridges, steel type beam bridges have been very widespread types since steel can carry both tension and compression. Concrete beam bridges have also been very common in beam bridges. However, as the materials used in beam bridges should be strong in both tension and compression and concrete is weak in tension, steel bars are used in the tension parts in order to strengthen the element [28].

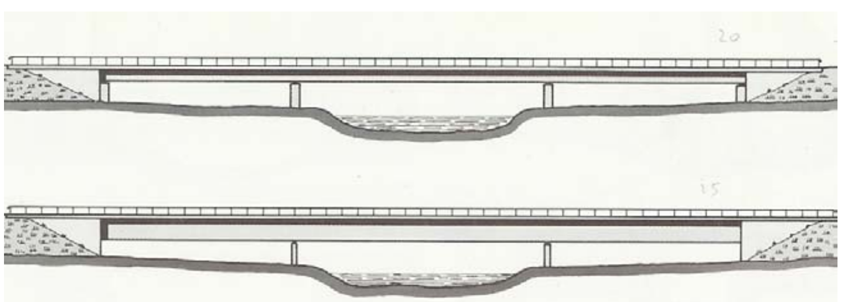

Figure 2.11 - Beam bridges with straight haunches [24]

The advantage of using beam type bridges is their simplicity and economy (Figure 2.11). The design and calculations are more straightforward than other different types of bridges.

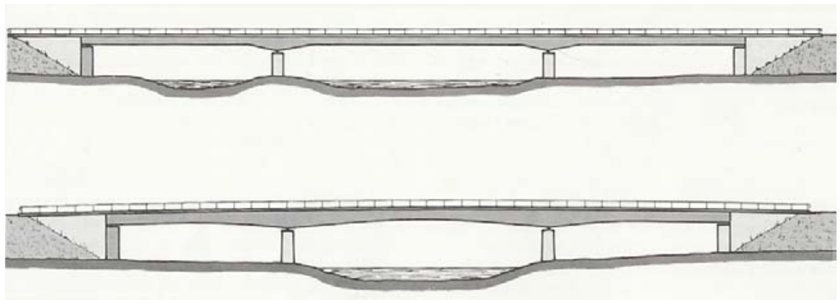

Figure 2.12 - Beam bridges with curved alignment [24]

In modern life needs, beam bridges are used as multi-span bridges. When the material is well known and well designed, the bridges might be shallow and light. When the load distribution is analyzed in these multi-span bridges, it is seen that, the strongest part is in the middle of the span. Therefore, the geometry of the structure can be chosen accordingly, making the cross-section thinner in the middle which will produce a more pleasant view than a simple bridge (Figure 2.12) [28].

2.3.2 Arch Bridges:

They are bridges with a parabolic shape in general. Although beam bridges are said to have the simplest form, arch bridges can be described as the most naturally formed bridges among all (Figure 2.13).

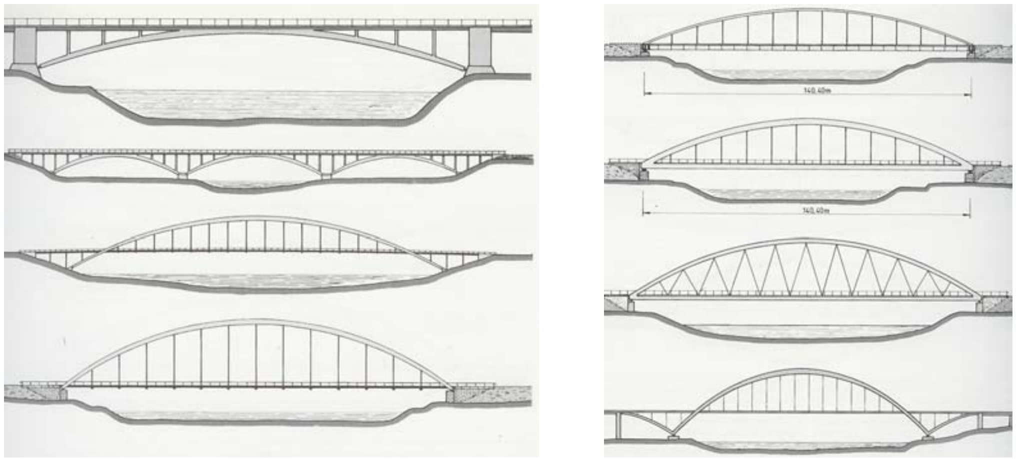

Figure 2.13 - Different alignments of arch bridges [24]

The transfer of loads is more dynamic in these types. The system of the arch form works only in compression. The tension forces are negligibly small, hence the materials are chosen according to these criteria, the most preferred one being stone or unreinforced concrete. As the load is transferred within the structure, there are both vertical and horizontal components of forces at the supports. Therefore, the supports should be designed according to these diagonal forces and not only to vertical ones as in beam type. The abutments should also be strong enough [28].

The advantage of arch bridges is a more dynamic and original design than beam bridges, and as they work only in compression, they can pass longer spans than beam bridges. But because of the same reason, the structure can not hold itself before its construction is over, which causes difficulty during its construction process [3].

2.3.3 Cable Supported Bridges

These are the bridges in which the system is supported by the components externally integrated with the deck.

2.3.3.1 Suspension Bridges

In suspension bridges, the deck is carried by the main cable and its many supporting cables. The shape of the main cable can be thought as the opposite version of the shape of the arch bridge, swaying between the towers. As far as this contrast is concerned; cables are all working in tension, opposite to arch bridges, in this case. However, this time the towers, which carry the entire load, are working in compression [3, 28].

Suspension bridges are advantageous and very successful for crossing long spans especially when an intermediate pier is not appropriate to construct. However, they are not suitable when the span is smaller but the loading is heavy, since the system would not work efficiently and the great amount of load could make the system work in the opposite direction. This can even cause the bridge to fail. Therefore, suspension bridges might be used in medium spanned bridges if the load is small such as pedestrian bridges [7].

In suspension bridges, the tower is a support for the main cables when they carry the load to the abutments. As loads are finally transferred to the ground, the conditions of the soil are important. The cables used might either be a compacted bundle of parallel high tensile steel strands or may be made up of a group of wire ropes [7].

2.3.3.2 Cable-stayed Bridges

Cable-stayed bridges are similar to suspension bridges. The visual perception and some geometry of the structures have similarities; however, the load transfer mechanism is different.

In cable-stayed bridges, the cables are connected to the towers. The cables carry the deck and they transfer the load directly to the towers. There are many straight cables as the opposite of the swaying main cable. The cables transfer the load from the deck, through the towers, to the ground. Extra abutments are not compulsory in these types of bridges. There are sometimes twin systems of cables and towers whereas there are also bridges with one system in the middle. But when the cables and towers are placed in the middle, the deck is essential to be box girder, in order to achieve torsional stability.

Even among cable-stayed bridges, the alignment of cables creates two subgroups: fan shaped and harp shaped. In harp shaped bridges, the cables are all parallel to each other and the joints of these cables to the tower are different. This type is known as the one in “good order.” (Figure 2.14)

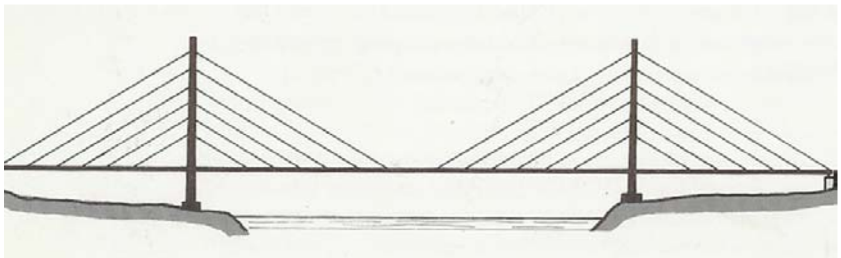

Figure 2.14 - Harp shape cable-stayed bridge [24]

In fan shape bridges, however, cables are jointed to the same point of the tower and they spread into different directions (Figure 2.15). If there are not too many cables, this type does not look very elegant. However, having a high number of cables spreading from the tower generally provides the alliance. This arrangement decreases the bending effects in the structure because of the triangulations [7, 24].

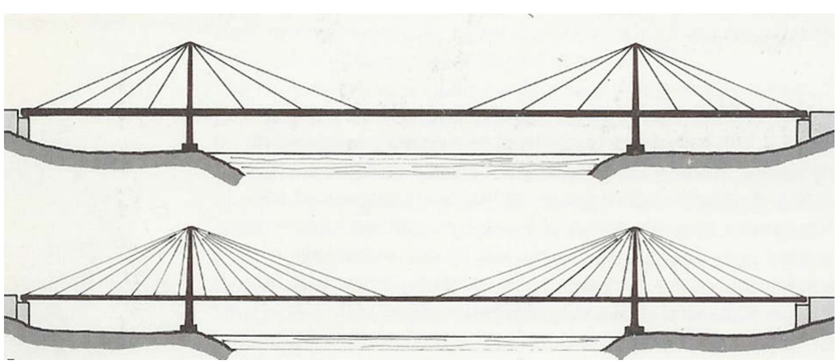

Figure 2.15 - Fan shape cable-stayed bridge [24]

When suspension bridges and cable-stayed bridges are compared, suspension bridges with a thin deck are said to be more beautiful than cable-stayed bridges. However, a cable-stayed bridge is more economical and also stiffer than a suspension bridge. Moreover, the construction time is shorter in cable-stayed bridges as the cables and the deck can be constructed at the same time, whereas in the suspension bridge, the deck can not be constructed before the towers and the anchorages are placed [7, 24].

The major advantage of both of these types is their capability of passing large spans. Nowadays, many of the important bridges constructed are in this group. The disadvantage is stated to be their economy and the difficulties integral to construction.

2.4 Basic Design Parameters of Bridges:

The design of every structure is a challenge, having particular difficulties and crucial points, formed by the parameters of the structure. Bridge design entails a complex structure of unknowns and variables and is based on many parameters, some of which are interrelated and some completely independent of other considerations. The ones that stand out among others are generally dependent on other parameters, which is why an optimization problem emerges at the beginning of the design stage. This is not a very easy task to manage.

For a bridge to be called a ‘bridge’, it is obvious that there should be a structural system that is standing against the internal and external loadings and also serves its necessary duties. This is the primary assumption while considering different parameters in the design.

Obviously, the most important parameter is the economy; as in many branches of engineering and even in mundane issues. The design of the structure should be economical, including all its construction and the maintenance costs. However, there should exist a properly functioning structure so that economy can be discussed. On the other hand having a structurally standing and very expensive project is not something any constructor can be persuaded into.

The second important point is how perfectly the structure is formed with the perfect agreement of architecture. As mentioned in previous chapters, bridges do not only exist because of their practical function but they also have a social role. In order to be counted a successful bridge, they have to have a perfect harmony in their structural constitution and architectural form. There is always restrictive data from the beginning of the design stages. The necessary evaluations are done by the engineer, considering the designer’s wishes about the concept. The required changes are applied and the final project is offered to the construction group. It is the cooperation between engineers and architects that brings the final solution to the structural problem and puts it in its final state. The bridge works perfectly and with alliance.

The last point that needs to be mentioned in bridge design is environmental conditions. A bridge is a structure with large dimensions, especially relative to other construction objects. It is visually and theoretically a part of the nature. Combined with its function of linkage, there is a lot to be considered related to the environment. The bridge must have a relationship with the natural formation around itself, the development conditions of the nearby settlements and also within itself. This parameter is not one of the problems for which a solution can easily be derived theoretically. The alliance with the other objects around and the alliance within itself should be foreseen and necessary adjustments made before the construction starts. It can be said that bridges should continue their function of linkage between the structure and the environment around them, not only physically but also visually.

As far as environmental conditions are concerned, the appearance becomes the major parameter to care about. The other parameters might be easier to evaluate or to study; because the solutions are specific, supported with the basic calculations derived by scientists. In environmental problems, the answers are derived by practical facts. At this point, it is not about 'one's opinion' but 'society's point of view.' Because the bridge created is designed for people to use in the safest and the most convenient way.

Bridges are first and foremost "utilitarian". They are built to get people from one side of a gap to the other. They are the structures constructed to satisfy people hence the most important opinion is the public's point of view. What people generally feel is that they care about the appearance but they first of all want to see that this need has been met safely, clearly and economically [13].

Bridges are criticized more than any other structure. The reason is their large dimensions and impact on society. The structure's intimacy with people gives right to many to talk about it and/or criticize it. If the criticism is professional, this judgment is based on technical issues. However, as stated; bridges are a piece of the daily life and ordinary people feel free to make critics on them. Therefore, they look at bridges more from the aesthetic side. On the other hand, even if the criticism is professional; the aesthetic parameter remains a vital issue. When other structures are concerned, the designer is more dependent on how to deal with the project in the most economical way. Artistic design is not of primary importance as there are a lot of similar examples in daily life. In bridges, the structure is always a special monument; even if it is a small one.

2.5 Significance of Footbridges

When bridges are grouped with respect to the type of their function, several main categories can be formed, such as: highway bridges, railway bridges, pedestrian bridges, water canals, *etc*.

Highway bridges are those that carry the heaviest and densest load among the rest of the types. Railroads also carry a massive amount of load. However, the period of the load acting on is shorter than the highway case and not as unpredictable as it is on the highway, where load configurations involve a great deal of uncertainty. On water canals (aqueducts), the inconsistency of the load is less than the ones mentioned above. Although water is a great unknown by itself, as the discharge can be determined and controlled, there can not be unexpected problems. There are hydraulic forces along the canal and all the flow is under control except in the case of flooding.

Footbridges are the last group of bridges that should be noted when there is a classification as mentioned above. With a theoretical glance they are very similar to highway bridges as they do not have specific load expectancy, the load acting on them is simultaneous. However, the total amount of load is very different from highway bridges. First of all the live load acting on footbridges is much smaller than the ones acting on regular highway bridges. Also, the self weight is smaller in footbridges, as they are smaller both in width and span.

Footbridges can be designed as lightweight structures with a delicate form because pedestrians are light loads compared with heavy trucks or railway trains. With smaller dimensions and less self weight, the effect of earthquake decreases. In addition loads such as wind, ice pressure *etc.* seem negligible for many footbridges. This facilitates the design of the bridge from the structural point of view and sets the designer free in other parameters, like aesthetics and visual features. However, there is the concept of vibration that does not count in ‘large span bridges’ but is an important concept in footbridges. The vibration is not as effective in large span bridges as in footbridges as the traffic is not slow enough. However, on footbridge passes, people can easily feel any kind of vibration. There is an important fact that people crossing the bridge would not want to feel the vibrations [24, 35].

Some of the best examples of footbridges are created by the famous Spanish architect Santiago Calatrava. His structures in any kind always have the priority to form and at the same time function is always carefully thought and organized. Some structures are designed to show the structural form whereas some take their beauty from simplicity (Figure 2.16).

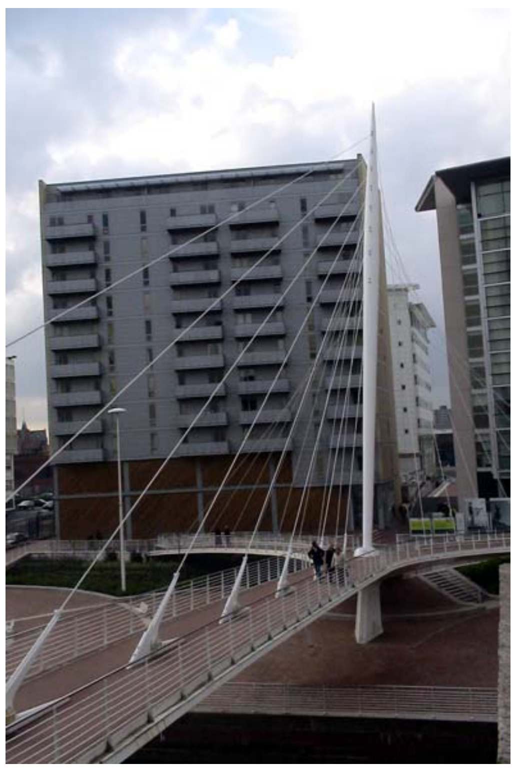

Figure 2.16 - Trinity Bridge in London [By courtesy of H.T. Örmecioğlu]

Footbridges should not be considered as purely functional structures, with only their economical aspect in mind. They have to match their surroundings and to comply with the needs of their users, i.e. pedestrians. The fact they are closer to people than any other kind of bridge is another important feature of these bridges. They are as a whole and in detail must be of human scale, delicate but of course durable as well. They are within human reach, they are bridges to touch. They are meant to be beautiful. One should enjoy looking at them, enjoy walking on them. The pedestrians are very close to the structure. Even when physical proximity is ignored; the space some footbridges create is completely different than any other. The time spent on footbridges is longer than the time on any highway bridge, which underlines the importance of the intimacy between the structure and the person [34, 35]. Some of the best examples for these kinds of bridges are again designed by Calatrava (Figure 2.17).

Figure 2.17 - Campo Volantin Footbridge in Bilbao, 1997 [41]

There is another feature that distinguishes footbridges from those for vehicles; which is also the reason of having separate footbridges: the increasingly heavy traffic in big cities and the crowd accompanying it. It is not feasible to add pedestrian crowds to this traffic. People would also not prefer to share a place with the dust and traffic of vehicles. Therefore, they should rather have a private space and the whole crowd will be divided into two [44].

Footbridges have great importance in the landscape. In fact, this argument is valid for all kinds of bridges. They symbolize the city they are built in. In contrast, footbridges carry more of the characteristics of people. If highway bridges are labeled as “engineering structures” then it would be suitable to call footbridges “architectural structures” in the landscape of a city. They have more of a visual value than “large bridges.” The time a pedestrian spends on a bridge is much longer than a vehicle traveling on a bridge, which gives them a natural priority in the city view.

As footbridges, rather than bridges carrying traffic, they are not subjected to the same engineering constraints hence could explore the idea of structural lightness and transparency, and the relationship of the structure with water, sky and place [27].

Footbridges can be considered as the furniture of the city. They serve people but at the same time they make the place worth living. They create the dynamic part of the city life. The buildings and other structures might have more of a usual design whereas footbridges are expected to have a more colorful contribution to the city. For example, they need not to be straight as highway bridges do. They may even swing a little, to make one feel that they are alive [34].

Footbridges are for the quality and architecture of cities as essential as the other buildings. There are a lot of building and few footbridges. In addition, buildings are only used by their own population whereas bridges are used by all in a city and even by tourists or travelers [34].

CHAPTER 3

STRUCTURE OF BRIDGES IN ARCHITECTURE

3.1 Importance of Bridges in Architecture

The fact that bridges last many generations and become symbols of a particular city makes them special for their designers and users not only in engineering but also in architecture. During the design, visual parameters are chosen carefully. With primary functional constraints applied, other elements are arranged in order to create an artistic piece. This is valid both for huge bridges and for the smaller, more common ones.

Throughout history, bridges were seen as one of the most enduring and beautiful symbols of any age or place. They illustrate the culture of the time and the ambition of the civilizations which built them. People identify places by bridges and not always just by large ones [4].

Figure 3.1 - Bridges of Prague [18]

Prague has always been regarded as a city of bridges (Figure 3.1). Tower Bridge is undoubtedly a symbol of London (Figure 3.2). Since 1930, San Francisco and Sydney have been symbolized by their great bridges [4].

Figure 3.2 - Tower Bridge in London, 1894 [15]

Many of the Roman bridge structures; including their aqueducts, have such classic appearance that their aesthetic value has long surpassed their functional value. Nevertheless, function can not be separated from aesthetics in bridge structure [22].

Bridges have a significant place in human civilization: They are built to enable people to pass large spans that are impossible to pass without any structure. They are also places to where people can spend some time, enjoy the view and engage even in other social activities such as prayer and shopping as they did in the past. Bridges are both a need and also monuments in the city landscape. Therefore, the design of bridge is not as easy as the design of an ordinary structure.

3.2 Bridges as Art

According to most engineers, bridge design is an essentially mathematical process of analysis to meet functional, brief and codified standards. Real design includes this process but also brings in a continuing search for intellectual logic, elegance of line and proportion, visual harmony of the components, finishes which look good in all lights and much more [4].

Designing any kind of structure can be thought as a sort of art. Creating a structure from scratch and designing every detail with care is a kind of art, for sure. Nevertheless, the place of art within bridges is completely different.

The major difference in the art of bridge construction and any other branch of art is the restrictions. The idea of art is generally to reveal emotions, intense feelings to another with the help of the object that is created. In bridges, there are emotions created instinctively on one hand and, on the other, requirements in order for the structure to exist and stand still. The requirements are generally the dominant one on emotions. Thinking about requirements, having restrictions in the design stage is the challenging part of designing a bridge. When an artistic study is made, the final piece created is expected to reflect the feelings of the artist. In the case of bridges, however, the priority is the function and only within the existing constraints, the designer can reveal his/her feelings.

Similar to the way the art of bridges has differences from other branches of art, there are also differences between the art of other structures and the art in bridges: buildings, complex structures or highways are some of those created with little care for art and more for engineering. The reason for this distinction between bridges and other structures is the nature of the structure, its physical conditions and intimacy with humans. The reason why bridges exist is different from other structures as the main purpose is to be the connection between the gaps. The structural formation of a bridge creates an area of its own releasing the feeling of been surrounded. It’s the body of the bridge that gives the feeling and that’s why this body should be handled with care while designing (Figure 3.3).

Figure 3.3 - Oudry Mesly Bridge, 1988 [38]

The art of architectural or landscape design consists in the creation of space and structure is generally the way to create this space. But since the function of a bridge is simply the continuation of a road over a void, its structure is both the way to the space and the space itself. Its reality lies not in space enclosed but in structure itself [28].

The success of the bridge comes not only with its function but its visual beauty. However, views on beauty differ so widely that it may appear that there could never be a clear understanding whether a building or bridge can be considered beautiful or not [26].

Bridges are highly visible elements in city life. How they are seen and perceived need attention during design. If a bridge is approved by the community, this will prolong the life time of the bridge and make the structure a part of that culture [12].

3.3 Concept of Harmony, Aesthetics and Beauty in Bridges

Bridges have been structures people needed throughout the history of civilization. It's because of this need of passing the span; bridges were first invented, then improved and used. In the beginning, the concern was how the system would work, how it would be stable and not give way to any kind of failure. The function, stability, stiffness and strength were the primary concerns of the designer. With the advancement of civilization, aesthetic parameters started to be considered. Aesthetics turned out to be one of the discussion subjects in the design stage [25].

The aesthetic impact is the effect created on the viewer by every aspect of a bridge in its entirety and individual parts, as it is seen by the viewer as he passes through, over or under the structure or views it from a distance. Architects, either deliberately or not, give shape to things. And the people who see or inhabit those things, criticize them either in full awareness or not [13, 29].

Aesthetic is by definition the appreciation of beauty, especially in arts [30]. It is a concept that is studied mainly in philosophy. There is no certain definition or exact fact about the concept of aesthetics. The history of philosophy has witnessed many ideas and their justifications being argued for, but a definite outcome is still not in sight. Studies carried out in the past on this matter also suggest that this ambiguity will continue forever as there would never be a certain, objective solution to this subjective concept.

Aesthetic is the appreciation of beauty. When the subject is “beauty,” then the concept of “being beautiful” needs to be defined. Discussions on both aesthetic and beauty involve two contrasting theories. One says the beauty is the self-quality of objects. The object has it in itself, it is not subjective. The other front claims that beauty is not within the object but it can be perceived by the observer and it depends on experiments of the observer. This definition makes beauty completely subjective, even causing difference in one’s decision in time. These two completely opposing ideas can hardly be made to come to terms in a third idea. According to this third theory; if the beauty is in the origin of the object, the properties of the object are important when designing. On the other hand if beauty comes from the eye of the beholder, then there should be some stimuli that affect the observer. The appreciation again comes from the self properties of the object. This leads to the conclusion that the design of objects is important in any case [24, 40].

Beauty is a word that defines a feeling that appears in human body as a result of some objects' interactions with the individual. There are numerous similar feelings in human life. And it is a fact that the definitions of feelings are obvious only to those who feel them. The words that are identified for some concepts are accepted universally but the content is not certain. Therefore, beauty is a concept that could be understood by seeing a universally accepted beauty and feeling the properties that make it beautiful and perceive the idea of beauty. This idea gave way to a dilemma. If someone can understand beauty by another person's definition, then this feeling is not personal but at least belongs to the person who introduced the concept of "beauty" in the first place [31].

If the understanding of beauty comes from other people's experiences or even past experiences, then the life a person had lived is important in his/her decision of "beauty." Different experiences cause different perceptions of aesthetics and result in different outcomes. These different past experiences are also seen in different professions. An architect and a doctor do not see objects similarly or perceive them differently. The interpretation is different.

Aesthetic and beauty can not be resolved and nor can the practical applications in the design of bridges. The hard part in practice is to combine the structural and environmental restrictions with the subjective concept of beauty [12].

3.4 Basic Parameters in the Design and Evaluation of Bridges

In the previous chapters, it has been stated many times that bridges are structures that have the very basic function of spanning a gap or passing over an obstacle. Additionally, bridges have visual importance in the daily lives of people in very different ways. These have all been previously mentioned too.

There is one more thing to discuss: the way to understand the concept of visual properties as it is one of the most important points in bridge design. Structural problems can be dealt with the necessary calculations and proper engineering judgment; there are rules, formula and facts about these problems. On the other hand, visual properties are both hard to perceive and to evaluate. There is no specific guideline or code for it.

Engineers and architects are partners in the design of any structure. They combine complex parameters, i.e. the structural parameters and visual elements. There should always be a serious cooperation between engineers and architects in the design stage. And in the case of bridges, this cooperation is more crucial and these two professions should work with great care and sensitivity, because bridges exist in our lives with their visual posture as well as functional advantages.

The appearance of the bridge is dominated by the shapes and sizes of structural elements themselves, not by additional properties such as color or texture.

Although these properties are important parts of a structure's aesthetic impact, it is the structure itself, its span, proportions and major elements that has the largest role in creating its effect (Figure 3.4) [14].

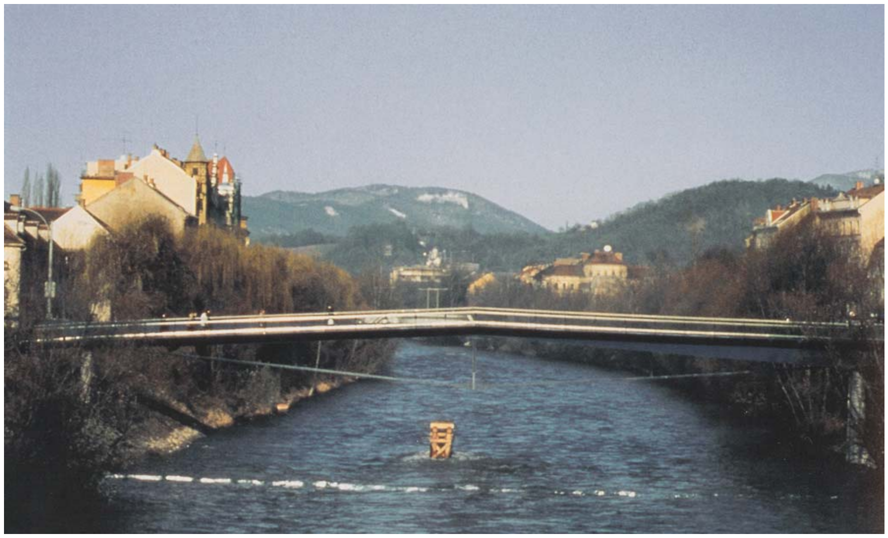

Figure 3.4 - Steg über der Mur, Austria [41]

A lot of studies were made and lots of discussions were carried out on aesthetics of bridges. However, there is no single solution. Yet, there are some results. For example, at the beginning of last century, making something beautiful may have meant adding frills and decoration to most people. This was not very preferable at that time because of the extra cost. However, in time, it was discovered that beauty is largely inherent in the more fundamental concepts of good proportions, shapes and careful workmanship rather than the mere addition of expensive decoration [8]. Another incontestable conclusion is that a structure's attractiveness does not depend on well-designed, separate elements in one. The structure should be created in one step, with all its elements, and the idea should be formed along. That is the only way to reach a successful result in the overall appearance [8].

There is a hierarchy in the decision-making process of the design stage: first comes the performance. Only after performance is ensured structural capacity, safety, durability and maintainability can be considered. Cost comes next, covering both construction and maintenance. The last parameter is the appearance. When an order is in question, it is believed that one parameter has to dominate the other. However, this is not true. Engineers can design bridges which achieve excellence in all three categories: performance, cost and appearance. The key is to put all three issues on the table at the same time and work on improving them all at the same time, to avoid sacrificing one for the other [14].

Visual evaluation is a kind of instinctive feeling. The shapes of certain proportions appeal to some unconscious sense of order of our physical and material composition, in the same way that in music certain chords are heard with pleasure and others cause teeth gritting. Save for the basic rules of good proportions, there are no applicable rules for evaluating or even designing a beautiful bridge. There are only some beliefs that are valid. One suggests that lightness and transparency are more agreeable to the human eye than plump and bulky. Another states that diversified and manifold structures feel more pleasant than uniform and monotonous ones. Human eye prefers movement over uniformity [13, 34].

The variables in the design of a structure are thought to have three dimensions which are height, length and width. This might be true for a single object design. However, in architecture, the dimensions are the dimensions of perceptual space. Since any independent variable can be a dimension, the number of dimensions can be expanded in many directions and is completely arbitrary, depending on what is significant to the problem. It is the three spatial dimensions that make the room but it is those three plus all the others relevant that make space complete [29].

Different professions also show other fluctuations in the evaluation of aesthetics. Three different professions are involved in an architectural project: clients, engineers and the public. These three types have completely different priorities. A client gives importance primarily to construction quality, followed by time and cost and then visual appearances. On the other hand, structural honesty, the elegance of the method of construction and economy are important to the engineer. The general public is mainly interested in the visual appearance [1].

One important point in the evaluation of aesthetics of bridges is again something common in all types of arts. When one knows something or is well-informed about it; then it is easier or more reliable for them to appreciate it. This is valid for all arts and also for bridge design. When someone understands about engineering and the difficulties that come up during design, construction and lifetime of the structure, it is easier for them to see the success within the structure [6].

There are two important aspects of the bridge structure within aesthetic evaluation. One is the relation of the bridge to the environment and the other is the bridge as an independent entity. When the bridge is evaluated only as an independent entity, there are even more different aspects. First of all there is the visual expression of the technical efficiency, not only the size but the slenderness of the structure. Secondly, there is order and unity which make up the organization of the structure. And finally the artistic shaping: visual expression of the flow of force [4].

The relation of a bridge to the environment is evaluated from remote observation. General features should appear in harmony with the natural elements close to the structure. The profile of that area should not be ruined with the indifferent texture of the structure.

On the other hand, when the bridge is evaluated as an independent entity, a closer observation is needed, allowing for a study of the details of form and structural system. Here intelligent solutions are appreciated. These details are more important especially in footbridges. While walking on them people see the details, touch them and feel them. There is a one-to-one relation between them. With the necessary structural constraints, a footbridge should be as simple as it can be.

Unless a bridge is very short, its form tends to be strongly influenced by its structural operation, its elegance or lack of this elegance conditioned by the way the span is achieved. Yet there is always a choice of structural forms, each with its own supporting theory and method of calculation, which is inevitably reflected in the result [20].

3.5 Dimensions and Beauty of Bridges

When an engineer builds a bridge, he/she creates a visible object in the environment. People see it and they react to what they see. The bridge will evoke excitement, appreciation, repulsion or perhaps boredom. Regardless of the fact that the designer has or has not thought about it, the bridge will make an impact [14].

A designer can not avoid making decisions that have aesthetic impacts. Every time he locates a pier or sizes a girder, he is making an aesthetic decision as well as a structural one. The major “structural” features of the bridge, its piers, girders, abutments, are also its major “aesthetic” features. Simply because of their size, they have a major role in the aesthetic impact of the bridge [13].

Structures, especially large ones, carry a great amount of load. The major part of this load is the weight of the structure itself. Bridges are structures that have larger dimensions than many of the structures do. As structures are expected to be designed in a stable way, having the smallest structural elements possible is to the benefit of the structure. The smaller the dimensions and the elements, the lesser the load carried by the structure. Thereby the strength that must be carried by the structure decreases and the system becomes a less challenging one.

On the other hand, as bridges affect the geography and their environment closely from many aspects, the design should avoid disturbing the environment and blocking the natural view. Bridges, unlike other structures, are in touch with the nature. They become a part of the nature from the moment they are constructed. Sometimes, by spanning a gap, they may even complete the whole scene. As there is a mutualism between the structure and nature, inflicting harm on the surroundings is not an option. In order not to ruin the natural harmony, the structure should be light, simple and thin. The benefit of having smaller dimensions with harmony in nature and its environment is obvious.

As mentioned before, bridges, and especially footbridges, are intimate structures to pedestrians, more so than any other structure can be. This property distinguishes them from the others. Although the ambiance of a space in a building or an enclosed area is palpable, the ambiance that a bridge creates owing to its function and form is completely different and more powerful. In order to ensure this ambiance, bridges need to have smaller and delicate elements within the structure and with its environment.

Given the fact that aesthetics is too subjective to be evaluated, these small but true arguments can help to decide on the dimensions of bridges. Having to span a gap and to feature noticeable dimensions, the bridge is at the center stage of social life. However, making the structure as slender as possible will result in harmony and delicacy.

CHAPTER 4

ANALYSIS OF SELECTED FOOTBRIDGES

4.1 General Framework

Bridges are unique structures. There are no certain applied rules in the architectural design or specific parameters to assess the beauty of the structure. Each has its own properties, distinctions and posture. When there is a slight change in a property of the structure, the rest of the parameters have to be changed from the beginning, taking the new circumstances into account. There is no specific formula.

The complex integrity of structures can not be generalized in any point of the analysis. The structural behavior under the applied loads can be obtained from computer software. As mentioned in the previous chapters, however, a bridge is not merely an engineered structure. Architectural concerns can only be resolved with human interaction. To comprehend bridges with their structural behaviors

and all other properties, models are created. Visual elements are evaluated with the help of these three dimensional models.
Some sample bridges were chosen among existing footbridges for purposes of analysis. The best way is choosing bridges that have a positive opinion within the community, become a landmark and attracted attention. In other words, the sample is chosen with concerns listed in the previous chapters.

Modeling is largely simplifying the actual form and structure by using the necessary properties, proportions and qualitative values. In this study, however, the models that are made are not the exact models of the existing structures but examples that are inspired by these sample structures. The main idea in the establishment of the elements and the flow of forces are the same, however dimensions and details are adapted. This change is applied in order to make comparisons and establish links with other bridges. Besides the aim of this study is not particularly to analyze some already existing bridges but build on some already developed ideas and use them in research. Structures that are already built can make the study more realistic instead of theoretical probes.

This study includes bridges that are used for inspiration while creating the models. However, the outcomes that have been obtained are never interpreted from the aspect of the real structures. The aim is rather to show what happens to the dimensioning of structures in the cases of using smaller or larger elements than required.

4.2 The Sample Bridges

In order to understand the footbridges and to see the structural capacity, some samples have been chosen among many of the footbridges in Ankara. There are a lot of new footbridges constructed in and around the city. The study focuses on the footbridges that are generally passing over main highways but having noticeable presence in the landscape and some symbolic value; not the common simple footbridges. There are a lot of these types of bridges too. In the study, eight of them among these are taken randomly as observation examples.

In Ankara, the number of footbridges has increased in the last few years. They are mostly similar to each other. Three main types have been constructed: truss bridge, cable-stayed bridge and arch suspension bridge. Eight of these bridges located in various spots of the city are observed, photographs are taken and the general principles of geometry are noted. The way the structures stand and the load transfer mechanism are observed. The choice of proportions and dimensions are examined. The decisions made by the designer are interpreted. These are all stated one by one.

Before moving on to examining these examples, there is one more example used in this study: the Royal Victoria Dock Bridge in London. With its form and structure, this bridge has been chosen as a successful example for footbridges.

4.2.1 Royal Victoria Dock Bridge

Royal Victoria Dock Bridge is a footbridge that was constructed in 1998, to the north of Silvertown, in London (Figure 4.1). A competition was held for this bridge in 1996. It had to be high enough for boats to pass under it. At the same time, the overall height of the structure was limited because it was close to the London City Airport. Lifschutz Davidson Design was the winning team [41].

Figure 4.1 - Royal Victoria Deck Bridge, London [41]

The transporter bridge is not a new idea, when the era of robust and inventive Victorian Engineering is considered. For this new footbridge in London's Docklands, Lifschutz Davidson reinterpreted the principles of the transporter bridge to create an elegant, lightweight structure that has become a new landmark for the area [36].

The bridge has a cabin of glass covered with a capacity of forty people. An adjustable suspension cable mechanism enables the gondola to be raised from the quayside and driven below the dock like a monorail. Alternately, it can float lightly just above the water when there are no boats in the vicinity [36].

There is also a broad deck where pedestrians can walk and enjoy the spectacular view over the dock. However, as it is not a closed structure, weather conditions restrict the use of the bridge [36].

The deck is 15 m above the water and has a span of 130 m, supported at each end by a pair of trestles (Figure 4.2). This particular structural form was selected for its capacity to combine lightness of construction with very long spans. At night, the bridge is perfectly illuminated, emphasizing the smooth profile of the structure [36].

Figure 4.2 - Royal Victoria Dock Bridge at night, London [41]

4.2.2 Footbridges of Ankara

In recent years, the number of footbridges has rapidly increased in and around the capital Ankara. This increase in number of bridges is supported by contemporary designs. In past, the footbridges were mainly basic beam bridges. New types and designs came to being recently. These contemporary designs attract attention and are becoming nominees for the new landmarks of the city.

As mentioned before, the structure has a special connection with people, being a footbridge, carrying them from one side to the other and mostly isolating them from traffic. Thus pedestrians establish an emotional connection with the structures.

During this study eight of these bridges were inspected. The locations of these bridges are shown in Figure 4.3

Bridge1 is an arch bridge that is located on Istanbul Highway (Figure 4.4). It might even be called a suspension bridge with a main steel arch. The span is approximately 35 m, traversing over Istanbul highway. The main arch constitutes steel elements with I-section. It starts as a two-sided system at the supports and in the middle of the span; two arches coincide at the top. This creates a slender vision in the whole bridge.

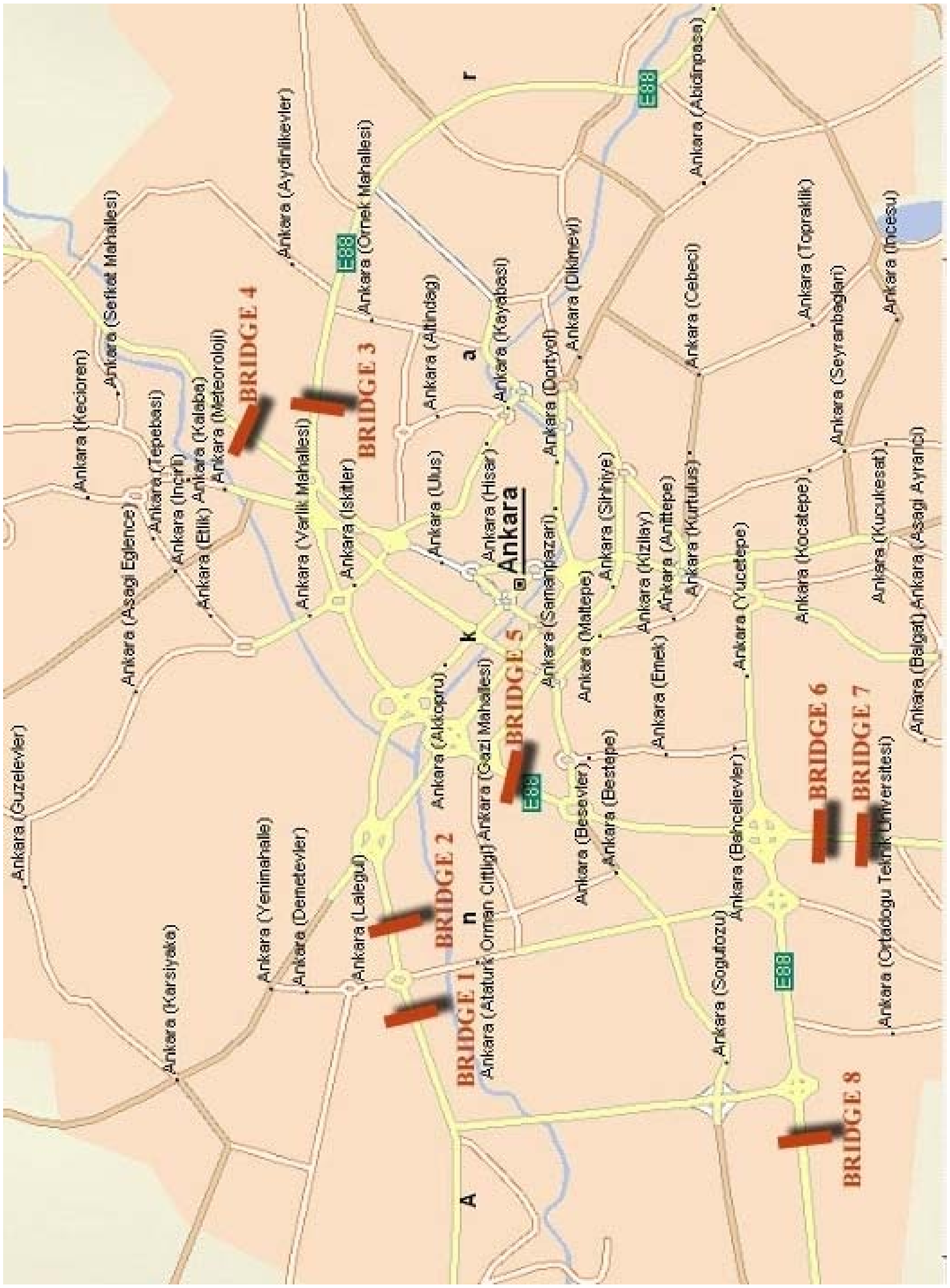

Figure 4.3 - Map of Ankara, with the sample bridge locations [32]

Figure 4.4 – Bridge1

Figure 4.5 - Details of Bridge1

The arch is suspended to the deck with cables. The deck also consists of some beams made up of I-sections at 1 m intervals. There are cross bracings in box section underneath the deck in order to provide the lateral stability. There are also circular elements between the two main arches to ensure the arch is stable (Figure 4.5).

Bridge2 is also located on Istanbul Highway, closer to the city center than the first one (Figure 4.6, 4.7). The structural formation and design idea of the bridge is the same with the previous one. The only difference is their span. This bridge has a span of 25 m whereas the other was approximately traversing 45m. The confusing part in the design of these two is that same dimensions are used for traversing different spans. The resulting ratio problems can easily be seen. The arch seems to be more squeezed from both sides.

Figure 4.6 - Bridge2

Figure 4.7 - Details of Bridge2

Problems resulting from using the same dimensions to traverse different spans are not only visual. Bridges are structures with unique characteristics. Changing one parameter and leaving all the others the same is a mistake in the design. If a particular amount of material is enough to traverse a certain span, a shorter span can be traversed by smaller elements or with a completely different idea.

Spanning approximately 45m, Bridge3 is located on the Samsun Highway, at the junction to Airport (Figure 4.8). It is a bridge that is suspended to a steel arch and is similar to the previous ones with only a few differences: The first difference is the cross section of the main arch, as circular section is used instead of I-sections. Another difference is not a very important one as far as the entire design of the bridge is concerned, which is the way the bracings are placed between the two main arches till they meet in the middle. The most important difference is the use of rods instead of cables for suspending the deck (Figure 4.9).

Figure 4.8 - Bridge3

The need to use cables in suspension bridges is an accepted scientific fact. As the elements that carry the deck and are connected to the main system are proved to be working in tension only, cables are the most efficient materials. The use of rods instead of cables creates extra load and forces in the system. Additionally in case one rod fails, the system probably can fail as a whole. However, the failure of one cable in a bunch of cables will not cause a sudden failure.

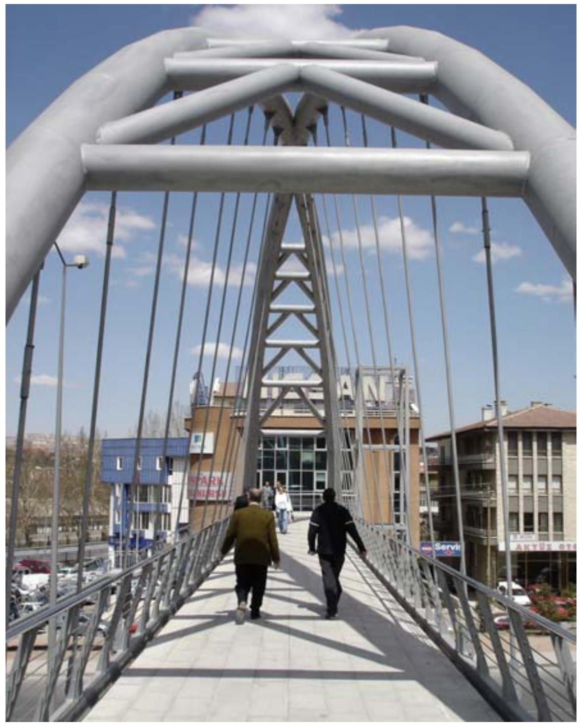

Figure 4.9 - Details of Bridge3

Bridge4 is located in front of Altınpark on the way to Atatürk Airport (Figure 4.10). It is positioned in the group of cable-stayed bridges. It has a span of 37.5 m. There are four rods on each side of the bridge, adding up to eight, carrying the deck to the tower and from the tower to the ground. The bridge has an A-shape tower with a coated upper half (Figure 4.11). The deck is made up of circular beams and circular bracings which are all in the same dimensions.

Figure 4.10 - Bridge4

Figure 4.11 - Details of Bridge4

This is another example for misuse of rods. Another point in this example showing the over design is the cross sections of the bracings underneath the deck. Without calculation, it can be claimed that the bracings might have been smaller than the cross section of the deck beams. This mistake both aesthetically and economically harms the structure beyond functional problems.

Bridge5 is a twin system (Figure 4.12). Twin bridges are located in front of *Etiler Orduevi* on Konya Highway. The span they cover is approximately 15 m. each. The bridge is an arch bridge, with two large circular steel arches lying parallel to each other. The deck is carried by rods with a thick diameter. The deck is made up of horizontal and lateral I-beams and bracings for lateral stability (Figure 4.13).

Figure 4.12 - Bridge5

Figure 4.13 - Details of Bridge5

The design problem can easily be seen in this bridge. The bridge works safely from the structural point of view. However, the ratios are disconcerting to the human eye. The reason is having dimensions larger than they needed to be. If the designer is economically so free that he is able to use cross sections like the ones in this example, he might even have passed the gap in a single span, using the same elements. At least, it would have been less disturbing visually.

In front of the old Traffic Hospital on Konya Highway, another footbridge has been constructed. Bridge6 is completely different from all the other sample bridges. It is a beam bridge with a basic truss system to carry the whole system (Figure 4.14). It is a covered bridge. The whole span is divided into two with a steel footing in the middle that is positioned on the pedestrian refuge. The clear span is approximately 20m. The system is carried by a beam which is horizontally carried by I-beams and assisted by L-shaped diagonal bracings (Figure 4.15).

Figure 4.14 - Bridge6

Figure 4.15 - Details of Bridge6

The advantage of this bridge comes from the fact that it is a covered one. In bad weather conditions, a bridge can even act as a shelter or when there is icing after rain, one would not slide on the bridge while walking. The system of this bridge is not very original but it's a simple truss system. However, here too is the problem of oversized elements. They are not harmful from the functional point of view. However, the system doesn't look elegant and is definitely not economical.

Bridge7 is a suspended arch bridge located on Konya Highway (Figure 4.16). It passes a span of approximately 45m. There are two steel arches lying parallel to each other on both sides of the deck. There are circular sections of horizontal bars that are placed between these arches in order to provide stability in the main system (Figure 4.17).

Figure 4.16 - Bridge7

Figure 4.17 - Details of Bridge7

The cables carrying the deck are again rods and in this case they are truly thick rods. They can not have free movement and in contrast to cables, they can even carry compression. They impose extra forces and loads on the structure. The beam is made up of box section beams and cross bracings.

The last example is the Bridge8 in front of the main gate of METU (Figure 4.18). It is another type of cable-stayed bridge. With a span of approximately 35m, it has a tower and 6 rods on each side, adding up to twelve in total. The tower that rods are connected is a rectangular tower with a height of approximately 16 m with some angle to the vertical. The twelve cables that are connected to the bridge are connected to the tower and from that; they are anchored to the ground in the same alignment (Figure 4.19).

Figure 4.18 - Bridge8

Figure 4.19 - Details of Bridge8

The system of the deck has a structure that is more like a fish bone. The cross sections of the beams are variable. This brought an alliance and movement to the overall posture of the structure.

4.3 Modeling

The recently constructed footbridges in Ankara which were mentioned in the previous section are examined and observed on site. Visual and structural properties are surveyed. The way the structural system stands and how the load transfer system is established in the structure are briefly explained.

In this study, however, the aim is not to analyze these structures or compare them with each other. They are merely tools that help to see the general overview of the structures. They are examples in three dimensions that help visualize and also explain the subject. Computer analysis shows the structures' capabilities and the effect of loads on the structures. That enables studies on real material instead of hypothetical concepts.

Among these eight examples, two of them are selected as the main examples to guide the models. The reason why these two are selected is simply because they are good examples of their types. These bridge samples are mentioned to be grouped into three according to their types of structural mechanisms. The reason for using two samples instead of three is, however, that the truss example is not compatible with the other bridges. On the other hand, Royal Victoria Dock Bridge is identified as the third sample, in order to have included a universally acknowledged example. Since this bridge is also a cable bridge, truss type bridge is completely excluded from our study.

The modeling consists only of the general structural idea of existing structures and mostly geometry and proportions. The proportions are taken from these existing bridges but there are no precise dimensioning similarities. The structural design idea is what is used throughout the study.

The models are firstly made in their original dimensions. Afterwards, the measurements are adjusted to the same units in order to be able to compare them with each other. Therefore, these three models entail some steps for observation.

In order to talk the same language and simplify the concept, the models that are inspired from the Royal Victoria Bridge, Bridge4 and the Bridge1 will be shortly referred to as B1, B2 and B3 respectively.

B1 is constructed with a span of 100 m where the real structure has a span of 130 m (Figure 4.20, 4.21). All the other dimensions are taken from the original bridge concerning the ratio of 100 m. to the real span of the bridge. A similar structure is obtained.

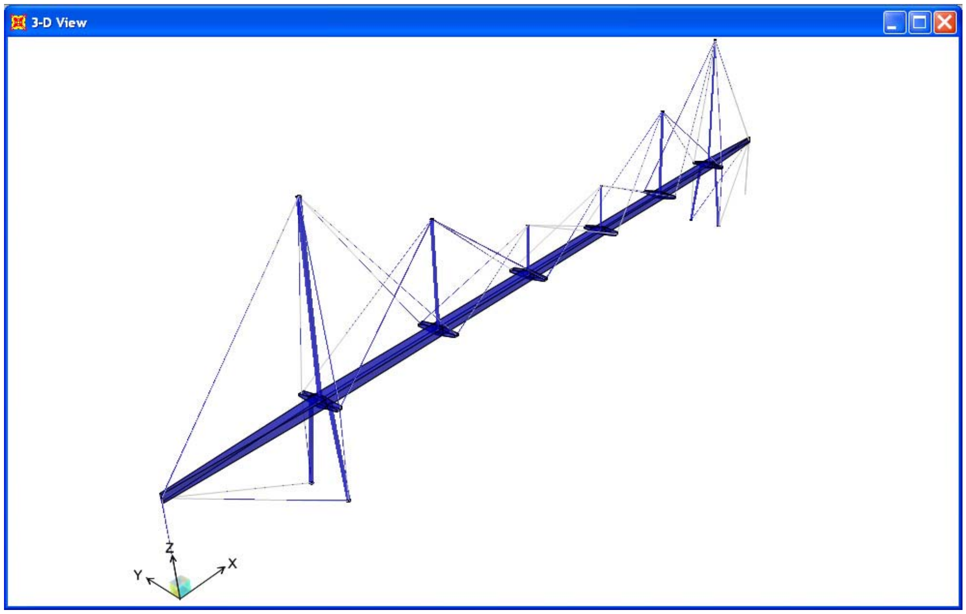

Figure 4.20 - General view of B1

Two types of loads are applied to the system. First one (L_1) is a unit load of 10 kN/m. This is used for comparisons of the bridges with each other. Second one (L_2) is the live load of 15 kN/m. The dead load of B1 is not given, as this bridge is accepted as a well-designed one and does not require an analysis of self design. The reason for using it as a sample is to compare the other examples with one that is recognized, beyond doubt, as “well-designed.”

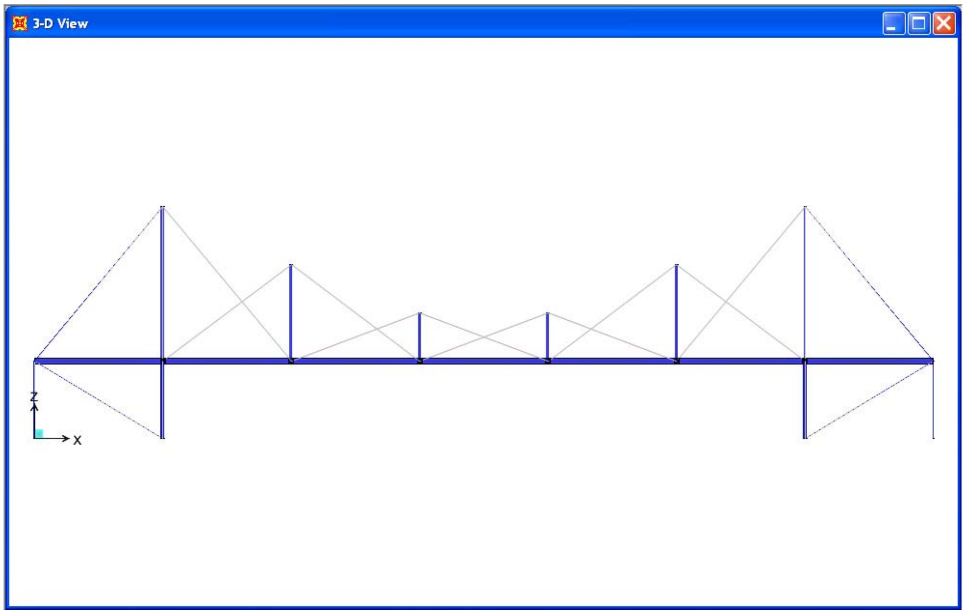

Figure 4.21 - Undeformed shape of B1

B2 is first designed with the original dimension of a span of 37.5 m., labeled B21 (Figure 4.22). Then the span is increased to 100 m in order to make it compatible with the other examples (Figure 4.23). The span is increased in two different ways. In the first one (B22), only the span is increased to 100 m and all the other coordinates stay same, as it is in B21. In this case the visual disorder can easily be distinguished. Then the second adaptation, (B23) is developed by using a ratio of the span to the height of the tower of B21 and using that ratio, using it to find the new elevation of the tower. In this case, the tower becomes approximately 50 m instead of 24 m.

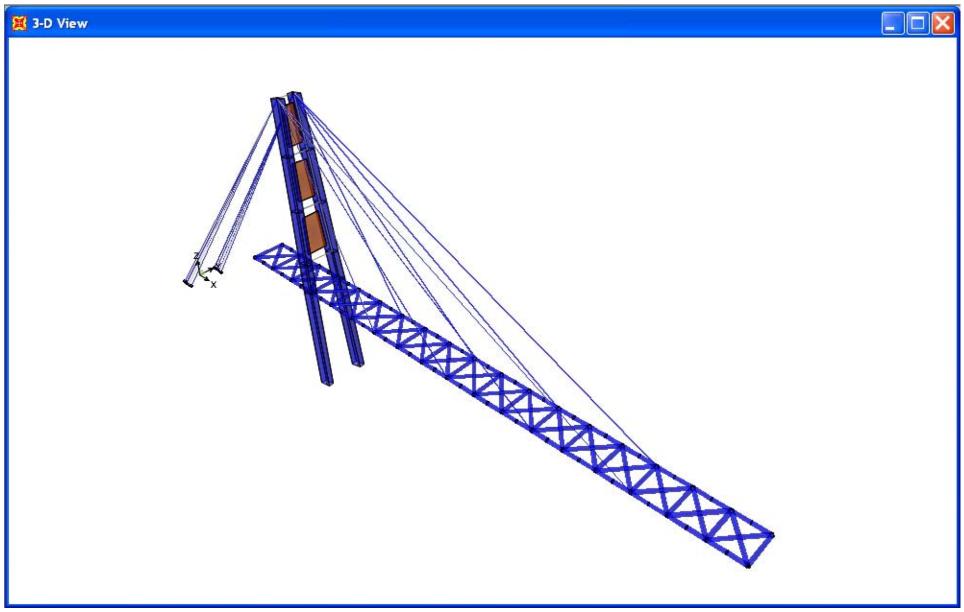

Figure 4.22 - General view of B21

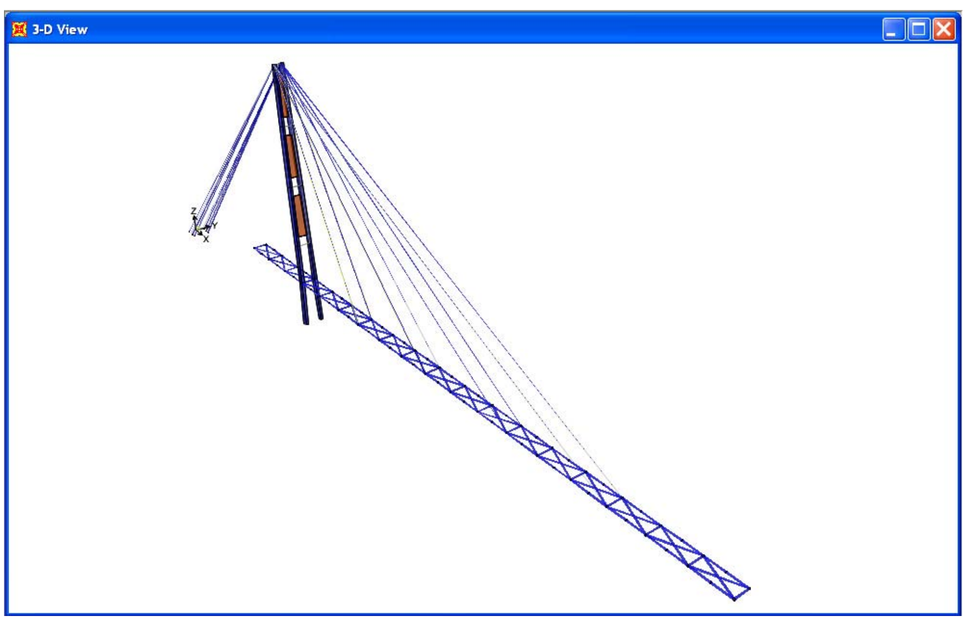

Figure 4.23 - General view of B23

B3 is first established with the original dimensions of 35 m span, labeled B31 (Figure 4.24). Then the second case (B32) is made by only changing the span (Figure 4.25). Again, an obvious visual problem emerges, even without any analysis. The third model (B33) is made by using the ratio of the span to the height of the bridge to increase the rest of the coordinates. In order to establish the same geometry, some adaptations are applied. With these adaptations, the new bridge has a span of 100 m and a height of approximately 30 m.

In both B2 and B3 variations, same loadings are applied. Four different combinations of loads are used in these cases. The first one (L_1), is the total load which is the sum of the dead load and live load. The second load (L_2) is the dead load and the third (L_3) is the live load. The fourth one (L_4) is again the unit loading as in B1.

The quantitative values for these loading cases are as follows:

Table 4.1 - Loadings applied to the structural models

	L_1 (kN/m)	L_2 (kN/m)	L_3 (kN/m)	L_4 (kN/m)
B1	10 : unit load	15: live load	-----------	------------
B2	10.5 : total load	7.5 : dead load	7.5 : live load	10: unit load
B3	10.5 : total load	7.5 : dead load	7.5 : live load	10: unit load

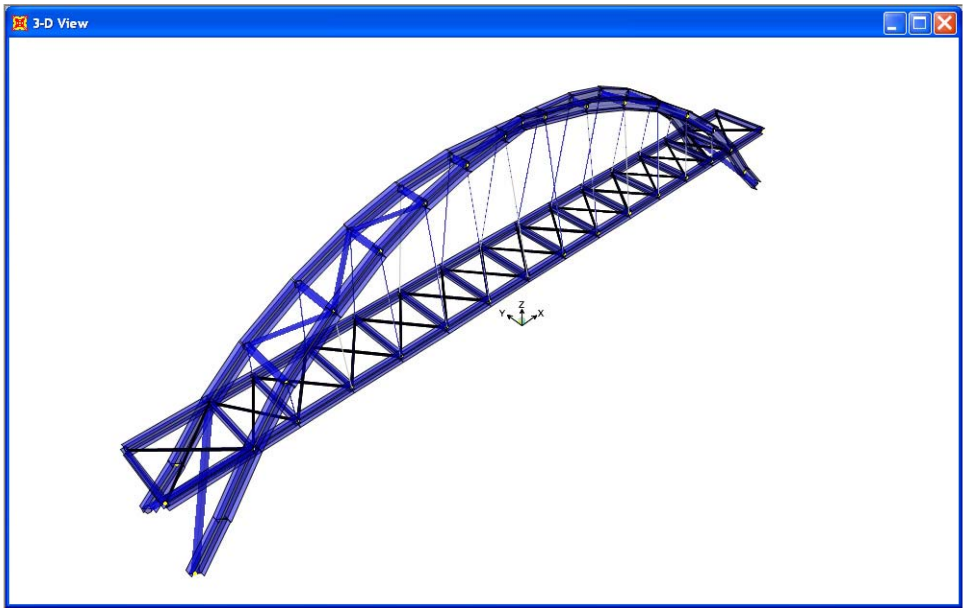

Figure 4.24 - General view of B31

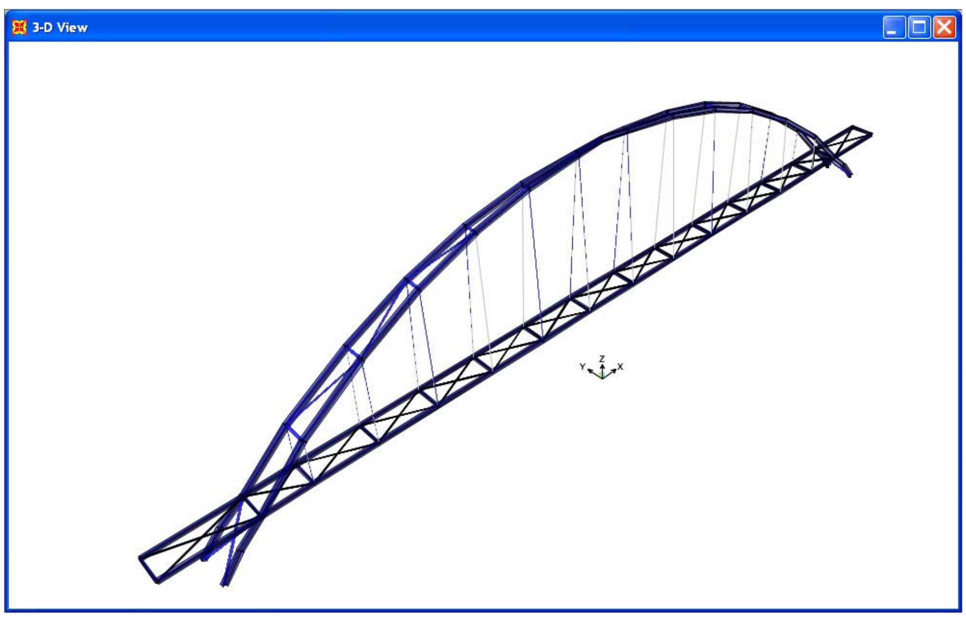

Figure 4.25 - General view of B33

The reason for having 4 loadings in B2 and B3 is that in these models, design needs to be verified and that is only possible by applying the total load on the structure. In B1, the verification is done by social acceptance.

The comparison with unit load expresses the performance of the structures in the same conditions, without considering the difference in dimensions. However, in the case of the live load, there is the effect of the difference in the capacities of the structures. In this case, the real performance comparison is done.

CHAPTER 5

DISCUSSION OF THE RESULTS OF THE ANALYSIS

5.1 Purpose of the Analysis

Constructing analytical model is creating a tool in order to understand the behavior of the structure easily. Establishing the right model is followed by running the program, obtaining the results and interpreting them.

The aim of this study is to analyze these analytical models and examine the effect of geometry and dimensions on the structural behavior. There are a couple of parameters to inspect in order to understand the behavior of the structure.

One of these parameters is the displacement which is a significant value for the analysis of a structure to display how the geometry of the elements and the original location of joints had changed under that specific loading. There are some limits for the values of displacements which are defined not only according to structural concerns but also according to serviceability conditions. When the values obtained for the displacements exceed a certain value; a failure is expected not necessarily because of the structural insufficiencies but also functional inadequacies. Displacement is a parameter to understand the physical problems that are encountered.

On the other hand, another parameter is the internal forces. The elements which are carrying the load should be analyzed and observed to check if the internal forces are within the limits or if there is any failure possibility through the structure. In the study, the elements are inspected according to the largest stresses created in the elements. Because the aim is to observe the ratio of the present behavior to the expected capacity of that element in the structure and understand how much of structure’s capacity is used with these geometry and dimensions.

During these observations, the most critical elements are considered because a structure should be designed according to the weakest point of the whole structural system. That is why the observations must be on these critical elements.

5.2 Interpretation of Displacements

In this study the analyses are performed under separate loadings in order to calculate the displacement values at the specific points on the analytical models.

The first loading is live load, showing the capacity of the structure under the service loads. It signifies the ability of the structure without concerning the structure's self weight. In the second loading case, total load (combination of self weight of the bridge and service load) is considered. In this case, the maximum load the structure can be exposed to is applied. The results are interpreted as the maximum deflection to occur in that specific structure

During the analyses, a live load of 5 kN/m^2 is applied. The probability of a footbridge exposed to this amount of live load is very small. This should be considered during the interpretation of the results. The displacement results are given in Table 5.1.

Table 5.1 - Deflection values under different loading cases

Model	Span (m)	Loading	Maximum Deflection (mm)
B1	100	L_2	317
B21	37.5	L_3	35
		L_1	48
B23	100	L_3	303
		L_1	424
B31	35	L_3	2.4
		L_1	3.4
B33	100	L_3	48
		L_1	68

B1 is a model that is established in order to be the guidance throughout the analyses. The results obtained are assumed to be in the limits of safety. Under live load conditions (L_2), the maximum displacement is observed to be 317 mm (Figure 5.1).

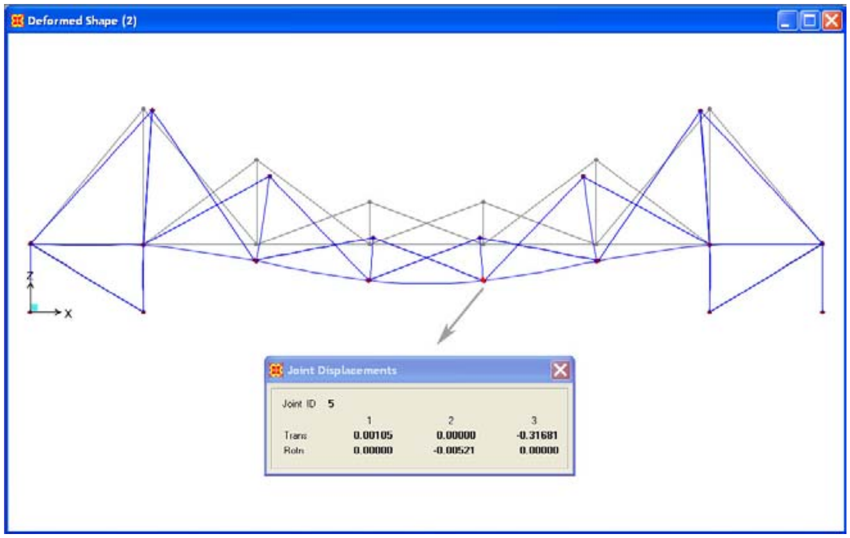

Fig 5.1 - Maximum displacement of B1 under the loading of L_2

In B21, the maximum displacement is calculated as 35 mm under live load conditions (L_3) (Figure 5.2). Knowing that the loading probability is very low, having 35 mm of deflection in this very rare case is more than acceptable. The structure can even be called as over designed.

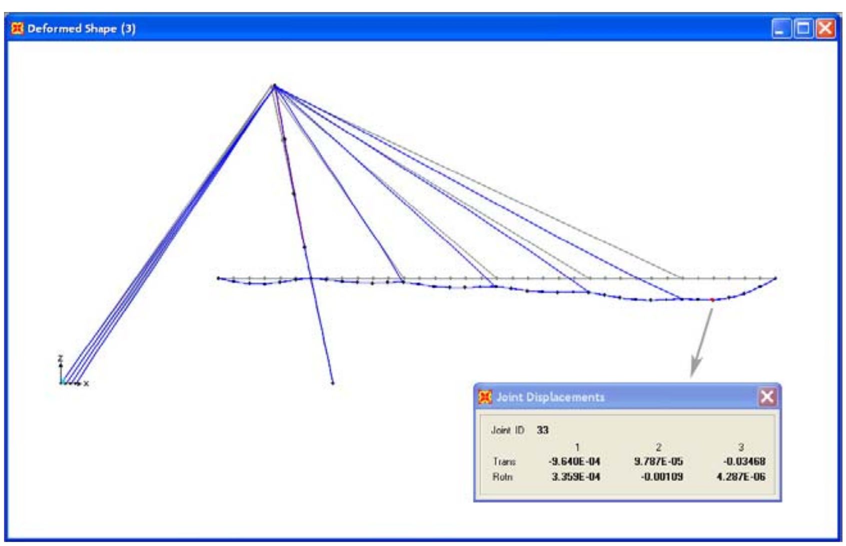

Fig 5.2 - Maximum displacement of B21 under the loading of L_3

Under total load conditions (L_1), which constitutes dead loads and live loads, the maximum displacement in B21 is reached to 48 mm (Figure 5.3). Again this value is not even close to the limits. The structure has no problem with displacements at all.

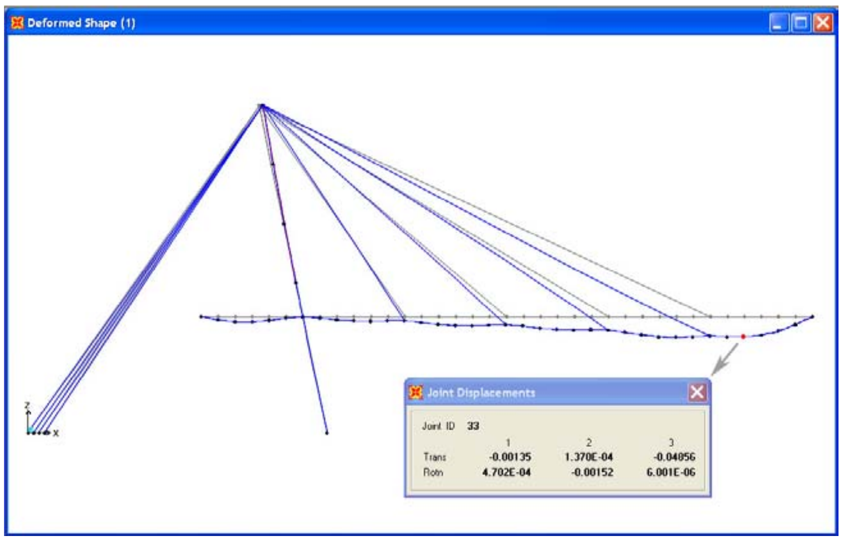

Fig 5.3 - Maximum displacement of B21 under the loading of L_1

In B23, the analyses are run under the similar loading cases. The maximum displacements under the live load (L_3) and the total load (L_1) are obtained as 303 mm (Figure 5.4) and 424 mm (Figure 5.5) respectively. The augment of displacements between these two cases is due to the increase in the dimensions and therefore due to the change of loads. However, considering the initial cambering and the small probability of having the loading exposed, this case might also be acceptable.

Initial cambering is the preliminary reverse deflection of a beam in order to have the straight geometry when it is loaded. This is applied especially in bridges and this partially diminishes the deflection problem or at least decreases.

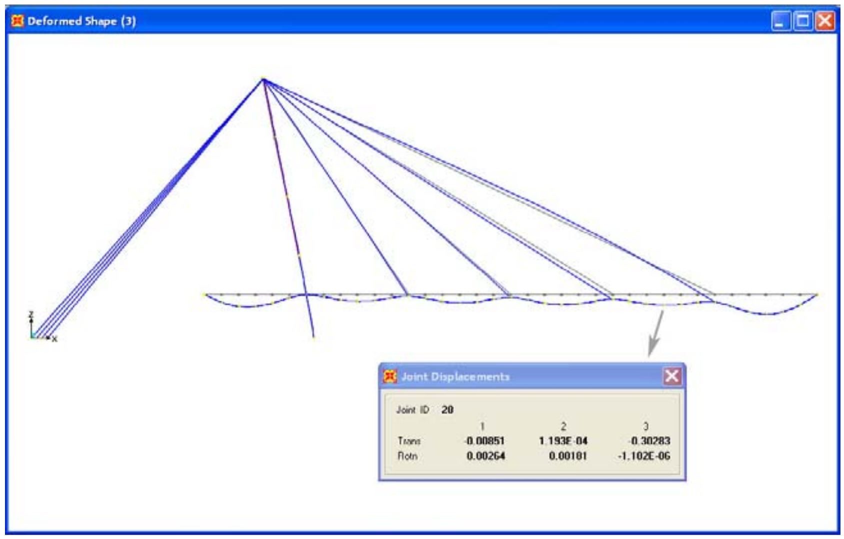

Fig 5.4 - Maximum displacement of B23 under the loading of L_3

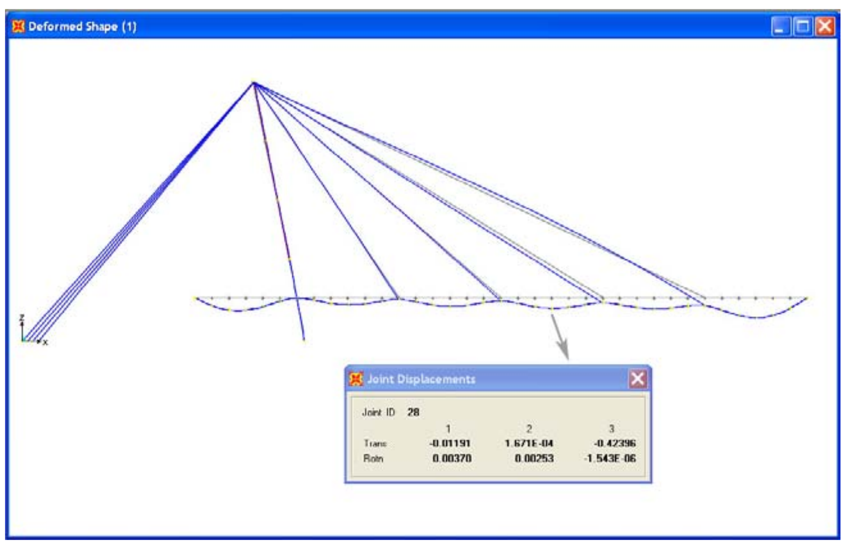

Fig 5.5 - Maximum displacement of B23 under the loading of L_1

Arch bridges are structural systems of having higher strength. In B31, the maximum displacement is found as 2.4 mm under the live load (L_3) (Figure 5.6).

This value is obviously far smaller than the expected performance of a regular bridge. In this case, the structure should be called not only over designed but inefficient.

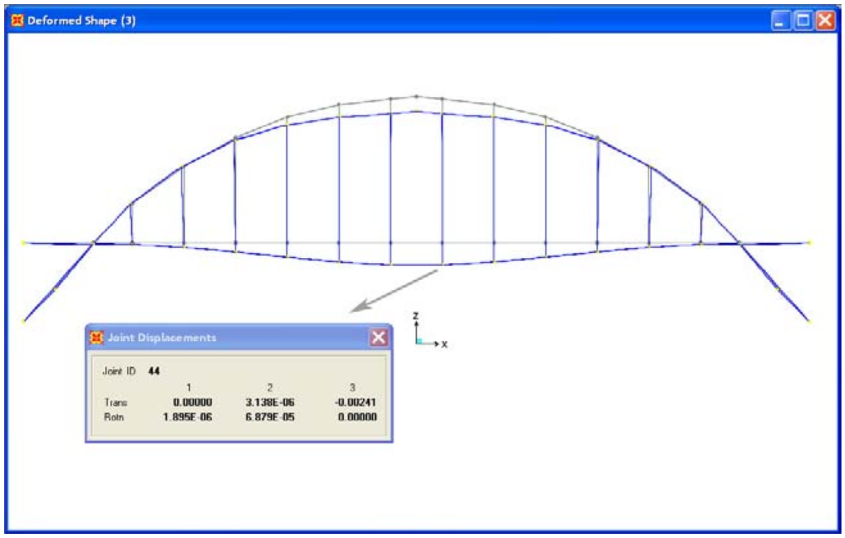

Fig 5.6 - Maximum displacement of B31 under the loading of L_3

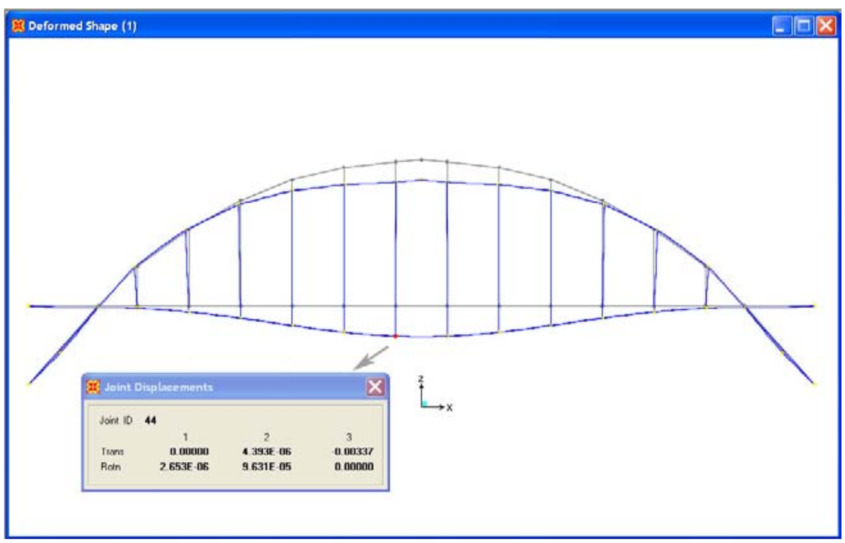

Fig 5.7 - Maximum displacement of B31 under the loading of L_1

Under the total load case (L_1), this displacement is 3.4 mm (Figure 5.7). Even under a very rare seen case; the maximum displacement is so small that the bridge is definitely stated as an over designed one.

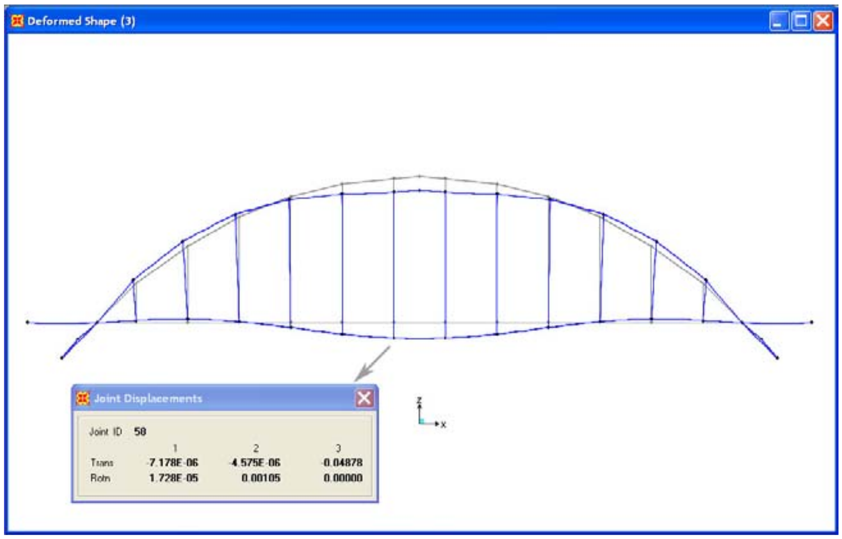

Fig 5.8 - Maximum displacement of B33 under the loading of L_3

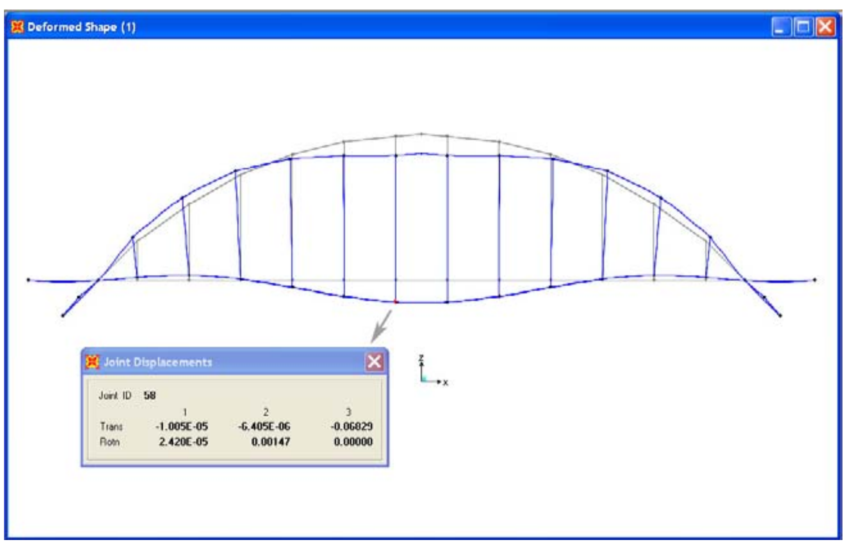

Fig 5.9 - Maximum displacement of B33 under the loading of L_1

In B33, the maximum displacement is 48 mm under live load case (L_3) (Figure 5.8). This indicates that even changing the dimensions of the structure approximately two and a half times, the maximum deflection stays in the limits. Under the total loading case (L_1), this value is increased to 68 mm (Figure 5.9). These values are satisfactory quantities for the design.

5.3 Interpretation of Internal Forces

In these four models (B21, B23, B31, B33), there are two essential elements for each to be checked. One is the main element that all the structure is carried with (the main arch or the tower) and the other is the part that the whole structural system is suspended or supported with (the cables or rods). The results taken from the software [33] are as in Table 5.2.

Table 5.2 - Maximum internal forces

Model	Span (m)	Location	Force (kN/m)	Moment (kN.m)
B21	37.5	Base of the tower	-833.9	248.42
		Most critical cable	191.424	----
B23	100	Base of the tower	-2072.99	568.53
		Most critical cable	544.63	-----
B31	35	Main arch	-216.02	27.90
		Cables	25.48	-----
B33	100	Main arch	-647.37	-199.58
		Cables	80.15	------

From the graphics obtained as the result of computer software [33], the critical values of internal forces and moments are read. These values have to be used in order to obtain the stresses existed within the elements.

In cables, as there is no moment, the stress calculation is as easy as there is only axial force to be processed. However in the other elements, there is the axial force and the bending moment. The necessary equations are:

$$\sigma = \frac{N}{A} \tag{5.1}$$

for cables where N: axial force and A: cross sectional area

$$\sigma = \frac{N}{A} \pm \frac{Mc}{I} \tag{5.2}$$

for bending case where N: axial force, A: cross sectional area, M: bending moment, c: largest distance from the neutral axis to the surface and I: moment of inertia

B21 and B23 are models of cable-stayed bridges. The deck is carried with eight cables, four on each side in both cases. The load on the beam is transferred to the tower by these cables. Therefore, the elements to be analyzed are the tower, working in compression and the most critical cable, working in tension.

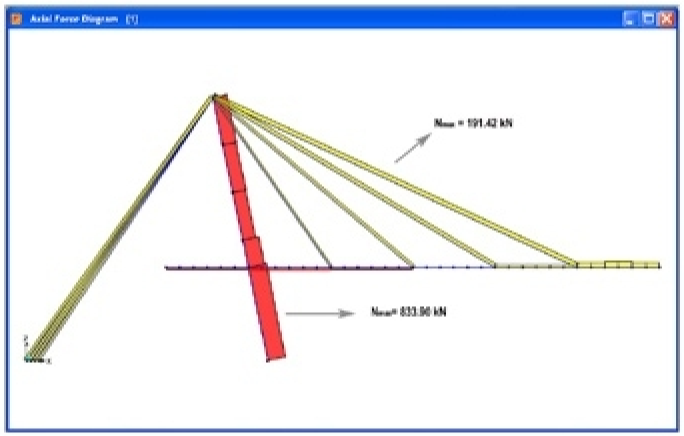

Figure 5.10 N- Diagram of B21

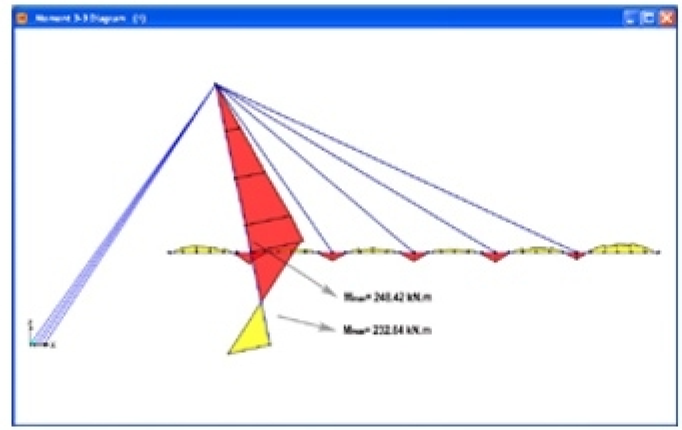

Figure 5.11 M- Diagram of B21

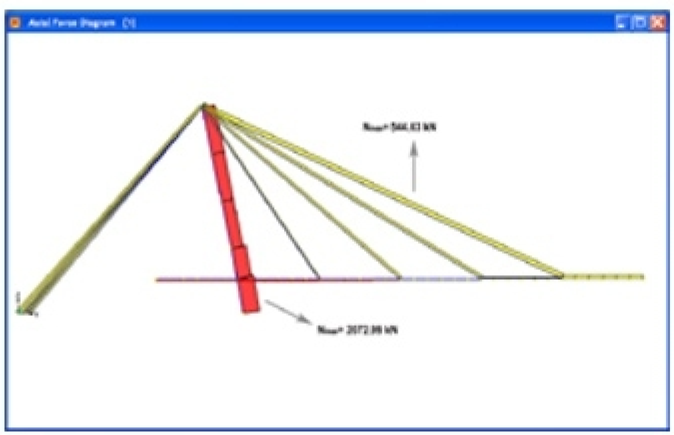

Figure 5.12 N- Diagram of B23

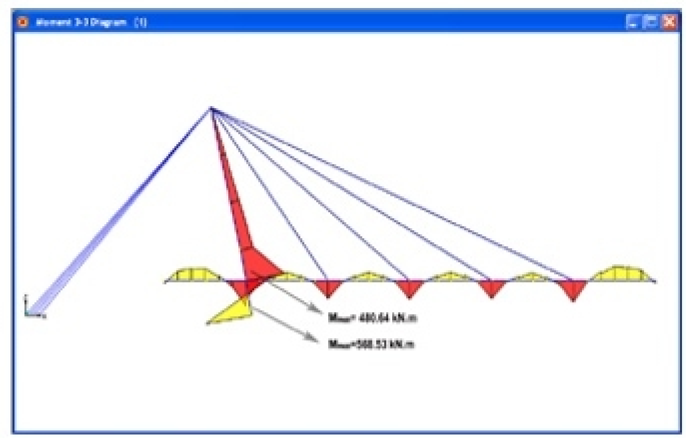

Figure 5.13 M- Diagram of B23

By referring to the Figures 5.10, 5.11, 5.12 and 5.13, the internal forces and bending moments at the critical cable and at the base of the tower are obtained and using the necessary equations (equation 5.1 or 5.2), the axial stresses are calculated. The ultimate stress of steel is known as 141 N/mm^2. Those values taken from the analysis are compared to this capacity of the material in order to see the capacity of the structural system.

In B31 and B33, the critical points to be inspected are the main arch in I-section and the cables. Similarly the forces and bending moments obtained from the analyses (Figure 5.14, 5.15, 5.16, and 5.17) are used in the calculations and the maximum stresses created in the structures are calculated by equation 5.1 or 5.2

With the analyses results and the necessary calculations, the most critical values are obtained. As the aim of the study is the capacity ratio, the percentage of these found values to the ultimate capacity are evaluated. In Table 5.3 the stress values and the percentage of capacities used are shown.

Table 5.3 - Maximum stresses created

	σ_{max}@ tower base	σ_{max}@ cable		σ_{max}@ arch	σ_{max}@ cable
B21	17.79	57.59	**B31**	12.20	36.05
	12.62 %	40.84 %		8.65 %	25.57 %
B23	42.27	164.14	**B33**	58.54	113.38
	29.98 %	100%		41.52 %	80.41 %

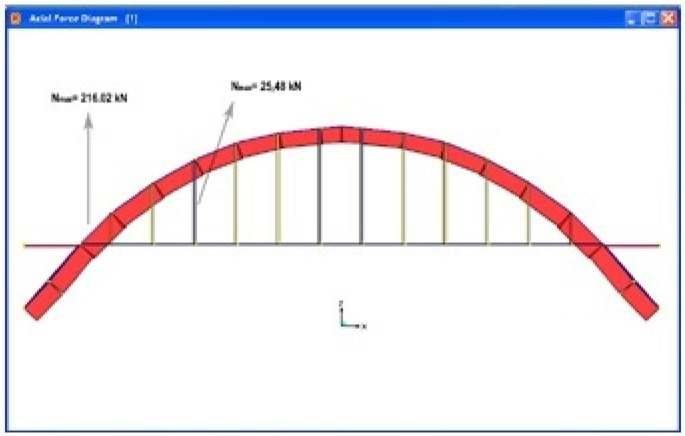

Figure 5.14 N- Diagram of B31

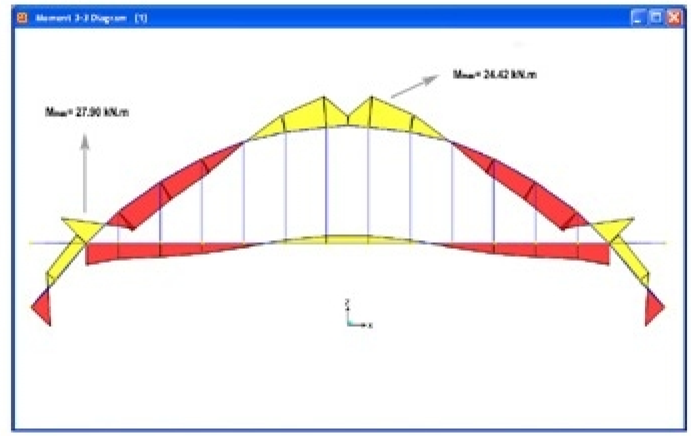

Figure 5.15 M- Diagram of B31

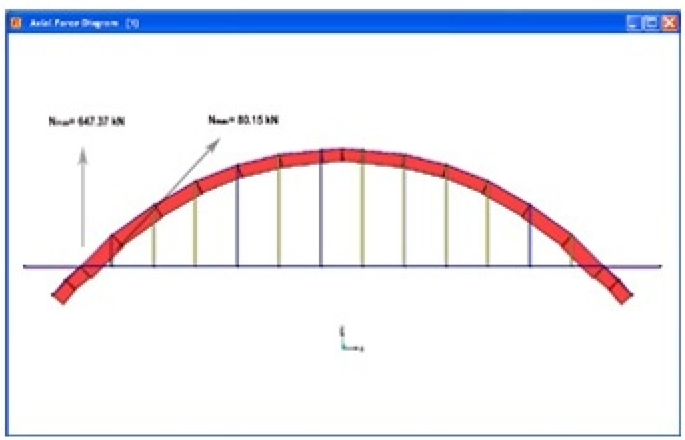

Figure 5.16 N- Diagram of B33

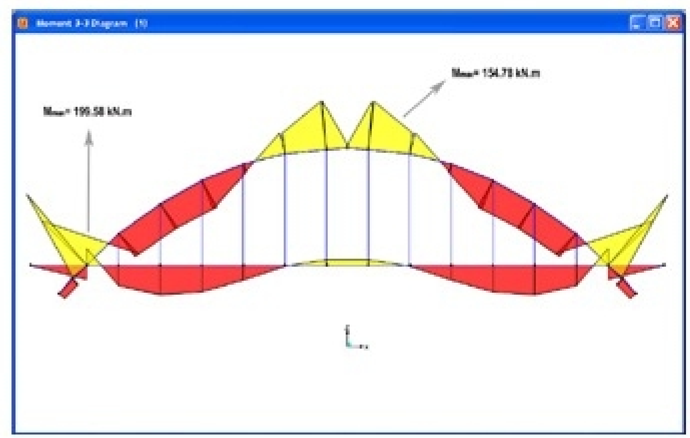

Figure 5.17 M- Diagram of B33

5.4 Discussion of Results:

The maximum stresses and the maximum displacements are tabulated above. The first thing observed is the inefficiency in the design of dimensions and geometry of these models. It is very hard to obtain a structural system working in its full capacity. However, the results displayed have a very high factor of safety as many of the capacity percentages are below 50%.

All kinds of forms of bridges have a structural advantage besides their aesthetic concerns. Cable-stayed or arch bridges have also special mechanism to carry the heavy load a bridge is generally exposed to. However, these systems in this study are firstly not working in the proper way that they have to be. They do not use most of their capacity. Over-designing the structure creates an unnecessary situation for that particular geometry.

Letting the structure work under its capacity also creates some visual problems. The dimensions are not only too big for structural needs but visually, they disturb the observer's taste of vision. Especially when it is a footbridge, the alliance becomes more important. When the aim is having the most harmonious structure, these ideas in these models do not seem the most optimum ones.

One important issue to discuss in an over-design structure is the economy. The major disadvantage is its economy. If the elements are chosen as smaller or less in amount, the overall cost decreases or with the same amount, other extra ideas can be created.

CHAPTER 6

CONCLUSION

In this study, a brief survey about bridges has been carried out. The way they were created, developed and became a significant component was analyzed. How structural requirements do not only exist as a necessity in overall design but also present in the visual integrity has been observed.

Engineering and architecture are two disciplines that work together in the design of any kind of structure, completing one another. In the case of bridge design, this cooperation becomes very important. Bridge design is not limited to structural needs. Aesthetic concerns and the harmony of the structure with its environment are issues to be dealt during the creation and construction of the structure.

Analytical models of some footbridges are developed during this study. Some of the footbridges in and around Ankara have been used for inspiration. The analyses were not based on these specific structures that already existed. The necessary adaptation has been applied to these models on their qualitative and quantitative properties. The existing samples have only been helpful guides to easily visualize the structures that are analyzed in three dimensions.

When these analytical models are analyzed results show that most of these bridges do not utilize most of their capacities under these loadings. Then the spans are increased using the same materials with the same cross section. This time a risk of failure emerged in some critical parts of the structure. However, this risk is acceptable as the loading was defined much larger than normal cases, which has a very little probability. That shows the possibility of using the same elements and spanning a larger gap, such as two and a half times the original span. The ability to pass a gap of that length with these elements using the same material shows how inefficient the design is. As mentioned before, this ruins the integrity of the structure economically, structurally and visually.

The results that are obtained from computer analyses are interpreted as:

- In the original configuration, the values at the critical points are not facing the risk of failure. Moreover, the structures do not use most of their capacities.

- With the analytical models formed by increasing the span to 100 m., the displacements and internal forces obtained are higher values. Even though the increment in the span is more then twice of the original structure, many of the resulting values stay within the limits.

- In the modeling process, the loadings are applied in a very rare combination. Therefore, after increasing the span and applying this rare loading case, the ones that are within the limits are logical.

The interpretations of the results reveal that structures that have elements with large dimensions are using a low percentage of their capacities. Some do not even use approximately half of their capacity. Unnecessarily oversized elements create problems in basic parameters, such as:

- Economy: The design is definitely not economical when the elements used are more than necessary. The costs of production, construction and maintenance are in excess if the material is more than the sufficient amount. The whole design becomes not feasible at all.

- Efficiency: The higher the self weight of the structure, the higher the load the structure has to carry. Expanding the dimensions boosts self weight and therefore the load that needs to be carried increases. This is completely a disadvantage for the structural system.

- Elegance: The visual alliance suffers from unnecessarily large dimensions. Bridges are known as the structures that are friendly to the environment. Especially footbridges are famous for their intimacy with nature and people.

Their design should aim for the least disturbance in and around themselves. However, in these cases, the design of elements seems to be chosen without environmental concerns.

Concerning these three important concepts in bridge design, it is obvious that not choosing proper dimensions and geometries ruins the overall design of the structure even tough there is no problem from the structural point of view.

Footbridges are mentioned as the furniture of the city in one of the previous chapters. They are glamorous and attractive. They are built not to be used as naked structures. They are slender and mostly simple functional structures and that makes them closer to people. These can all be counted as excuses for scrutiny in detailing the design. In this study, the geometry and the dimensions are discussed and the importance of design is emphasized.

For the future studies, in this field, some more studies can be recommended for other footbridges in Ankara and in other major cities in Turkey. The analysis could be also done from the architectural point of view and the functionality could be investigated. Some observations and also recommendations could be formulated with regard to functionality and daily use of those bridges.

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