REPUBLIC OF TÜRKİYE

ALTINBAŞ UNIVERSITY

Institute of Graduate Studies

Civil Engineering

CALCULATION AND PROGRAMMING OF PRESTRESSED COMPOSITE CONCRETE BEAMS WITH DIFFERENT SECTION FORMS IN SPANS OF BRIDGES AND HOUSING

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Master's Thesis

Supervisor

Prof. Dr. Zeki HASGÜR

Istanbul, 2023

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The thesis titled CALCULATION AND PROGRAMMING OF PRESTRESSED COMPOSITE CONCRETE BEAMS WITH DIFFERENT SECTION FORMS IN SPANS OF BRIDGES AND HOUSING prepared by ABDULRAHEEM RABAYA'A and submitted on 07/04/2023 has been **accepted unanimously** for the degree of Master of Science in Civil Engineering.

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I hereby declare that all information presented in this graduation project has been obtained in full accordance with academic rules and ethical conduct. I also declare all unoriginal materials and conclusions have been cited in the text and all references mentioned in the Reference List have been cited in the text, and vice versa as required by the abovementioned rules and conduct.

Abdulraheem RABAYA'A

Signature

DEDICATION

To my darling mother, dear father, brothers, and my lovely sisters whose always motivated me to achieve my dreams and gave me the full support all along. And a special thanks to Prof. Dr. Zeki Hasgür for his support, worth notes and close follow up.

ABSTRACT

CALCULATION AND PROGRAMMING OF PRESTRESSED COMPOSITE CONCRETE BEAMS WITH DIFFERENT SECTION FROMS IN SPANS OF BRIDGES AND HOUSING

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Date: 04/2023

Pages: 96

This research can be considered as the first step on the way of advancement of construction world, especially the housing and bridges projects. The designing of prestressed composite concrete beams with different section forms in spans of bridges and housing is dealt here.

The research focuses on the designing of the prestressed composite concrete beams with different section forms by using a programmed Excel spreadsheet, which deals with the safety stresses for each beam section and for the cast-in-situ slab as well. Also, it deals with the ability of the structure to resist the applied loads and checks the ability of the composite beam sections to resist the cracking forces for the section and the cracking during the transportation. The study concludes by highlighting areas that still require investigation before prestressed composite concrete beams can be used in construction projects.

Keywords: Prestressed Concrete, Composite Concrete Beams, Bridges and Housing Projects, Different Section Forms, Different Span Lengths.

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LIST OF SYMBOLS

P : Prestressing Force

I : Moment of Inertial

C : The Distance From The Top and From The Bottom of The Beam To The Centroid

M : Moment

A : Area

L_t : The Length of Short Side of Span

L_{ef} : Effective Length of Short Side of The Span

L : Span Length

E : Modulus of Elasticity

σ : Stress

L_s : Cable Losses

D : Depth

f_r : Cracking Resistance

γ_s : Steel Coefficient

γ_c : Concrete Coefficient

ρ_s : Steel Density

M_{cr} : Cracking Moment

1. INTRODUCTION

1.1 BACKGROUND ABOUT COMPOSITE STRUCTURES

Currently, during the design phase, there is a growing focus on reducing the time and expense associated with building construction. Concurrently, the architects present the engineers with more difficult tasks, such as increasing the length of the spans or the demand to minimize the element hights for the designed building.

However, the ever-increasing requirements drive engineers to produce cost-effective design solutions and more innovative and prestressed composite concrete structures are one of the best solutions. Prestressed composite structures have become quite popular, serving as the primary technology in the construction of structures with various shapes or purposes because of the extensive potential for improving cross-sectional efficiency and the accelerated pace of construction.

Composite structures can be defined as structure created by using two materials or more bonded with each other to ensure the cooperation during the transferring of the load [1].

1.1.1 Prestressed Composite Beams

Prestressed composite beams consist of precast beams and reinforced concrete slabs cast on them at the construction site and this is also considered as a composite structure because the concrete grade of prestressed precast beams may be several levels higher than that of cast - in- place concrete while they are fabricated materials.

The benefit of such a design is the effective use of component materials, which enables the design parts to have significantly better durability criteria while consuming less material and weighing less. Bridge construction and floors are two principal applications for prestressed composite beams. Due to their high rigidity and load capacity, they are excellent as frame components. For example, in bridge construction, the pre-cast beams are brought to the construction site and placed on legs spaced apart or side by side, while if there is a gap between the beams, a formwork element called filigree is placed in between. After that, the concrete of the deck (grip concrete or topping) is poured, and the beams start to work as a composite structure after the setting of the concrete. However, the pre-cast beam should

Carry the weight of its own as well as the weight of the deck and the weight of the formwork if there is a gap in between. After the composite system is achieved, the fixed loads and live loads, even the traffic load will be carried by the composite beams. The same situation will be applied on the composite floors. Due to this composite system, the deflection and deformation values are reduced as well as significant economic savings.

1.2 OBJECTIVES

The following points provide a summary for the study objectives:

i. To design prestressed composite beams with different section forms in spans of bridges and housing.

ii. To program an Excel spreadsheet to achieve the best section characteristics.

iii. To perform safety stress analysis for the structure.

iv. To determine if the improved system serviceable and safe or not.

v. To better management of concrete quality.

vi. To start a modern design trend for prestressed composite beams.

1.3 THE RESULT APPLICATIONS

By finishing the study successfully, the building sector will benefit by:

i. Providing modern solution to the long span bridges and floors.

ii. Improving the traditional methods of prestressed composite beam designs.

iii. Create concrete products that are ecologically friendly.

iv. Give alternatives to the building industry that is expanding quickly.

v. Making architectural design growth easier, which improves the development of structure appearance.

1.4 THE RESEARCH STRUCTURE

The research has been formed with seven chapters and divided into different sections. The introduction was provided with the purpose of the study as well as the application of the design.

The second chapter includes a discussion of several literatures to stand over the principles of prestressed concrete.

The third chapter covers the prestressed composite beam section design methods. It addresses the specifications of the materials, the loading conditions as well as the design process.

The fourth chapter addresses the design of a prestressed composite concrete beam section, It discusses the section characteristics that have been used as well as the stress diagram for the analysed section.

Chapter five covers the design of prestressed composite concrete beam with different section forms in spans of bridges and housing projects using the programmed Excel spreadsheet. It addresses the results obtained from the spreadsheet as well as new design for both projects with different span lengths.

Chapter six highlights the discussion about the obtained results from the spreadsheet for the bridges and housing projects. Also, it shows the most suitable section forms for each project.

Chapter seven highlights the conclusion and the recommendations derived from the research. The last section contains the resources that were used for this research to succeed.

2. PRESTRESSED CONCRETE

2.1 INTRODUCTION

Prestressed concrete can be defined as a concrete with an introduced internal stress of an appropriate distribution and magnitude, so the stresses brought on from the external and internal loads are prevented to the required degree. In reinforced concrete elements, by tensioning the steel reinforcement, the prestress is introduced.

Prestressing has been used since ancient times, as evidenced by one of the first examples of wooden barrel construction using force-fitting metal bands and shrink-fitting metal tyres on wooden wheels. The problem of having weak tensile strength appears to have been a role in the development of composite materials like reinforced concrete as the tensile strength of concrete is only a fraction of its compressive strength [2].

A new substance called “prestressed concrete” was created because of reinforced concrete cracking. As a result of the need to remove the compressive prestress before applying the tensile stress, the application of persistent compressive stress to a material as concrete, which is extraordinarily strong under compression but very weak in tension, enhance the apparent tensile strength of that material. In 1904, a French engineer called Eugène Freyssinet used high strength steel and a methodical technique to solve the issue. That was the first efficiently used method of prestressing concrete [2, 3].

Prestressed concrete combines high strength steel in an active manner, which is accomplished by tensioning the steel and holding it against the concrete, putting the concrete into compression. In contrast to reinforced concrete, which combines steel bars and concrete by placing them together and allowing them to act together, prestressed concrete combines high strength steel silently. However, the behaviour of both materials is improved by this active combination. Steel is ductile and is now prestressed to respond under high tension. Contrarily, prestressed concrete has improved its tensile strength while maintaining its compressive strength, making it a move brittle material. As a result, prestressed concrete is the ideal fusion of contemporary high strength materials [4].

2.1.1 Development of Prestressed Concrete

The continual study conducted in this subject over the past century by engineers and scientists is what has led to the current degree of progress in prestressed concrete. Jackson of San Francisco submitted a patent application in 1886 for the "building of artificial stone and concrete pavements," which employed prestress by tightening the reinforcing rods inserted into sleeves. To prevent cracks, Dohring of Germany produced slabs and tiny beams in 1888 using imbedded tensioned wires in concrete [2].

The Austrian engineer Mandl proposed prestressing as a means of relieving load-related stresses for the first time in 1896. German researcher M. Koenen expanded on the topic by writing a study on the loss of prestress owing to elastic shortening of concrete in 1907. Around 1908 in the US, Steiner became the first person to realize the significance of prestressing losses caused by concrete shrinkage. High-tensile steel wires were linked to pipes at stresses ranging from 160 to 800 N/mm^2 in 1923 by Emperger of Vienna, who created a technique for creating wire-bound reinforced concrete pipes [2].

Dischinger showed the use of unbonded tendons in the construction of a significant deep-girder bridge in 1928, where prestressing wires were installed inside of the girder with no bonds. By tensioning the wires afterward, prestress losses were made up for. Freyssinet demonstrated the benefits of employing high-strength steel and concrete in 1928 to account for the various losses of prestress due to creep and shrinkage of concrete based on extensive investigations of the characteristics of both materials [2].

From 1935 on, the usage of prestressed concrete expanded quickly, and between 1945 and 1950, long-span bridges were built in both Europe and the United States. Precast concrete has been utilized extensively over the past 60 years to build a variety of buildings, including long span bridges, industrial shell roofs, marine structures, nuclear pressure vessels, water-retaining structures, transmission poles, and railroad sleepers [2].

Precast concrete was first developed in Belgium and France, but it was soon followed by Germany, England, Holland, Switzerland, Italy, and Soviet Russia. Precast concrete has been used to construct around 47% of the bridges constructed in Germany since 1965. In 1950, there was only one precast pre-tensioning facility in the United States; by 1961, there were 229. In 1962, it was anticipated that about 1,530,000 m3 of precast prestressed concrete

products were produced, of which 50% were used for bridges and the remainder for buildings and other projects. There were 500 prestressing and pre-casting plants operating in the United States, according to a survey conducted by a prestressed concrete institution in 1975 [5]. More than 45% of the bridges constructed in the United States since 2010 have been composed using prestressed concrete, according to research by Abdel-Jaber H. in 2019 [6].

2.1.2 The Advantages and Disadvantages of Prestressed Concrete

In recent decades, pre-stressed concrete, which has many advantages over conventional reinforced concrete, has been employed extensively in the construction of buildings. During its service life, a prestressed concrete member typically experiences compression. This fixes several concrete's flaws. Concrete cracking is a major drawback of reinforced concrete members, although prestressing eliminates it. Prestressed concrete has several benefits since, for a prestressed member, the concrete does not crack under service conditions. The main benefit we receive from un-cracked concrete is a decrease in corrosion. Pre-tensioned members are more durable because of less steel corrosion. The second benefit is that the section is being used, which results in a larger moment of inertia, higher stiffness, and less deformation, all of which increase the section's serviceability. On the other side, shear's capacity will also rise. A member with no cracks is ideal for use in liquid storage tanks. Because it is not ideal for this type of building to have fissures running through its parts, which could allow water to leak in. Prestressing is therefore used in this kind of building. Additionally, performance is enhanced by resilience to fatigue and dynamic loading. Large constructions may experience multiple patterns of loads that might cause a member to get fatigued; yet, when the member is prestressed, its behaviour is improved [7, 8].

Prestressing is used for big spans such as buildings with huge columns, open spaces, and bridges because of the high span to depth ratios for prestressed concrete members, which can be extremely high. For a non-prestressed slab, the usual span to depth ratios can be as high as 28:1, while for a prestressed slab, the ratio can reach up to 45:1. However, this property supports the building's possible applications in the future. A prestressed member has a shallower depth than reinforced concrete for the same span. Due to a less usage of concrete, a reduction of the self-weight of the section can be obtained which creates a more economical structure [4, 7].

Another advantage of prestressing is that it is very proper for precast constructions. The advantages of precast construction are the rapid construction, better quality control, reduced maintenance, its suitable for repetitive constructions and a multiple use of formwork, which leads to reduction of formwork, and availability of standard shapes. The advantages of precast construction can be fully utilized, and this leads to much faster construction [7].

However, the benefits of prestressed concrete over reinforced concrete in serviceability, safety and the economy can be summarized as follows:

Serviceability: In the typical reinforced concrete, The cross section may be fractured under operating stresses, while the prestressed concrete cross section is more effective under the operating stresses. Additionally, by increasing the eccentricity of the prestressing force in the prestressed structural part, a dead load might be detected within specific limits. Due of these specifications, prestressed concrete is the best material for long-span construction, such as bridges [2].

Safety: It would be hard to say that prestressed concrete structure is safer than normal concrete structure or vice versa. However, when the internal pressure in a prestressed concrete system is increased over the maximum design stress, concrete undergoes gradual tensile cracking until continuous through cracks are created. Although these cracks do not represent failure as well as they do not cause rapture of the steel and the tensile load in the cracked cross sections is carried by the mild stress of reinforced concrete as well as by the prestressing tendons [9].

Economy: When the span length and load conditions are the same, a prestressed concrete member has a shallower depth than a reinforced concrete component. Moreover, prestressed concrete requires less concrete and about 20 to 35 percent of the amount of reinforced steel. However, the reduction of wight of the materials is compensated by the cost for the superior materials which is required for the prestressing. Additionally, prestressing processes cost more regardless of the technology utilized because the formwork is more complicated, and the geometry of prestressed sections is frequently made up of flanged sections with thin webs [10].

2.2 PRESTRESSING TYPES

Prestressed concrete can be categorized based on varied factors for example:

i. The source of prestressing force.

ii. The location of the prestressing tendon.

iii. The amount of prestressing force.

iv. The shape of the prestressed member.

v. The sequence of casting concrete.

vi. The mechanism of casting concrete.

2.2.1 The Source of Prestressing Force

The source of the prestressing force serves as the basis for this classification. It depends on how the prestressed force is generated and there are four sources for these forces, which are:

Hydraulic prestressing: This sort of prestressing, which generates a significant prestressing force, is regarded as the simplest type of prestressing. The hydraulic jack that is used to tension the tendons has accurate pressure scales that show the exact amount of force created during tensioning. Even though this method is the most used for adding prestress to steel before it is transferred to concrete [11].

Mechanical prestressing: In this style of prestressing the devices used includes wire-wending machines, screw jacks with or without gear drives, geared transmissions combined with pulley blocks, and weights with or without lever transmission. However, this kind of prestressing is used in large-scale manufacturing. Therefore, mechanical prestressing is dependent on machinery with mechanical components, and this technology is more frequent when prestressed members are produced on a large scale [11].

Electrical prestressing: In this kind of prestressing, the steel wire is electrically heated and anchored before placing concrete in the moulds. This type of prestressing is also called as thermo-electric prestressing, which means that when the wire is heated it expands and then it is allowed to cool down and transfer the prestress to the concrete [11].

Chemical prestressing: When doing this kind of prestressing, expansive cement is utilized, and the amount of expansion is managed by adjusting the curing conditions, as cement sets, its expansion activity is constrained. As a result, the tendons experience tensile forces as well as compressive stresses in concrete. It is possible to transfer prestress to the concrete using this technique, but it is quite rare to do so [11].

2.2.2 The Location of Prestressing Tendon

External prestressing: When prestressing is accomplished using components outside of the concrete, for example in I- girders or walls, it is called external prestressing. This method is used for strengthening structures and bridges [11].

Internal prestressing: It is referred to as internal prestressing when the prestressing is accomplished using components inside the concrete member, such as embedded tendons. Most prestressing applications are internal [11].

2.2.3 The Shape of The Prestressed Member

This classification is made depending on how the member is prestressed. Prestressing in a circular pattern, such as the circumferential prestressing of tanks, is done when a part is curved, changing the direction of the prestressing. Contrarily, linear prestressing is used when the member being prestressed is straight or flat in the direction of prestressing, for example, The prestressing of beams, poles, piles, and slabs [11].

2.2.4 The Amount of Prestressing Force

This classification is based on the amount of prestressing force, which are:

Full prestressing: The full prestressing is defined as when there is no tensile stress permitted in the concrete under the service loads due to the level of prestressing. However, The concrete cannot be under tension in a fully prestressed part during service life [11].

Limited prestressing: The limited prestressing can be defined as when the quantity of prestressing is such that the tensile stress while carrying the service load is within the concrete's cracking stress. Therefore, in a limited prestressed member, tension in the concrete is permitted, but it is ensured that it is lower than the member's tensile strength [11].

Partial prestressing: The partial prestressing is referred to as the level of prestressing is such that cracking may occur under tensile stresses brought on by service loads, but the crack widths are constrained to predicted limits [11].

2.2.5 The Sequence of Casting Concrete

2.2.5.1 Pre-tensioning system

In this technique, concrete members are cast around steel tendons that are tensioned between end-anchorages in the form of strands or wires. The end-anchorages are removed once the concrete has sufficiently hardened, at which point the prestress force is transferred to the concrete via the link between the steel and concrete. To create the finished concrete part, the remaining ends of the tendons are then removed. However, the pre-tensioned elements typically have numerous strands or wires to supply the prestress force because the force in them is developed by bonding to the nearby concrete and a large area of surface contact is preferred [3].

This technology is ideal for factory production since it requires extraordinarily large anchorages to secure all the tendons and allows for the casting of several members along a single set of tendons. However, it is crucial to make sure the members can move freely along the prestressing bed to prevent the creation of unwanted tensile stresses in them when the end-anchorages are released [3].

2.2.5.2 Post-tensioning system

In this technology, the member made of cast concrete is subjected to a prestress force that is applied by jacking steel tendons. However, this technique is used for the majority of cast in situ prestressing. The tendons flow through ducts that are cast into the concrete, or in a few rare instances it passes through outside the concrete area. The jacking force is transferred to the concrete through a specific anchoring when the tendons are fully tightened [3, 12].

In post-tension members, the prestress force is typically generated by numerous individual wires or strands bundled into large tendons and attached to the same anchorage. To prevent the concrete around the anchorage from splitting, reinforcing is needed since the focused force which has been transferred to the anchorage creates a complicated condition of stress on the surrounding concrete. Most of the post-tensioned concrete applications inject a

cement grout into the area between the tendon and the duct to protect the tendons and increase the member's final strength capacity [3].

The post-tensioning system has the advantage over pre-tensioning in that the tensioning can be done in stages for all the tendons in the member or just some of them. This feature may be especially helpful in situations where the load is applied in clearly defined stages. However, the post-tensioning technique is more appropriate for heavy cast-in-place components.

2.2.6 The Mechanism of Casting Concrete

Depending on the casting processes of concrete, prestressed concrete is categorized as precast members, cast in-place and composite structural members.

Cast in-place: This type of concrete is produced at the site of the construction and used in heavy construction like bridges, which helps in reducing the cost of transportation as well as the cost of erection. Thus, it requires more form and false work per unit of product [11].

Precast members: In this type, the concrete is casted outside the site of the construction, then erected at the final location and can be used to support the cast in-situ slab without additional scaffolding or shoring [11].

Composite structural members: In this type, precast beam is brought to the construction site and placed spaced apart or side by side on legs. After that, the concrete of the topping is poured, and the system starts to work as a composite following the setting of concrete. This type is usually used in bridge construction [13]. Figure 2.1 shows the concept of composite structural elements.

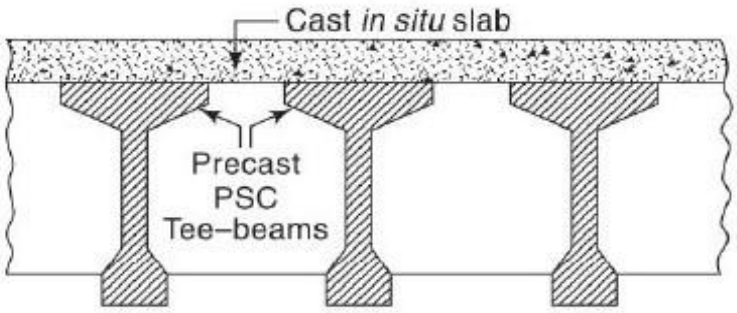

Figure 2.1: The Concept of Composite Structure

2.3 MATERIALS USED IN PRESTRESSED CONCRETE

2.3.1 Concrete

Pre-stressed concrete needs concrete with higher tensile and compressive strengths than regular concrete, especially at young ages. High value of young modulus, low shrinkage and minimum creep characteristics are deemed necessary for concrete used for prestressed elements. Concrete's strength has a significant effect on several desirable qualities, including durability and abrasion resistance [4].

Under uniaxial compression, the stress-strain behaviour of concrete is initially elastic and linear. Microcrack creation causes the behaviour to become nonlinear and inelastic. Thus, the strain increases while the resisting stress decreases until the specimen reaches the pick stress.

The Euro Code 2 part 1-1 1992 [14] states the stress-strain relationship for design cross section as follows:

$$\sigma_c = f_{cd}\left[1-\left(1-\frac{\varepsilon c}{\varepsilon c2}\right)^n\right], \text{for } 0 \le \varepsilon c \le \varepsilon c2 \qquad (2.1)$$

$$\sigma_c = f_{cd}\ , \text{for } \varepsilon_{c2} \le \varepsilon c \le \varepsilon_{cu2}$$

Where:

σ_c: is the compressive stress.

ε_{cu2}: is the ultimate strain according to Table 3.1 of Euro code 2 part 1-1 1992.

n: the exponent according to Table 3.1 of Euro code 2 part 1-1 1992.

ε_{c2}: strain reaching to the maximum strength according to Table 3.1 of Euro code 2 part 1-1 1992.

f_{cd}: The design compressive strength.

f_{ck}: The compressive strength.

Figure 2.1 shows the parabola-rectangular diagram for concrete under compression.

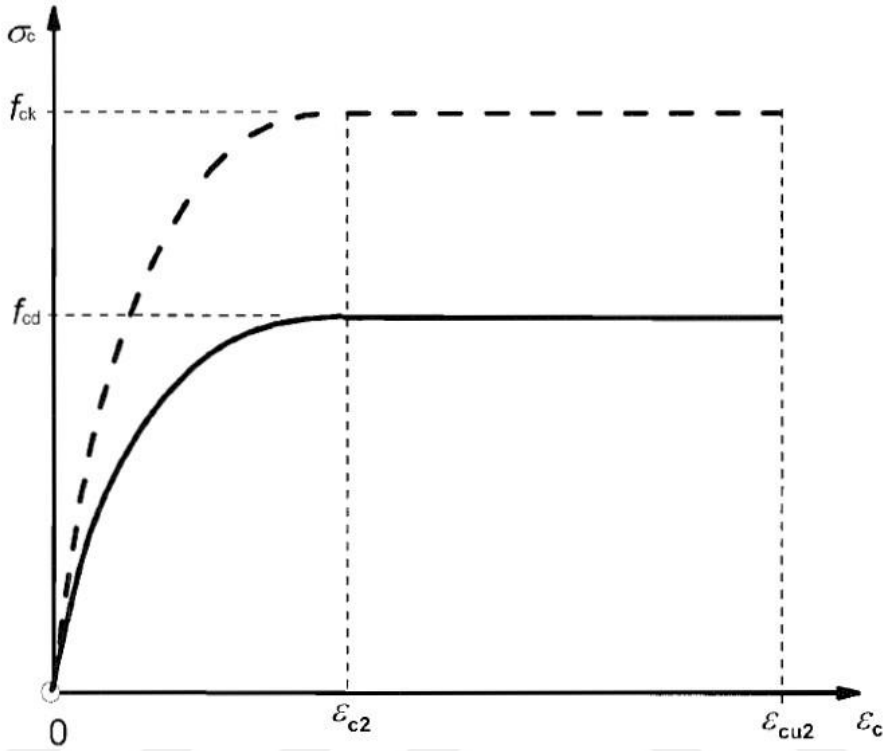

Figure 2.2: Parabola-Rectangular Diagram for Concrete Under Compression [14].

Figure 2.3 shows the rectangular stress distribution in concrete.

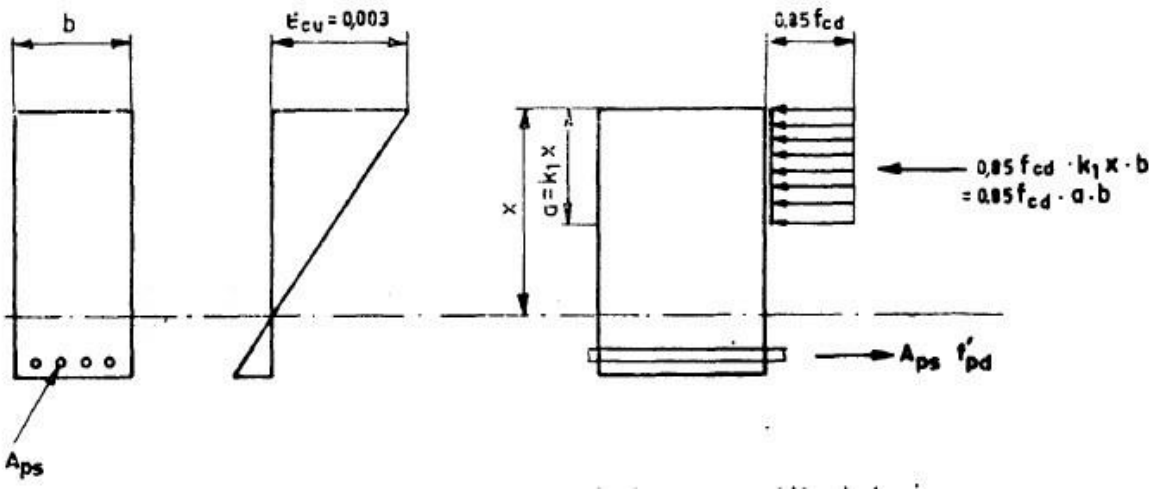

Figure 2.3: Rectangular Stress Distribution In Concrete [15].

2.3.2 Prestressing Steel

The prestressing steel have different shapes as follows [4]:

i. Wires: a single unit made of steel. Nominal diameters of wires could be used, for example 2.5mm, 3mm, 4mm, 5mm, 7mm, 8mm.

ii. Stands: a few wires were weaved together in helical form to form a prestressing stand. However, these stands can be two-wire stands, three-wire stands, or seven-wire stands.

iii. Tendon: a group of stands wounded to form a prestressing tendon.

iv. Cable: a group of tendons.

v. Bar: a tendon made up of a single steel bar. Thus, the diameter of the bar is much larger than that of a wire.

Properties of prestressing steel:

i. Low corrosion.

ii. High strength.

iii. Adequate ductility.

iv. Low relaxation which reduces losses.

v. High bond strength, which is required especially in pre-tensioning systems.

Prestressing steel is considered as one of the main load resisting elements in prestressed concrete bridges [16]. The tensile strength of the prestressing steel is given in terms of characteristic tensile strength, denoted by f_{pu}. The characteristic strength which is defined as the ultimate tensile strength of coupon specimens below, which not more than 5% of the test results are expected to fall [4].

2.4 LOSSES IN PRESTRESSED CONCRETE

The losses in prestressed concrete can be categorized into two main groups depending on the time of occurring, the first group is the losses occurring during the transfer such as elastic shortening, friction, and anchor slip losses, while the second group is the time-dependent losses, for example concrete shrinkage, creep, and strand relaxation losses [17].

Elastic shortening losses: These losses occur immediately after transferring the prestressing to the concrete and due to this operation, the concrete contracts elastic under the pressure which in turn create this type of losses [17].

Friction losses: These losses occur only in the post-tensioned prestressed systems. The friction losses are the summation of the losses due to the curvature and irregularity. The curvature losses occur since the cables are curved in most of the post-tensioned systems and due to the curvature, the friction occurs between the curved cable and the sheath. While the irregularity losses occur because of the placement of the cable between fixing points [13].

Anchors slip losses: During the transfer of the prestressing force of the steel from the jack to the anchorage a slippage occurs in the anchor in this operation. However, this type of losses occurs only in the post-tension systems [13].

Shrinkage losses: This type of losses occur due to concrete shrinkage which is created when the water loses away from the concrete. This type of losses depends on the climatic characteristics of the environment [13].

Creep losses: This type of losses can be defined as the increasement in the deformation of the material under a specific load over time [13].

Strand relaxation losses: This type of losses occur due to the decrement of stresses in the steel bar over the time while the length of bar stay constant by fixing it to a bench from both ends [13].

According to Table 8 from Turkish Standards TS 3233 showed in Table 2.1, an approximate value for the losses can be taken in term of percentage of initial prestressing P_i. However, the total losses in the prestressed concrete can reach up to 25% in the pre-tensioned systems and up to 20% in the post-tensioned systems [15].

Table 2.1: The Losses In Prestressed Concrete [15].

Shrinkage, creep and elasic shortening looses (percentages of initial prestressing)

Loss Values	Pretensioning	Posttensioning
Shrinkage in concrete	7	6
Elastic Shortening in Concrete Prestressing or Transfering	3	1
Creep in Concrete	6	5
Relaxiation in Steel	Manufacturer's recommendation	Manufacturer's recommen.

2.5 PRESTRSSED COMPOSITE BEAMS

The prestressed composite member casting method plays a significant role in prestressed concrete design. The usage of several types of concrete in a structure and the increase of the ability of the structure to resist the shear loads using a smaller number of stirrups create a significant savings in construction materials, which in terms reduces the total cost of the structure. However, the most important benefits of such a design are the reduction of the required time for the construction process as well as giving a shorter depth with a safer design for the structure [13].

2.5.1 Stresses In Prestressed Composite Concrete

The prestressed composite beams are often made to manage not only the stresses placed on them during construction but also the weight of the cast-in-place concrete in the slab and any additional loads. However, the composite part supports the dead and live loads that are applied after the slab hardens. A composite section with a high moment of inertia and an extraordinarily high resisting moment will result from the combination of the two components. Using a precast prestressed beam composed of high-strength concrete and a slab built of standard grade concrete is typically extremely cost-effective. However, while calculating the composite characteristics, it is vital to take into consideration the different modulus of elasticity for both types [18].

However, the application of stresses in composite structures is divided into three stages, which are: transmission stage, serviceability state stage and final stage. Figure 2.4 shows the stresses in the prestressed composite beam structure [2].

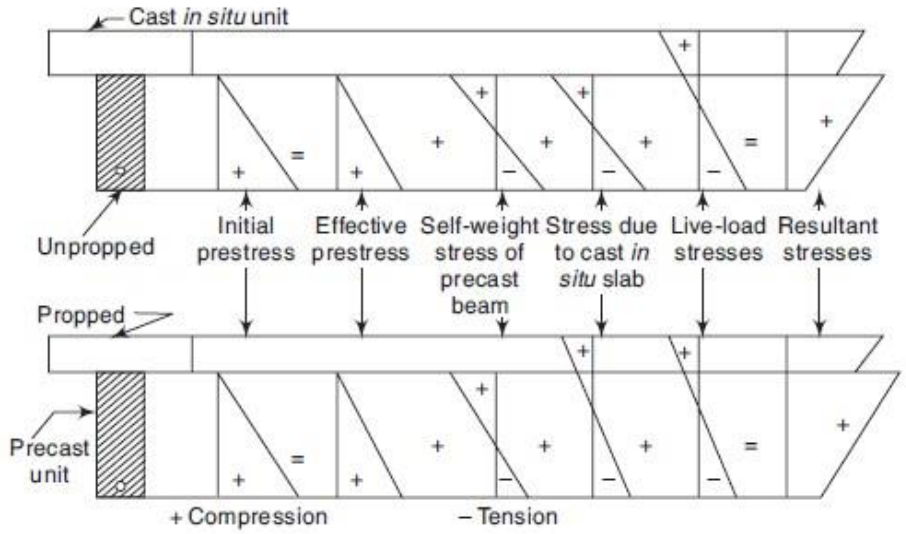

Figure 2.4: Stresses In Composite Beam Structure [2].

2.5.1.1 Transmission stage

Transmission stage is when the precast prestressed unit is unpropped during the placing of in-place concrete, and the stresses that develop in the precast unit are the summation of stresses due to the self-weight of the member, the prestressing force acting at a given eccentricity and the prestressing force in the member [2].

2.5.1.2 Serviceability state stage

The service state stage is when the cast-in-place concrete is freshly poured in the precast prestressed units, and the stresses on the precast unit are the summation of stresses due to the self-weight of the precast member, self-weight of the cast-in-place concrete, effective prestressing force acting at a given eccentricity and the effective prestressing force in the member [13].

2.5.1.3 Final stage

The final stage is when the cast-in-place concrete has hardened, the whole section is assumed to work as a composite structure and the stresses that develop due to subsequent live load

and traffic load are computed using the properties of the composite section [2]. Also, the stresses should be calculated for the bottom and the top of the beam as well as the stresses for the bottom and the top of the deck. In composite beams, at the junction section of the precast beam and cast in-situ part, under the assumption that sufficient shear strength is provided, the unit deformations that will occur due to the bending will be the same within elastic limits, and calculations are made as if the whole section is made of beam concrete. For this purpose, the width of the cast in-situ part must be reduced by multiplying the width of the cast-in-place deck by λ [13].

2.5.2 Elastic Limits of Prestressed Composite Concrete Structures

Concrete is classified according to its compressive strength, and it is determined by testing 28-days-old cylindrical concrete specimens. However, this test is used to determine the concrete characteristic compressive strength f_{ck}. These characteristics show the ability of the concrete to resist compression and tensile stresses. According to the Turkish Standards TS500, the value of compressive strength characteristic can be obtained by using the Table 3.2 from Turkish Standards TS500 [19].

However, according to the Turkish Standards TS3233, the minimum compressive strength that can be used in prestressed composite beams is 30 Mpa for the prestressed beams and the 25 Mpa for the deck [15].

2.5.3 Crack Resistance of Prestressed Composite Beams

To analysis, the design moment due to dead load, live load and traffic load is calculated as well as the ability of the structure to resist this moment according to the Turkish Standards TS3233. The resisting moment of the structure must be higher than the design moment. Also, the beam sections should be checked for cracking and the value of the cracking moment must be less than the resisting moment of the structure [15, 20].

2.5.4 Transporting Precast Sections

The used method for transporting the precast concrete sections can affect the design of the structure due to the weight limitations and size restrictions. However, most of the precast sections are transported by flatbed or low-boy trailers. In order to install the precast sections

on these trailers an erection equipment should be used such as truck-mounted, hydraulic cranes, crawler mobile cranes, tower cranes and derricks [2]. Figure 2.5 shows the handling of the precast sections using two cranes [21].

Figure 2.5: The Handling of Precast Sections Using Two Cranes [21].

The handling of the precast sections using equipment should take into consideration the cracking of the precast section. Careful planning of the erection sequence should take into consideration to ensure the structural stability and safety. The equipment used, bracing equipment (Hook-up), and factors of safety should be evaluated for each section [22].

3. METHODOLOGY

3.1 INTRODUCTION

The design of prestressed composite concrete beam section starts by using a section with specified properties to support the design loads. The property of this section depends on the characteristics of the concrete and prestressing steel used in the design. These characteristics should be determined considering the losses in these fabricated materials. After determining the characteristics of the used materials, the section should be checked for the stresses affecting each stage. However, the stresses affecting the structure should not exceed the allowable stresses for the section.

3.2 THE CHARACTERISTICS OF MATERIALS

3.2.1 Concrete Characteristics

According to the composite prestressed structure concept, the type of concrete used for the deck should be different from the one used for the prestressed beams and while the loads on the beams will be higher, the type of concrete used in the prestressed beams should be higher. The characteristics of the concrete such as modulus of elasticity which depends on the compressive strength characteristic f_{ck} can be obtained using the following equation.

$$E_c = \left(3250 \times \sqrt{f_{ck}}\right) + 14000\ MPa \tag{3.1}$$

The modular ratio of the concrete λ can be obtained as follows.

$$\lambda = \frac{E_{c\ \text{deck}}}{E_{c\ \text{precast}}} \tag{3.2}$$

the characteristic compressive strength of "j" days old concrete f_{cjk} can be determined by using the following equation.

$$f_{cjk} = 0.75 \times f_{ck}\ \ MPa \tag{3.3}$$

3.2.2 Prestressing Steel Characteristics

While the objective of using the prestressing steel is to resist the tension loads in the prestressed structure, the main characteristic of the prestressing steel is the tensile strength denoted by f_{pu}. According to Table 5.4.4.1-1 from AASHTO-LRFD Bridges Design Specifications [23] the tensile strength for prestressing steel can be obtained as shown in Table 3.1.

Table 3.1: The Tensile Strength for Prestressing Steel [23].

Material	Grade or Type	Diameter (in.)	Tensile Strength, f_{pu} (ksi)	Yield Strength, f_{py} (ksi)
Strand	250 ksi 270 ksi	1/4 to 0.6 3/8 to 0.6	250 270	85% of f_{pu}, except 90% of f_{pu} for low-relaxation strand
Bar	Type 1, Plain Type 2, Deformed	3/4 to 1-3/8 5/8 to 1-3/8	150 150	85% of f_{pu} 80% of f_{pu}

The characteristics of the prestressing steel can be obtained using the following equations:

$$f_{pi} = 0.75 \times f_{pu} \ \ MPa \qquad (3.4\ a)$$

$$P_i = A_{ps} \times f_{pi} \ \ KN \qquad (3.4\ b)$$

$$f_{pef} = (1 - the\ precentage\ of\ losses\ in\ prestressing) \times f_{pi} \ \ MPa \qquad (3.4\ c)$$

$$P_{ef} = A_{ps} \times f_{pef} \ \ KN \qquad (3.4\ d)$$

3.2.3 The Losses In Prestressing

The total percentage of losses in prestressing for the pre-tensioned systems can be obtained according to the following equation.

$$L_s = L_{s\ elastic\ shortening} + L_{s\ shrinkage} + L_{s\ creep} + L_{s\ relaxation} \qquad (3.5)$$

The losses for elastic shortening can as a percentage can be obtained as follows.

$$N_p = \frac{E_{ps}}{E_{cj}} \qquad (3.6\ a)$$

$$\Delta P = \left(\frac{P_i}{A} \times \left(1 + \left(\frac{e^2}{i^2}\right)\right)\right) - \left(\frac{M_{g1} \times e}{I}\right) \times \left(N_p \times A_{ps}\right) KN \qquad (3.6\ b)$$

$$L_{s\ elastic\ shortening} = \frac{\Delta P}{P_i} \times 100\% \qquad (3.6\ c)$$

Where:

E_{ps} is the modulus of elasticity for the prestressing steel according to AASHTO-LRFD Bridges Design Specifications 2010.

A: the area of the section.

e: The eccentricity.

M_1: The moment due to the section self-weight.

i: The gyration of moment of inertia.

I: The moment of inertia.

A_{ps}: The area of prestressing steel.

The losses of shrinkage can be calculated according to the ACI 318 [24] equations as follows.

$$\Delta P = \left(117.21 - (1.034 \times humidity)\right) \times A_{ps}\ KN \qquad (3.7\ a)$$

$$L_{s\ shrinkage} = \frac{\Delta P}{P_i} \times 100\% \qquad (3.7\ b)$$

According to the Turkish Standards TS3233 the creep losses which depend on the concrete compressive strength in the transfer stage f_{cjk} by defining a value for each 0.1 Mpa for the concrete with a f_{cjk} value equal 35 which equals 48×10^{-7}. If the compressive strength in transfer stage is less than 35 then the value of loss should be multiplied by a factor equal 35 divided by the compressive strength in transfer. The percentage of creep losses can be obtained according to the following equations.

$$\varepsilon_{creep} = \left(\frac{\frac{3 \times f_{cjk}}{8}}{0.1}\right) \times \left(\frac{35 \times 48 \times 10^{-7}}{f_{cjk}}\right) \qquad (3.8\ a)$$

$$\Delta P = \varepsilon_{creep} \times E_{ps} \times A_{ps}\ KN \qquad (3.8\ b)$$

$$L_{s\ creep} = \frac{\Delta P}{P_i} \times 100\% \qquad (3.8\ c)$$

According to the ACI 318, the calculation of the relaxation for the cables depends on the type of the cables used in design. The value of the relaxation losses depends on the shrinkage losses ,the losses due to the creeping as well as the losses due to the elastic shortening as shown in the following equations.

$$CRs = 137.88 - \left(0.4 \times \Delta P_{elastic\ shortening}\right) - (0.2 \times \left(\Delta P_{creep} + \Delta P_{shrinkage}\right)\ KN (3.9\ a)$$

$$L_{s\ creep} = \frac{CRs}{P_i} \times 100\% \qquad (3.9\ b)$$

However, in the low-relaxation type of cables and according to the ACI 318 the value of CRs should be reduced by multiplying the equation with 0.25 [24].

3.2.4 The Safety Stresses of Prestressed Concrete

The safety stresses of the structure are calculated considering the concrete type for both the beam section and the deck. These safety stresses are divided into two types which are the safety stresses in the transmission stage and the safety stresses in the serviceability stage. In general, the safety stresses depend on the types of the used concrete. The safety stresses in the transmission stage for the precast section can be obtained according to the following equations.

$$\sigma_{ci} = 0.4 \times f_{cjk}\ \ MPa \qquad (3.10\ a)$$

$$\sigma_{cti} = 0.5 \times \sqrt{f_{cjk}}\ \ MPa \qquad (3.10\ b)$$

While the safety stresses in the service stage for the precast section can be obtained by the following equations

$$\sigma_{cp} = 0.4 \times f_{ck}\ \ MPa \qquad (3.11\ a)$$

$$\sigma_{ctp} = 0.5 \times \sqrt{f_{ck}}\ MPa \qquad (3.11\ b)$$

On the other hand, the safety stresses for the cast-in-place deck can be calculated using the following equations.

$$\sigma_{c,em} = 0.4 \times f_{ck}\ MPa \qquad (3.12\ a)$$

$$\sigma_{t,em} = 0.5 \times \sqrt{f_{ck}}\ MPa \qquad (3.12\ b)$$

Although, the cracking resistance of the concrete due to the transportation of the section can be obtained using the following equation.

$$f_{ct} = 2.2 \times \sqrt{f_{ck}}\ \text{kgf}/cm^2 \qquad (3.13)$$

3.3 THE STRESSES AFFECTING THE STRUCTURE

According to the construction process of the prestressed composite concrete beam, there are three different stages with different types of stresses affecting the section. These stages are transmission stage, serviceability state stage and the final stage, respectively. The stresses in each stage should be calculated for the bottom and for the top of the sections considering the sign convention for the tension and compression stresses.

3.3.1 Transmission Stage

The stresses affecting prestressed section are the stress resulting from the initial prestressing force, the stress from the initial prestressing force at a given eccentricity as well as the stress resulting from the dead load moment. The value of these stresses can be obtained using the following equations.

$$\sigma_1 = \frac{P_i}{A}\ MPa \qquad (3.14\ a)$$

$$\sigma_2 = \frac{P_i \times e}{W}\ MPa \qquad (3.14\ b)$$

$$\sigma_3 = \frac{M_{g1}}{W}\ MPa \qquad (3.14\ c)$$

Where:

M_{g1}:The moment due to the self-weight of the section.

W: The section moduli.

The stresses in the transmission stage should be lower than the safety stresses of the structure for this stage which are the concrete pressure in transfer and the tensile strength of the concrete in transfer.

3.3.2 Serviceability State Stage

The stresses affecting the section in the serviceability state stage are the stress from the effective prestressing force in the member after subtracting the losses, the stress from the effective prestressing force acting at a given eccentricity, the stress due to resulted moment from the weight of the deck, and the stress resulting from the dead load moment. The value of the stresses can be obtained using the following equations.

$$\sigma_3 = \frac{M_{g1}}{W}\ MPa \qquad (3.15\ a)$$

$$\sigma_4 = \frac{P_{ef}}{A}\ MPa \qquad (3.15\ b)$$

$$\sigma_5 = \frac{P_{ef} \times e}{W}\ MPa \qquad (3.15\ c)$$

$$\sigma_6 = \frac{M_{deck}}{W}\ MPa \qquad (3.15\ d)$$

The stresses in the serviceability state stage should be lower than the safety stress of the structure for this stage which is concrete pressure in operation allowable stress.

3.3.3 The Final Stage

In the final stage, the concept of composite structure should be considered, which means a new section with a higher characteristic value will be obtained. The live and traffic load will be resisted by the composite section. The characteristics of the composite section can be obtained using the following equations.

$$L_{ef} = (L_t + d) \times \lambda \ cm \tag{3.16 a}$$

$$A_k = A + \left(d \times L_{ef}\right) cm^2 \tag{3.16 b}$$

$$c_{ak} = \frac{(A \times c_a) + \left(L_{ef} \times d \times (D + d')\right)}{A_k} \ cm \tag{3.16 c}$$

$$c_{uk} = D + d - c_{ak} \ cm \tag{3.16 d}$$

$$I_k = \frac{I + (A \times (c_{ak} - ca)^2) + \left(\frac{L_{ef} \times d^3}{12}\right) + \left(L_{ef} \times d \times (c_{uk} - d')^2\right)}{10^8} \ m^4 \tag{3.16 e}$$

$$W_{ak} = \frac{I_k}{c_{ak}} \ cm^3 \tag{3.16 f}$$

$$W_{uk} = \frac{I_k}{c_{uk}} \ cm^3 \tag{3.16 g}$$

$$W_{uk\ precast} = \frac{I_k}{c_{uk} - d} \ cm^3 \tag{3.16 h}$$

$$W_{uk\ deck} = \frac{W_{uk}}{\lambda} \ cm^3 \tag{3.16 i}$$

Where:

d: The depth of the deck.

L_{ef}: The effective length of the short side of the span.

L_t: The length of the short side of the span.

d': The cover depth.

D: The depth of the section.

However, the stresses affecting the structure at the final stage can be calculated using the following equation.

$$\sigma_3 = \frac{M_{g1}}{W} \ MPa \tag{3.17 a}$$

$$\sigma_4 = \frac{P_{ef}}{A}\ MPa \qquad (3.17\ b)$$

$$\sigma_5 = \frac{P_{ef} \times e}{W}\ MPa \qquad (3.17\ c)$$

$$\sigma_6 = \frac{M_{deck}}{W}\ MPa \qquad (3.17\ d)$$

$$\sigma_7 = \frac{M_{g2}}{W_k}\ MPa \qquad (3.17\ e)$$

$$\sigma_8 = \frac{M_q}{W_k}\ MPa \qquad (3.17\ f)$$

However, summation of the stresses should be lower than the allowable stresses for the section in this stage, which are the tensile strength of the concrete in transfer, the concrete pressure in operation, the maximum compression strength in the deck, and the maximum tensile strength in the deck.

3.4 THE RESISTANCE AND CRACKING MOMENTS

The ability of the structure to resist the design moment should be checked as well as the cracking moment of the section. The design moment M_d according to the Turkish Standards TS3233 can be obtained using the following load combination:

$$M_d = (1.4 \times dead\ load\ moments) + (1.6 \times Live\ load\ moments)\ KN.m \qquad (3.18)$$

While The resisting moment of the structure can be obtained using the Turkish Standards TS 3233 method which depends on the coefficients of concrete and steel according to the Turkish Standards TS 3233, the density of the steel, the breaking strength of the steel f_{pd} as well as the bearing force for torsional moment. The value of resisting moment can be obtained using the following equations:

$$\rho_s = \frac{A_{ps}}{\left(D \times (D + d - d')\right)}\ mm^2/mm^2 \qquad (3.19\ a)$$

$$f_{pd} = \frac{f_{pu}}{\gamma_s} \times \left(1 - \left(0.4 \times \rho_s \times \left(\frac{f_{pu}}{\gamma_s} \div \frac{f_{ck\ deck}}{\gamma_c}\right)\right)\right) MPa \qquad (3.19\ b)$$

$$T = A_{ps} \times f_{pd} \ \ KN \tag{3.19 c}$$

$$a = \frac{A_{ps} \times f_{pd}}{0.85 \times \frac{f_{ck\ deck}}{\gamma_c}} \ \ mm \tag{3.19 d}$$

$$M_{res} = T \times \left(D + d - d' - \frac{a}{2}\right) \ KN.m \tag{3.19 e}$$

Where:

a: The concrete equivalent rectangular compression zone depth in mm.

According to the Turkish Standards TS3233 the value of the resistance moment must be higher than the design moment. On the other hand, the cracking moment of the section can be calculated using the following equations.

$$f_r = 0.4 \times \sqrt{f_{ck\ beam}} \ \ MPa \tag{3.20 a}$$

$$M_{dead\ loads} = M_{g1} + M_{deck} \ \ KN.m \tag{3.20 b}$$

$$\sigma_{a,pre} = 1000 \times (\sigma_{4a} + \sigma_{5a}) \ kPa \tag{3.20 c}$$

$$\sigma_{beam+deck} = 1000 \times (\sigma_{3u} + \sigma_{6u}) \ kPa \tag{3.20 d}$$

$$M_{cr} = M_{dead\ loads} + \left(\frac{I_k \times 100}{c_{ak}} \times \left(\sigma_{a,pre} + (f_r \times 1000) - \sigma_{beam+deck}\right)\right) \ KN.m \tag{3.20 e}$$

The value of the cracking moment of the section should be less than the resistance moment according to the following equation.

$$M_{res} \geq 1.2\ M_{cr} \tag{3.21}$$

In order to maintain the cracking during the transportation of the precast beam section, the position of the hook-up for the bracing equipment should be calculated and the cracking stress due to the transportation should not exceed the allowable value. Figure 3.1 shows the concept of handling the precast concrete beam.

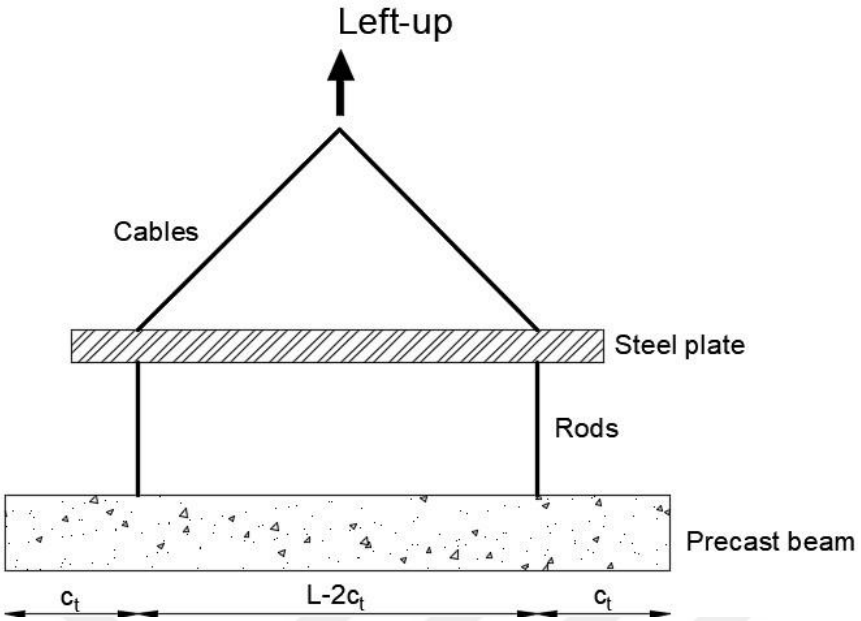

Figure 3.1: The Concept of Handling The Precast Concrete Beam.

The distance between the hook-up and the edge can be calculated using the following equations.

$$M_a = W \times \frac{c_t^2}{2}\ t.m \qquad (3.22\ a)$$

$$M_c = \frac{1}{8} \times W \times (L - 2c_t)^2 - M_a\ t.m \qquad (3.22\ b)$$

$$\sigma_a = \sigma_c\ \ kgf/cm^2 \qquad (3.22\ c)$$

$$\frac{M_a \times c_u}{I} = \frac{M_c \times C_a}{I} \qquad (3.22\ d)$$

After finding the value of c_t, The value of stresses due to the transportation multiplied by an impact factor should be less than the allowable stress for the precast section according to the following equation.

$$f_{ct} \geq Impact\ factor\ \times \sigma\ kgf/cm^2 \qquad (3.23)$$

4. DESIGN OF PRESTRESSED COMPOSITE BEAM SECTIONS

A representative geometry was adopted in this section to analyse and design the prestressed composite concrete beam sections. An I section as analysed in this part to illustrate the design method. The section was analysed under the following assumptions.

i. The concrete used in the precast section is C45 and C35 for the deck.

ii. The live and traffic loads are 3 and 16 KN/m. respectively.

iii. The deck depth is assumed to be 20 cm.

iv. The used prestressing steel is 9 pieces 0.6-inch cables of grade 270K with f_{pu} equals 1860 MPa and modulus of elasticity equals 1.965×10^5 MPa.

v. The humidity ratio is 60%.

vi. The concrete cover for the prestressing steel is assumed to be 10 cm.

vii. The span length is assumed to be 17 m and the short side span length is 80 cm with an impact factor value for transportation equal 2.

4.1 THE MATERIAL CHARACTERISTICS

4.1.1 Section Characteristics

The characteristics of the section are assumed to be as shown in Table 4.1 and Figure 4.1 shows the shape of the assumed section.

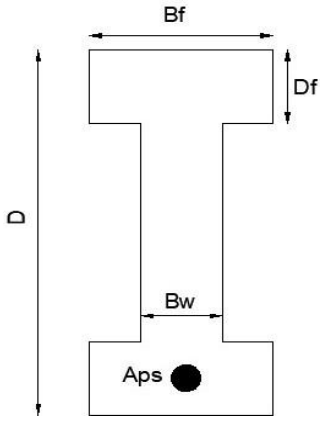

Figure 4.1: The Assumed Section Shape.

Table 4.1: The Characteristics of The Assumed Section.

Characteristic	Value
The width of the flange B_f [mm]	350
The depth of the flange D_f [mm]	200
The width of the web B_w [mm]	200
The depth of the section D [mm]	1000
The span length [m]	17
The area of the section A [mm^2]	260000

Due to the symmetry of the section, the distance from the bottom of the section to the centroid c_a equals the distance from the top of the section to the centroid c_u which equals 50 cm. The Moment of inertia for the section can be obtained as follows.

$$I = \left(2 \times \frac{35 \times 20^3}{12}\right) + \left(2 \times 35 \times 20 \times \left(50 - \frac{20}{2}\right)^2\right) + \left(\frac{20 \times 60^3}{12}\right) = 2646666.67\ cm^4$$

Also, due to the symmetry of the section, the section moduli for the bottom of the section W_a equals the section moduli for the top of the section W_u and can be calculated as follows.

$$W_a = W_u = \frac{2646666.67}{50} = 52933.33\ cm^3$$

Since the depth of the centroid is 50 cm, then the clear distance between the prestressing steel and the centroid (the eccentricity) is equal 40 cm.

The self-weight of the concrete and the moment due to it can be calculated as follows.

$$W_1 = 0.26 \times 24 = 6.24\ KN/m$$

$$M_{g1} = \frac{6.24 \times 17^2}{8} = 225.42\ KN.m$$

4.1.2 Concrete Characteristics

For the prestressed beam sections a concrete of type C45 is used, and while the compressive strength of this type f_{ck} is 45 Mpa the characteristic compressive strength of "j" days old concrete can be determined as follows.

$$f_{cjk} = 0.75 \times 45 = 33.75\ MPa$$

The modulus of elasticity for the concrete and for the concrete in transfer can be calculated as follows.

$$E_{45} = \left(3250 \times \sqrt{45}\right) + 14000 = 35801.66\ MPa$$

$$E_{45j} = \left(3250 \times \sqrt{33.75}\right) + 14000 = 32880.79\ MPa$$

The used cast-in-place concrete is C35 type concrete with a compressive strength of 35 Mpa, the modulus of elasticity is obtained as shown.

$$E_{c35} = \left(3250 \times \sqrt{35}\right) + 14000 = 33227.26\ MPa$$

4.1.3 Prestressing Steel

In the design, 9 pieces of 270K cables were used with a 0.6-inch diameter. The area of each piece is 140 mm^2, with an ultimate strength f_{pu} 1860 Mpa with a total area A_{ps} 1260 mm^2. The initial prestressing force can be obtained as shown.

$$f_{pi} = 0.75 \times 1860 = 1395\ MPa$$

$$P_i = \frac{1260 \times 1860}{1000} = 1757.70\ KN$$

Since the prestressed beam section is pre-tensioned, the losses in prestressing are the elastic shortening, shrinkage, creeping and steel relaxation losses. The total percentage losses are the summation of these losses. The losses as obtained as follows.

The elastic shortening loss percentage can be obtained as follows.

$$N_p = \frac{1.965 \times 10^5}{32880.79} = 5.98$$

$$i^2 = \frac{0.02647}{0.26} = 0.1\ m^2$$

$$\Delta P = \left(\left(\frac{1757.70}{0.26} \times (1 + \left(\frac{0.4^2}{0.1}\right)) - \frac{225.42 \times 0.4}{0.02647}\right)\right) \times (5.98 \times 1260 \times 10^{-6}) = 105.26\ KN$$

$$L_{s\ elastic\ shortening} = \frac{105.26}{1757.70} \times 100\% = 5.99\%$$

The percentage of the shrinkage loss is obtained as follows.

$$\Delta P = \left(117.21 - (1.034 \times 60)\right) \times 1260 \times 10^{-3} = 69.51\ KN$$

$$L_{s\ shrinkage} = \frac{69.51}{1757.70} \times 100\% = 3.95\%$$

The percentage of the creep loss is calculated as follows.

$$\varepsilon_{creep} = \left(\frac{\frac{3 \times 33.75}{8}}{0.1}\right) \times \left(\frac{35 \times 48 \times 10^{-7}}{33.75}\right) = 0.00063$$

$$\Delta P = 0.00063 \times 1.965 \times 10^5 \times 1260 \times 10^{-3} = 155.98\ KN$$

$$L_{s\ creep} = \frac{155.98}{1757.70} \times 100\% = 8.87\%$$

The percentage of the relaxation loss is obtained as follows.

$$CRs = 137.88 - (0.4 \times 105.26) - (0.2 \times (69.51 + 155.98) = 50.67\ KN$$

$$L_{s\ creep} = \frac{50.67}{1757.70} \times 100\% = 2.88\%$$

The total percentage of the losses equals 21.70% of the total prestressing.

The value of the effective prestressing is obtained as follows.

$$f_{pef} = (1 - 0.217) \times 1395 = 1092.27\ \ MPa$$

$$P_{ef} = 1260 \times 1092.27 \times 10^{-3} = 1376.26\ \ KN$$

4.1.4 The Safety Stresses of The Structure

The value of the allowable stresses for the precast section in the transfer stage are calculated as follows.

$$\sigma_{ci} = 0.4 \times 33.75 = 13.5\ MPa$$

$$\sigma_{cti} = 0.5 \times \sqrt{33.75} = 2.90\ MPa$$

On the other hand, the values of the allowable stresses for the precast section in the service stage are obtained as follows.

$$\sigma_{cp} = 0.4 \times 45 = 18\ MPa$$

$$\sigma_{ctp} = 0.5 \times \sqrt{45} = 3.35\ MPa$$

The values of the allowable stresses for the cast-in-situ deck are obtained as follows.

$$\sigma_{c,em} = 0.4 \times 35 = 14\ MPa$$

$$\sigma_{t,em} = 0.5 \times \sqrt{35} = 2.96\ MPa$$

The value of cracking resistance due to the transportation is obtained as follows.

$$f_{ct} = 2.2 \times \sqrt{458.87} = 47.13\ kgf/cm^2$$

4.2 DESIGN OF THE STRUCTURE FOR THE SAFETY STRESSES

4.2.1 The Loads Affecting The Structure

The moments affecting the structure due to the deck weight, live load and traffic load are obtained respectively as follows.

$$M_{deck} = \frac{1 \times 0.2 \times 24 \times 17^2}{8} = 173.40\ KN.m$$

$$M_{g2} = \frac{3 \times 17^2}{8} = 108.38\ KN.m$$

$$M_q = \frac{16 \times 17^2}{8} = 578.00\ KN.m$$

4.2.2 Stresses at Transmission Stage

The value of the stresses affecting the precast section in the transmission stage for the bottom and the top of the section while taking into consideration the sign convention is obtained as follows.

$$\sigma_{1a} = \frac{1757.70}{\frac{260000}{10^3}} = 6.76\ MPa$$

$$\sigma_{1u} = \frac{1757.70}{\frac{260000}{10^3}} = 6.76\ MPa$$

$$\sigma_{2a} = \frac{1757.70 \times 0.4}{\frac{52933.33}{10^3}} = 13.28\ MPa$$

$$\sigma_{2u} = \frac{-1757.70 \times 0.4}{\frac{52933.33}{10^3}} = -13.28\ MPa$$

$$\sigma_{3a} = \frac{-225.42}{\frac{52933.33}{10^3}} = -4.26\ MPa$$

$$\sigma_{3u} = \frac{225.42}{\frac{52933.33}{10^3}} = 4.26\ MPa$$

The stresses affecting the structure in the transmission stage and the allowable stresses can be summarized in Table 4.2.

Table 4.2: Stresses at Transmission Stage In MPa.

Stress [MPa]	Bottom of the beam	Top of the beam
σ_1 [MPa]	6.76	6.76
σ_2 [MPa]	13.28	-13.28
σ_3 [MPa]	-4.26	4.26
The Total stress [MPa]	15.78	-2.26
Allowable stresses [MPa]	**13.50**	**-2.90**

According to the values above, the total stresses at the bottom of the beam exceeds the allowable values so that, the section dimensions should be modified. Table 4.3 shows the characteristics of the modified section.

Table 4.3: The Characteristics of The Modified Section.

Characteristic	Value
The width of the flange B_f [mm]	450
The depth of the flange D_f [mm]	200
The width of the web B_w [mm]	200
The depth of the section D [mm]	1000
The area of the section A [mm^2]	300000
The moment of inertia of the section I [cm^4]	3300000.00
The distance from the bottom to the centroid of the section C_a [cm]	50.00
The distance from the top to the centroid of the section C_u [cm]	50.00
The section moduli of the bottom of the section W_a [cm^3]	66000.00
The section moduli of the top of the section W_u [cm^3]	66000.00

By changing the dimensions of the section, the value of the losses in prestressing should be recalculated as well as the effective prestressing force. The percentage of losses in prestressing under the new section characteristics equals 20.99% and the value of the effective prestressing P_{ef} equals 1388.69 Kn. Under the new conditions, the value of stresses affecting the section in the transmission stage and the allowable stresses can be summarized in Table 4.4.

Table 4.4: The Stresses at Transmission Stage for The Modified I Section In MPa.

Stress [MPa]	Bottom of the beam	Top of the beam
$\boldsymbol{\sigma}_1$ [MPa]	5.86	5.86
$\boldsymbol{\sigma}_2$ [MPa]	10.65	-10.65
$\boldsymbol{\sigma}_3$ [MPa]	-3.94	3.94
The Total stress [MPa]	12.57	-0.85
Allowable stresses [MPa]	**13.50**	**-2.90**

The summation of stresses affecting the section is less than the allowable stresses for the section, which means that the section is comfortable in the transmission stage.

4.2.3 Stresses at Serviceability State Stage

The value of the stresses affecting the precast section in the Serviceability state stage for the bottom and the top of the are obtained as follows.

$$\sigma_{3a} = \frac{-260.10}{\frac{66000}{10^3}} = -3.94\ MPa$$

$$\sigma_{3u} = \frac{260.10}{\frac{66000}{10^3}} = 3.94\ MPa$$

$$\sigma_{4a} = \frac{1388.69}{\frac{300000}{10^3}} = 4.63\ MPa$$

$$\sigma_{4u} = \frac{1388.69}{\frac{300000}{10^3}} = 4.63\ MPa$$

$$\sigma_{5a} = \frac{1388.69 \times 0.4}{\frac{66000}{10^3}} = 8.42\ MPa$$

$$\sigma_{5u} = \frac{-1388.69 \times 0.4}{\frac{66000}{10^3}} = -8.42\ MPa$$

$$\sigma_{6a} = \frac{-173.40}{\frac{66000}{10^3}} = -2.63\ MPa$$

$$\sigma_{6u} = \frac{173.40}{\frac{66000}{10^3}} = 2.63\ MPa$$

The stresses affecting the structure in the serviceability state stage and the allowable stresses can be summarized in Table 4.5.

Table 4.5: The Stresses at Serviceability State Stage In MPa.

Stresses	Bottom of the beam	Top of the beam
$\boldsymbol{\sigma}_4$ [MPa]	4.63	4.63
$\boldsymbol{\sigma}_5$ [MPa]	8.42	-8.42
$\boldsymbol{\sigma}_3$ [MPa]	-3.94	3.94
$\boldsymbol{\sigma}_6$ [MPa]	-2.63	2.63
The total stress [MPa]	6.48	2.78
Allowable stresses [MPa]	**18.00**	**18.00**

The stresses affecting the section is less than the allowable stresses for the section, which means that the section is comfortable in the serviceability state stage. Figure 4.2 shows the shape and the dimensions of the structure in the serviceability state stage.

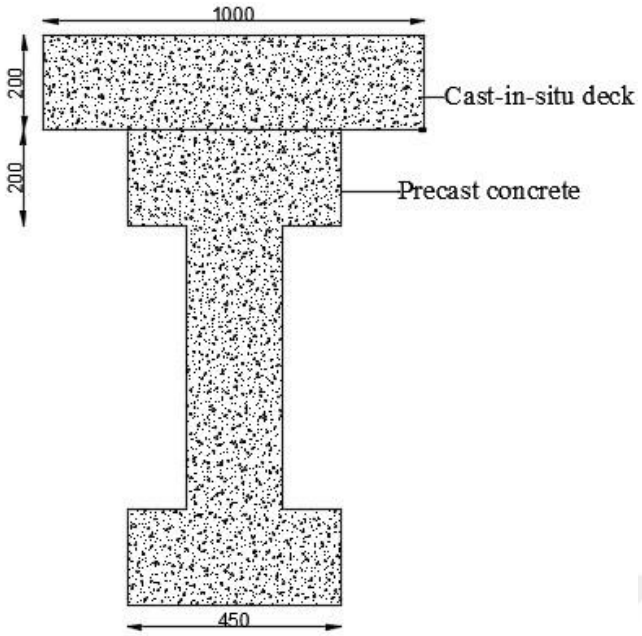

Figure 4.2: The Shape of The Structure at Serviceability State Stage.

4.2.4 Stresses at Final Stage

The characteristics of the composite section can be obtained as follows.

$$L_{ef} = (80 + 20) \times 0.9281 = 92.81\ cm$$

$$A_k = 3000 + (20 \times 92.81) = 4856.19\ cm^2$$

$$c_{ak} = \frac{(3000 \times 50) + (92.81 \times 20 \times 110)}{4856.19} = 72.93\ cm$$

$$c_{uk} = 100 + 20 - 72.93 = 47.07\ cm$$

$$I_k = \frac{3300000 + (3000 \times 22.93^2 + \left(\frac{92.81 \times 20^3}{12}\right) + (92.81 \times 20 \times 37.07^2}{10^8}$$

$$= 0.0749\ m^4$$

$$W_{ak} = \frac{0.0749 \times 10^8}{72.93} = 102695.35\ cm^3$$

$$W_{uk} = \frac{0.0749 \times 10^8}{47.07} = 159137.13\ cm^3$$

$$W_{uk\ precast} = \frac{0.0749 \times 10^8}{27.07} = 276728.47\ cm^3$$

$$W_{uk\ deck} = \frac{159137.13}{0.9281} = 171466.87\ cm^3$$

Figure 4.3 illustrates the shape and the dimensions of the composite section.

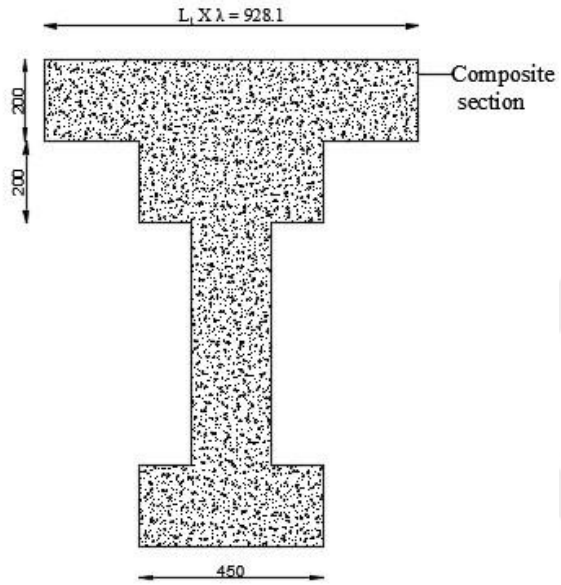

Figure 4.3: The Shape of The Composite Section.

The stresses affecting the structure in the final stage are the same as serviceability state stage in addition to the stresses due to the live and traffic loads. The values of live and traffic load stresses are obtained as follows.

$$\sigma_{7a} = \frac{-108.38}{\frac{102695.35}{10^3}} = -1.06\ MPa$$

$$\sigma_{7u} = \frac{108.38}{\frac{276728.47}{10^3}} = 0.39\ MPa$$

$$\sigma_{7u\ deck} = \frac{108.38}{\frac{171466.87}{10^3}} = 0.63\ MPa$$

$$\sigma_{8a} = \frac{-578.00}{\frac{102695.35}{10^3}} = -5.63\ MPa$$

$$\sigma_{8u} = \frac{578.00}{\frac{276728.47}{10^3}} = 2.09\ MPa$$

$$\sigma_{8u\ deck} = \frac{578.00}{\frac{171466.87}{10^3}} = 3.37\ MPa$$

$$\sigma_{a\ deck} = 0.9281 \times (0.39 + 2.09) = 2.67\ MPa$$

The stresses affecting the structure in the final stage can be summarized in Table 4.6.

Table 4.6: The Stresses at The Final Stage In MPa.

Stress [MPa]	Bottom of the beam	Top of the beam	Top of the deck	Bottom of the deck
σ_4 [MPa]	4.63	4.63	-	-
σ_5 [MPa]	8.42	-8.42	-	-
σ_3 [MPa]	-3.94	3.94	-	-
σ_6 [MPa]	-2.63	2.63	-	-
σ_7 [MPa]	-1.06	0.39	0.63	0.36
σ_8 [MPa]	-5.63	2.09	3.37	1.94
Total stresses [MPa]	-0.21	5.26	4.00	2.30
Allowable stresses [MPa]	**-3.35**	**18.00**	**14.00**	**2.96**

The stresses affecting the section is less than the allowable stresses for the section, which means that the section is comfortable in the final stage. However, Figure 4.4 shows the stress diagram for the section at the top and bottom of the deck as well as the top and the bottom of the precast section.

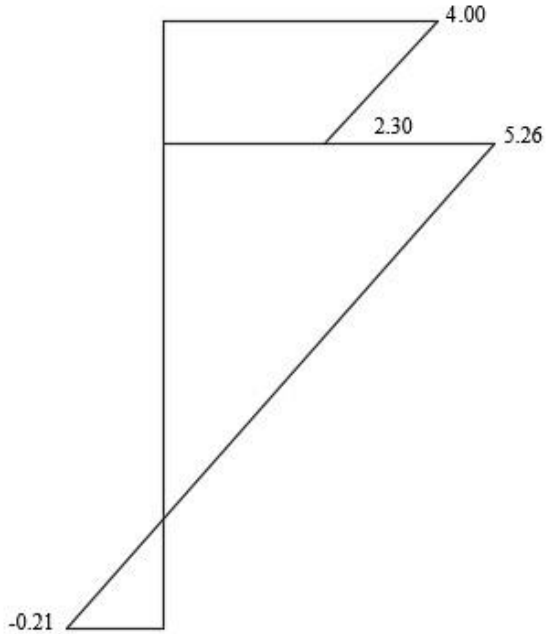

Figure 4.4: Stress Diagram for The Section.

4.3 DESIGN FOR RESISTANCE AND CRACKING MOMENTS

The value of the design load affecting the structure is obtained as follows.

$$M_d = \big(1.4 \times (260.10 + 173.40)\big) + \big(1.6 \times (108.38 + 578.00)\big) = 1705.10\ KN.m$$

The value of the ability of structure to resist the design load is calculated as follows.

$$\rho_s = \frac{1260}{(1000 \times (1000 + 200 - 100)} = 0.00114545\ mm^2/mm^2$$

$$f_{pd} = \frac{1860}{1.15} \times \left(1 - \left(0.4 \times 0.00114545 \times \left(\frac{1860}{1.15} \div \frac{35}{1.5}\right)\right)\right) = 1566.02\ MPa$$

$$T = \frac{1260 \times 1566.02}{1000} = 1973.19\ KN$$

$$a = \frac{1260 \times 1566.02}{0.85 \times \frac{35}{1.5} \times 1000} = 99.49\ mm$$

$$M_{res} = \frac{1973.19 \times \left(1000 + 200 - 100 - \frac{99.49}{2}\right)}{1000} = 2072.35\ KN.m$$

The ability of the structure is higher than the design moment. Also, the cracking moment of the section has been calculated as follows.

$$f_r = 0.4 \times \sqrt{45} = 2.6833\ MPa$$

$$M_{dead\ loads} = 260.10 + 173.40 = 433.2\ KN.m$$

$$\sigma_{a,pre} = 1000 \times (4.63 + 8.42) = 13050\ kPa$$

$$\sigma_{beam+deck} = 1000 \times (3.94 + 2.63) = 6570\ kPa$$

$$M_{cr} = 433.2 + \left(\frac{0.0749 \times 100}{72.93} \times (12850 + 2683.3 - 6570)\right) = 1374.23\ KN.m$$

$$2072.35 > 1649.01\ KN.m$$

According to the analysis above, dimensions of the section is suitable for such a design. Thus, the distance between the hook-up and the edge of the section has been calculated as follows.

$$M_a = 0.72 \times \frac{c_t^2}{2} = 0.63c_t^2\ \ t.m$$

$$M_c = \frac{1}{8} \times 0.72 \times (17 - 2c_t)^2 - 0.63c_t^2\ \ t.m$$

$$\frac{0.63c_t^2 \times 0.5}{0.033} = \frac{0.09 \times (17 - 2c_t)^2 \times 0.5}{0.033}$$

$$c_t = 3.52\ m$$

$$\sigma_a = \sigma_c = \frac{0.63 \times 3.52^2 \times 0.5}{0.033} \times 0.1 = 6.76\ kgf/cm^2$$

$$13.52 < 47.13\ kgf/cm^2$$

According to the results above, the distance between each hook-up and the edge of the beam is 3.52 m.

5. DESIGN OF BEAMS IN BRIDGE AND HOUSING SPANS

5.1 INTRODUCTION

In order to facilitate the designing of prestressed composite concrete beam sections an Excel spreadsheet was programmed. The spreadsheet is programmed to design different types of sections which are two I sections, a T section, a rectangular section, a rectangular hollow section, and a Tee section. However, The shape of the Tee section is shown in Figure 5.1.

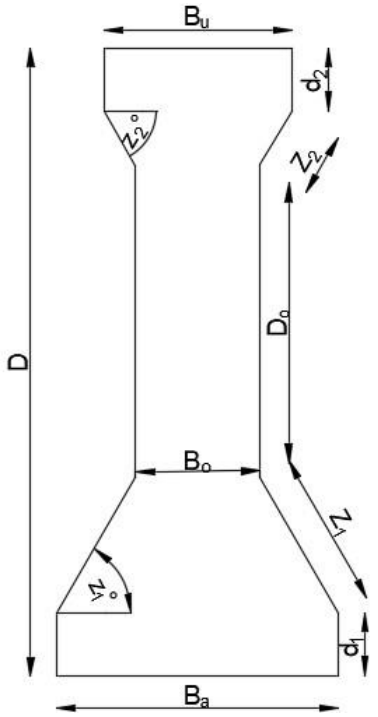

Figure 5.1: The Shape of The Tee Section.

5.2 DESIGNING SECTIONS USING EXCEL SPREADSHEET

For designing the prestressed composite concrete beam sections first, the loads affecting the structure such as live load, traffic load, the depth of the deck, and the span length should be entered to the spreadsheet. Secondly, the characteristics of the concrete should be entered, then the type of the prestressing steel and the percentage of humidity should be entered. After that, the distance between sections (the length of the short side of the span) should be entered. The excel spreadsheet is giving the value of stresses affecting the structure in every stage of the three stages and calculating the resistance and cracking as well as the design moments

for the structure. As well, the spreadsheet is designed for calculating different spacing between the sections.

For using the spreadsheet, a structure contains the five sections was designed. The design has been done by taking the characteristics of the concrete and the prestressing steel as well as the loads and span length same as the previous chapter. While the distance between the section is as shown in Table 5.1, the dimensions of the sections are obtained as in Table 5.2, Table 5.3, and Table 5.4, respectively.

Table 5.1: The Distance Between The Sections In cm.

Section	Distance [cm]
I_1 section	80
T section	100
Rectangular section	65
I_2 section	75
Rectangular hollow section	80
Tee section	110

Table 5.2: The Obtained Dimensions for The Sections.

Section	B_f [mm]	D [mm]	D_f [mm]	B_w [mm]	Length [m]
I_1 section	450	1000	200	200	17
T section	700	1000	200	300	17
Rectangular section	350	1000	-	-	17
I_2 section	450	1000	200	200	17

Table 5.3: The Obtained Dimensions for The Rectangular Hollow Section.

Characteristic	Value
B_o [mm]	500
D_o [mm]	1000
B_i [mm]	300
D_i [mm]	500
Length [m]	17

Table 5.4: The Obtained Dimensions for The Tee Section.

Characteristic	Value	Characteristic	Value
B_a [mm]	450	Z_2 [mm]	100
d_1 [mm]	100	Z_2 [^{o}]	60
Z_1 [mm]	250	d_2 [mm]	100
Z_1 [^{o}]	60	B_u [mm]	300
B_o [mm]	200	D [mm]	1003.11
D_o [mm]	500	Length [m]	17

The shape of the I_1, T, rectangular, I_2, rectangular hollow, and Tee sections with the shape of the deck are shown in Figure 5.2, Figure 5.3, Figure 5.4, Figure.5.5, Figure 5.6, and Figure 5.7, respectively.

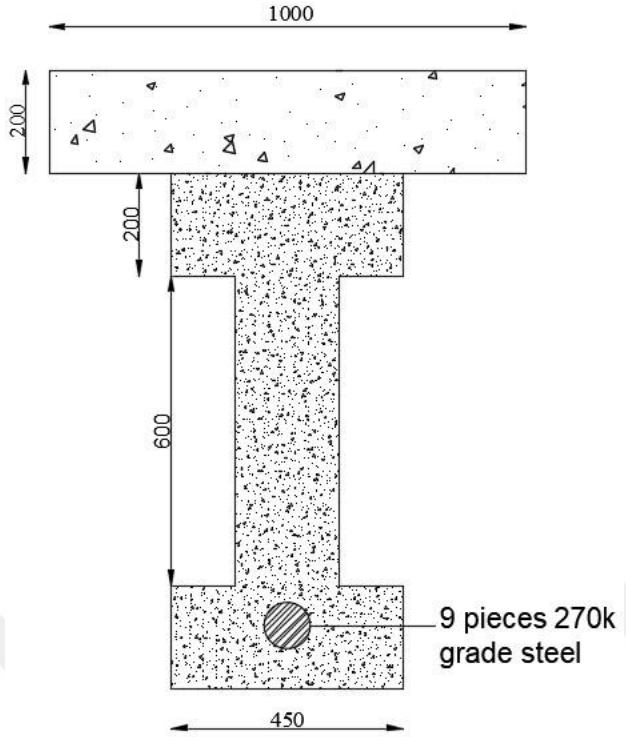

Figure 5.2: The Shape of I_1 Section With The Deck.

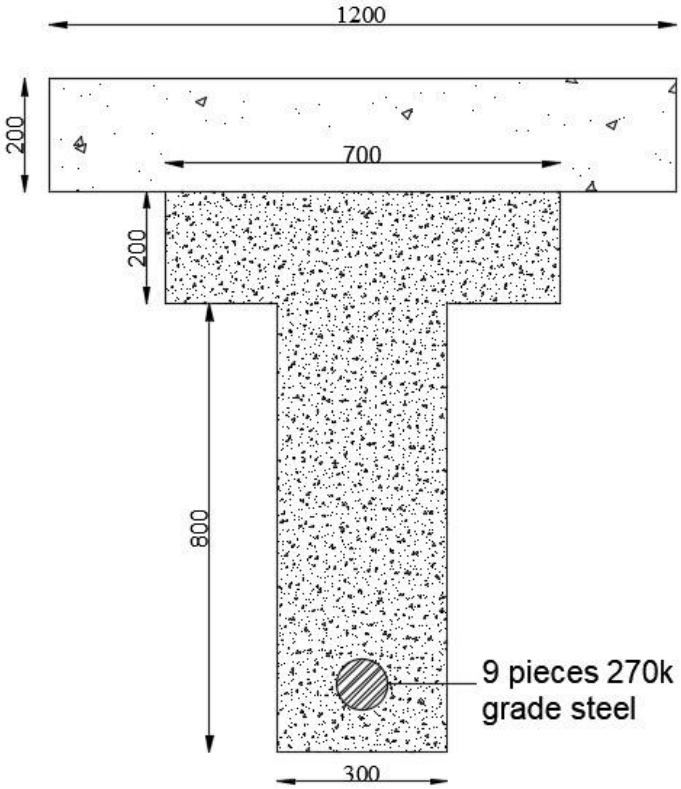

Figure 5.3: The Shape of T Section With The Deck.

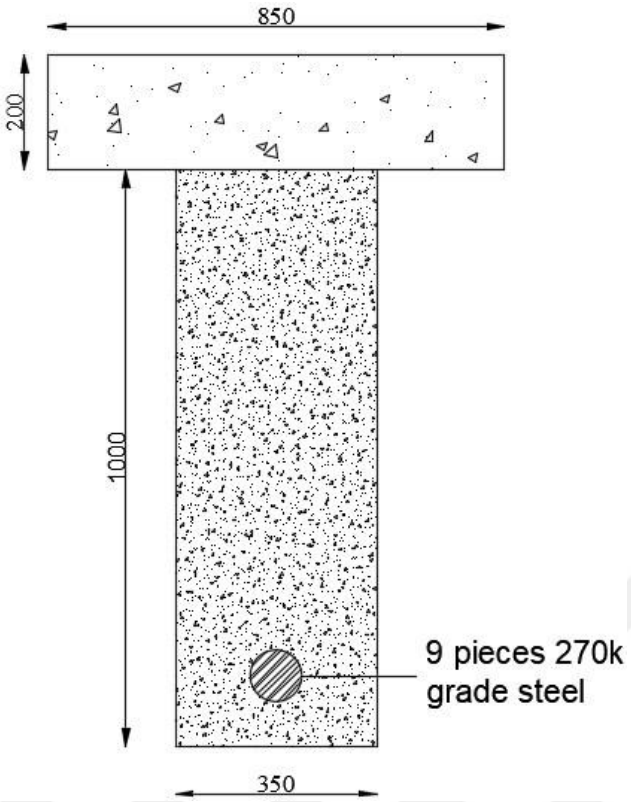

Figure 5.4: The Shape of Rectangular Beam With The Deck.

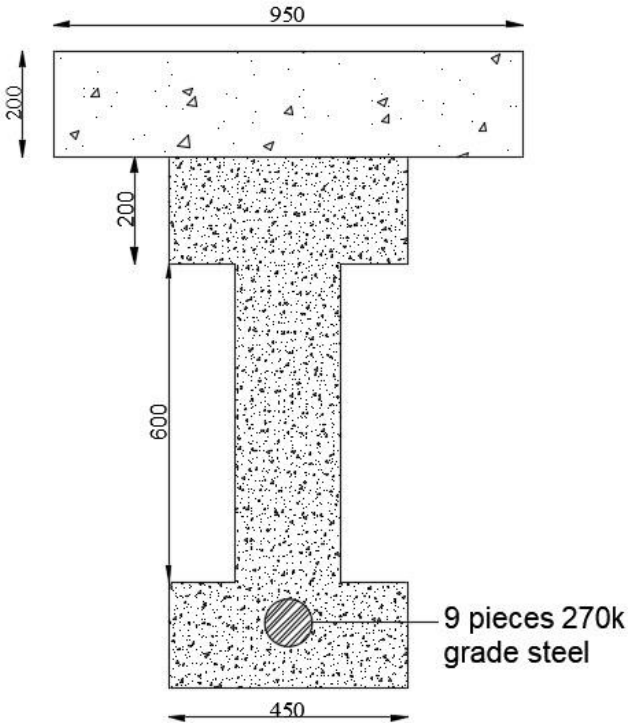

Figure 5.5: The Shape of I_2 Section With The Deck.

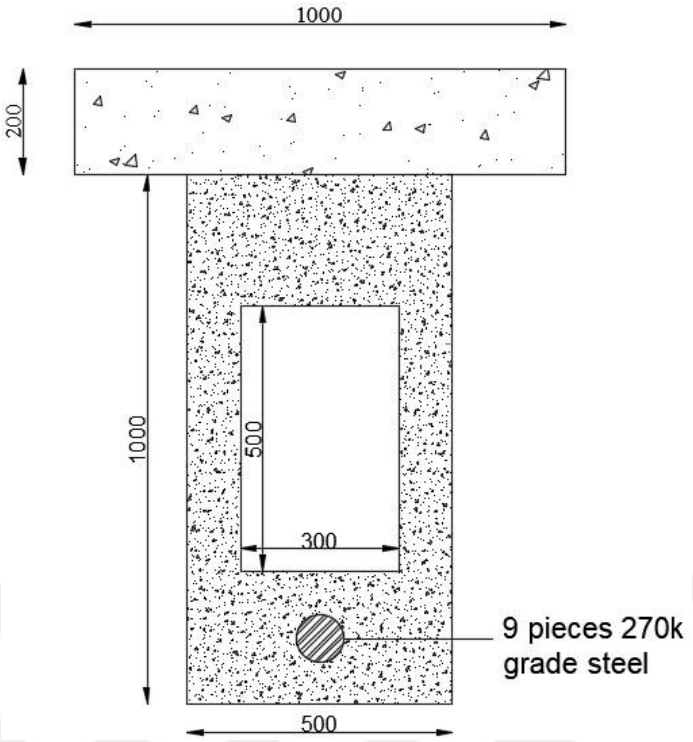

Figure 5.6: The Shape of Rectangular Hollow Section With The Deck.

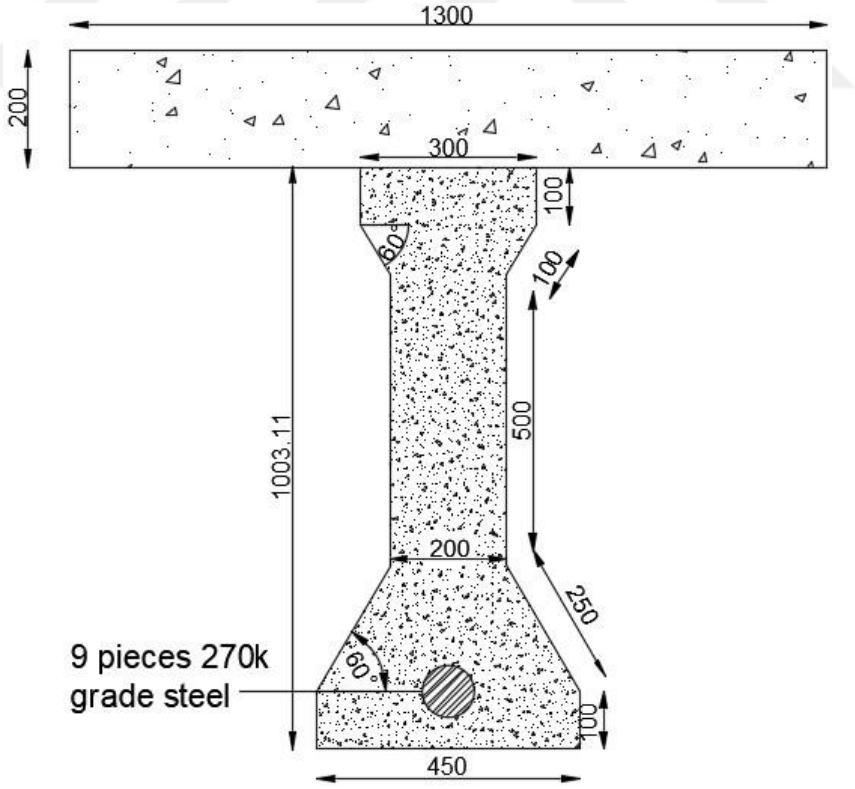

Figure 5.7: The Shape of Tee Section With The Deck.

5.2.1 The Resulting Values Using The Programmed Excel Spreadsheet

5.2.1.1 The safety stresses of the structure

The safety stresses of the structure has been obtained by using the Excel spreadsheet, the values of safety stresses in MPa are shown in Table 5.5 as obtained.

Table 5.5: The Safety Stresses for The Structure In MPa.

Safety stress [MPa]	Value
σ_{ci} [MPa]	13.50
σ_{cti} [MPa]	2.90
σ_{cp} [MPa]	18.00
σ_{ctp} [MPa]	3.35
$\sigma_{c,\,em}$ [MPa]	14.00
$\sigma_{t,\,em}$ [MPa]	2.90

5.2.1.2 The prestressing losses

The calculation of losses in the initial prestressing force as a percentage and the effective prestressing steel force has been obtained using the programmed Excel Spreadsheet for I_1, T, rectangular, I_2, rectangular hollow, and Tee sections can be shown in Table 5.6, Table 5.7, Table 5.8, Table 5.9, Table 5.10, and Table 5.11, respectively.

Table 5.6: The Effective Prestressing Force for I_1 Section.

Elastic shortening losses for the section		**Shrinkage losses for the section**	
Variable	**Value**	**Variable**	**Value**
E_{cj} [MPa]	32880.79	Humidity %	60
E_{ps} [MPa]	196500.58	$\Delta\sigma$ [MPa]	55.17
A_{ps} [mm^2]	1260.00	ΔP [KN]	69.51
N_p	5.98	Loss ratio %	3.95
A [m^2]	0.300	**Creep losses for the section**	
I [m^4]	0.033	Final creep strain [mm]	0.000004978
i^2 [m^2]	0.11	Greatest stress [MPa]	12.66
e [m]	0.40	ε_{creep}	0.000630
W_1 [KN/m]	7.20	Δf_p [MPa]	123.80
M_{g1} [KN.m]	260.10	ΔP [KN]	155.98
f_c [KN.m]	11228.45	Loss ratio %	8.87
Δf_p [MPa]	67102.94	**Steel relaxation losses for the section**	
ΔP [KN]	84.55	CR_s [KN]	58.96
Loss ratio %	4.81	Loss ratio %	3.35
The effective prestressing force in the section			
Variable	Total losses %	F_{pef} [MPa]	P_{ef} [KN]
Value	**20.99**	**1102.14**	**1388.69**

Table 5.7: The Effective prestressing force for T Section.

Elastic shortening losses for the section		**Shrinkage losses for the section**	
Variable	**Value**	**Variable**	**Value**
E_{cj} [MPa]	32880.79	Humidity %	60
E_{ps} [MPa]	196500.58	$\Delta\sigma$ [MPa]	55.17
A_{ps} [mm^2]	1260.00	ΔP [KN]	69.51
N_p	5.98	Loss ratio %	3.95
A [m^2]	0.38	**Creep losses for the section**	
I [m^4]	0.04	Final creep strain [mm]	0.000004978
i^2 [m^2]	0.09	Greatest stress [MPa]	12.66
e [m]	0.484	ε_{creep}	0.000630
W_1 [KN/m]	9.12	Δf_p [MPa]	123.80
M_{g1} [KN.m]	329.46	ΔP [KN]	155.98
f_c [KN.m]	11766.27	Loss ratio %	8.87
Δf_p [MPa]	70317.03	**Steel relaxation losses for the section**	
ΔP [KN]	88.60	CR_s [KN]	57.34
Loss ratio %	5.04	Loss ratio %	3.26
The effective prestressing force in the section			
Variable	Total losses %	F_{pef} [MPa]	P_{ef} [KN]
Value	**21.13**	**1100.21**	**1386.26**

Table 5.8: The Effective Prestressing Force for Rectangular Section.

Elastic shortening losses for the section		**Shrinkage losses for the section**	
Variable	**Value**	**Variable**	**Value**
E_{cj} [MPa]	32880.79	Humidity %	60
E_{ps} [MPa]	196500.58	$\Delta\sigma$ [MPa]	55.17
A_{ps} [mm^2]	1260.00	ΔP [KN]	69.51
N_p	5.98	Loss ratio %	3.95
A [m^2]	0.35	**Creep losses for the section**	
I [m^4]	0.03	Final creep strain [mm]	0.000004978
i^2 [m^2]	0.08	Greatest stress [MPa]	12.66
e [m]	0.40	ε_{creep}	0.000630
W_1 [KN/m]	8.40	Δf_p [MPa]	123.80
M_{g1} [KN.m]	303.45	ΔP [KN]	155.98
f_c [KN.m]	10502.64	Loss ratio %	8.87
Δf_p [MPa]	62765.36	**Steel relaxation losses for the section**	
ΔP [KN]	79.08	CR_s [KN]	61.15
Loss ratio %	4.50	Loss ratio %	3.48
The effective prestressing force in the section			
Variable	Total losses %	F_{pef} [MPa]	P_{ef} [KN]
Value	**20.81**	**1104.74**	**1391.97**

Table 5.9: The Effective Prestressing Force for I_2 Section.

Elastic shortening losses for the section		**Shrinkage losses for the section**	
Variable	**Value**	**Variable**	**Value**
E_{cj} [MPa]	32880.79	Humidity %	60
E_{ps} [MPa]	196500.58	$\Delta\sigma$ [MPa]	55.17
A_{ps} [mm^2]	1260.00	ΔP [KN]	69.51
N_p	5.98	Loss ratio %	3.95
A [m^2]	0.300	**Creep losses for the section**	
I [m^4]	0.033	Final creep strain [mm]	0.000004978
i^2 [m^2]	0.11	Greatest stress [MPa]	12.66
e [m]	0.40	ε_{creep}	0.000630
W_1 [Kn/m]	7.20	Δf_p [MPa]	123.80
M_{g1} [KN.m]	260.10	ΔP [KN]	155.98
f_c [KN.m]	11228.45	Loss ratio %	8.87
Δf_p [MPa]	67102.94	**Steel relaxation losses for the section**	
ΔP [KN]	84.55	CR_s [KN]	58.96
Loss ratio %	4.81	Loss ratio %	3.35
The effective prestressing force in the section			
Variable	Total losses %	F_{pef} [MPa]	P_{ef} [KN]
Value	**20.99**	**1102.14**	**1388.69**

Table 5.10: The Effective Prestressing Force for Rectangular Hollow Section.

Elastic shortening losses for the section		**Shrinkage losses for the section**	
Variable	**Value**	**Variable**	**Value**
E_{cj} [MPa]	32880.79	Humidity %	60
E_{ps} [MPa]	196500.58	$\Delta\sigma$ [MPa]	55.17
A_{ps} [mm^2]	1260.00	ΔP [KN]	69.51
N_p	5.98	Loss ratio %	3.95
A [m^2]	0.35	**Creep losses for the section**	
I [m^4]	0.04	Final creep strain [mm]	0.000004978
i^2 [m^2]	0.11	Greatest stress [MPa]	12.66
e [m]	0.40	ε_{creep}	0.000630
W_1 [KN/m]	8.40	Δf_p [MPa]	123.80
M_{g1} [KN.m]	303.45	ΔP [KN]	155.98
f_c [KN.m]	9169.51	Loss ratio %	8.87
Δf_p [MPa]	54798.38	**Steel relaxation losses for the section**	
ΔP [KN]	69.05	CR_s [KN]	65.16
Loss ratio %	3.93	Loss ratio %	3.71
The effective prestressing force in the section			
Variable	Total losses %	F_{pef} [MPa]	P_{ef} [KN]
Value	**20.46**	**1109.52**	**1398.00**

Table 5.11: The Effective Prestressing Force for Tee Section.

Elastic shortening losses for the section		**Shrinkage losses for the section**	
Variable	**Value**	**Variable**	**Value**
E_{cj} [MPa]	32880.79	Humidity %	60
E_{ps} [MPa]	196500.58	$\Delta\sigma$ [MPa]	55.17
A_{ps} [mm^2]	1260.00	ΔP [KN]	69.51
N_p	5.98	Loss ratio %	3.95
A [m^2]	0.27	**Creep losses for the section**	
I [m^4]	0.031	Final creep strain [mm]	0.000004978
i^2 [m^2]	0.12	Greatest stress [MPa]	12.66
e [m]	0.36	ε_{creep}	0.000630
W_1 [KN/m]	6.41	Δf_p [MPa]	123.80
M_{g1} [KN.m]	231.50	ΔP [KN]	155.98
f_c [KN.m]	11072.24	Loss ratio %	8.87
Δf_p [MPa]	66169.36	**Steel relaxation losses for the section**	
ΔP [KN]	83.37	CR_s [KN]	59.43
Loss ratio %	4.74	Loss ratio %	3.38
The effective prestressing force in the section			
Variable	Total losses %	F_{pef} [MPa]	P_{ef} [KN]
Value	**20.95**	**1102.70**	**1389.40**

5.2.1.3 The characteristics of the sections

The characteristics of each section has been obtained by the spreadsheet as shown in Table 5.12.

Table 5.12: The Characteristics of The Sections.

Section	Area [cm^2]	C_a [cm]	C_u [cm]	I [m^4]	W_a [cm^3]	W_u [cm^3]
I_1 section	3000.00	50.00	50.00	0.033000	66000.00	66000.00
T section	3800.00	58.42	41.58	0.035372	60546.55	85071.73
Rectangular section	3500.00	50.00	50.00	0.029167	58333.33	58333.33
I_2 section	3000.00	50.00	50.00	0.033000	66000.00	66000.00
Hollow rectangular section	3500.00	50.00	50.00	0.038542	77083.33	77083.33
Tee section	2670.15	45.62	54.69	0.031299	68612.83	57223.97

5.2.1.4 The loads affecting the structure

The loads affecting each section has been obtained by using the programmed Excel Spreadsheet. However, the live and traffic loads have the same value on each section. Yet, the dead load and the deck weight may differ due to the usage of different spaces between the sections. Table 5.13 shows the value of loads and the moments affecting each section as obtained by the spreadsheet.

Table 5.13: The Loads and The Moments Affecting Each Section.

Load/Section	I_1 section	T section	Rectangular section	I_2 section	Rectangular hollow section	Tee section
Dead load [KN/m]	7.20	9.12	8.40	7.20	8.40	6.41
Deck load [KN/m]	4.80	5.76	4.08	4.56	4.80	6.24
Live load [KN/m]	3.00	3.00	3.00	3.00	3.00	3.00
Traffic load [KN/m]	16.00	16.00	16.00	16.00	16.00	16.00
M_{g1} [KN.m]	260.10	239.46	303.45	260.10	303.45	231.50
M_{deck} [KN.m]	173.40	208.08	147.39	164.73	173.40	225.42
M_{g2} [KN.m]	108.38	108.38	108.38	108.38	108.38	108.38
M_q [KN.m]	578.00	578.00	578.00	578.00	578.00	578.00

5.2.1.5 The stresses affecting the sections at transmission stage

The stresses affecting I_1, T, rectangular, I_2, rectangular hollow, and Tee sections at the transmission stage has been obtained using the spreadsheet as shown in Table 5.14, Table 5.15, Table 5.16, Table 5.17, Table 5.18, and Table 5.19, respectively.

Table 5.14: I_1 Section Stresses at Transmission Stage In MPa.

Stress [MPa]	Bottom of the beam	Top of the beam
$\boldsymbol{\sigma}_1$ [MPa]	5.86	5.86
$\boldsymbol{\sigma}_2$ [MPa]	10.65	-10.65
$\boldsymbol{\sigma}_3$ [MPa]	-3.94	3.94
The Total stress [MPa]	12.57	-0.85
Allowable stresses [MPa]	**13.50**	**-2.90**

Table 5.15: T Section Stresses at Transmission Stage In MPa.

Stress [MPa]	Bottom of the beam	Top of the beam
$\boldsymbol{\sigma}_1$ [MPa]	4.63	4.63
$\boldsymbol{\sigma}_2$ [MPa]	14.06	-10.00
$\boldsymbol{\sigma}_3$ [MPa]	-5.44	3.87
The Total stress [MPa]	13.24	-1.51
Allowable stresses [MPa]	**13.50**	**-2.90**

Table 5.16: Rectangular Section Stresses at Transmission Stage In MPa.

Stress [MPa]	Bottom of the beam	Top of the beam
σ_1 [MPa]	5.02	5.02
σ_2 [MPa]	12.05	-12.05
σ_3 [MPa]	-5.20	5.20
The Total stress [MPa]	11.87	-1.83
Allowable stresses [MPa]	**13.50**	**-2.90**

Table 5.17: I_2 Section Stresses at Transmission Stage In MPa.

Stress [MPa]	Bottom of the beam	Top of the beam
σ_1 [MPa]	5.86	5.86
σ_2 [MPa]	10.65	-10.65
σ_3 [MPa]	-3.94	3.94
The Total stress [MPa]	12.57	-0.85
Allowable stresses [MPa]	**13.50**	**-2.90**

Table 5.18: Rectangular Hollow Section Stresses at Transmission Stage In MPa.

Stress [MPa]	Bottom of the beam	Top of the beam
σ_1 [MPa]	5.02	5.02
σ_2 [MPa]	9.12	-9.12
σ_3 [MPa]	-3.94	3.94
The Total stress [MPa]	10.21	-0.16
Allowable stresses [MPa]	**13.50**	**-2.90**

Table 5.19: Tee Section Stresses at Transmission Stage In MPa.

Stress [MPa]	Bottom of the beam	Top of the beam
σ_1 [MPa]	6.58	6.58
σ_2 [MPa]	9.12	-10.94
σ_3 [MPa]	-3.37	3.37
The Total stress [MPa]	12.33	-0.98
Allowable stresses [MPa]	**13.50**	**-2.90**

5.2.1.6 The stresses affecting the sections at serviceability state stage

The value of the stresses affecting I_1, T, rectangular, I_2, rectangular hollow, and Tee section has been obtained as shown in Table 5.20, Table 5.21, Table 5.22, Table 5.23, Table 5.24, and Table 5.25, respectively.

Table 5.20: I_1 Section Stresses at Serviceability State Stage In MPa.

Stresses	Bottom of the beam	Top of the beam
σ_4 [MPa]	4.63	4.63
σ_5 [MPa]	8.42	-8.42
σ_3 [MPa]	-3.94	3.94
σ_6 [MPa]	-2.63	2.63
The total stress [MPa]	6.48	2.78
Allowable stresses [MPa]	**18.00**	**18.00**

Table 5.21: T Section Stresses at Serviceability State Stage In MPa.

Stresses	Bottom of the beam	Top of the beam
σ_4 [MPa]	3.65	3.65
σ_5 [MPa]	11.09	-7.89
σ_3 [MPa]	-5.44	3.87
σ_6 [MPa]	-3.44	2.45
The total stress [MPa]	5.86	2.08
Allowable stresses [MPa]	**18.00**	**18.00**

Table 5.22: Rectangular Section Stresses at Serviceability State Stage In MPa.

Stresses	Bottom of the beam	Top of the beam
σ_4 [MPa]	3.98	3.98
σ_5 [MPa]	9.54	-9.54
σ_3 [MPa]	-5.20	5.20
σ_6 [MPa]	-2.53	2.53
The total stress [MPa]	5.79	2.16
Allowable stresses [MPa]	**18.00**	**18.00**

Table 5.23: I_2 Section Stresses at Serviceability State Stage In MPa.

Stresses	Bottom of the beam	Top of the beam
σ_4 [MPa]	4.63	4.63
σ_5 [MPa]	8.42	-8.42
σ_3 [MPa]	-3.94	3.94
σ_6 [MPa]	-2.50	2.50
The total stress [MPa]	6.61	2.65
Allowable stresses [MPa]	**18.00**	**18.00**

Table 5.24: Rectangular Hollow Section Stresses at Serviceability State Stage In MPa.

Stresses	Bottom of the beam	Top of the beam
σ_4 [MPa]	3.99	3.99
σ_5 [MPa]	7.25	-7.25
σ_3 [MPa]	-3.94	3.94
σ_6 [MPa]	-2.25	2.25
The total stress [MPa]	5.06	2.93
Allowable stresses [MPa]	**18.00**	**18.00**

Table 5.25: Tee Section Stresses at Serviceability State Stage In MPa.

Stresses	Bottom of the beam	Top of the beam
σ_4 [MPa]	5.20	5.20
σ_5 [MPa]	7.21	-8.65
σ_3 [MPa]	-3.37	4.05
σ_6 [MPa]	-3.29	3.94
The total stress [MPa]	5.76	4.54
Allowable stresses [MPa]	**18.00**	**18.00**

5.2.1.7 The composite section characteristics

The characteristics of the composite sections has been obtained as shown in Table 5.26.

Table 5.26: The Characteristics of The Composite Sections.

Section	L_t [cm]	L_{ef} [cm]	A_k [cm^2]	C_{ak} [cm]	C_{uk} [cm]	I_k [m^4]	W_{ak} [cm^3]	W_{uk} [cm^3]	$W_{uk\ precast}$ [cm^3]	$W_{uk\ deck}$ [cm^3]
I_1 section	100.00	92.81	4856.19	72.93	47.07	0.07490	102695.35	159137.13	276728.47	171466.87
T section	120.00	111.37	6027.42	77.48	42.52	0.07347	94826.95	172806.08	326288.38	186194.86
Rectangular section	85.00	78.89	5077.76	68.64	51.36	0.06884	100291.45	134048.79	219547.71	144434.71
I_2 section	95.00	88.17	4763.38	72.21	47.79	0.07357	101879.38	153947.24	264747.18	165874.87
Rectangular hollow section	100.00	92.81	5356.19	70.79	49.21	0.08283	116997.00	168320.90	283581.52	181362.17
Tee section	130.00	120.65	5083.19	76.33	43.94	0.08516	111565.42	193606.40	355055.83	208606.67

5.2.1.8 The stresses affecting the sections at the final stage

The stresses affecting The sections has been obtained as shown in Table 5.27, Table 5.28, Table 5.29, Table 5.30, Table 5.31, and Table 5.32, respectively.

Table 5.27: I_1 Section Stresses at Final Stage In MPa.

Stress [MPa]	Bottom of the beam	Top of the beam	Top of the deck	Bottom of the deck
σ_4 [MPa]	4.63	4.63	-	-
σ_5 [MPa]	8.42	-8.42	-	-
σ_3 [MPa]	-3.94	3.94	-	-
σ_6 [MPa]	-2.63	2.63	-	-
σ_7 [MPa]	-1.06	0.39	0.63	0.36
σ_8 [MPa]	-5.63	2.09	3.37	1.94
Total stresses [MPa]	-0.21	5.26	4.00	2.30
Allowable stresses [MPa]	**-3.35**	**18.00**	**14.00**	**2.96**

Table 5.28: T Section Stresses at Final Stage In MPa.

Stress [MPa]	Bottom of the beam	Top of the beam	Top of the deck	Bottom of the deck
σ_4 [MPa]	3.65	3.65	-	-
σ_5 [MPa]	11.09	-7.89	-	-
σ_3 [MPa]	-5.44	3.87	-	-
σ_6 [MPa]	-3.44	2.45	-	-
σ_7 [MPa]	-1.14	0.33	0.58	0.31
σ_8 [MPa]	-6.10	1.77	3.10	1.64
Total stresses [MPa]	-1.38	4.18	3.69	1.95
Allowable stresses [MPa]	**-3.35**	**18.00**	**14.00**	**2.96**

Table 5.29: Rectangular Section Stresses at Final Stage In MPa.

Stress [MPa]	Bottom of the beam	Top of the beam	Top of the deck	Bottom of the deck
σ_4 [MPa]	3.98	3.98	-	-
σ_5 [MPa]	9.54	-9.54	-	-
σ_3 [MPa]	-5.20	5.20	-	-
σ_6 [MPa]	-2.53	2.53	-	-
σ_7 [MPa]	-1.08	0.49	0.75	0.46
σ_8 [MPa]	-5.76	2.63	4.00	2.44
Total stresses [MPa]	-1.05	5.29	4.75	2.90
Allowable stresses [MPa]	**-3.35**	**18.00**	**14.00**	**2.96**

Table 5.30: I_2 Section Stresses at Final Stage In MPa.

Stress [MPa]	Bottom of the beam	Top of the beam	Top of the deck	Bottom of the deck
σ_4 [MPa]	4.63	4.63	-	-
σ_5 [MPa]	8.42	-8.4	-	-
σ_3 [MPa]	-3.94	3.94	-	-
σ_6 [MPa]	-2.50	2.50	-	-
σ_7 [MPa]	-1.06	0.41	0.65	0.38
σ_8 [MPa]	-5.67	2.18	3.48	2.03
Total stresses [MPa]	-0.13	5.24	4.14	2.41
Allowable stresses [MPa]	**-3.35**	**18.00**	**14.00**	**2.96**

Table 5.31: Rectangular Hollow Section Stresses at Final Stage In MPa.

Stress [MPa]	Bottom of the beam	Top of the beam	Top of the deck	Bottom of the deck
σ_4 [MPa]	3.99	3.99	-	-
σ_5 [MPa]	7.25	-7.25	-	-
σ_3 [MPa]	-3.94	3.94	-	-
σ_6 [MPa]	-2.25	2.25	-	-
σ_7 [MPa]	-0.93	0.38	0.60	0.36
σ_8 [MPa]	-4.94	2.04	3.19	1.90
Total stresses [MPa]	-0.80	5.35	3.78	2.25
Allowable stresses [MPa]	**-3.35**	**18.00**	**14.00**	**2.96**

Table 5.32: Tee Section Stresses at Final Stage In MPa.

Stress [MPa]	Bottom of the beam	Top of the beam	Top of the deck	Bottom of the deck
σ_4 [MPa]	5.20	5.20	-	-
σ_5 [MPa]	7.21	-8.65	-	-
σ_3 [MPa]	-3.37	4.05	-	-
σ_6 [MPa]	-3.29	3.94	-	-
σ_7 [MPa]	-0.97	0.31	0.52	0.28
σ_8 [MPa]	-5.18	1.63	2.77	1.51
Total stresses [MPa]	-0.40	6.47	3.29	1.79
Allowable stresses [MPa]	**-3.35**	**18.00**	**14.00**	**2.96**

5.2.1.9 The design, resistance, and cracking moments

The design and resistance moments has been obtained for each section by the spreadsheet as shown in Table 5.33.

Table 5.33: The Design and Resistance Moments for The Sections In KN.m.

Section/ characteristic	M_d [KN.m]	ρ_s [mm^2/mm^2]	F_{pd} [MPa]	T [KN]	a [mm]	M_{res} [KN.m]
I_1 section	1705.10	0.00114545	1566.02	1973.19	99.49	**2072.35**
T section	1850.76	0.00114545	1566.02	1973.19	99.49	**2072.35**
Rectangular section	1729.38	0.00114545	1566.02	1973.19	99.49	**2072.35**
I_2 section	1692.96	0.00114545	1566.02	1973.19	99.49	**2072.35**
Rectangular hollow section	1700.77	0.00114545	1566.02	1973.19	99.49	**2072.35**
Tee section	16722.87	0.00113868	1566.33	1973.57	99.51	**2078.87**

The cracking moment of each section has been obtained as shown in Table 5.34.

Table 5.34: The Cracking Moment for The Sections In KN.m.

Section/ characteristic	f_r [MPa]	$M_{beam+deck}$ [KN.m]	I_k/C_{ak} [m^3]	$\sigma_{a\ pre}$ [KPa]	$\sigma_{beam+deck}$ [KPa]	M_{cr} [KN.m]
I_1 section	2.6833	433.50	0.102695	13045.30	6568.18	**1374.23**
T section	2.6833	537.54	0.094827	14734.46	6318.67	**1590.03**
Rectangular section	2.6833	450.84	0.100291	13522.02	7728.69	**1300.97**
I_2 section	2.6833	424.83	0.202879	13045.30	6436.82	**1371.49**
Rectangular hollow section	2.6833	476.85	0.116997	11248.73	6186.16	**1383.09**
Tee section	2.6833	456.92	0.1115654	12415.65	7984.80	**1250.61**

The distance between the hook-up and the edge of I_1, T, rectangular, I_2, rectangular hollow and Tee sections are obtained as shown in Tables 5.35, 5.36, 5.37, 5.38, 5.39, and 5.40, respectively.

Table 5.35: The Distance Between Hook-Up and I_1 Section Edge.

Variable	Value	Variable	Value
C_a [m]	0.50	M_c [t.m]	4.46
C_u [m]	0.50	σ_a [kgf/cm^2]	6.76
I [cm^4]	3300000.00	σ_c [kgf/cm^2]	6.76
W [t]	0.72	Impact factor	2.00
f_c [kgf/cm^2]	458.87	Modified σ_a [kgf/cm^2]	13.52
c_t [m]	**3.52**	Modified σ_c [kgf/cm^2]	13.52
M_a [t.m]	4.46	f_{ct} [kgf/cm^2]	47.13

Table 5.36: The Distance Between Hook-Up and T Section Edge.

Variable	Value	Variable	Value
C_a [m]	0.58	M_c [t.m]	4.40
C_u [m]	0.42	σ_a [kgf/cm^2]	7.27
I [cm^4]	3537192.98	σ_c [kgf/cm^2]	7.27
W [t]	0.91	Impact factor	2.00
f_c [kgf/cm^2]	458.87	Modified σ_a [kgf/cm^2]	14.54
c_t [m]	**3.68**	Modified σ_c [kgf/cm^2]	14.54
M_a [t.m]	6.18	f_{ct} [kgf/cm^2]	47.13

Table 5.37: The Distance Between Hook-Up and Rectangular Section Edge.

Variable	Value	Variable	Value
C_a [m]	0.50	M_c [t.m]	5.21
C_u [m]	0.50	σ_a [kgf/cm^2]	8.93
I [cm^4]	2916666.67	σ_c [kgf/cm^2]	8.93
W [t]	0.84	Impact factor	2.00
f_c [kgf/cm^2]	458.87	Modified σ_a [kgf/cm^2]	17.85
c_t [m]	**3.52**	Modified σ_c [kgf/cm^2]	17.85
M_a [t.m]	5.21	f_{ct} [kgf/cm^2]	47.13

Table 5.38: The Distance Between Hook-Up and I_2 Section Edge.

Variable	Value	Variable	Value
C_a [m]	0.50	M_c [t.m]	4.46
C_u [m]	0.50	σ_a [kgf/cm^2]	6.76
I [cm^4]	3300000.00	σ_c [kgf/cm2]	6.76
W [t]	0.72	Impact factor	2.00
f_c [kgf/cm^2]	458.87	Modified σ_a [kgf/cm^2]	13.52
c_t [m]	**3.52**	Modified σ_c [kgf/cm^2]	13.52
M_a [t.m]	4.46	f_{ct} [kgf/cm^2]	47.13

Table 5.39: The Distance Between Hook-Up and Rectangular Hollow Section Edge.

Variable	Value	Variable	Value
C_a [m]	0.50	M_c [t.m]	5.21
C_u [m]	0.50	σ_a [kgf/cm^2]	6.75
I [cm^4]	3854166.67	σ_c [kgf/cm^2]	6.75
W [t]	0.84	Impact factor	2.00
f_c [kgf/cm^2]	458.87	Modified σ_a [kgf/cm^2]	13.51
c_t [m]	**3.52**	Modified σ_c [kgf/cm^2]	13.51
M_a [t.m]	5.21	f_{ct} [kgf/cm^2]	47.13

Table 5.40: The Distance Between Hook-Up and Tee Section Edge.

Variable	Value	Variable	Value
C_a [m]	0.46	M_c [t.m]	4.50
C_u [m]	0.55	σ_a [kgf/cm^2]	6.56
I [cm^4]	3129851.69	σ_c [kgf/cm^2]	6.56
W [t]	0.64	Impact factor	2.00
f_c [kgf/cm^2]	458.87	Modified σ_a [kgf/cm^2]	13.12
c_t [m]	**3.42**	Modified σ_c [kgf/cm^2]	13.12
M_a [t.m]	3.76	f_{ct} [kgf/cm^2]	47.13

5.2.2 The Stress Diagram for The sections

The stress diagram for the I_1, T, rectangular, I_2, rectangular hollow, and Tee sections can be drawn as shown in Figures 5.8, 5.9, 5.10, 5.11, 5.12, and 5.13, respectively.

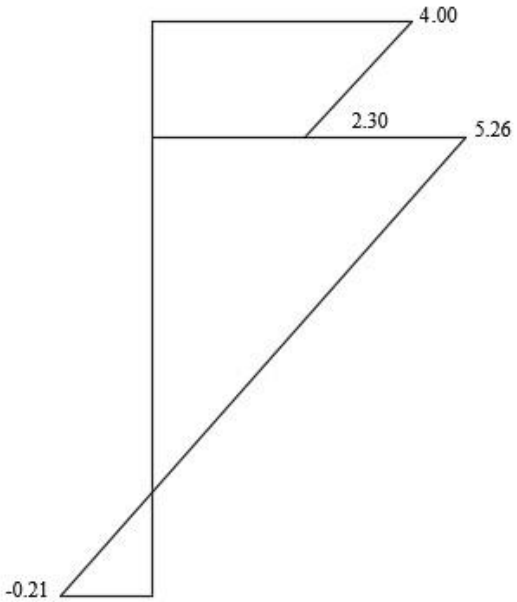

Figure 5.8: The Stress Diagram for I_1 Section In MPa.

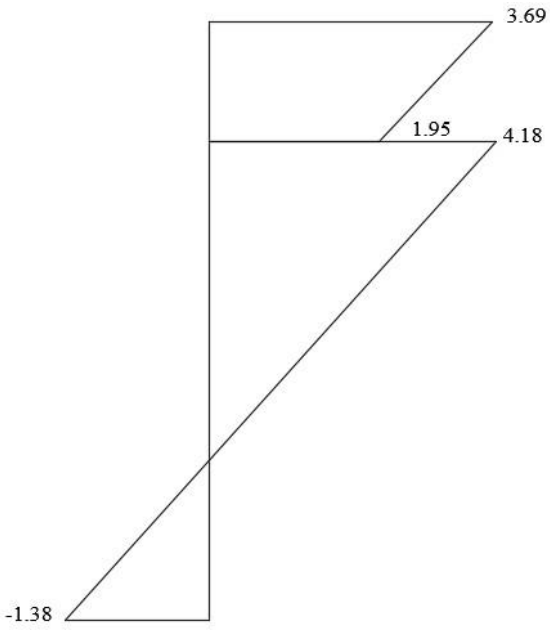

Figure 5.9: The Stress Diagram for T section In MPa.

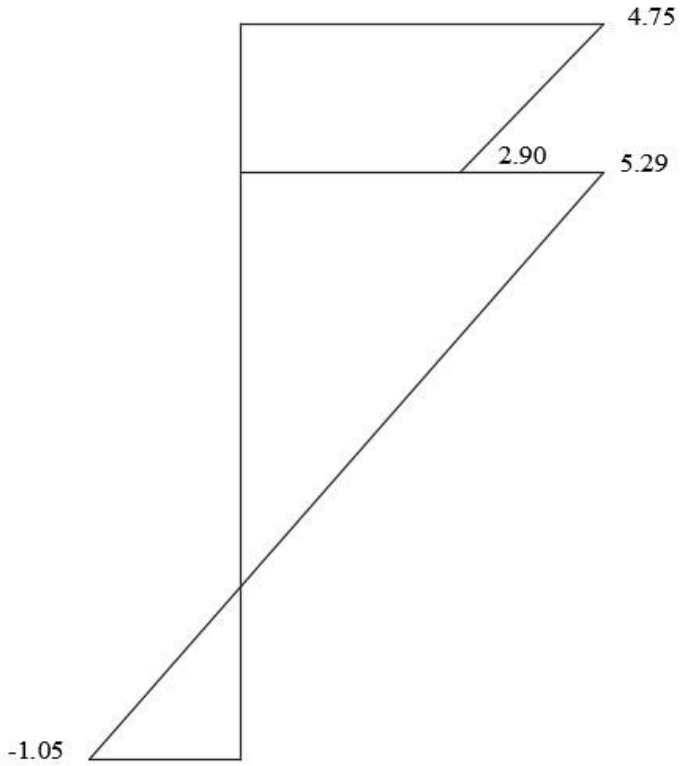

Figure 5.10: The Stress Diagram for Rectangular Section In MPa.

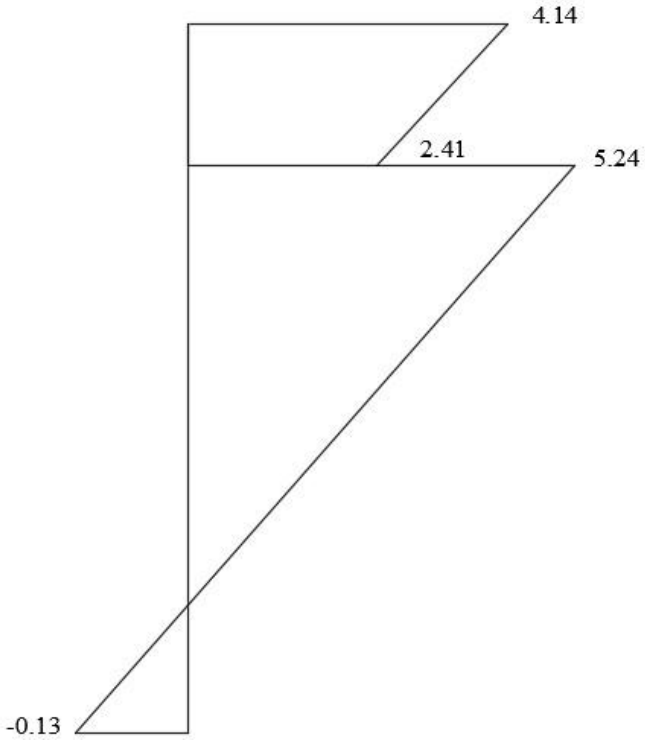

Figure 5.11: The Stress Diagram for I_2 Section In MPa.

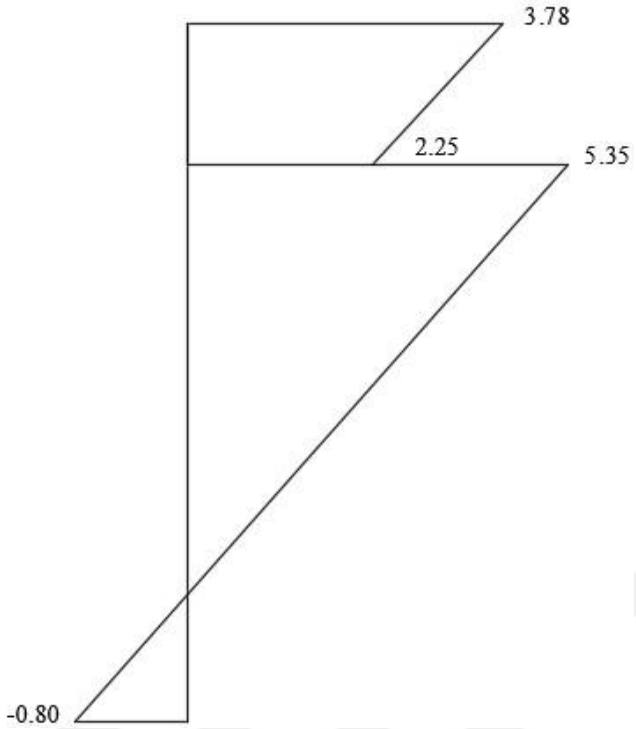

Figure 5.12: The Stress Diagram for Rectangular Hollow Section In MPa.

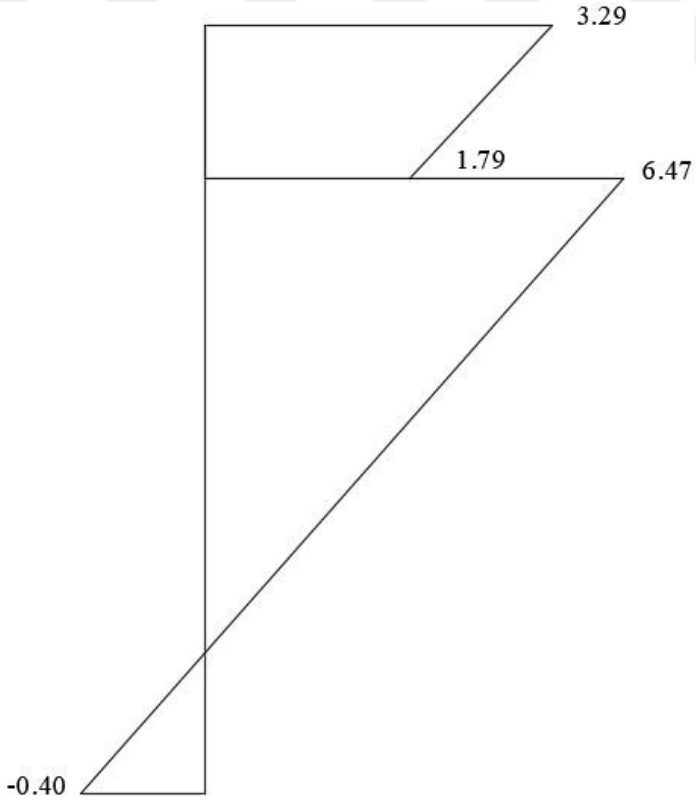

Figure 5.13: The Stress Diagram for Tee Section In MPa.

5.3 DESIGN OF DIFFERENT SECTION FORMS IN SPANS OF BRDIGES

The characteristics of the sections for bridge projects can be obtained and tables can be created. The design has been made by using C45 concrete for the precast sections and a C35 concrete for the deck with a depth of 20 cm with a short side span length equals 80 cm. The obtained results for I, T, rectangular, rectangular hollow, and Tee sections can be shown in Tables 5.41, 5.42, 5.43, 5.44, and Table 5.45, respectively.

Table 5.41: The Design of I Section In Spans of Bridges.

	Dimensions [mm]				**Prestressing steel**		**Stresses [MPa]**		**Moment [KN.m]**		**Hook-up distance [m]**
Span Length [m]	B_f	D_f	B_w	D	Steel grade	Pieces	σ_{max}	$\sigma_{allowable}$	M_{res}	M_{cr}	c_t
16.00	500	200	200	800	270	9Φ0.6	-1.61	**-3.35**	1650.34	1063.05	3.31
17.00	450	200	200	900	270	9Φ0.6	-1.55	**-3.35**	1862.08	1202.33	3.52
18.00	450	200	200	950	270	9Φ0.6	-2.53	**-3.35**	1967.37	1260.35	3.73
19.00	400	200	200	1100	270	9Φ0.6	-1.99	**-3.35**	2281.54	1474.94	3.94
20.00	400	200	200	1200	270	9Φ0.6	-2.36	**-3.35**	2489.89	1614.18	4.14

Table 5.42: The design of T section in spans of bridges.

	Dimensions [mm]				**Prestressing steel**		**Stresses [MPa]**		**Moment [KN.m]**		**Hook-up distance [m]**
Span Length [m]	B_f	D_f	B_w	D	Steel grade	Pieces	σ_{max}	$\sigma_{allowable}$	M_{res}	M_{cr}	c_t
16.00	700	200	350	800	270	9Φ0.6	-2.69	**-3.35**	1650.34	1211.68	3.45
17.00	700	200	350	900	270	9Φ0.6	-2.99	**-3.35**	1862.08	1365.01	3.66
18.00	750	200	300	1000	270	9Φ0.6	-3.02	**-3.35**	2072.35	1579.30	3.91
19.00	750	200	250	1200	270	9Φ0.6	-1.66	**-3.35**	2489.89	1934.60	4.15
20.00	700	200	250	1300	270	9Φ0.6	-2.15	**-3.35**	2697.59	2076.03	4.35

Table 5.43: The Design of Rectangular Section In Spans of Bridges.

	Dimensions [mm]		Prestressing steel		Stresses [MPa]		Moment [KN.m]		Hook-up distance [m]
Span length [m]	B	D	Steel grade	Pieces	σ_{max}	$\sigma_{allowable}$	M_{res}	M_{cr}	c_t
15.00	400	750	270	9Φ0.6	-1.53	**-3.35**	1543.76	956.13	3.11
16.00	400	800	270	9Φ0.6	-2.76	**-3.35**	1650.34	1001.15	3.31
17.00	400	900	270	9Φ0.6	-3.11	**-3.35**	1862.08	1130.69	3.52
18.00	350	1000	270	9Φ0.6	-3.04	**-3.35**	2072.35	1267.40	3.73

Table 5.44: The Design of Rectangular Hollow Section In Spans of Bridges.

	Dimensions [mm]				Prestressing steel		Stresses [MPa]		Moment [KN.m]		Hook-up distance [m]
Span Length [m]	B_o	D_o	B_i	D_i	Steel grade	Pieces	σ_{max}	$\sigma_{allowable}$	M_{res}	M_{cr}	c_t
16.00	500	800	250	400	270	9Φ0.6	-1.97	**-3.35**	1650.34	1051.28	3.31
17.00	500	900	300	550	270	9Φ0.6	-1.52	**-3.35**	1862.08	1212.96	3.52
18.00	450	950	200	550	270	9Φ0.6	-2.98	**-3.35**	1967.37	1242.62	3.73
19.00	400	1100	150	700	270	9Φ0.6	-2.53	**-3.35**	2281.54	1454.19	3.94
20.00	450	1200	200	850	270	9Φ0.6	-2.88	**-3.35**	2489.89	1606.10	4.14

Table 5.45: The Design of Tee Section In Spans of Bridges.

	Dimensions [mm]											Prestressing steel		Stresses [MPa]		Moment [KN.m]		Hook-up distance [m]
Span Length [m]	B_a	d_1	Z_1	$Z_1°$	B_o	D_o	Z_2	$Z_2°$	d_2	B_u	D	Steel grade	Pieces	σ_{max}	$\sigma_{allowable}$	M_{res}	M_{cr}	c_t
16.00	475	80	220	60	255	390	70	60	80	325	801	270	9Φ0.6	-1.19	-3.35	1653	985	3.24
17.00	450	100	250	60	200	400	100	60	100	300	903	270	9Φ0.6	-1.01	-3.35	1869	1106	3.42
18.00	450	100	250	60	200	500	100	60	100	300	1003	270	9Φ0.6	-1.33	-3.35	2079	1228	3.62
19.00	450	100	250	60	200	500	100	60	100	300	1003	270	9Φ0.6	-2.89	-3.35	2079	1183	3.83
20.00	450	100	250	60	200	600	100	60	100	300	1103	270	9Φ0.6	-3.15	-3.35	2288	1300	3.42

5.4 DESIGN OF DIFFERENT SECTION FORMS IN SPANS OF HOUSING

The Excel spreadsheet can design the prestressed composite concrete beam sections for the housing projects as well. The design has been made by using C45 concrete for the precast sections and a C30 concrete for the deck with a depth of 20 cm, with a short side span length equals 80 cm. The design of I, T, rectangular, rectangular hollow, and Tee sections with different span lengths can be obtained as shown in Table 5.46, Table 5.47, Table 5.48, Table 5.49, and Table 5.50, respectively.

Table 5.46: The Design of I Section In Spans of Housing.

	Dimensions [mm]				Prestressing steel		Stresses [MPa]		Moment [KN.m]		Hook-up distance [m]
Span Length [m]	B_f	D_f	B_w	D	Steel grade	Pieces	σ_{max}	$\sigma_{allowable}$	M_{res}	M_{cr}	c_t
8.00	375	100	150	275	250	3Φ0.6	-0.87	-3.35	229.03	148.63	1.66
9.00	350	100	120	350	250	3Φ0.6	-0.05	-3.35	281.54	199.95	1.86
10.00	350	100	100	400	250	3Φ0.6	-0.73	-3.35	315.45	213.25	2.07
11.00	350	100	130	500	250	3Φ0.6	-0.83	-3.35	381.80	261.97	2.28
12.00	350	100	175	550	250	3Φ0.6	-1.69	-3.35	414.51	271.59	2.49

Table 5.47: The Design of T Section In Spans of Housing.

	Dimensions [mm]				Prestressing steel		Stresses [MPa]		Moment [KN.m]		Hook-up distance [m]
Span Length [m]	B_f	D_f	B_w	D	Steel grade	Pieces	σ_{max}	$\sigma_{allowable}$	M_{res}	M_{cr}	c_t
8.00	450	125	300	300	250	3Φ0.6	-0.90	**-3.35**	246.83	180.05	1.70
9.00	500	150	250	350	250	3Φ0.6	-2.02	**-3.35**	281.54	226.65	1.95
10.00	500	120	250	400	250	3Φ0.6	-2.90	**-3.35**	315.45	241.74	2.16
11.00	550	100	200	500	250	3Φ0.6	-2.09	**-3.35**	381.80	316.92	2.40
12.00	500	100	175	600	250	3Φ0.6	-1.99	**-3.35**	447	365.80	2.62

Table 5.48: The Design of Rectangular Section In Spans of Housing.

	Dimensions [mm]		Prestressing steel		Stresses [MPa]		Moment [KN.m]		Hook-up distance [m]
Span length [m]	B	D	Steel grade	Pieces	σ_{max}	$\sigma_{allowable}$	M_{res}	M_{cr}	c_t
8.00	325	300	250	3Φ0.6	-1.24	**-3.35**	246.83	129.74	1.66
9.00	300	350	250	3Φ0.6	-2.28	**-3.35**	281.54	138.74	1.86
10.00	300	450	250	3Φ0.6	-1.95	**-3.35**	348.82	190.72	2.05
11.00	300	550	250	3Φ0.6	-2.12	**-3.35**	414.51	237.45	2.28
12.00	250	700	250	3Φ0.6	-1.46	**-3.35**	511.55	318.05	2.49

Table 5.49: The Design of Rectangular Hollow Section In Spans of Housing.

	Dimensions [mm]				Prestressing steel		Stresses [MPa]		Moment [KN.m]		Hook-up distance [m]
Span Length [m]	B_o	D_o	B_i	D_i	Steel grade	Pieces	σ_{max}	$\sigma_{allowable}$	M_{res}	M_{cr}	c_t
8.00	350	300	100	150	250	3Φ0.6	-0.62	**-3.35**	246.83	139.03	1.66
9.00	400	400	200	200	250	3Φ0.6	-0.14	**-3.35**	315.54	201.23	1.86
10.00	400	400	175	225	250	3Φ0.6	-2.52	**-3.35**	315.54	169.26	2.07
11.00	400	500	225	325	250	3Φ0.6	-1.82	**-3.35**	381.80	229.24	2.28
12.00	350	575	150	450	250	3Φ0.6	-2.65	**-3.35**	430.78	244.47	2.49

Table 5.50: The Design of Tee Section In Spans of Housing.

	Dimensions [mm]											Prestressing steel		Stresses [MPa]		Moment [KN.m]		Hook-up distance [m]
Span Length [m]	B_a	d_1	Z_1	$Z_1°$	B_o	D_o	Z_2	$Z_2°$	d_2	B_u	D	Steel grade	Pieces	σ_{max}	$\sigma_{allowable}$	M_{res}	M_{cr}	c_t
8.00	330	25	30	30	278	220	30	30	25	330	300	250	3Φ0.6	-0.05	**-3.35**	247	149	1.66
9.00	300	35	40	30	231	240	40	30	35	300	350	250	3Φ0.6	-0.61	**-3.35**	282	167	1.86
10.00	280	30	40	30	210	300	40	30	30	280	400	250	3Φ0.6	-1.89	**-3.35**	316	173	2.07
11.00	280	30	40	30	210	375	40	30	30	280	475	250	3Φ0.6	-2.50	**-3.35**	365	199	2.28
12.00	260	30	40	30	190	450	40	30	30	260	550	250	3Φ0.6	-3.03	**-3.35**	415	223	2.49

6. RESULTS

6.1 INTRODUCTION

By using the programmed Excel spreadsheet, the most suitable section dimensions can be obtained. However, the concept of the spreadsheet depends on the trial-and-error method, the design starts by entering assumed dimensions for the section and the type of the prestressing steel and the type of the concrete for both deck and precast section as well as the loads affecting the structure, the deck depth, and the weather condition. Then, the spreadsheet will automatically calculate the percentage of losses in the initial prestressing force and the effective prestressing force as well. After that, the spreadsheet will calculate the stresses affecting the section in each stage and show the allowable stress for the structure, if the stresses affecting the section are exceeding the allowable stresses the user should modify the section dimensions or the prestressing steel. After that, the spreadsheet calculates the resistance and cracking moments and shows the value of these moments in KN.m as shown in the previous chapter tables.

In order to facilitate the design, the design of the different sections has been done at different span lengths for both bridges and housing projects. These tables show the designer the most economical characteristics for the sections taking into consideration the safety of the structure.

6.2 DISTANCE BETWEEN SECTIONS

According to the results which has been obtained in the previous chapter, the distance between sections (the length of the short side of the span) is playing a major role in the stresses affecting the structure especially at the final stage which could be noticed in the stresses affecting I_1 and I_2 sections. While they have the same dimensions, the stresses affecting each section at the final stage is different due to the difference in the composite section area and moment of inertia as well. As a result, the increment of the distances between the sections will increase the stresses affecting the bottom and the top of the beam section and the stresses affecting the top and the bottom of the deck will be increased. Also, the cracking moment will be increased too by increasing the distance between the sections.

6.3 SECTION PROPERTIES

The design results for the different sections show that the resulted area differs between sections for the same span length. According to the results of the design, the most suitable section which gives high moment of inertia, and a less cross-section area is the Tee section. Which means, to have a less weight and more economical structure the Tee section should be used. Although, the usage of rectangular section is not economical for bridge projects with high span lengths.

For housing projects, due to the fact that the Tee section is extremely complicated to work with, the I, rectangular, and rectangular hollow sections and in few cases T section could be good alternatives for such a project. On the other hand, for the bridge spans the usage of Tee, rectangular hollow and I sections are good alternatives.

7. CONCLUSION AND RECOMMENDATIONS

The research intended to study the designing of prestressed composite beam sections with a different section form in spans of bridges and housing and calculating the safety stresses, moment resistance and cracking moment for each section and check if the structure will be safe or not. The following conclusions and recommendations can be extracted regarding the results.

7.1 CONCLUSION

i. The usage of different types of concrete will decrease the cost of the used materials and the cost of the project in total.

ii. The current study can be considered as a first step in the research on prestressed composite beams with different section forms in spans of bridges and housing.

iii. The prestressed composite beam design is an ideal method for bridges and floors with high span lengths.

iv. The usage of prestressed composite beams increases the characteristics of the sections.

v. The usage of prestressed composite beam design method increases the ability of the sections to resist the loads and the ability of the section to resist the affecting stresses as well.

vi. The usage of different prestressed composite beam sections and different distances between sections allows the architects and designers to perform a different shape of structures and even more complex.

vii. By using the programmed Excel spreadsheet, the optimum section characteristics can be easily obtained by entering the load values and the characteristics of the materials.

viii. By using the Excel spreadsheet, a better control over the concrete and the prestressing steel can be obtained.

ix. By using the Excel spreadsheet, the decision of whether the structure is safe under the design loads or not can be determined easily.

x. By using the spreadsheet, the distance between the hook-up and the edge of the section can be determined, which makes the transportation of the precast sections easier.

7.2 RECOMMENDATIONS

i. The research discusses the design of five different section forms and can be procced to design another different type of sections.

ii. The placing of beam sections side by side has not been studied.

iii. The study of deflection for the structure is not included.

iv. The visibility of the research should be procced to study the shear resistance of the prestressed concrete composite beam sections.

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