T.C.
VAN YÜZÜNCÜ YIL UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES
CIVIL ENGINEERING DEPARTMENT

THE EFFECTS OF SUPPORT CONDITIONS AND NUMBER OF HINGES ON BEHAVIOR OF THE ARCH BRIDGES

M.Sc. THESIS

PREPARED BY: Mahmoud M. Mahmoud BADER
SUPERVISOR: Assoc. Prof. Dr. Murat MUVAFIK

VAN – 2019

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ACCEPTANCE AND APPROVAL PAGE

This thesis entitled "THE EFFECTS OF SUPPORT CONDITIONS AND NUMBER OF HINGES ON BEHAVIOR OF THE ARCH BRIDGES" prepared by Mahmoud M. Mahmoud BADER under the supervision of Assoc. Prof. Dr. Murat MUVAFIK in the department of Civil Engineering has been accepted as a Master Thesis according to the rules of Higher Education Instruction of Republic of Turkey on 20/05/2019 unanimity the member of jury.

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THESIS STATEMENT

All information presented in the thesis obtained in the frame of ethical behavior and academic rules. In addition all kinds of information that does not belong to me have been cited appropriately in the thesis prepared by the thesis writing rules.

(Signature)

Mahmoud M. Mahmoud BADER

ÖZET

MESNET ŞARTLARI VE MAFSAL SAYISININ KEMER KÖPRÜLERİN DAVRANIŞI ÜZERİNDEKİ ETKİSİ

BADER, Mahmoud M. Mahmoud
Yüksek Lisans Tezi, İnşaat Mühendısliği Anabilim Dalı
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2019, 97 sayfa

Dünyadaki nüfusun orantısız bir şekilde artmasıyla, kentsel planlamada alternatif yollara duyulan ihtiyacı karşılamak ve yol güzergahlarındaki sürekliliği korumak için köprülere giderek daha fazla ihtiyaç duyulmaktadır. Köprüler, insanların vadi, nehir vb. engelleri geçmek için inşaasına ihiyaç duyulan dev yapılardır.

Köprünün tasarımında, ihtiyacı karşılayacak şekilde, köprü şekli ve köprü tipini belirlerken, köprünün maliyetini de gözönünde tutmak gerekmektedir. Bu açıdan bakıldığında kullanılacak malzeme seçimi de son derece önemlidir.

Bu çalışmada kemer köprülerde mesnet şartlarının ve mafsal sayısının değişmesiyle kemer köprülerinin davranışının nasıl değiştiği incelenmektedir. Çalışmada sadece kemer köprülere yaygın olarak etki eden düşey yayılı yükler dikkate alınmıştır.

Yapılan analizler sonucunda, kemer köprüler için maksimum yüksekliğin artması durumunda deplasmanın ciddi oranda azaldığı görülmüştür. Kemer köprünün uzunluğunun artması ise deplasmanın artmasına sebep olmuştur. Analiz sonuçları incelendiğinde köprülerin daha küçük parçalar halinde birleştirilmesinin yani hassasiyetin artmasının sonuçlara pek etkisi olmadığı görülmüştür. Kemer köprü yapımında mesnet koşullarının seçimi sonuçları ciddi ornda etkilemektedir.

Anahtar kelimeler: Yol ağı, Kemer köprüsü, Köprü, Sapma

ABSTRACT

THE EFFECTS OF SUPPORT CONDITIONS AND NUMBER OF HINGES ON BEHAVIOR OF THE ARCH BRIDGES

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M. Sc., Civil Engineering
Supervisor: Assoc. Prof. Dr. Murat MUVAFIK
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With the disproportionate growth of the world's population, bridges are increasingly needed to meet the need for alternative roads in urban planning and to maintain continuity on road routes. Bridges, giant valleys, rivers, etc. are the giant structures that need to be built to cross barriers.

In the design of the bridge, it is necessary to consider the cost of the bridge while determining the bridge shape and type of bridge to meet the need. From this point of view, the choice of materials to be used is extremely important.

In this study, it is examined how the behavior of belt bridges changes with the change of support conditions and number of joints in arch bridges. In this study, only vertical spread loads which are commonly applied to arch bridges are taken into consideration.

As a result of the analysis, it was observed that displacement decreased significantly when maximum height increased for arch bridges. The increase in the length of the belt bridge caused the displacement to increase. When the results of the analysis were examined, it was seen that the bridging of the bridges into smaller pieces, ie increasing the sensitivity, had little effect on the results. The choice of support conditions in the construction of the arch bridge affects the results seriously.

Key Words: Arch Bridge, Bridge, Deflection.

FOREWORDS

Praise be to Allah in the first and last. My advisor, Assoc. Prof. Dr. Murat MUVAFIK, thank you for your help and support. It was so much for me to work with him under his guidance, to progress through the stages of writing this thesis with his passion, knowledge and uninterrupted support. I am also grateful to my professors in the department, Dr. Namik YALTAY, Dr. Mucip TAPAN, Dr. Baris ERDİL, and Dr. Mehmet TÜRKMENOĞLU.

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2019
Mahmoud M. Mahmoud BADER

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SYMBOLS AND ABBREVIATIONS

Along with a description some symbols and abbreviations used in this study are presented below:

Symbols	**Explanation**
f	Maximum height of the arch
L	The span of the arch
y	Height at any point on the arch
x	Any point along the arch
$\mathbf{M(x)}$	is the arch moment at any section corresponding to x
$\mathbf{M_0(x)}$	is the moment for the simply supported beam corresponding to x
H	is the horizontal force (horizontal reactions)
y(x)	Vertical coordinate of any point corresponding to x

Abbreviations	**Explanation**
3-D FE	Three-Dimensional Finite Element
F.F-1H	Fixed support - Fixed support in the case of which there is one hinge.
P.P-NH	Pinned support - Pinned support in the case of which there is no hinge.
P.P-H	Pinned support - Pinned support in the case of which there is one hinge
F.F-NH	Fixed support - Fixed support in the case of which there is no hinge

INTRODUCTION

Bridges design is a major contributor as a solution to transport problems in both the developing and developed countries. In some cases, the demand for bridges is becoming very urgent due to the increase in traffic from the country's logistics. In addition to the increase in the population, which means the need to expand the infrastructure, associated with the streets and roads.

Civil engineering is considered as a sector that shows the importance of bridge design according to this request. Given that loads from tiles and walls, bridges are horizontal structural elements that can be mounted horizontally on their axis. In order to weaken the tension of concrete, there are three options which they are: the self-weight, pressure strength and surface strength will be reduced.

To minimize the unnecessary loads, the unused material will be removed completely from the section to obtain the empty box.

Arches can be used to reduce the bending in long-span structures. Essentially, an arch’s works as an inverted cable, so it receives its load mainly in compression although, because of its rigidity, it must also resist some bends it depending upon how it is loaded and shaped.

To facilitate transportation between islands or between rivers, a strong convenient and safe infrastructure is needed to use, including bridges. Therefore, bridge design has a very important role in the world of civil engineering.

The arch bridge is a semi-circular structure with supports on both sides. The curved design naturally converts the load which received by platform of the bridge carriage to the pillar that keeps both sides of the bridge from movement.

In this study, the effect of support conditions and the number of hinges on the behavior of arch bridges will be investigated.

1.1.Definition of the Bridges

Bridges are defined as the elements carrying different types of loads of vehicles and pedestrian. The space below the bridge may be a natural gap such as watercourses, rivers, trenches or dry places such as valleys as in Figure 1.1.

Figure 1.1 The bridges used for crossing the valleys

By looking at the curved bridge, the semi-circular structure has two struts on both sides of the body, unlike linear bridges that need much support to carry the bridge. In the arch bridges, bending actually distributes the force of the load to the outside. These bridges were made of brick or stone, but nowadays they are made by steel and concrete to ensure the durability of the bridge under heavy pressure. These bridges are characterized by strength and durability due to this physical property in energy dissipation all along the curve. Bridges require a lot of structures or cables. Moreover, the construction process is not reasonably reliable and does not require a large range of raw materials.

Bridges usually receive different loads from several different sources such as multi-type vehicles that run on bridges, trains of various types and pedestrians, as well as loads resulting from weights for the materials used in the implementation these bridges may carry pedestrians and vehicles. This facilitates the use of materials that bear pressure and cannot withstand tensile strength in its construction such as natural or artificial stone in building any bridge.

One of the eldest bridge structure was built in Ancient Greece time. It is an arch bridge that has abutments at each end that hold the weight of the bridge.

Tied arch bridges (or bowstring arches) also have an arch-shaped superstructure but their arch is above the level of the bridge.

The loads that act on the bridges can be classified as follow:

- *Dead load:* The weight of the bridge itself.
- *Live load:* It means the transit traffic to be seen on the surface of the bridge and mobile loads including any temporary or transient forces that act on a bridge.
- *Dynamic loads*: Earthquake Load

A range of effects must be taken into accounts, such as thermal variability and its effect on bridge expansion or contraction. This effect becomes very important in relatively long bridges.

Bridges can be classified in relation to several aspects, for example:

1. Purpose of the usage
2. Construction system of the bridge.

1. Classification by purpose of the bridge:
    - Pedestrian bridges.
    - Pedestrian bridges and cars.
    - Railway bridges.
2. Classification by the construction of the system:

Beam Bridge: A type of bridge whose top section consists of multiple steel or concrete beams, which are cast in place with the slab at once or prefabricated. This type of bridge is the simplest structure of the bridge extensions supported by a pillar at each end. The cross-sections of this type of bridge may be in various shapes such as (T, double-T, Bulb-T, I).

Suspension Bridge: A suspension bridge is a type of bridge in which the deck (the load-bearing portion) is hung below suspension cables on vertical suspenders. The first modern examples of this type of bridge were built in the early 1800s.

<u>Advantages</u>

- It allows the possibility of building bridges with a large span.
- Easy to build, fast execution, and durability thus reduce the cost of construction, compared to other construction systems of bridges.
- More tolerable earthquakes, because of their lightweight.

Disadvantages

- It needs to be strengthened to make it safer if it is exposed to strong winds.
- Its ability to withstand large (mobile) loads such as trucks (Shaker, 2012, p. 242).

Arch Bridges: The arch bridge is one of the oldest types of bridges, consisting of pillars formed at the end of the curve. These bridges work by moving the weight of the bridge and loads in part in the horizontal direction by the pillars on both sides.

1.2.Concrete Arch Bridge

Concrete plays an important part in the construction of arch bridges. Concrete with its high strength in compression and limited strength in tension is an ideal construction material for the arch since its primary internal force is compression.

Arch bridges derive their strength from the fact that vertical loads on the arch generate compressive forces in the arch ring, which is constructed of materials that are able to withstand these forces.

Modern concrete arch bridges utilize pre-stressing or reinforcing to resist the tensile stresses that can develop in slender arch rings. Arch bridges are probably the most common form of concrete bridge today, thanks to the success of precast which are structurally more efficient whether created in-situ or using precast

Concrete arch bridge is one of the most dramatic ways of building a bridge. The building starts with the construction of the abutments and piers. Then, from each pier, the bridge is constructed in both directions simultaneously. In this way, each pier remains stable - hence 'balanced' - until finally the individual structural elements meet and are connected together by joints. It is are necessary to allow movement as the structure expands under the heat of the summer sun and contracts during the cold of winter.

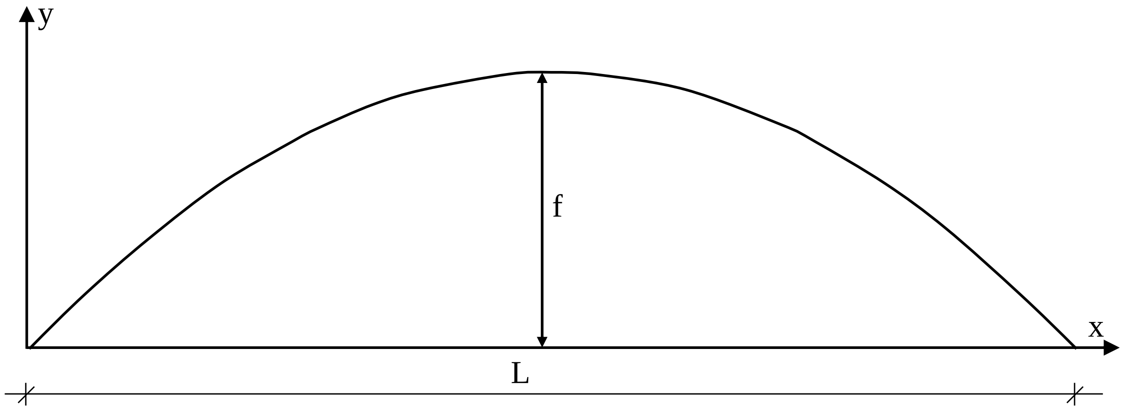


Figure 1.2 Typical shape of an arch bridge

For analysis, the whole arch is divided into equal parts.

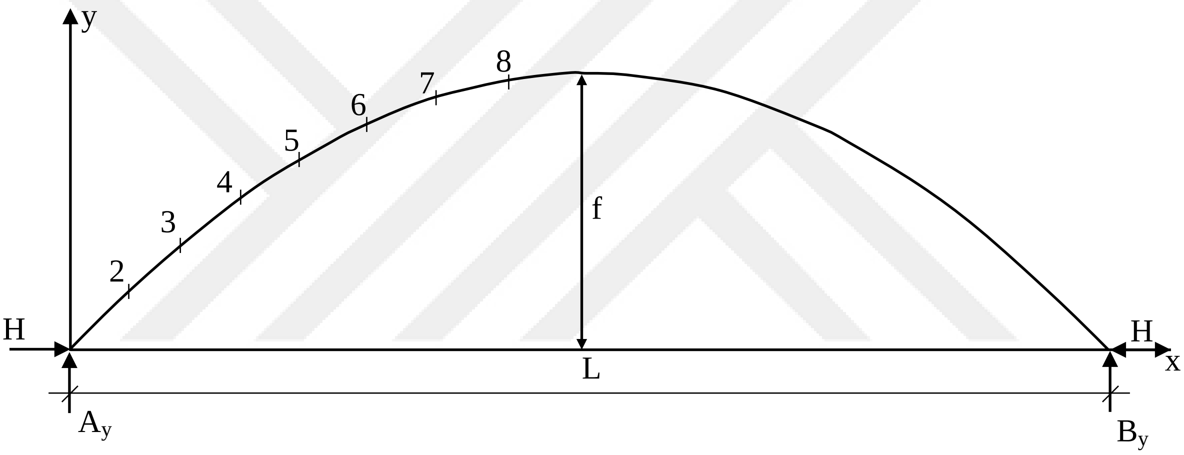


Figure 1.3 Equally divided arch for obtaining the model to analyze.

The equation of a general parabola is:

$$y(x) = ax^2 + bx + c \qquad (1.1)$$

If the constants (a, b and c) are obtained by using boundary conditions of the arch bridge, then this equation can be written as;

$$y(x) = 4f\left(\frac{x}{L} - \frac{x^2}{L^2}\right) \qquad (1.2)$$

$$y(x) = \frac{4f}{L^2}x(L - x) \qquad (1.3)$$

Where:

y(x) : Vertical coordinate of any point corresponding to x

f : Maximum height of the arch

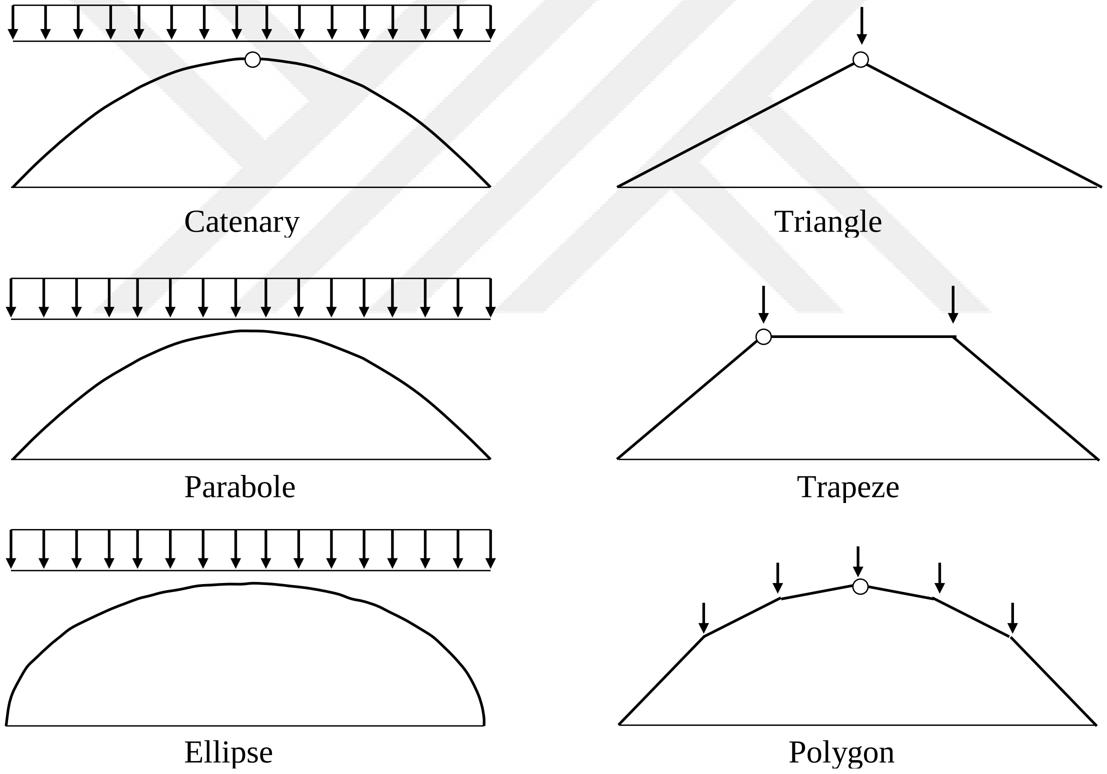
L : The span of the arch

x : Any point along the arch

1.3.Structural Behavior of the Arch

The arch is a sturdy structure. Its shape causes it to be subjected to compression stress. The arches transfer most of the compression which applied on in the structure and sends it to the supports (pillars) which, in turn, pass it the foundations.

In the ideal case, the shape of the arch coincides precisely with the flow of forces. The shape of the arch varies accordingly.



Catenary

Triangle

Parabole

Trapeze

Ellipse

Polygon

Figure 1.4 Some typical shapes of three hinged structures

1.4. Engineering Methodology for Determining the Bending Moments

One of the methods suitable to determine an arch bridge geometry in order to be in compression is to determine the bending moments due to the proper load of the arch bridge and the loads coming from the board in a simply supported beam with the same span of the arch.

Reinforced concrete arch bridges, with the increase in span, the section of the girder increases to such an extent that the self-load of the girders becomes a substantial part of the total loads. The dead load moments in an arch bridge are almost absent when the arch is properly designed. This is illustrated in Fig. 1.5.An arch is a curved structural member in a vertical plane. The dead load and (live load impact) shear forces and bending moments at various sections of the bridge are combined to obtain the design (maximum positive and/or negative) shear forces and bending moments.

The bending moments and shear forces being small compared to a girder that requires larger section to withstand larger bending moments and shear forces caused by the same loading. This is due to the fact that while a simply supported girder will have only the sagging (positive) moment on account of external loads. An arch, on the other hand, will have not only the same sagging moment but will also have a hogging (negative) moment of opposite nature to partly balance the sagging moment thereby reducing the sagging moment to a considerable extent. The hogging moment is generated by a horizontal force (H) at the support due to the shape of the arch as in a portal frame see Fig. 1.5

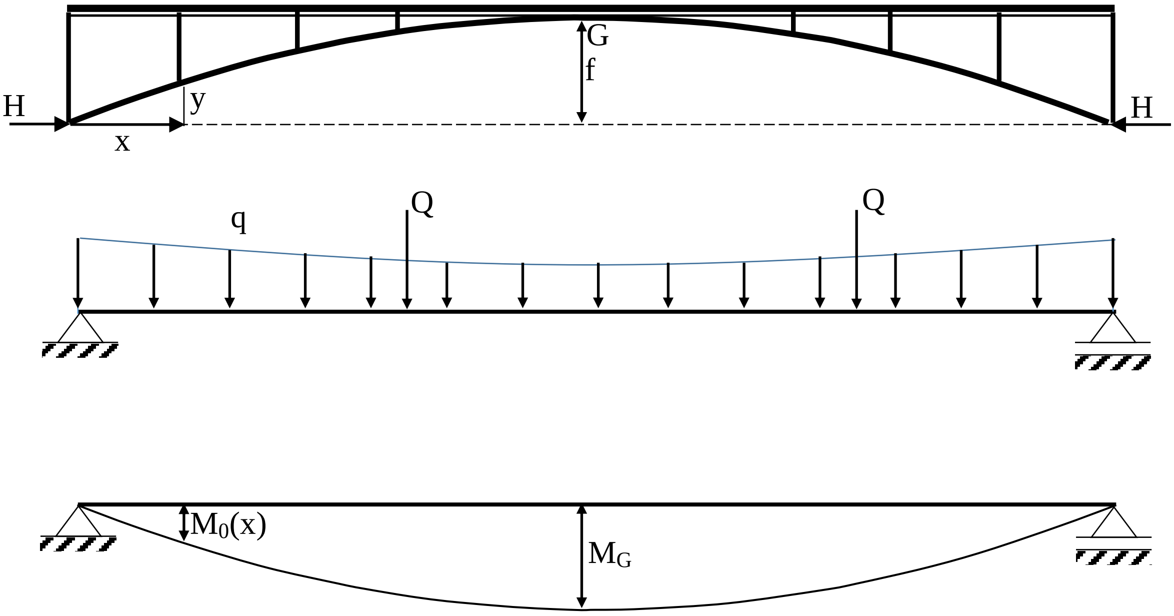


Figure 1.5 Bending moments in a beam simply supported under the weight of an arch bridge

The main parameter of an arch bridge is the ratio of the rise to the span, f/L. This ratio varies from 1/6 to 1/10 depending upon the site conditions and the surroundings. The greater is the ratio, the lesser is the thrusts on the supports. From the consideration of economy.

The moment of an arch is given by:

$$M(x) = M_0(x) - Hy(x)$$

(1.4)

Where

f : is the height of the hinge

$M(x)$: is the arch moment at any section, x

$M_0(x)$: is the moment considering the arch as a simply supported beam

H : is the horizontal force (horizontal reactions)

y(x) : is the vertical ordinate of the arch center at section x

Thus the y coordinate of the arch bridge can be written as;

$$\mathrm{y(x)} = \frac{\mathrm{M(x)} - \mathrm{M_0(x)}}{\mathrm{H}}$$

(1.5)

It is not possible in practice to attain a complete coincidence of the arch axis with the center of pressure since the arch is subjected to live loads of various distribution, which requires checking the design under worst condition of loading in addition to dead loads, temperature variations and the effect of creep and shrinkage etc.

Therefore, attempts are made to achieve the lowest values of the design forces and moments as far as possible. Since the arch ribs are subjected to direct axial thrust and moment, they are designed based on section subjected to eccentric compression. The rib section may be a rectangular or a T- section. Reinforcement are provided in both faces of the section since moment of opposite sign may occur at the section due to various combination of loadings.

The arch bridges can be double-encased, bi-articulated or tri-articulated. In these three types they are almost the same, however, the bending moments have many variations when it experiences a distributed load. Similar behavior is observed for the deformations such as horizontal movements of foundations, temperature. For the tri-articulate arch, there are no bending moments (Madrid, 2004).

LITERATURE REVIEW

Robert Hooke was the first to carry out scientific research on arches. His main finding was about the shape of an arch which could stand on its own. He distributed his finding in a re-arranged word (Hooke, 1675); as hangs the adaptable line, so however altered will stand the inflexible curve about two decades later, Gregory (1697) suggested the theoretical correct shape for an arch centerline where the arch took the form of Hooke's catenary. He concluded that an arch will stand only if a catenary can be wholly contained within the thickness of the arch ring. At about half a century later, both concepts by Hooke and Gregory were adopted by Poleni (1748) to investigate the safety of St. Peter's dome. Couplet (1729) produced a `Memoire' which demonstrated the idea of thrust-line and the mechanism of failure of a voussoir arch. The concepts of the thrust-line and the mechanism have been developed even until today. In the past few decades, with the advent of modem computers, many arch bridge assessment programs.

Harvey and Smith analyzed arch bridges using the mechanism method and developed a computer program Archie (Harvey W. J., Semicircular Arches. Proc. Instn Civ., 1987; Harvey W. J., 1988a; Harvey W. J., 1988b; Harvey W. J., 1991b; Harvey W. J., 1991a). The thrust line for a given applied load acting on an arch is calculated. By specifying the compressive yield strength of the arch, the zone of thrust is obtained by dividing the thrust by the yield strength. Minimum arch thickness can then be defined based on this zone of thrust. The most important contribution of this program is the inclusion of soil-structure interaction effects. Load dispersal angle, passive pressure distribution, and the position of any backing can be defined in this program. The height of backing is simply a level at which the thrust line is allowed to leave the ring before reaching the springers. This program can also be used to analyze multi-span viaducts and arches. The Archie program has been widely used for arch bridge assessments because of its ease of use. However, this mechanism based method can work only when all variable loads and reactions are proportional and their proportionality is known. A fixed soil pressure configuration has to be defined before the analysis is run. This means the load capacity obtained from this method is only pertinent to that pressure configuration which may or may not be the correct distribution at failure. It is therefore not appropriate for arch bridges where soil resistance is important.

Melbourne and Gilbert introduced a new technique known as the rigid-block method for analyzing arch bridges (Gilbert. M., 1994; Gilbert, 1998; Melbourne, 1995a; Melbourne, 1997). This method has been computer coded and used to determine the collapse load of structures comprising a number of masonry blocks. The method uses the upper-bound theory of plasticity in conjunction with geometrical compatibility criteria to obtain solutions to problems of single and multi-span arches. Specific parameters such as ring separation and attached or detached spandrel walls can be modelled using this method. The removal of the `no-sliding' restriction increases the generality of the method, permitting adjacent blocks greater freedom of movement. However, there are limitations associated with the rigid-block method such as the assumption of normality at frictional interfaces and from the utilization of small-deflection theory. An analysis on open spandrel masonry arch bridges was also carried out by Melbourne (Melbourne, 1995a). The findings showed that the proportions of the main span are critical to the overall stability of the bridge.

A dimensionless analysis was carried out to study the scale effects in masonry arch bridges (Choo, 1994). The results from scale model test (Royles, 1991) were used to compare with prototype results. A 3-D FE method was also used to model the specific weight of the arch material which cannot be modelled in small scale arches. The influence of the ratio of arch-fill was investigated and it was concluded that the predicted collapse load was directly proportional to the arch backfill weight ratio. However, the arch material properties cannot be modelled accurately with small scale arches. The arch tensile strength which is the most influential material property was not considered in the 3-D FE analysis. The arch elastic modulus and the arch compressive strength are interchangeable in her model due to the similarity of dimension of unit of both material properties. It must be noted that the arch elastic modulus and the arch compressive strength have significantly different contributions to the collapse load and must not be ' interchangeable.

An optimal design of arch bridges integrating genetic algorithms and Heyman's plastic method was developed (Peng D. M., 1997; Peng D. M., 1999). Three different optimizations were presented:

1. Optimize the design with respect to minimizing the ratio of quarter the span ring thickness to the rise to the intrados at the crown.
2. Optimize with respect to minimizing the arch cross-sectional area.
3. Optimize with respect to maximizing the ultimate load. This genetic algorithm based optimization method has been widely used over the last thirty years until today and is accepted by many as an efficient optimization tool However, integrating genetic algorithms and Heyman's plastic method to obtain an optimal design.

Possibly, the earliest recorded test was carried out by Gautier (1717) in France. Half arches of nine wooden voussoirs were constructed between the ground and a vertical surface to determine horizontal thrust due to the self-weight. Danyzy (1778) constructed small plaster voussoirs and tested them to determine the manner in which those arches failed. His works were mainly concentrated on failure modes and minimum pier sizes for arch stability. Lesage (1810) recorded the work done by Boistard in which he constructed 22 model arches and tested to find the abutment thrust exerted by the self-weight of the arch ring. Barlow (1846) demonstrated different possible positions of the thrust line within the arch. Timber voussoirs were used and joints were made up of wooden strips which could be inserted and withdrawn between the voussoirs. By removing the three of the four strips at each joint in different configurations.

Extensive experiments on model arches were carried out by Pippard et al. (1938; 1941; 1951; Pippard A. J., 1936). The first test involved 23 steel voussoirs with span and rise of 3048mm and 762mm respectively giving a span to rise ratio of four. The ring thickness was 254mm and the width was 152mm. The dead load of the fill was represented by hanging equivalent weights at the center of each voussoir. Series of tests were carried out on this model and results were then compared with those obtained from a similarly proportioned solid steel rib. He concluded that the voussoir arch behaved elastically within a limiting load and failed by 4-hinged mechanism. His second test was carried out using mass concrete voussoirs with similar geometries. Non hydraulic lime mortar and rapid hardening Portland cement mortar were used as jointing material. The conclusions drawn from these tests were the arch behaved elastically until formation of the first hinge or crack and it failed in a similar manner by 4-hinged mechanism.

Pippard noticed that after the first hinge occurred, there was a significant amount of reserve strength in the arch before collapse.

The rotation construction method for arch bridges was developed by Chinese engineers in 1977, and includes horizontal rotation, vertical rotation, and a combination method of horizontal and vertical rotations (Zhang, 2002).

Chettoe & Henderson (1957) carried out elastic tests on 13 real bridges in Britain. All bridges tested were in good condition. The maximum applied load was limited to 90 tones so as to prevent any significant damage to those bridges. The load versus deflection measurements obtained were elastic and agreed with the findings of Pippard's work. They concluded that the 45° load dispersal angle was appropriate for assessment purpose. However, Fairfield (1994a) commented that such a conclusion was purely speculative because the dispersal angle was an unknown without any pressure measurements in the fill and extrados.

Sibbald, Fairfield and Bensalem based at Napier University, analyzed the dynamic response of arch bridges using non-destructive testing (Bensalem, Non-Destructive Evaluation Of The Dynamic Response Of A Brickwork Arch, 1997a). A large scale semicircular arch ring was constructed and tested in the laboratory. Experimental results were compared with dynamic finite element analyses and close agreements were achieved both in time and frequency domains. A void defect was introduced in the backfill over the crown and was detected in the change in behavior of the frequency response function. A 3-D finite element model was also generated to study the effect of material stiffness on the dynamic characteristics of arch bridges (Bensalem, 1997b). The results indicated that the introduction of the backfill increased the damping ratios and decreased the resonant frequencies. The work also forms part of the ongoing monitoring of Kimbolton Butts bridge (Ali-Ahmed, 1999).

Both theoretical and experimental works are still being carried out on arch bridges although this type of structure has been studied for more than 300 years. Many classical theories on arch bridges are still in use today such as the theory of thrust line and mechanism of collapse. Classical structural theory such as Castigliano's method is also used to analyze arch bridges. This doesn't mean that the current analytical methods are merely imitations of the old. Many classical theories have been refined or improved due to advances in scientific structural knowledge. The advent of high-speed electronic digital computers has given tremendous impetus to all numerical analyses. Many classical analyses on arch bridges have been computer coded thus enabling such complex structures to be analyzed more easily, more rapidly and more accurate. Experimental works form a major part in arch bridge research. It may be because the complexity of arch behavior such as the influence of soil-structure interaction cannot be explained or quantified theoretically and realistically. It is believed that proper understanding of soil-structure interaction is vital in order to solve the mystery of arch bridges. It is quite unfortunate that most of the full scale arch bridge tests carried out by Davey and Page did not consider soil pressure measurements Full scale tests provide valuable information if properly monitored. The chance to have full scale tests these days is slender due to financial and environmental reasons as well as the lack of availability of abandoned arch bridges.

Most of the currently available arch bridge assessment methods are idealized representations of reality. Many unrealistic or subjective assumptions have to be made in order to make the analysis easier or indeed even possible. In the mechanism and although arch bridges have been subjected to scientific research for 300 hundred years, the scope for further research is wide

MATERIALS AND METHODS

The traditional building materials for bridges are stones, timber and steel, and more recently reinforced and pre-stressed concrete. For special elements aluminum and its alloys and some types of plastics are used. These materials have different qualities of strength, workability, durability and resistance against corrosion. They differ also in their structure d, texture and color or in the possibilities of surface treatment with iffering texture and color. For bridges one should use that material which results in the preferable bridge regarding shape, technical quality, economics and compatibility with the environment. The panels are mounted on bridges, which in turn carry the main components that are based on columns, beams, etc., and sidewalks, railing and other accessories in the bridge.

When planning structures, for example, spans, builds cautiously pick the materials by foreseeing the powers the materials (the structural components) flexible materials, for example, steel, aluminum and different metals are utilized for segments that experience elastic burdens. Weak materials, for example, solid, earthenware production and glass are utilized for segments that experience compressive burdens. This material was utilized until the eighteenth and nineteenth hundreds of years. The principal individuals who advance the development of the extensions were the Romans.

When humans became skilled at creating iron (hence the "Iron Age"), a new material became available for bridge building. However, iron is a brittle material and can break suddenly without warning. So, people tinkered with it to invent a more refined iron, called steel. Steel is a useful bridge material because of its high strength in both compression and tension. Steel is also a ductile material, meaning that it can be bent or shaped easily into different forms. Steel sounds like the perfect material, but, steel is also expensive.

Concrete is another vital material. In 1824, an English stone artisan named Joseph Aspdin delivered cement in his Research Laboratory. This first type of cement was composed of a heated mixture of finely ground limestone and clay that was further ground into a powder. When this powder was mixed with water, it hardened. With this invention, Aspdin laid the foundation for today's cement industry.

1.5.General history of ancient arch bridges

Masonry arches have been used for bridges for several thousand years. Surprisingly, some of these ancient arches still stand although scientific structural knowledge was not available at that time. This is because this form of structure is more honest to its material and function. It is also an unforgiving form because its profile must be accurate to be suitable for the imposed loads. Arches have been a popular structural profile in China up to 5000 years ago. Even today, the Chinese still treat arches as the most desirable form of structure from aesthetical and engineering standpoints. The most precise masonry arch bridge still in use today is the Zhou Bridge (see Figure 3.1). In China with the span of 37.02 m built in the Sui Dynasty nearly 1400 years ago. This bridge has a span to rise ratio of 5.25 and 1.03m ring thickness. Qian (1987) investigated this bridge using the mechanism method. He revealed that this ancient bridge was very similar to a modem bridge in its appearance and he proved by calculation that the design was in good accord with modem bridge building thinking. Qian's mechanism analysis showed that for an imposed line load of 80kNm' located at the 1/4-span point, the bridge is safe with a geometrical factor of safety of 3.7.

Pont du Aqueduct Gard Bridge from the spectacular Roman constructions in Nimes, and the 2,000-year, a UNESCO World Heritage Site., based on the engineering relations the concepts of the engineering bases of the forces that will be contained within the dimensions (Murad, 2015)(see Figure 3.2).

Figure 3.1 Zhau Thou bridge in China: 1400 years old

Figure 3.2 Pont du Aqueduct Gard Bridge

After the Romans era, there were no major developments in bridges or arch construction, until the 10th century. The temples through that period was start to take the movement in constructing bridges and roads and continue to use stone until the 14th century. Ponte Vecchio Bridge (Fig. 3.3) appears in Florence.

Figure 3.3 Ponte Vecchio Bridge

During the Renaissance, the first scientific novelties appeared and begin to constructed bridges with arches widely, in the sixteenth and seventeenth centuries, the form of arches and slender pillars and larger spans started spread too. Examples are the Rialto Bridge in Venice, the Ponte Santa Trinita in Florence and the Ponte Royale in Paris, all of which are in elliptical arches (Murad, 2015).The techniques for the construction of stone arches evolved in the 18th century, which considers as a century full of more structured and scientific knowledge, at that period of time popped up the first school of civil engineering in France (Murad, 2015). Later, with the industrial revolution, the construction with iron (1779) began, the first Bridge was an arch bridge –Coalbrookdale Bridge. The arch bridges had a bad effect due to vibrations caused by steam locomotives (Murad, 2015). As in the (Figure 3.4).

Figure 3.4 Coalbrookdale Iron bridge

Then the bridges were constructed of steel, which was initially extremely expensive and as such was only used for tools or weapons. In the middle of the 19th century, a process is developed to produce steel and this has become competitive. The first important steel bridges constructed in the U.S.A. in 1874 - the St Louis Bridge (Figure 3.5). His 1775 design proposed a single arch, avoiding the need to build piers in the river, and that causing no obstacle to boats. First bridge built of iron is in Shropshire England. The Iron Bridge was constructed in 1779 by Abraham Darby. (UNESCO, 2012) The five ribs for the bridge were cast in two pieces and joined together at the top – construction of the arch took only three months.

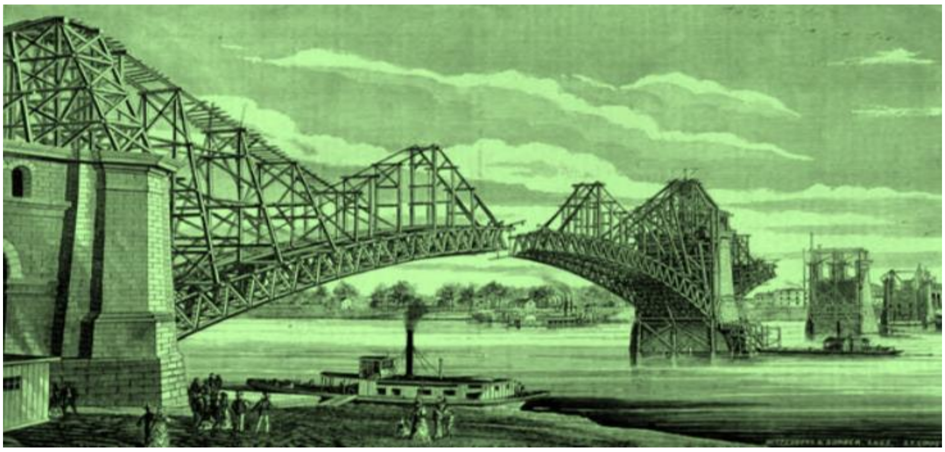


Figure 3.5 Ponte James Eads St. Louis Bridge

At the beginning of the 20th century, amongst bridge materials, concrete has the highest strength qualities, and it is therefore suitable for the arch bridges. It was a scarce and valuable material, with the end of World War II and the construction of infrastructures, was there are many bridges reinforced concrete, it gave the ductility to the structures. The first to design reinforced concrete bridges were the Swiss engineer Robert Maillart, one of his best-known examples being the bridge Salginatobel (Figure 3.6) in 1930.

Figure 3.6 Ponte Salginatobel Bridge

Nowadays, arch bridges are quite sophisticated, modern materials, icons in cities, where the aesthetic function plays a relevant role, especially in the pedestrian bridges in urban centres Common the presence of an architect in the team of project. New materials have been used in this line. For example, aluminium where was used for the first time (Murad, 2015). This material presented as light and durability materials. As an example of an innovative pedestrian bridge, the purpose of which is not just to cross the river, but also to mark and beautify the urban space, is presented in Figure 3.7.

Figure 3.7 Gateshead Millennium Bridge

This bridge, in Newcastle, consists of a pair of arches, which can be moved to open the way to the boats to pass through it. In this process, the two arches are inclined as a single rigid structure.

Timber is becoming an increasingly more popular material due to its good strength to weight ratio, is a relatively cheap and renewable material. Timber has mainly been used in smaller buildings, houses, and pedestrian bridges. However, increasing knowledge of manufacturing techniques for glue-laminated timber (glulam) has made possible to use timber in several bigger timber constructions, such as multistory buildings and bridges for the road.

The wooden bridges used for construction soft timber and hard timber. The second type is preferred because it is more hardened and less prone to permanent formations under the influence of fixed loads. The wood is used against moisture and insects, especially termites, taking into account the work of periodic detection and maintenance of this type of bridges, which are usually bridges for pedestrians, as shown in Figure 3.8.

Figure 3.8 The wooden bridge in Sneek, Holland

1.6.Methods

In this part of the thesis, the details of the arch bridge structure systems, the effect of different design effects (support conditions, number of hinges, max. height (f) and bridge span) on the bridge and the analysis stages of the arch bridge systems on SAP 2000 are explained in detail.

3.2.1. Structural system of an arch bridge

In simple terms, an arch bridge is associated with 7 different parameters. These parameters can be listed such as support conditions,number of hinges, max. height, bridge span, bridge width, bridge thickness and loads on the bridge (Figure 3.9).

Figure 3.9 2D and 3D drawings by SAP2000 of an sample arch bridge.

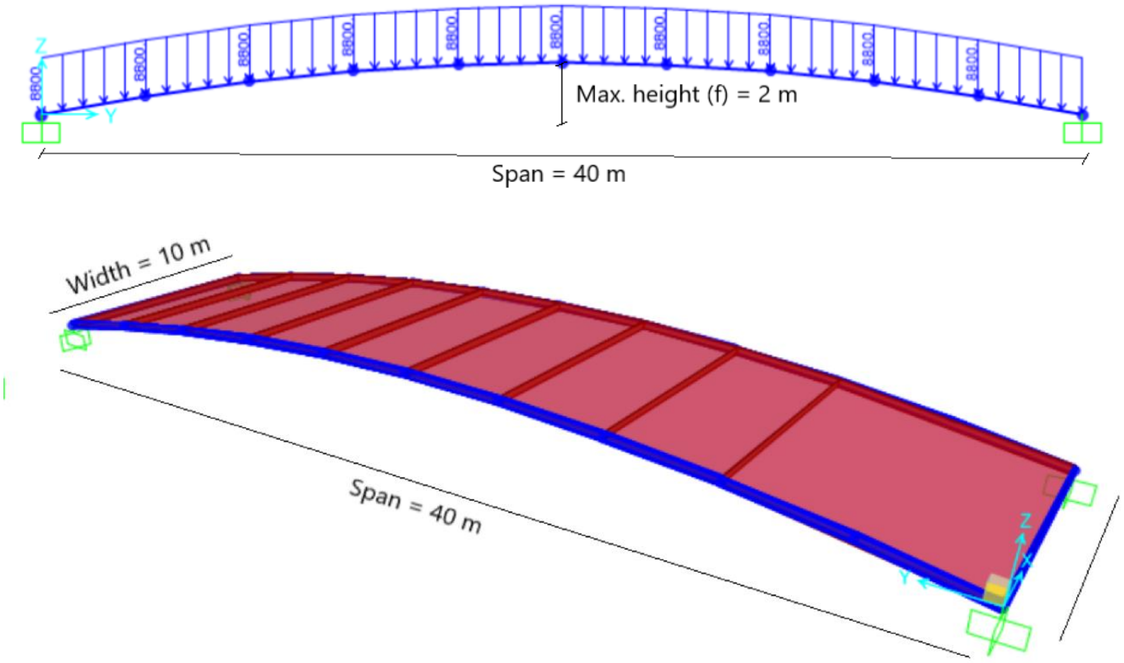
This study is aimed to make inferences about bridge internal forces (axial and shear force, bending moment, section rotation) and bridge movement (displacements, periods) by making changes in parameters affecting arch bridge behavior.

The parameter effects examined in the study can be listed as follows.

1- Support conditions and number of hinges

2- Change in maximum height

3- Change in bridge span



4- Sensitivity measurement

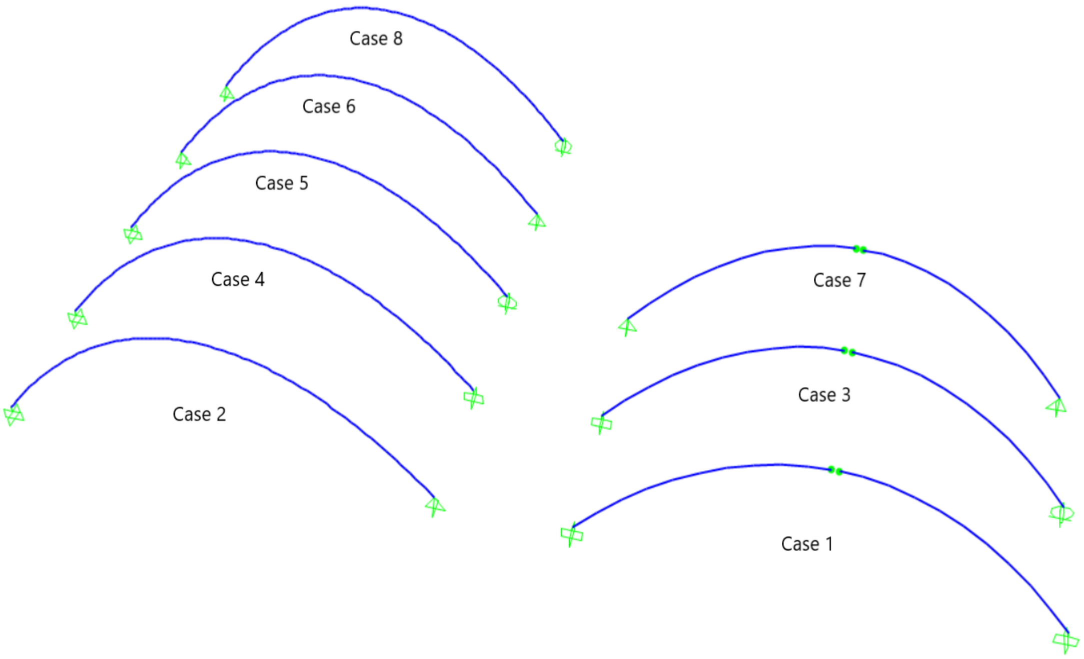
3.2.1.1. Support conditions and number of hinges

One of the most important factors for structural systems is support conditions. The selected support conditions should make the system stable and should create the smallest internal forces for the system. Therefore, it is very important to see the effects of support conditions on the system. In this study, 8 different support conditions which can be formed on arch bridge are examined.

Table 3.1 Supports and hinges conditions on arch bridge

Case	**Abbreviation**	**Explanation**
1	F.F-1H	Fixed support - Fixed support In case of existence (hinge).
2	F.P-1H	Fixed support-Pinned support In case of existence (without hinge).
3	F.V-1H	Fixed support - Vertical support In case of existence (hinge).
4	F.F-NH	Fixed support - Fixed support In case of existence (without hinge).
5	F.V-NH	Fixed support-Vertical support In case of existence (without hinge).
6	P.P-2H	Pinned support - Pinned support In case of existence (without hinge).
7	P.P-3H	Pinned support -Pinned support In case of existence (hinge).
8	P.V-1H	Pinned support-Vertical support In case of existence (without hinge).

Figure 3.10 Representation of different support conditions and hinges on SAP2000



3.2.1.2. Change in maximum height

Another important parameter is the maximum height of the bridge. It is known that as the height of the arch bridge increases, the amount of displacements occurring on the bridge decreases. Already this situation has led to the emergence and use of arch bridges. It is known that as the height of the arch bridge increases, the amount of displacements occurring on the bridge decreases. Already this situation has led to the emergence and use of arch bridges. In this study, 11 max. height which can be formed on arch bridge are examined.

Table 3.2 Max. height values on arch bridge (f)

Case	Max. Height (m)
1	f = 0
2	f =1
3	f =2
4	f =3
5	f =4
8	f =7
9	f =8
10	f =9
11	f =10

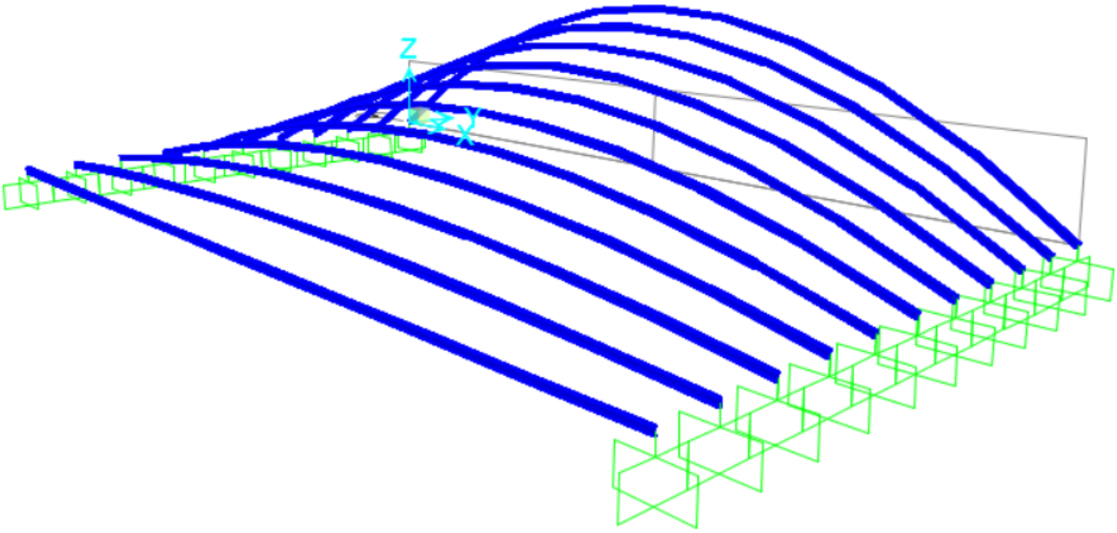


Figure 3.11 Representation of different maximum height (f) on SAP2000 (from 0 to 10)

3.2.1.3. Change in bridge span

Increased bridge span leads to an increase in the displacement of the bridge. Therefore, the selection of the appropriate bridge span is as important as possible. In this study, 10 different bridge spans were selected and the most suitable span for the bridge was determined.

Table 3.3 Changed span values on arch bridge (L)

Case	Span (m)
1	L = 10
2	L = 20
3	L = 30
4	L = 40
5	L = 50
6	L = 60
7	L = 70
8	L = 80
9	L = 90
10	L = 100

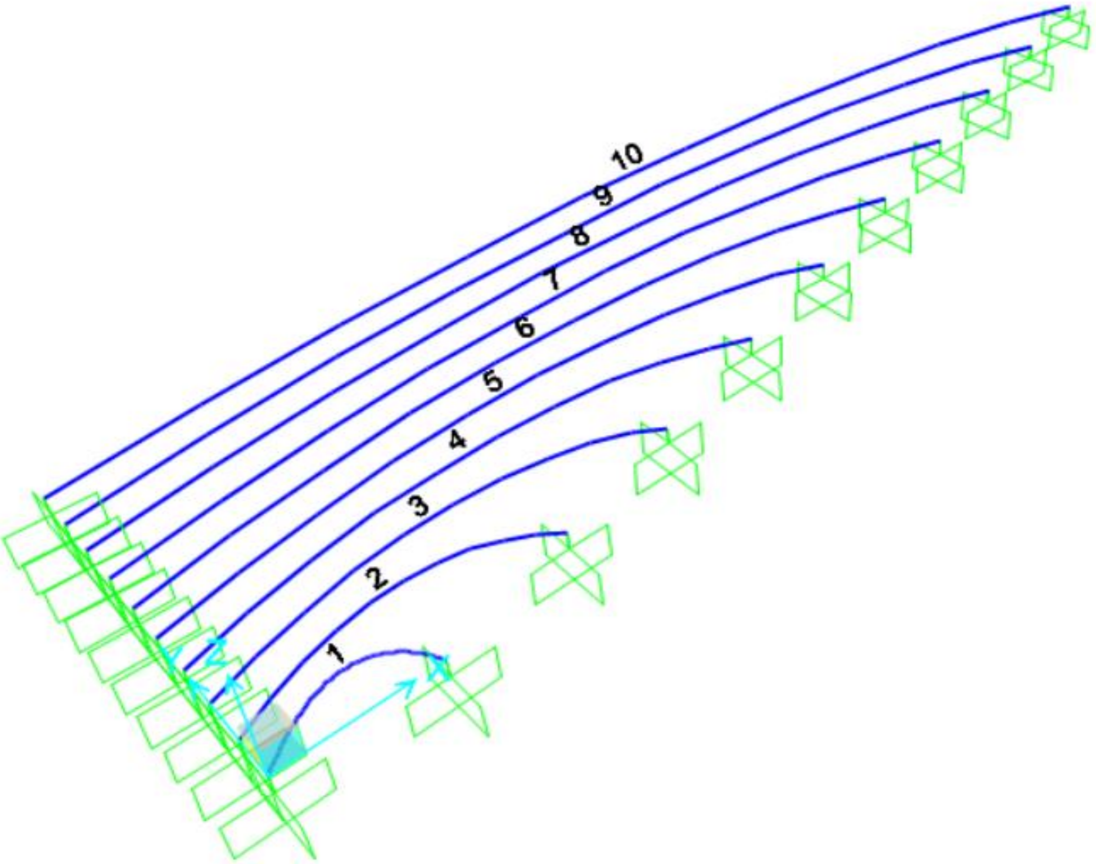


Figure 3.12 Representation of different arch spans (L) on SAP2000 (from 10 to 100)

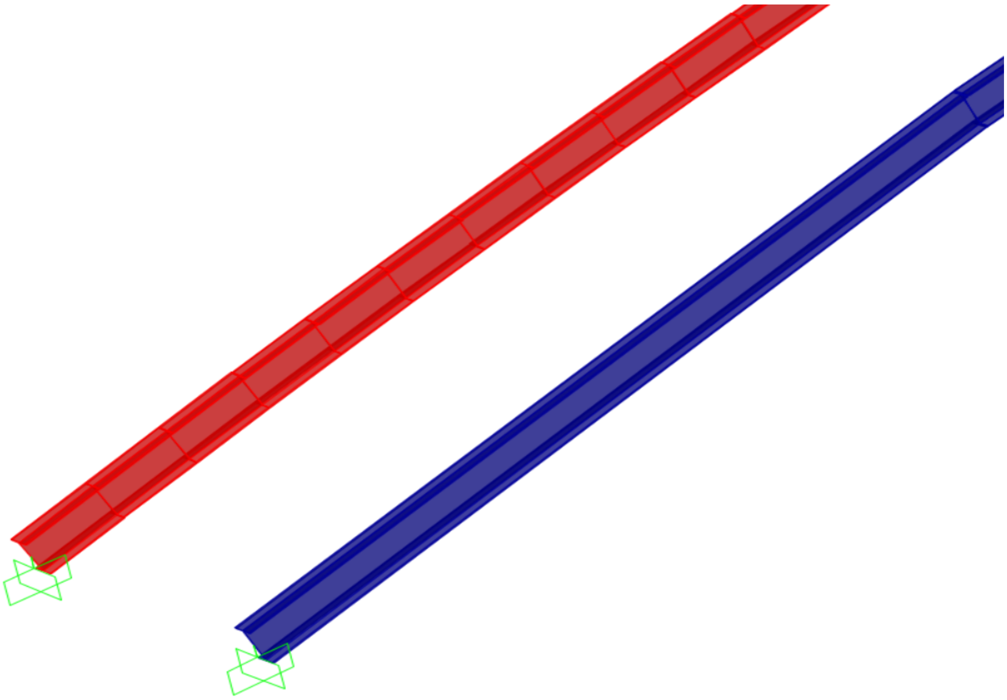
3.2.1.4. Sensitivity measurement

Since bridges are large span structures, it is not correct to solve them in one piece on analysis programs. To make the results of the bridge analysis more accurate, the bridges are drawn in pieces and analyzed. The higher the number of pieces divided, the higher the accuracy and the accuracy of the results. At the same time, increasing the number of parts increases the workload. Therefore, it is very important to find the optimal number of parts for bridges. In this study, two different cases were examined in terms of sensitivity.

Table 3.4 Number of pieces divided

Case	Number of pieces (m)
1	10
2	100

Figure 3.13 Representation of different division states of the same bridge piece (Red ones
100 pieces, blue ones 10 pieces)



In this study, In this study, 8 different support and hinge conditions, 10 different bridge span status, 11 different arch bridge max. height condition and 2 different sensitivity conditions (10 pieces and 100 pieces), totally 31 different arch bridge types were examined. All different arch bridge types were drawn, analyzed and internal forces of bridges calculated using SAP2000 program (Structure Analysis Program).

Data obtained as a result of analysis;

1- Displacement values and shapes

2- Rotation values

3- Internal force values (Axial, Shear and Moment)

A total of 1760 drawings were made to obtain all these values. By using these drawings, it was aimed to see the effect of bearing conditions, number of joints, maximum height value, bridge clearance distance and sensitivity on arch bridges. At the same time, the effect of these parameters was applied to bridges both alone and in combination with other parameters. Thus, the results of the combined effects were observed.

4. RESULTS

In this study, the effect of support conditions, number of hinges, maximum height, bridge span distance and sensitivity on arch bridges were investigated. In order to examine the effects of these parameters correctly, the parameters were applied to the bridges individually and in combination. A total of 1760 drawings and analyzes were performed to observe the most accurate results. As a result of these analyzes, displacement shapes of the arch bridges, maximum displacement values, the amount of rotation of the bridge sections, axial force formed within the bridge due to external forces, shear force and moment values were obtained.

The values obtained were collected under different headings according to each parameter type. The shapes and values of the analysis outputs obtained in this section of the study are shown.

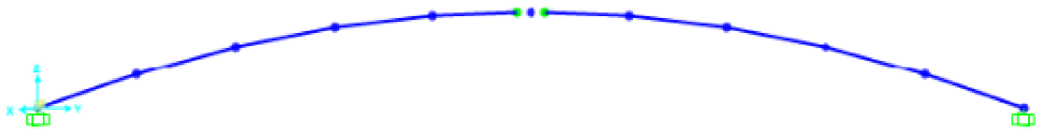
4.1. Effect of Type of Support Conditions And Number of Hinges on Arch Bridge

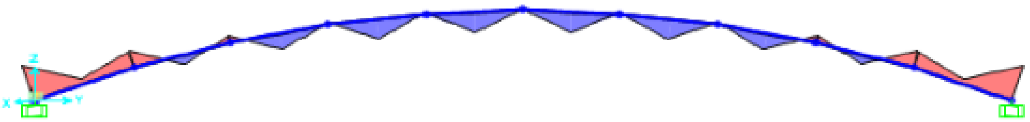
The support condition and the number of hinges are quite different but related parameters. Therefore, it was examined under the same title. These two parameters are the most important parameter for arch bridges. Depending on the changing support conditions and the number of hinges, the internal forces to be formed on the bridge vary considerably. The main purpose of arch bridge construction is to reduce the amount of displacement. That is, arch bridges make less vertical displacement under the same loads compared to flat bridges.

The main purpose of arch bridges design is to reduce the possible internal forces as much as possible. Therefore, the most suitable support conditions for the bridge should be determined. In order to find the optimum support and articulation conditions for arch bridges under static loads, 8 different cases were examined (Table 3.1).

4.1.1. **Case 1: Fixed support - Fixed support In case of existence (hinge)**

The most common arch bridge supported today is the condition. In this case, both ends of the bridge are fixed. Thus, the horizontal and vertical displacement movement of the bridge and rotation are prevented. Being prevented from moving in many ways causes a significant amount of internal forces to form inside the bridge.





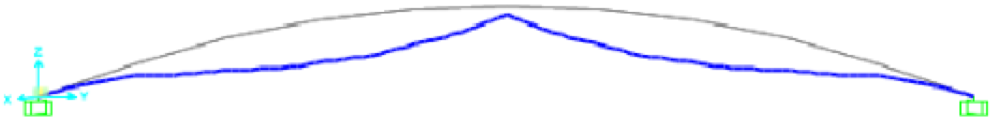


Figure 4.1 Case 1 drawing on SAP2000 and internal force outputs

The shape of the arch bridge (top), the graphical representation of the bending moment values (middle) and the shape of displacement (bottom) are shown in Figure 4.1. As you can see, the displacement is quite low in the middle of the arch bridge. This is expected and shows the main reason for arch bridge construction. It is also obvious that there is no moment in the hinge in the middle of the bridge.

4.1.2. **Case 2: Fixed support-Pinned support in case of existence (without hinge)**

In this case, one of the support is allowed to rotate. Thus, while the bending moment to be formed in the bridge decreases, rotation in the pinned bearing section will occur. At the same time, since there is no hinge in the middle of the arch bridge, bending moment will occur.

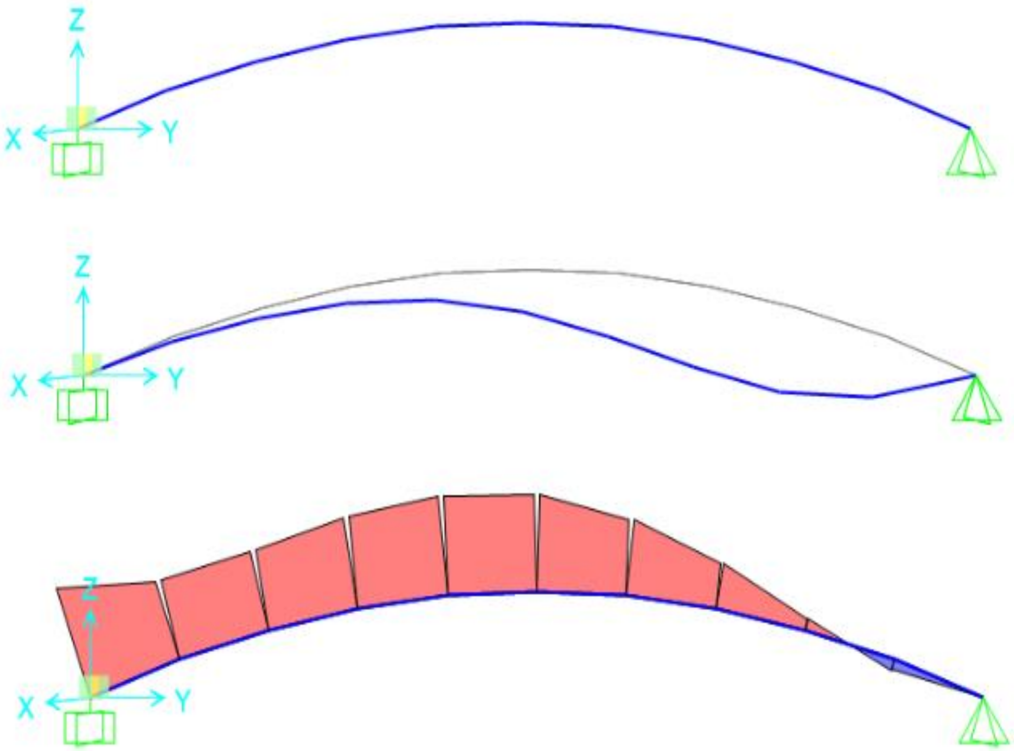


Figure 4.2 Case 2 drawing on SAP2000 and internal force outputs

The glazing of the figures is the same as in case 1. As can be seen clearly from the figure, while fixed support section has a low displacement value with serious bending moment, very small bending moment values and large displacement values have been formed in the pinned support section. In these cases, the support requirement depends on the designer. The most appropriate support conditions are determined by considering the limit conditions given in the regulations.

4.1.3. **Case 3: Fixed support - Vertical support in case of existence (hinge)**

This is a very special and rarely used support condition. Because in this case the arch bridge is able to move horizontally. This reduces the internal forces by releasing the energy of the loads coming to the bridge. This highly sensitive system needs to be designed very carefully and in accordance with regulatory requirements.

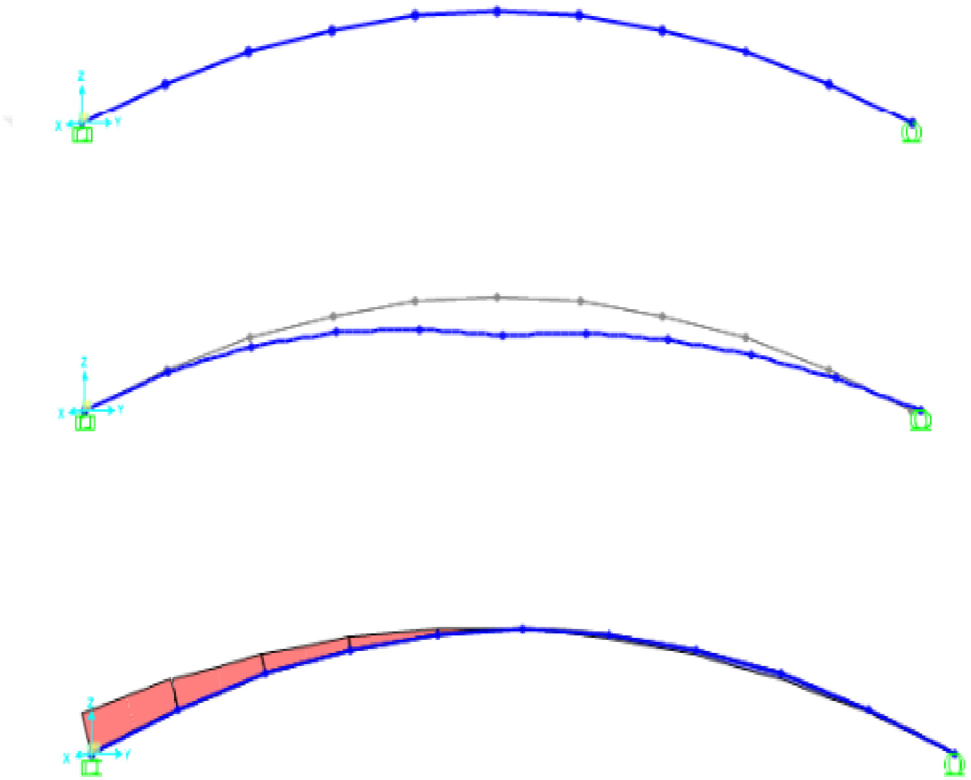


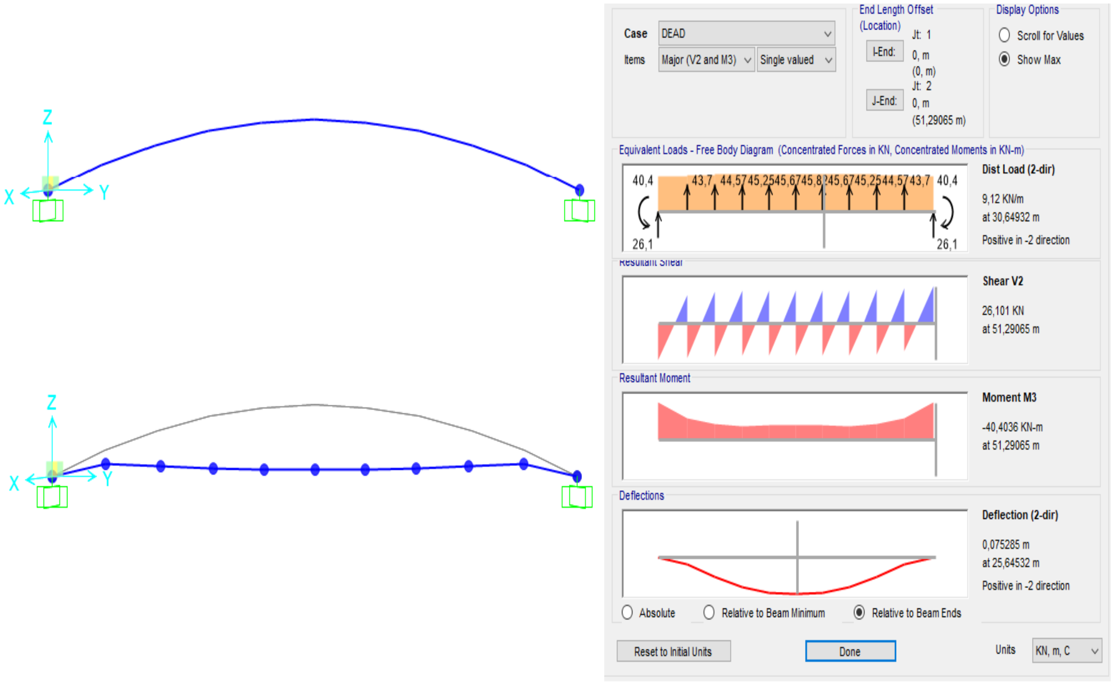
Figure 4.3 Case 3 drawing on SAP2000 and internal force outputs

As seen in the figure, the bending moment values are quite low. It is seen that the bending moment value is 0 in the joint in the middle of the arch bridge. At the same time, the bridge made 18 mm horizontal displacement.

The horizontal, vertical and rotational displacement plots of all support conditions are shown in chapter 5.

4.1.4. **Case 4: Fixed support - Fixed support in case of existence (without hinge)**

This is similar to case 1. The only difference is that in case 1 there is a hinge in the middle of the arch bridge, in this case there is no hinge. This means the formation of moment and the force of the section in the middle of the arch bridge which is a very critical point.



Case: DEAD
Items: Major (V2 and M3) | Single valued

End Length Offset (Location)
I-End: Jt: 1 0, m (0, m)
J-End: Jt: 2 0, m (51,29065 m)

Display Options
○ Scroll for Values
● Show Max

Dist Load (2-dir)
9,12 KN/m
at 30,64932 m
Positive in -2 direction

Shear V2
26,101 KN
at 51,29065 m

Moment M3
-40,4036 KN-m
at 51,29065 m

Deflection (2-dir)
0,075285 m
at 25,64532 m
Positive in -2 direction

○ Absolute ○ Relative to Beam Minimum ● Relative to Beam Ends

Units: KN, m, C

Figure 4.4 Case 4 drawing on SAP2000 and internal force outputs

In Figure 4.4., fixed-fixed supported and non-hinge arch bridge drawing, displacement shape and internal forces are shown (Shear force, torque and rotation amounts). As can be seen, there is a significant difference between the displacement drawings of hinge and non-hinge in fixed-fixed supported bridges. There is also a serious displacement in the middle of the non-hinge bridges. As in displacement, a significant increase in bending moment values is observed.

4.1.5. **Case 5: Fixed support-Vertical support in case of existence (without hinge)**

This is similar to case 3. The only difference is that in case 3 there is a hinge in the middle of the arch bridge, in this case there is no hinge. This means the formation of moment and the force of the section in the middle of the arch bridge which is a very critical point.

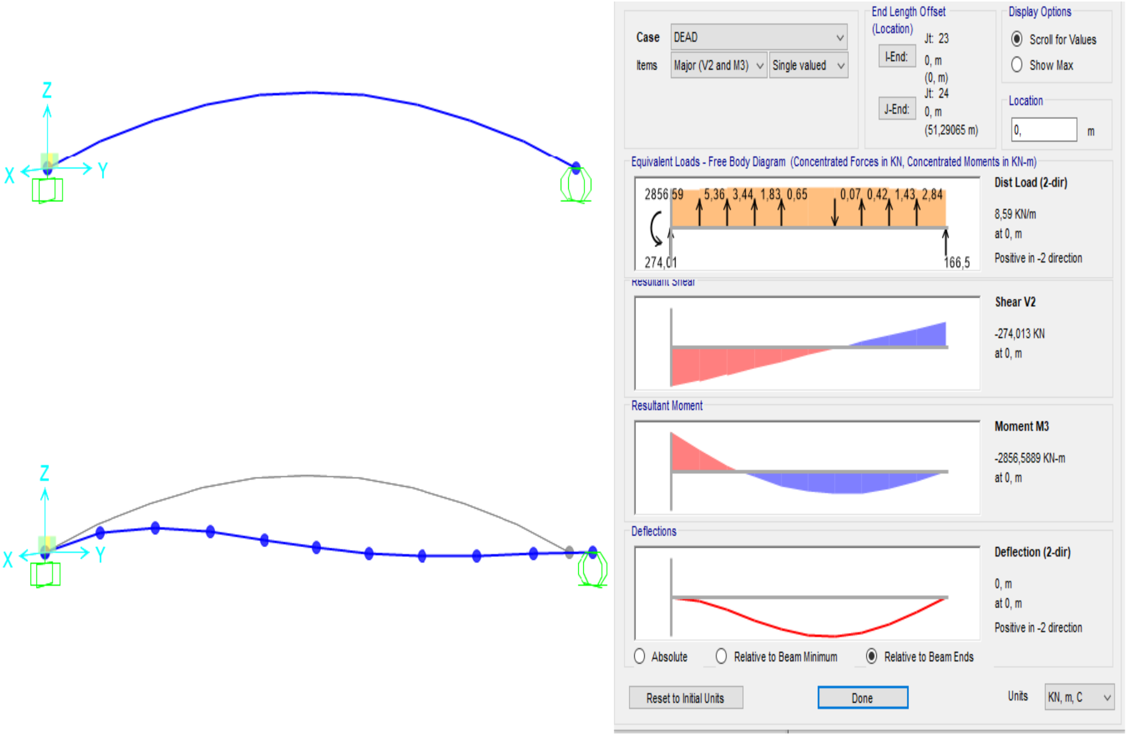
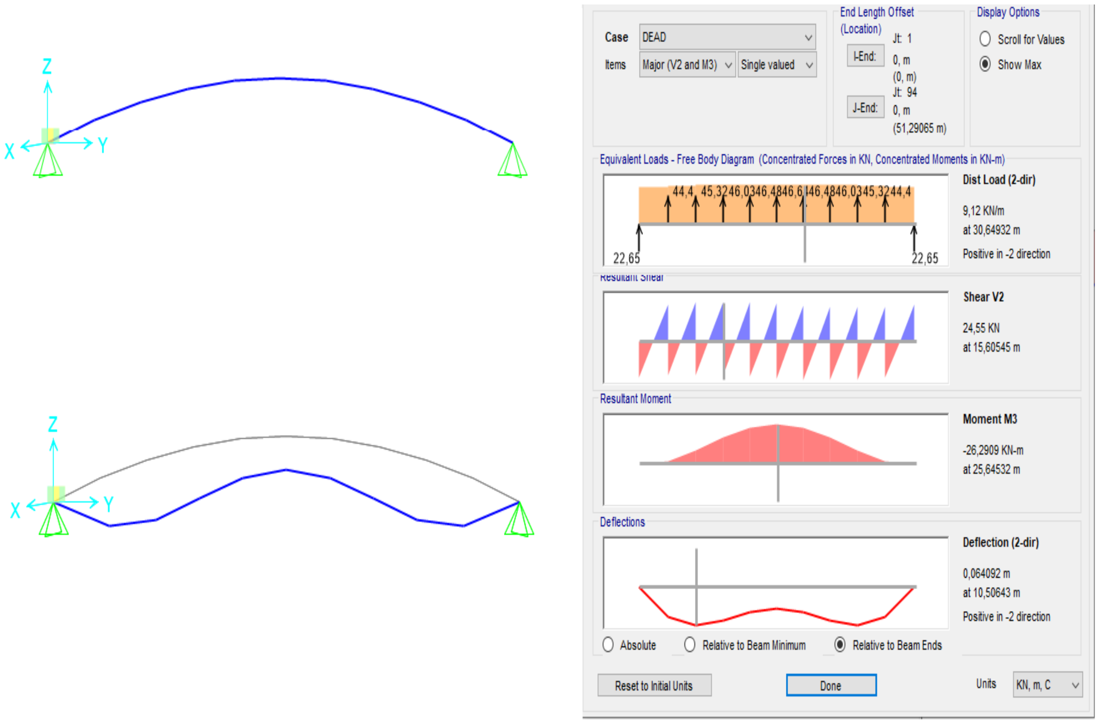

Case: DEAD
Items: Major (V2 and M3), Single valued
End Length Offset (Location)
I-End: Jt: 23, 0, m (0, m)
J-End: Jt: 24, 0, m (51,29065 m)
Display Options: ● Scroll for Values ○ Show Max
Location: 0, m
Equivalent Loads - Free Body Diagram (Concentrated Forces in KN, Concentrated Moments in KN-m)
Dist Load (2-dir): 8,59 KN/m at 0, m, Positive in -2 direction
Shear V2: -274,013 KN at 0, m
Moment M3: -2856,5889 KN-m at 0, m
Deflection (2-dir): 0, m at 0, m, Positive in -2 direction
○ Absolute ○ Relative to Beam Minimum ● Relative to Beam Ends
Units: KN, m, C

Figure 4.5 Case 5 drawing on SAP2000 and internal force outputs

As shown in the figure, the displacement low bending moment values are high in the fixed supported section while the displacement low bending moments are high in the vertical supported section. At the same time, it is clearly seen that the bridge moves horizontally. When compared with Case 3, the displacement values increased significantly.

4.1.6. **Case 6: Pinned support - Pinned support in case of existence (without hinge)**

In this case, the arch bridge was supported as pinned on both sides. This means that rotation will occur at both ends of the bridge, which in turn means less bending moments. The fact that there is no hinge in the middle of the belt bridge has also caused serious vertical displacements.



Case: DEAD
Items: Major (V2 and M3) | Single valued

End Length Offset (Location)
I-End: Jt: 1 0, m (0, m)
J-End: Jt: 94 0, m (51,29065 m)

Display Options
○ Scroll for Values
● Show Max

Dist Load (2-dir)
9,12 KN/m
at 30,64932 m
Positive in -2 direction

Shear V2
24,55 KN
at 15,60545 m

Moment M3
-26,2909 KN-m
at 25,64532 m

Deflection (2-dir)
0,064092 m
at 10,50643 m
Positive in -2 direction

○ Absolute ○ Relative to Beam Minimum ● Relative to Beam Ends

Units: KN, m, C

Figure 4.6 Case 6 drawing on SAP2000 and internal force outputs

As shown in Figure 6, the maximum bending moment is formed in the middle of the bridge. This situation is quite expected. Because there is no hinge in the middle of the bridge. It is also seen that the displacement is high at low bending moments and the displacement is low at high bending moments.

4.1.7. **Case 7: Pinned support -Pinned support in case of existence (hinge)**

This is similar to case 6. The only difference is that in case 6 there is a hinge in the middle of the arch bridge, in this case there is no hinge. This means the formation of moment and the force of the section in the middle of the arch bridge which is a very critical point.

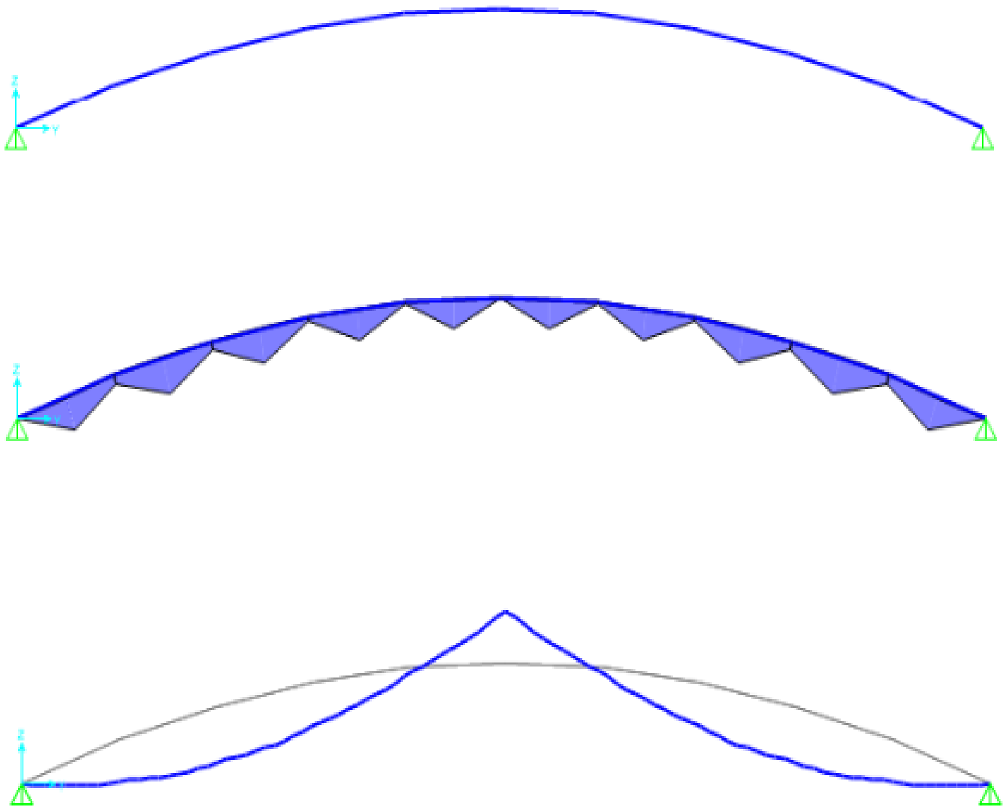
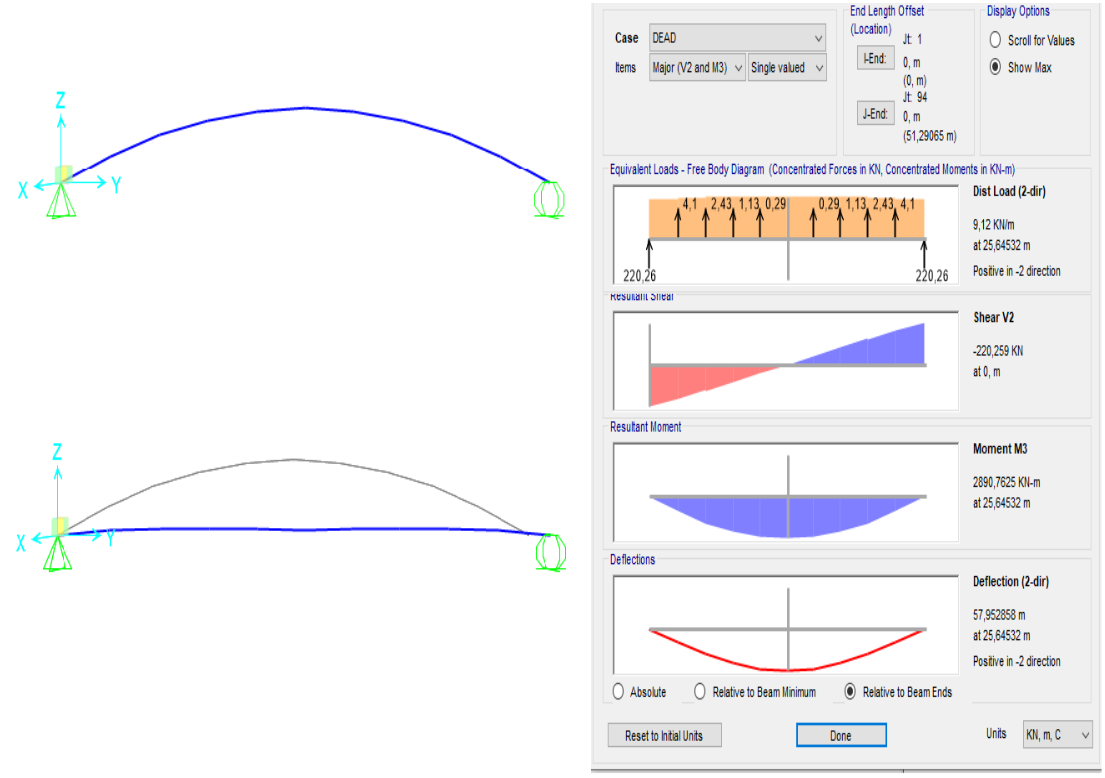


Figure 4.7 Case 7 drawing on SAP2000 and internal force outputs

As it can be seen in Figure 4.7, the arch has no displacement in the middle of the bridge but the bridge has moved upwards. This clearly hinges the effect of the joint on the arch bridge. As in the case of support with other hinges, there is no articulation in the middle of the bridge.

4.1.8. **Case 8: Pinned support-Vertical support in case of existence (without hinge)**

This is the most critical situation. Because, in this case, with the formation of the lowest internal forces, a very high amount of horizontal displacements and rotation values occur. Allows rotation at both ends of the system. Böyle bir sistemde mafsal olamaz. Çünkü mafsal olduğu takdirde sistem oynak olur ve taşıyıcılığını kaybeder.



Case: DEAD

Items: Major (V2 and M3) | Single valued

I-End: Jt: 1 — 0, m (0, m)

J-End: Jt: 94 — 0, m (51,29065 m)

○ Scroll for Values
● Show Max

Dist Load (2-dir)
9,12 KN/m
at 25,64532 m
Positive in -2 direction

Shear V2
-220,259 KN
at 0, m

Moment M3
2890,7625 KN-m
at 25,64532 m

Deflection (2-dir)
57,952858 m
at 25,64532 m
Positive in -2 direction

○ Absolute ○ Relative to Beam Minimum ● Relative to Beam Ends

Units: KN, m, C

Figure 4.8 Case 8 drawing on SAP2000 and internal force outputs

As shown in the figure, major displacements have occurred throughout the system. In such a system, it is clearly seen that the bending moment value is at most in the middle of the bridge.

4.2. Effect of Change in Maximum Height on Arch Bridge

One of the most important parameters of arch bridges is the maximum height (f) value. This value is the basic working principle of arch bridges. It is very important and useful to build an arch bridge instead of a straight bridge. Because of this, the displacements in the bridges are reduced significantly.

As the maximum height of the bridges increases, the displacements decrease. In addition, shear and axial force values are reduced in bending moments.

Table 4.1 Change in displacement and internal forces according to changing f values

	Max. Bending Moments (kNm)	Max. Shear Forces (kN)	Max. Displacement (cm)	Max. Axial Forces (kN)
f=0	-43.766	6,565	-16,7	0
f=5	-1.033	0.777	-0.106	-14,909
f=10	-1.57	0.909	0.0004	-10.246

The effect of the maximum height value is clearly seen in table 4.1. In order to see this effect formally, the following graph should be examined.

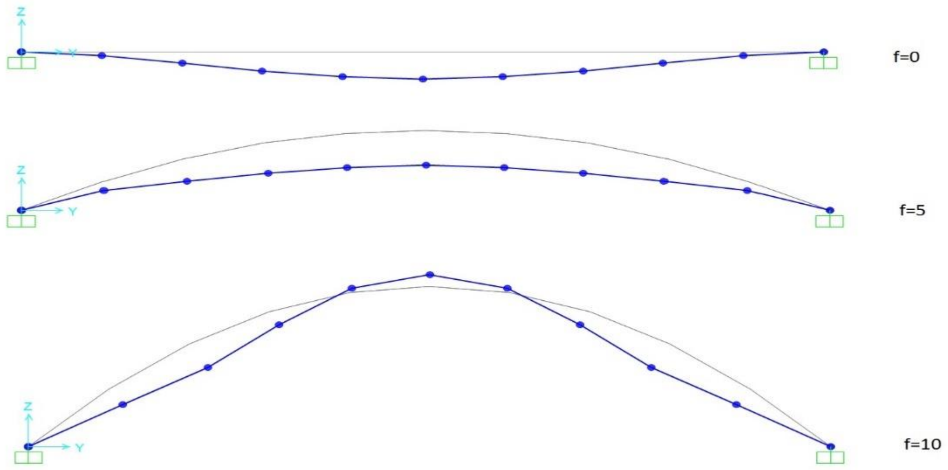


Figure 4.9 Formal appearance of the change in the displacements of the changing f values

4.3. Effect of Change in bridge span on Arch Bridge

Another important parameter in the belt dogs is the bridge opening. Increasing the bridge clearance will increase the static loads on the bridge. The increase in static loads will significantly increase the displacement values, internal forces and rotation values on the bridge.

Table 4.2 Change in displacement and internal forces according to changing L values

	Max. Bending Moments (kNm)	Max. Shear Forces (kN)	Max. Displacement (cm)	Max. Axial Forces (kN)
L=10	-1.384	2.547	0.039	-51.69
L=50	-404.036	26.101	7.528	-618.622
L=100	-136.58	49.47	123.553	-2318.449

As the bridge clearance increases, the increase in displacement and internal forces is clearly seen. The greatest displacements always occur in the middle of the bridges. This is quite normal.

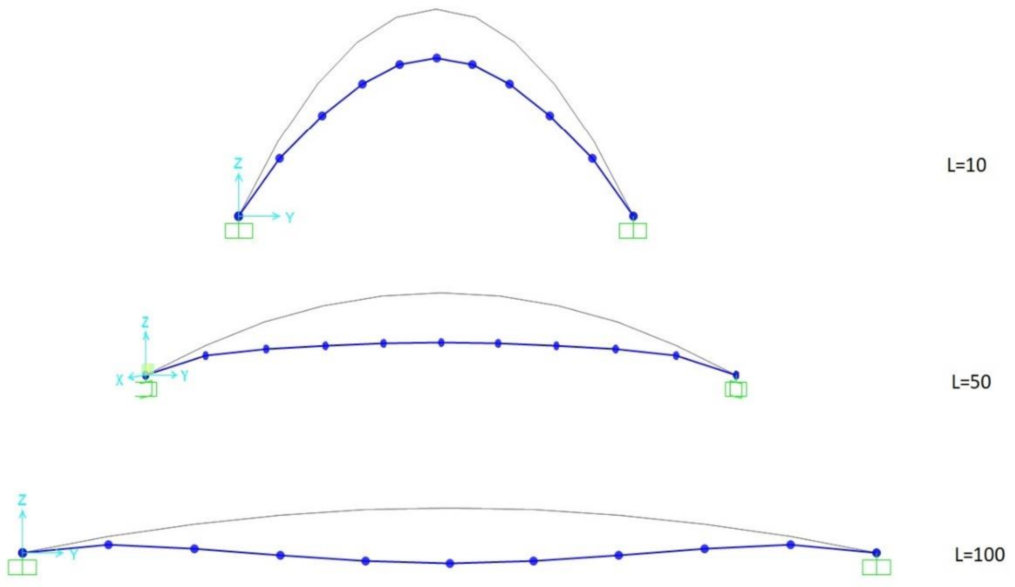


Figure 4.10 Formal appearance of the change in the displacements of the changing L values

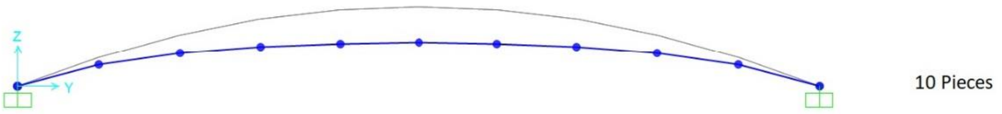
4.4. Effect of Sensitivity measurement on Arch Bridge

Arch bridges can have fairly long span values. Therefore, it is not possible to construct such structures in one piece. This causes bridges to be built in pieces. The higher the number of parts that make up the bridge in the bridge design, the more accurate the results. However, the large number of parts will increase the processing load. It is therefore important to find the optimal number of parts.

Table 4.3 Change in displacement and internal forces according to changing sensitivity

	Max. Bending Moments (kNm)	Max. Shear Forces (kN)	Max. Displacement (cm)	Max. Axial Forces (kN)
10 pieces	-1.033	0.777	0.1081	-14.909
100 pieces	0.593	0.233	0.1075	-14.924

The values shown in the figure belong to the bridge which has a bridge span of 40 meters with pinned-pinned support conditions and a maximum height of 5 meters. Although it has the same bridging characteristics as the values shown, values change as the number of pieces increases. This shows the importance of sensitivity.



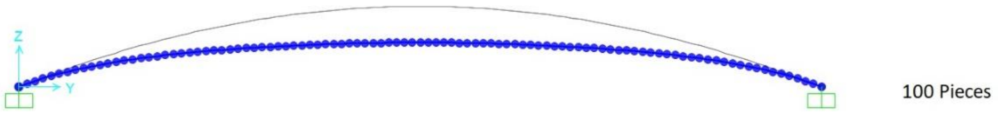


Figure 4.11 Formal appearance of the change in the displacements of the changing sensitivity measurement

Drawings and analyzes were made for all different situations. Table and graphical results of these results are shown. And each of these four influences was found to be very important for the bridges. Using the results obtained, the effects of these parameters on arch bridges were examined in more detail by making comparisons (Chapter 5).

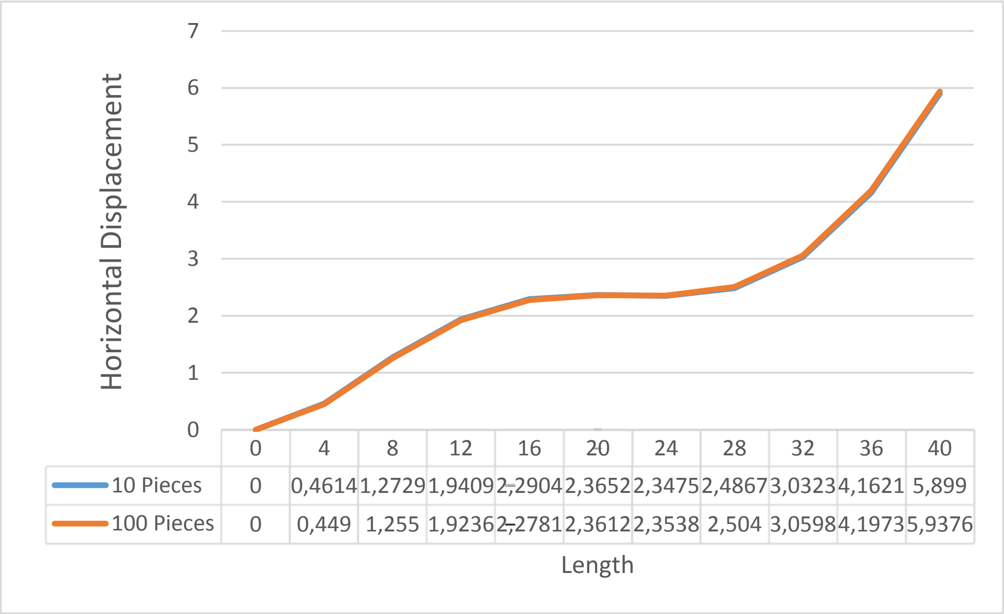
5. DISCUSSION

Some conclusions will be made using the results obtained in this section. For this, the following 5 basic questions were asked.

1. What is the effect of the change in bridge span (L) on the arch bridge?
2. What is the effect of the change in maximum height (f) on the arch bridge?
3. What is the effect of the change in support conditions on the arch bridge?
4. What is the effect of the change in degree of sensitivity on the arch bridge?

In this section, comparative graphs are given to the above questions and answers are given.

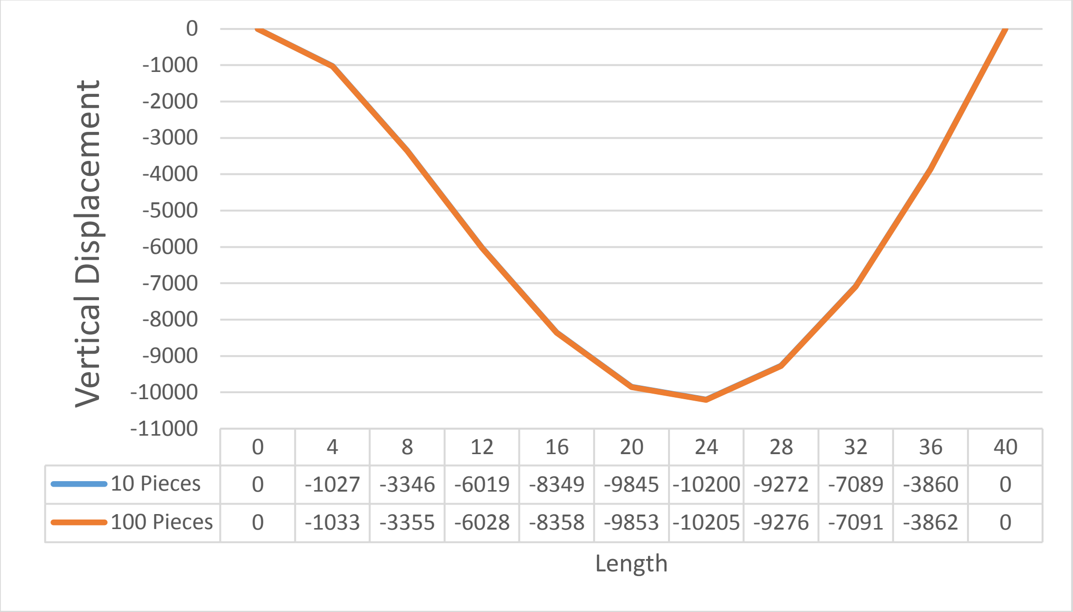
Arch bridges can have fairly long span values. Therefore, it is not possible to construct such structures in one piece. This causes bridges to be built in pieces. The higher the number of parts that make up the bridge in the bridge design, the more accurate the results. However, the large number of parts will increase the processing load. It is therefore important to find the optimal number of parts.



	0	4	8	12	16	20	24	28	32	36	40
10 Pieces	0	0,4614	1,2729	1,9409	2,2904	2,3652	2,3475	2,4867	3,0323	4,1621	5,899
100 Pieces	0	0,449	1,255	1,9236	2,2781	2,3612	2,3538	2,504	3,0598	4,1973	5,9376

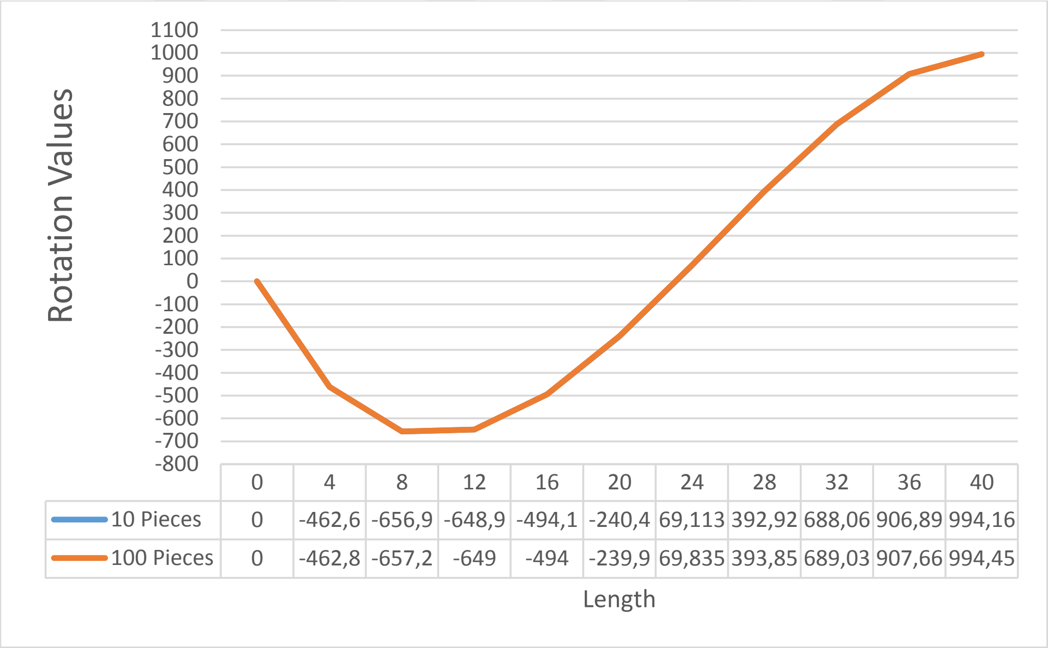
Figure 5.1 Effect of degree of sensitivity on horizontal displacement of arch

bridge



	0	4	8	12	16	20	24	28	32	36	40
10 Pieces	0	-1027	-3346	-6019	-8349	-9845	-10200	-9272	-7089	-3860	0
100 Pieces	0	-1033	-3355	-6028	-8358	-9853	-10205	-9276	-7091	-3862	0

Figure 5.2 Effect of degree of sensitivity on horizontal displacement of arch bridge



	0	4	8	12	16	20	24	28	32	36	40
10 Pieces	0	-462,6	-656,9	-648,9	-494,1	-240,4	69,113	392,92	688,06	906,89	994,16
100 Pieces	0	-462,8	-657,2	-649	-494	-239,9	69,835	393,85	689,03	907,66	994,45

Figure 5.3 Effect of degree of sensitivity on horizontal displacement of arch bridge

These values apply to fixed-vertical support conditions and arch bridges with a bridge width of 40 meters and a maximum height of 5 meters.

The displacement values change significantly as the number of parts seen from all figures increases. However, it is clear that the change in values is not much. The fact that only static loads are activated is another reason for the small values.

The result is that the number of parts to be deduced, that is, sensitivity has an effect on the arch bridge, but it affects less than the other parameters. Another conclusion is that we can divide an arch bridge into 10 parts.

Another important factor is the maximum height. This value is the basic working principle of arch bridges. It is very important and useful to build an arch bridge instead of a straight bridge. Because of this, the displacements in the bridges are reduced significantly. As the maximum height of the bridges increases, the displacements decrease. In addition, shear and axial force values are reduced in bending moments.

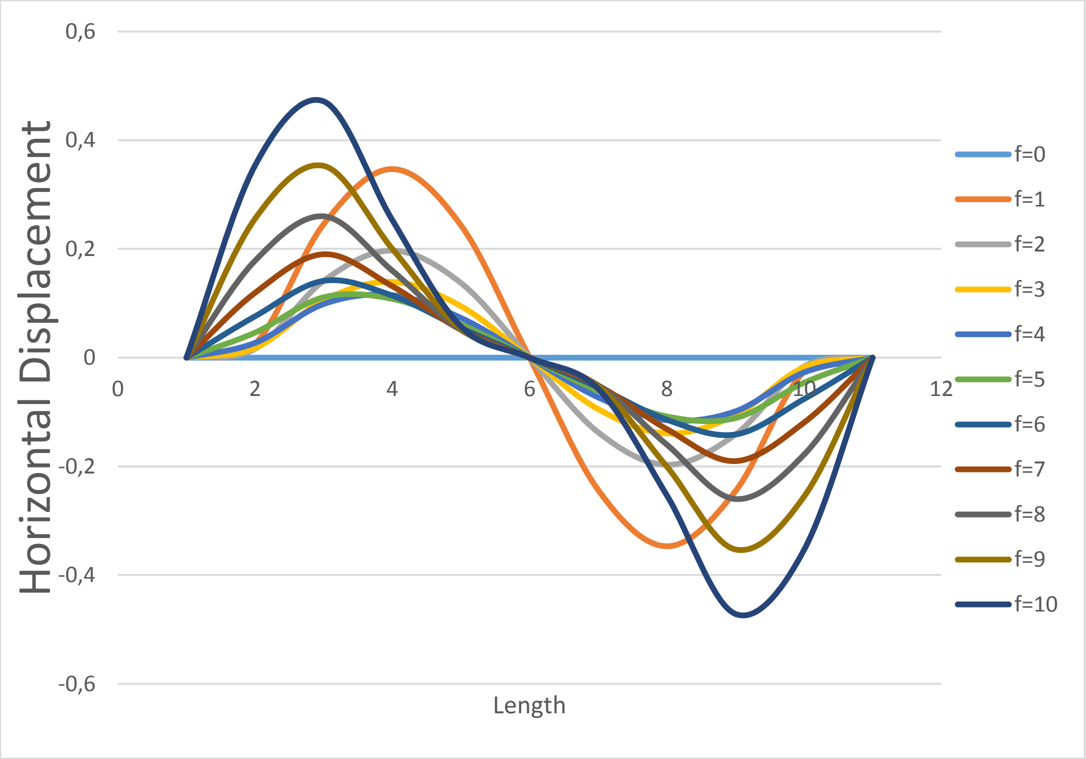


Figure 5.4 Effect of maximum height on horizontal displacement of arch bridge

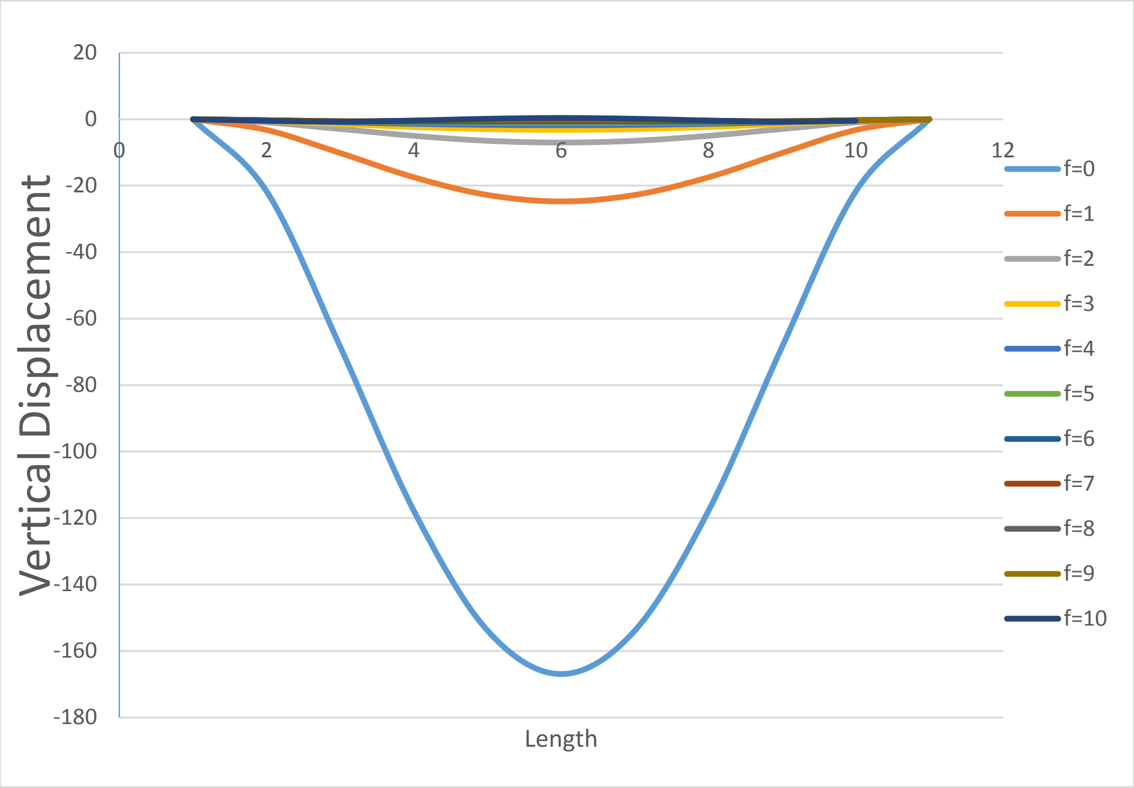


Figure 5.5 Effect of maximum height on vertical displacement of arch bridge

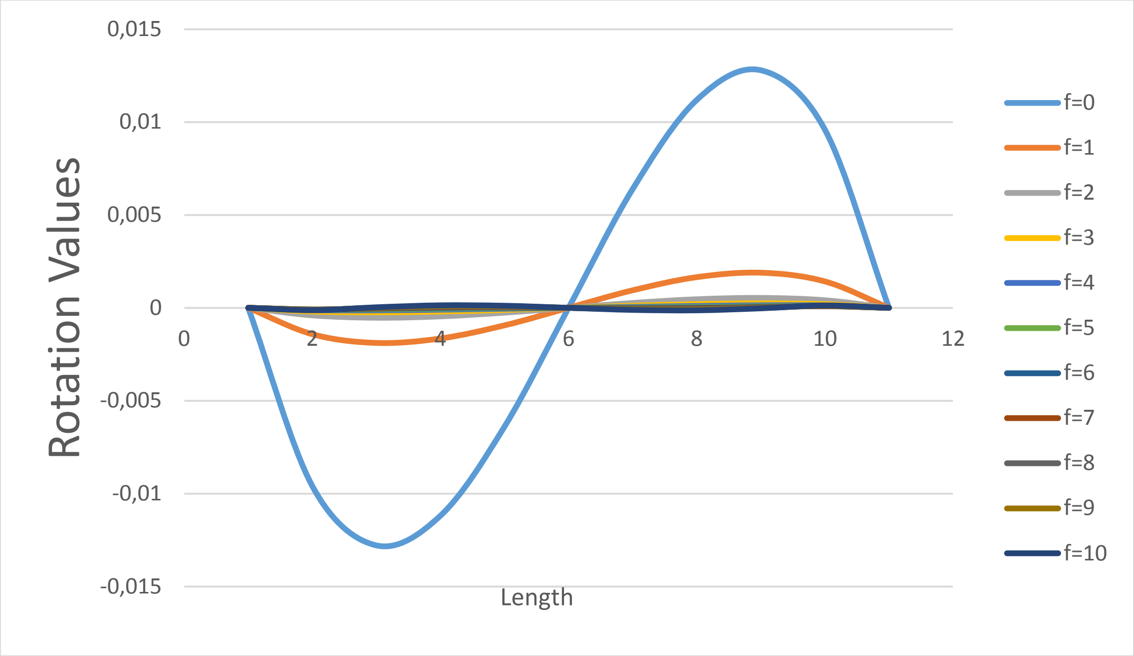


Figure 5.6 Effect of maximum height on rotation displacement of arch bridge

These values apply to bridges with fixed-fixed support conditions with a bridge span of 40 meters and divided into 10 parts. As can be seen from the plotted graphs, the increase in the maximum height decreases the displacement values to a great extent. This shows the importance of the parameter. This value is the basic working principle of arch bridges. It is very important and useful to build an arch bridge instead of a straight bridge. Because of this, the displacements in the bridges are reduced significantly. As the maximum height of the bridges increases, the displacements decrease. In addition, shear and axial force values are reduced in bending moments.

Another important parameter is the support conditions and the number of hinges. The support condition and the number of hinges are quite different but related parameters. Therefore, it was examined under the same title. These two parameters are the most important parameter for arch bridges. Depending on the changing support conditions and the number of hinges, the internal forces to be formed on the bridge vary considerably.

The main purpose of arch bridge construction is to reduce the amount of displacement. That is, arch bridges make less vertical displacement under the same loads compared to flat bridges.

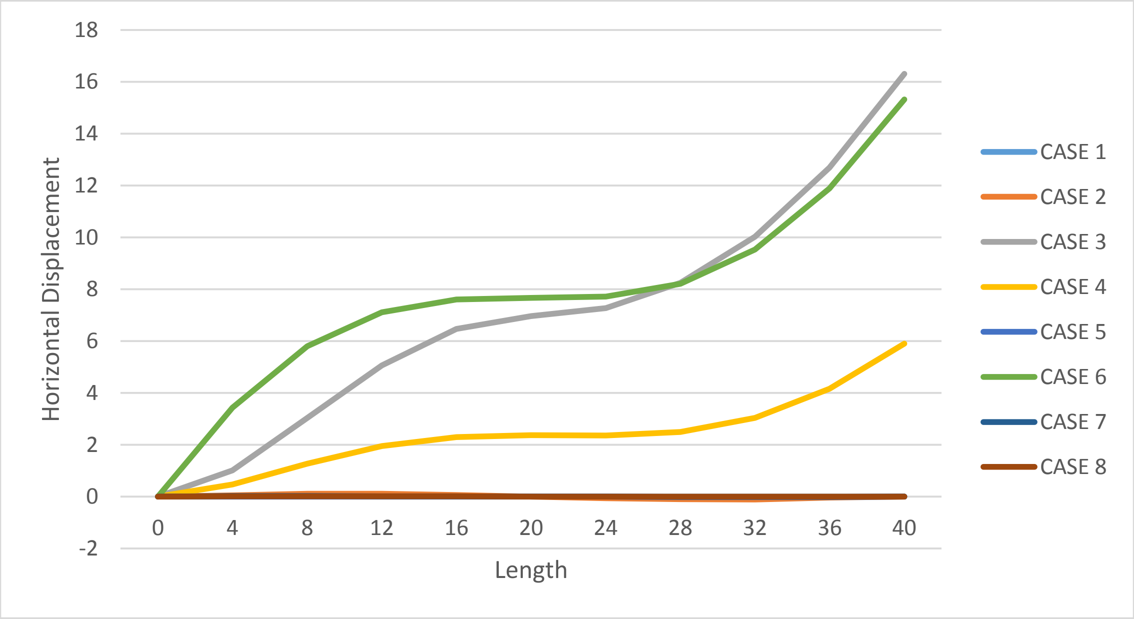


Figure 5.7 Effect of maximum height on horizontal displacement of arch bridge

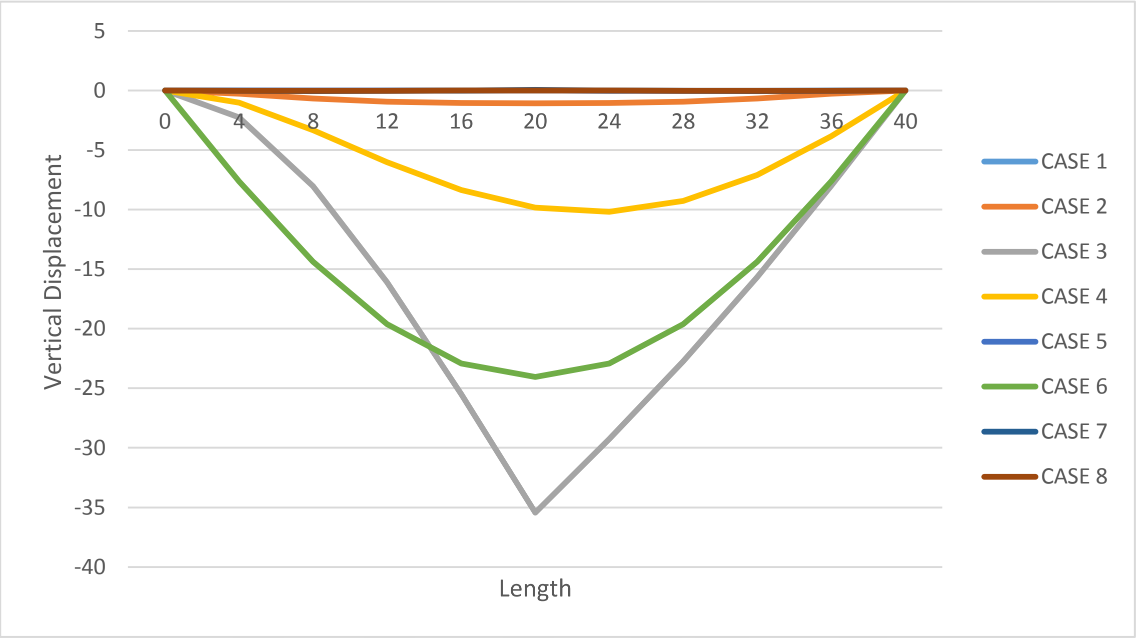


Figure 5.8. Effect of support conditions and number of hinges on vertical displacement of arch bridge

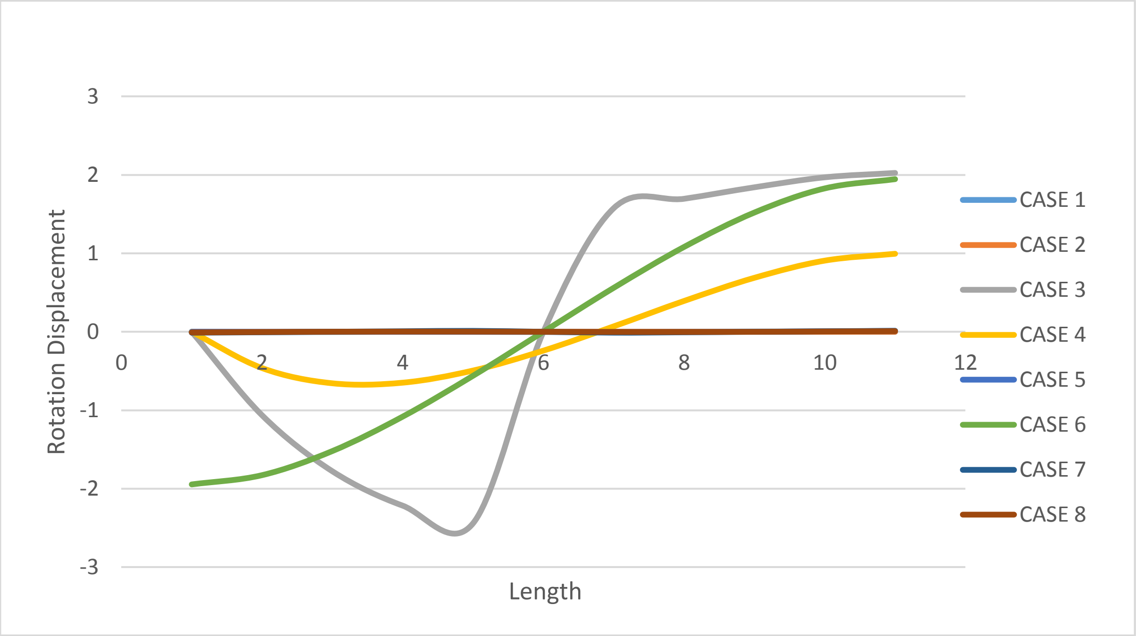


Figure 5.9. Effect of support conditions and number of hinges on rotation displacement of arch bridge

As can be seen from the figures, the support conditions and the number of hinges are very important for the displacement values of the bridges. All horizontal support displacement conditions were found to have vertical support condition. As can be seen from the figures, it has been seen that as the degree of freedom of support conditions increases, internal forces and displacement values decrease. The supported conditions and the number of joints seen from the obtained graphics are very important and effective for arch bridges.

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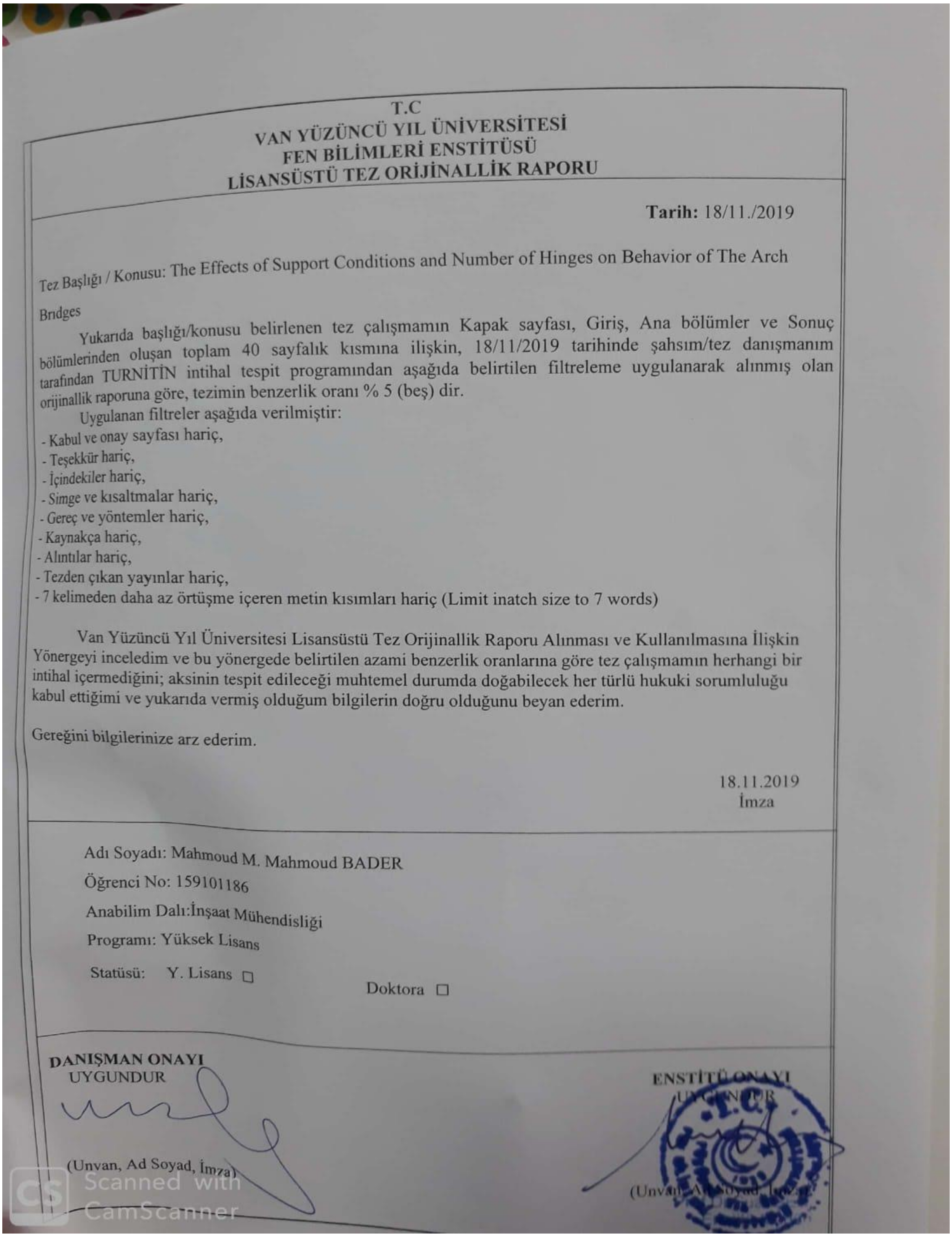

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FEN BİLİMLERİ ENSTİTÜSÜ
LİSANSÜSTÜ TEZ ORİJİNALLİK RAPORU

Tarih: 18/11./2019

Tez Başlığı / Konusu: The Effects of Support Conditions and Number of Hinges on Behavior of The Arch Brıdges

Yukarıda başlığı/konusu belirlenen tez çalışmamın Kapak sayfası, Giriş, Ana bölümler ve Sonuç bölümlerinden oluşan toplam 40 sayfalık kısmına ilişkin, 18/11/2019 tarihinde şahsım/tez danışmanım tarafından TURNİTİN intihal tespit programından aşağıda belirtilen filtreleme uygulanarak alınmış olan orijinallik raporuna göre, tezimin benzerlik oranı % 5 (beş) dir.

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- Kaynakça hariç,
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