FINAL THESIS

ALTERNATIVE OF A DOUBLE TRACK RAILWAY BRIDGE

Composed by:

Suwanda Suwanda

1525994

International Bachelor of Civil Engineering

Faculteit Natuur en Techniek

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Submission to fulfill the requirements for finishing the Bachelor of Science degree

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ALTERNATIVE OF A DOUBLE TRACK RAILWAY BRIDGE

Student name : Suwanda Suwanda

Student number : 1525994

E-mail : swd_learntofly@yahoo.co.id

Supervisor : Koos Blitterswijk

E-mail : koos.blitterswijk@grontmij.nl

Teacher 1 : Frans van Heerden

E-mail : frans.vanheerden@hu.nl

Teacher 2 : Rene Camerik

E-mail : rene.camerik@rws.nl

FOREWORD

Only by the blessing of the Almighty God, Allah SWT, who gives me life, health and spirit for studying, I can finish this final thesis report as a compulsory requirement to obtain my bachelor degree.

This final thesis report is about the design of railway bridges. This report is intended to find the alternative design of the approach bridge by only emphasizing in concrete bridges. The result is a void slab bridge with post-tensioned system. The design has been done by considering the effective shape of the bridge deck, the losses of the prestressing force, layout of the cable, and the requirements according to the Netherlands' code.

This report has been made during the internship at Grontmij, a Dutch consultant company, in De Bilt, the Netherlands. The internship itself has been done within 4 months. I was not only working for final thesis project but also working as a drafter. I found that was a valuable work experience for my study.

I realise that without any help from people around me, it is impossible to get everything right. Therefore, I would like to dedicate gratitude for:

1. Mr.Koos Blitterswijk as my supervisor from Grontmij who has already helped me so much with guidance in designing and finishing the project;
2. Ir.Frans van Heerden as a program manager of International Civil Engineering Hogeschool Utrecht and also as a mentor who has given me advises, opinions, and help during my study;
3. Ir.Rene Camerik as a mentor who has been very patient, very helpful for giving me advises, critics, guidance, and valuable knowledge;
4. Mr.Alexander Milenkovic as the head of Road Department of Grontmij and Mr.Evert Lans as the team leader of drawing office in Road Department of Grontmij;
5. Grontmij (de Bilt, The Netherlands) especially Road Department for internship opportunity, providing and supporting my final thesis project and work experience which are precious for me;
6. Mr.Paul Minee, Mr Fons Dehing and all persons who involve in EXISTENTE scholarship project;

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8. Prof. Ir. Siti Malkhamah, M.Sc., Ph.D., as a teacher who has been helpful in the procedure of double degree program;
9. My Parents, Fauzan and Mugiwati, for always giving me cares, prayers, and encouragement;
10. My sisters, Santi Maulina and Suci Ramadhani for prayers and supports.
11. Miss Rumartha P.S, for supports and encouragements;
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13. All of my friends at Gadjah Mada University, Indonesia;
14. All of my friends, persons that I cannot mention here.

Since I am still in the studying process, I realize that this report is far from perfect. In accordance of improving and development, I am very welcome for the improvement comments, critics, and suggestion about the content or organization of the report, or regarding the calculation. I hope that this final thesis report can be valuable for everyone.

The Netherlands, June 2007

Suwanda

ABSTRACT

Suwanda

Final Thesis Report

ALTERNATIVE OF A DOUBLE TRACK RAILWAY BRIDGE

The demands of rail transport in the Netherlands are getting higher. New route has to be built to improve the effectiveness of mobility of the people. The new connection will improve the economical aspect and also will help the development of the city. In designing the new route, it cannot be avoided that the railway route will cross with many obstacles, for instance roads, land farms, rivers or any kind of natural obstacles.

In this project, the route of the railway has to pass across the river. The bridge consists of main bridge over the river and the approach bridges. Grontmij Netherlands, recently, is busy with the design of the main bridge as well as the approach bridge. The main bridge will be designed as steel truss bridge whereas the approach bridge is designed as composite steel-concrete bridge.

The bridge is intended for a double track railway. The total length of the approach bridge that will be built is approximately 626.5 meter. A forty-meter long from support to support divide those long bridges into a number of spans.

This report is intended to find the alternative design of the approach bridge by only emphasizing in concrete bridges. After considering some aspects from several types of concrete bridges, I propose a void slab bridge to be designed further. Due to the limited time, I only focus in the superstructure design.

The voids are introduced in the slab bridge hence there is a significant reducing self-weight in the structure. The use of high strength concrete and pre-stressing system makes the structure has more durablity, more strength, less crack, and less height of the cross section.

In this report, the void slab bridge is designed by considering the losses of the prestressing force, layout of the cable, the requirements according to the Netherlands' code in Ultimate Limit States, Service Limit States and also Fatigue Limit States. *Alp 2000* software is used in the designing the structure and also *Debt* is used to check the strength of the structure in every cross section.

Keywords: *Alternative of a double track railway bridge, prestressing, void slab bridge.*

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LIST OF SYMBOLS

A_c	Area of the concrete in cross section
e	Eccentricity
E_c	Modulus of elasticity of normal weight concrete
E_p	Modulus of elasticity of pre-stressing steel
f_{ck}	Characteristic compressive cylinder strength of concrete at 28 days
$f'_{ck,cube}$	Characteristic compressive cube strength of concrete at 28 days
f_b	The tensile strength of concrete
f_{top}	Stress occurring at the top of the structure
f_{bott}	Stress occurring at the bottom of the structure
f_{pk}	Characteristic tensile strength of pre-stressing steel
f_p	Tensile strength of pre-stressing steel
$f_{p0,1k}$	Characteristic 0.1 % proof-stress of pre-stressing steel
h	Total height of the structure
I	Moment of inertia of the structure
k_c	The factor, which depends on relative humidity
k_d	The factor, which depends on quality of the concrete and the phase age
k_b	The factor, which depends on the strength of the concrete as cylinder shape (f'_{ck})
k_h	The factor, which depends on the fictive height of the cross section of the structure (h_m)
k_p	The factor, which depends on the percentage of reinforcement
k_t	The factor, which depends on the time of applied load in day (t)
k_A	The reduction factor due to bended steel and welding
k_N	The coefficient of the loads changing
L	Length of the structure
L_{pA}	The thickness of anchorage set

L_c	Horizontal length of the cables
M	Bending moment
M_{DD}	Bending moment of dead loads
M_{LL}	Bending moment of live loads
M_u	The Ultimate moment of the structure
P	Pre-stressing force
P_0	Initial force at the active end of the tendon immediately after stressing
P_∞	Pre-stressing force after losses at indefinite time
q	Uniformly distributed loads
q_{DL}	Uniformly distributed load of dead loads
R	Radius of the parabola
t	Time
V	Force in vertical direction
W	The length influenced by anchorage set
x	The length of a pre-stressing tendon from the jacking end to the point considered
y_a	Distance from the top of the structure to the neutral line
y_b	Distance from the bottom of the structure to the neutral line

β_τ	The factor for double tracks railway
δ	The deflection of the structure
γ_c	The density of concrete
γ_{rail}	The density of rails
γ_{fat}	Safety factor
ε_u	Strain of pre-stressing steel at maximum load
ε'_c	Basic shrinkage factor
λ_τ	The coefficient due to the length of the span
$\sigma_{p,0}$	Stress of the prestressing cable at tensioning phase

Φ	The sum of absolute values of angle change in the pre-stressing steel layout from jacking end
$\Phi 1$	The wobble friction coefficient (radians/m)
μ	Friction coefficient
$\phi_{\max}$	The maximum value of creep coefficient based on the strength of concrete and the relative humidity
$\Delta_{p,1000}$	The maximum relaxation, which happen after 1000 hours
$\Delta\sigma_{pS+p\varphi}$	Pre-stressing losses due to creep and shrinkage
$\Delta\sigma_{pS}$	Pre-stressing losses due to shrinkage
$\Delta\sigma_{pR}$	Pre-stressing losses due to relaxation
ΔF_{pF}	Pre-stressing losses due to the friction losses and the Wobble effect
Δf_{ak}	The different stress characteristic of steel

CHAPTER I

CHAPTER I
INTRODUCTION

1.1 Project Background

The demand of rail transport in the Netherlands is getting higher. Most of the people who need to travel everyday to other cities prefer rail transport than other means of transport. Trains can transport a highly number of passenger from one place to another and have an average velocity that is faster than using private cars.

A new route has to be built to improve the effectiveness of mobility of the people. Therefore, the people can travel directly to the destination city without changing the route. The new connection will improve the economical aspect and also stimulate the development of the city.

In designing the new route, it cannot be avoided that the railway route will cross with many obstacles, for instance roads, land farms, rivers or any kind of natural obstacles. The basic purpose for railway track is to create public travels which will go smoothly, continuously, and convenient enough for the passengers.

In this project, the route of the railway has to pass across the river. The bridge consists of main bridge over the river and the approach bridges. Grontmij Netherlands, a Dutch consultant company, recently is busy with the design of the main bridge as well as the approach bridge. The main bridge is designed as steel truss bridge whereas the approach bridge is designed as composite steel-concrete bridge.

In this report, I am more focus in designing the approach bridge, the bridge that has to be built to connect the main bridge across the river and the railway construction at the landside. The approach bridge has to provide a good vertical alignment and a slope due to the maximum slope allowed for trains that is 10‰.

Figure 1.1 *The Map of the Netherlands*

1.2 Problem Description

Problems, which I found after analysing the existing preliminary design, are that the approach bridges are relatively long, 40 m long in each span, and have to carry heavy loads. The deflection at the middle of the span is commonly a problem for a long span bridge. In addition, cracks, which are possible to occur, have an influence with durability of the bridge. Normally the design life of bridges in the Netherlands is for 100 years and it has to be considered that bridges are durable enough.

The alternative of the approach bridge in this case is by using concrete as the primary material. Comparing with steels, concrete is heavy material due to the volume needed in the structure and has a restriction because of the weakness of tension force that it can support. That becomes a problem to design such a long span with concrete materials.

In the bridge design, self-weight of the bridge, most of the time, is the critical aspect that has to be considered. To support heavy loads, normally, a big structure is needed that is because the loading will be distributed to certain cross section area of the bridge. However, in the fact that the bigger the structure the heavier the dead loads so that we need to design efficiently, not only the volume of material but also the shape of the bridge.

Since trains will frequently pass the bridge, the repetition of the live loads can trigger the fatigue of the structure. The fatigue can cause crack in the structure and crack itself becomes worst after certain number of cycles of loading. Therefore, the bridge structure has to be checked according to the fatigue resistance in its design life.

1.3 Boundary Conditions

In the bridge design, especially for railway bridge, there are many aspects to design such as:

1. The excavation works;
2. Construction of the railway;
3. Foundation design;
4. Pier design;
5. Superstructure bridge design;
6. Reinforcement.

Since the project covers very wide aspect to consider and the time is limited, I am only going to design some parts of them.

1.3.1 The Scope of the Final Thesis

In this report, the author will more focus about the superstructure of the approach railway bridge. Scopes of the superstructure design are:

1. Type of the bridge;
2. Dead and live loads applied to the structure;

3. Reinforcement design;
4. Cross-section and longitudinal section of bridge;
5. Verification of the structure based on the regulation.

The bridge is intended for a double track railway. The total length of the approach bridge that will be built is approximately 626.5 meter. A forty-meter long from support to support divides those long bridges into a number of spans. The total length of the bridge that the author will design is 120 meter (3x40 m). For a bridge overview, see **ANNEX 7.**

1.3.2 Boundary Conditions of the Project

1. The bridge is an approach bridge to the main bridge.
2. The span of the bridge is 40 m.
3. The function of the bridge is a construction for a double track railway.
4. The Netherlands' codes are used in the design.

1.3.3 The Traffic Envelopes

General designs of railway track that used in this project are as follow:

1. Track consists of a flat formwork made up of rails, sleepers, and supported on the ballast. The ballast bed rests on sub-ballast layer, which strengthens the foundation of railway.
2. The route of railway consists of two tracks.
3. Maximum speed for design is 160 km/h.
4. The bridge has to accommodate at least minimum distance for traffic envelopes and also free space **(Figure 1.2).**

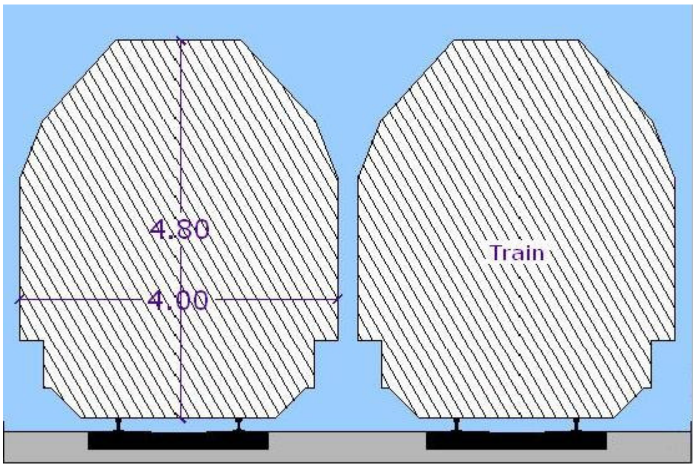


Figure 1.2 *The dimension of train free area (unit in m)*

1.4 Research Questions

1. In the designing
   a. Which part of the project is going to be studied?
   b. What are the limitations and the restrictions in designing the bridge in the Netherlands?
   c. What are the loads that have to be applied?
   d. What type of concrete and steel that are going to be used?
   e. What are the dimensions of the structure?
   f. What type of the support will be used?
   g. Which software can be used to calculate and design the bridge?
   h. How can we analyse the output from the software?
   i. Is the design fulfilling the requirement?
   j. How does the behaviour of prestressing system in the structure?

1.5 Main Objectives

The final thesis will be done by studying the preliminary design by Grontmij and finding the reasonable alternative solution for that. The final thesis will be done in 3 months or approximately 600 hours.

The objectives for this project are:

1. For the project itself

   The result of this final thesis can be used to give the idea about another possible solution for an approach railway bridge. After getting the idea how other bridges will behave, then we will know whether the alternative, which is being studied by the author, is more effective or not and also if there are any advantages or disadvantages when the bridge is built in other types.

2. For the author

   The values that the author can get by finishing this project are:

   a. Gaining more knowledge how to design the bridge;
   b. Learning how to design the bridge using the software that is commonly used in The Netherlands;
   c. Exploring, studying and applying The Eurocode and The Netherlands' code.

CHAPTER II

CHAPTER II
SELECTION OF POSSIBLE SOLUTIONS

2.1 The Bridge Alternatives

The fast developing of bridge, nowadays, has produced many alternatives to design a bridge structure. Aesthetic, the length of the span, function, material, surround environment, and all that kind of aspects will lead to the type of bridge, which is appropriate to be design.

In this report, the author is more focus in concrete bridge. Some possibilities of concrete bridge, which is commonly used, are:

1. Void slab bridge;
2. Deck-girder bridge;
3. Box-girder bridge;
4. Rigid-frame bridge;
5. U-shape bridge.

2.1.1 Void Slab Bridge

A void slab bridge is a bridge that consists of a monolithically plate slab that spans between the support and the use of certain number of void in the slab has a function of reducing the self weight **(Figure 2.1)**. Void slab is usually made as pre-stressed fabricated concrete. Therefore it is economical when many spans are involved and has relatively short construction time.

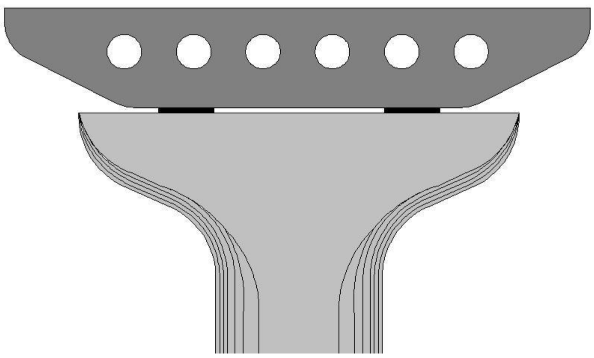


Figure 2.1 *The cross section of void slab bridge*

The advantages of the void slab bridge system are:

- Efficient structure for shorter spans;
- Pre-cast system of the void slab will shorten the construction time;
- Require less formwork when constructed by in situ method;
- Simple structure Easy in design;
- The height of the structure is relatively low.

The disadvantage of the slab bridge system is:

- For longer span, the self-weight of the structure is very heavy. The necessary thickness will be so high that creates a heavy structure only for self-weight. However, the use of voids reduces the weight of the structure.

2.1.2 Deck-Girder Bridge

The deck-girder system consists of a concrete slab and supported with the use of girders in the longitudinal direction **(Figure 2.2)**. The deck-girder bridge can be made either pre-cast or cast-in-place, but it is more economical to construct as pre-cast and better to use when the false work is prohibited.

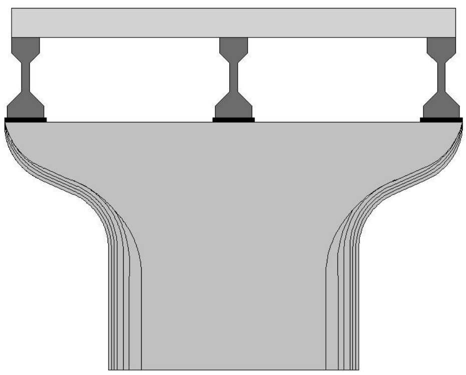


Figure 2.2 *The cross section of deck-slab bridge*

The advantages of deck-girder bridge are:

- Simple in design;
- By using pre-cast system, this type of bridge is easy to construct and faster in the construction time;
- Economical structures for certain length of span.

The disadvantages of deck-girder bridge are:

- Adequate bond and shear resistance must be provided, in the case of the use of pre-stressed concrete or pre-cast concrete, at the junction of slab and girder to maintain the assumption that they are integral.
- The formwork for this type of bridge is complicated when using cast in place.

2.1.3 Box Girder Bridge

A box girder bridge is a bridge that consists of slab at the top and the bottom integral with the girder, which form a shape of box **(Figure 2.3)**. The typical box girder has two webs and two flanges. However, in some cases there are more than two webs, creating a multiple box girder.

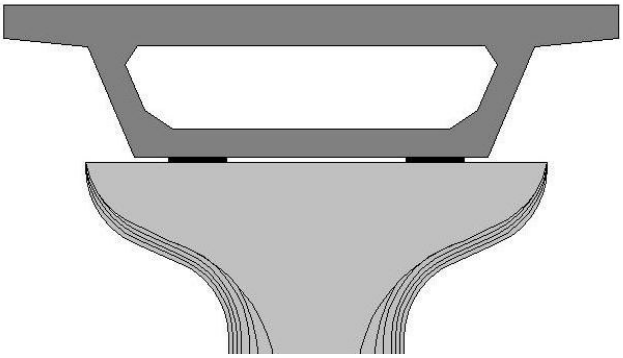


Figure 2.3 *The cross section of box girder bridge*

The advantages of box girder system are:

- This system is useful for a large range of span lengths;
- Great resistance of torsion;
- Particularly adaptable as continuous structure;
- Less weight of the structure.

The disadvantages of box girder system are:

- More expensive to fabricate than plate girder;
- Require more time and effort to design.

2.1.4 Rigid Frame Bridge

Frame bridge structure is a structure in which the columns are made very stiff that the connected girders are fixed ends. A rigid frame bridge is one in which the piers and girder are one solid structure **(Figure 2.4).**

The advantages of frame bridge are:

- This system makes possible to the reduction of depth at the centre of the span, thereby reducing dead load where it is most critical;
- It is possible to reduce the number of piers needed;
- It makes possible to design a shallower girder, or slab, to fulfil both strength and stiffness requirements;
- It can reduce the use of materials, therefore this system is more economic;
- It has better architectural point of view.

The disadvantages of frame bridge are:

- The bases of columns are usually approximately hinged, therefore the section here is relatively thin and not capable of supporting a large resisting moment;
- A rigid frame bridge is more difficult in designing compared to those of simple girder bridges.

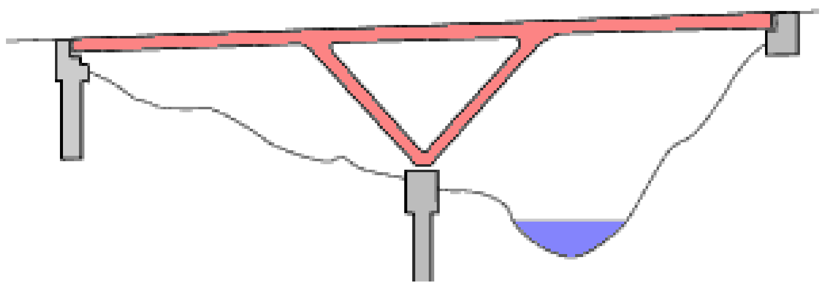


Figure 2.4 *The longitudinal section of rigid frame bridge*

2.1.5 U-Shape Bridge

U-shape bridge is a relative new type of bridge. This bridge consists of main slab that supports traffic loads and the girder in both sides forming the U-shape bridge **(Figure 2.5).** Since the position of the girders that are not beneath the slab, the stiffness of the structure has to be considered to get the proper distribution in cross section area so that the loads do not concentrate to the slab but also distribute to the girder.

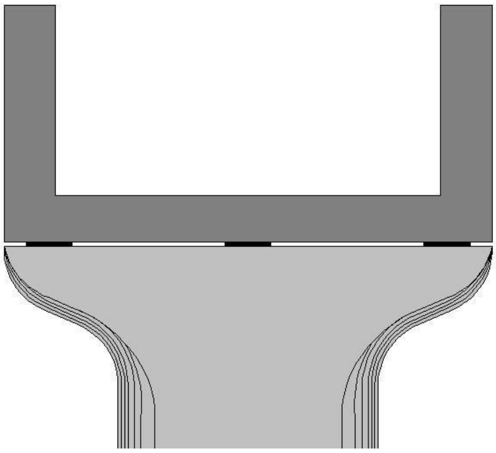


Figure 2.5 *The cross section of U-shape bridge*

The advantages of U-shape bridge are:

- The side girders can be used as noise barrier;
- It creates more space available beneath the bridge.

The disadvantages of U-shape bridge are:

- It is not better architectural point of view;
- The structure has to be very stiff so that the loads distribute properly to the side girder. Therefore, it is difficult to be designed.

2.2 Chosen Possibility

The author choose a void slab bridge which will be executed using pre-stress tendon and high strength concrete for the approach railway bridge.

2.3 Design and Calculation Methods

The railway bridge will be executed by using the pre-stressed tendon with the high quality of concrete. The elevation of the railway has been determined in the preliminary design by Grontmij therefore the height of the total construction has to adjust that elevation.

The execution for this project can be distinguished into three parts:

1. Introduction, description and explanation about the project;
2. Design and calculation of the structure.

Calculation of the structure will be executed as seen in **Table 2.1**

Calculation	Execution method	
Bending moment and shear force	Alp 2000	-
Cross section of the bridge (based on trial on error)	Alp 2000	Hand calculation
Prestressing	Alp 2000	Hand calculation
Verification	Alp 2000/Dbet	Hand calculation

Table 2.1 *Execution methods of the bridge design*

3. Drawings and sketches

Drawings and sketches using AUTOCAD will be done to give the idea how is the shape of the structure and also to show the other construction that needed to make the bridge complete.

2.4 Regulations

The author realised that the bridge is state in The Netherlands. Therefore, the regulation that normally used in Europe especially in The Netherlands will be used in further design. For The regulation, which will be used by the author for this final thesis, are:

1. Eurocode
   a. NEN-EN 1992-1-1 Eurocode 2: Design of Concrete Structure "Part 1-1: General Rules and Rules for Building";
   b. NEN-EN 1992-2 Eurocode 2:Design of Concrete Structure "Concrete bridge – Design and Detailing Rules";
   c. NEN-EN 1991-2 Eurocode 1: Action and Structures "Part 2: Traffic Loads on Traffic".

2. The Netherlands’ code
    a. NEN 6723–VBB 1995 “Concrete Bridge. Structural Requirements and Calculation Methods”.
    b. NEN 6702-TGB 1990 “Technical Principles for Building Structures- Loading and Deformations”.
    c. NEN 6720-VBC 1995 “Regulation for Concrete Structural Requirements and Calculation Methods”.

2.5 Software

Some software will be used to design and calculate the bridge for the final thesis. However, the hand calculation is also be used to get an idea and to analyse the result from the software.

Some software that will be used in the report are:

1. *Alp 2000* version: 4.1.0
2. *Dbet* version: 4.1.0
3. *Microsoft Excel* version: 2003-SP2

Alp 2000 is software, which is used especially for designing reinforced and prestressed concrete bridge. By using this software, the bridge is calculated in two-dimensional analysis. For calculating prestressed bridge, this software provides features that are able to calculate the curvature of the cables, losses of the prestressing forces, and optimizing the forces. *Alp 2000* is created by FEMMASE BV, a Netherlands company, and its design is based on The Netherlands’ code.

It can be used in three modes of analysis. The first mode is the design mode where the construction stages are not considered and prestressing is modelled as an external load. The second is the build mode where construction stage can be considered. The stiffness of prestressing is included. Elastic as well as viscoelastic can be performed. The third is the expert mode where more or less same with build mode, only the loads combination that is not preset.

The structural design in *Alp 2000,* afterwards, can be verified by using *Dbet. Dbet*, the software that interconnected with *Alp 2000,* is used to calculate and check if the bridge structures satisfy the requirement in the cross section area.

CHAPTER III

CHAPTER III
BASIC THEORIES

3.1 Concrete

Concrete is common material used to build civil constructions. Concrete is workable, thus, we can form structures in any shape based on the design. Usually, concrete is poured to the formed casting to get a shape needed.

The raw materials of concrete consist of water, fine aggregate, coarse aggregate, and cement. Those materials can be found in most areas of the world. Concrete is a mixture of paste and aggregate. The paste, composed of cement and water, fills the area among the aggregates. Because of the chemical reaction called hydration, the mixture of paste and aggregates hardens and gains the strength.

The increasing strength of the concrete depends on time. The compressive strength at 28 days is often used as a standard measure of strength. The compressive strength of concrete is determined by testing the specimens in the shape of cube and cylinder. The standard class of concrete according to the Netherlands's code are shown on **Table 3.1**.

Class of concrete	The cube strength ($f'_{ck,cube}$)	The cylinder strength (f'_{ck})	The tensile strength of concrete (f_b)	Modulus Elasticity of concrete (E_c)
C28/35	35	28	2.8	31000
C35/45	45	35	3.3	33500
C45/55	55	45	3.8	36000
C53/65	65	53	4.3	38500
C60/75	75	60	4.5	38900
C70/85	85	70	4.7	39300

Table 3.1 *The characteristics of the concrete***

Notes:

** Table is taken from NEN 6720-Regulations for concrete, Structural requirements and calculation method

Nowadays, the research and development in concrete technology are being done to get the composition of concrete, which is strong, durable, and workable. Concrete should withstand the weathering, chemical action, and loads, which subjected to it over a certain period thus durability is an important property of the concrete. High strength concrete is the answer of engineering needs in high quality structure.

The strength of concrete can be increased by decreasing water-cement ratio, using admixtures, and using higher strength concrete. The commonly used admixtures in high-strength concrete are fly ash, silica fume, super plasticizer, and water retarder.

The Portland Cement Association propose a way to create a high strength concrete is by using a super plasticizer in combination with a water-reducing retarder. The super plasticizer gives the concrete adequate workability at low water-cement ratios, leading to concrete with greater strength. The water-reducing retarder slows the hydration of the cement and allows workers more time to place the concrete.

3.2 Prestressing

Prestressing system is commonly used for bridge structure. The use of high quality steel and concrete make the structure stronger and more durable. Prior to design the prestressing, it is better to know the idea of prestressing.

3.2.1 Prestressing Steel

The behaviour of steel is usually characterized by the stress-strain curved under tension loading. The curve begins with a linear elastic portion with a slope, which is calculated as the modulus of elasticity of steel (E_p). Afterwards, the strains and the stresses are not linearly increasing, but form a curve until the maximum stress (f_{pk}) and maximum strain (ε_{uk}) is reached. The graphic of strain-stresses for prestressing steel is shown on **Figure 3.1**.

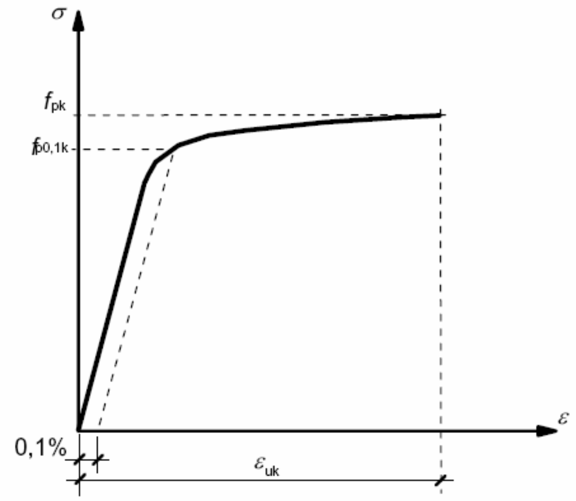


Figure 3.1 *Stress-strain diagrams for typical prestressing steel**

Notes:

* Figure is taken from NEN-EN 1992-1-1 Eurocode 2: Design of concrete structures Part 1-1: General rules and rules for building

f_{pk}	Characteristic tensile strength of prestressing steel
f_p	Tensile strength of prestressing steel
$f_{p0,1k}$	Characteristic 0.1 % proof-stress of prestressing steel
ε_u	Strain of prestressing steel at maximum load

As it can be seen from **Figure 3.1**, the steel used for prestressing system is different with the normal steel reinforcement. The basic difference is that in prestressing, high quality of steel is used thus the steel does not yield so much after the certain forces is given to it. The border between the elastic and plastic regions is not very clear. Therefore, the yield point is often defined as the stress at intersection between offset line of elastic portion line (typically 0.1%) and the stress-strain curve.

There are two types of tendon, which are usually used in prestressing system. They are wires and strands. Strands consist of a number of wires spun together in helical configuration. The material properties of prestressing steel are shown in **Table 3.2**.

The type of steel		f_{pk} (N/mm^2)	f_p (N/mm^2)	$f_{p0,1k}$ (N/mm^2)	$f_{p0.1k}/1.1$ (N/mm^2)	ε_u (%)
Wires	FeP 1670	1670	1520	1440	1310	3.5
	FeP 1770	1770	1610	1520	1380	3.5
Strands	FeP 1860	1860	1690	1600	1450	3.5

Table 3.2 *Prestressing steel properties***

Notes :
** Table is taken from NEN 6720-VBC 1995-Regulations for concrete, Structural requirements and calculation methods

3.2.2 The Theory of Prestressing

Prestressing is a process to stretch a group of cables in a concrete structure by using hydraulic jacks. In the term given in The Eurocode EN-1990, the definition of prestressing is the process of prestressing consists in applying forces to the concrete structure by stressing tendon relative to the concrete member. The effect of prestressing on structural concrete is often considered as force applied to the concrete.

Once the concrete reaches the required strength, the tendons are stretched by hydraulic jacks. After that, permanent anchorages are installed replacing the jack. The anchorage shall hold the forces that already been given to the prestressing steel. As the steel reacts to regain its original length, the tensile stresses are translated into a compressive stress in the concrete and creating uplift forces. The uplift forces generated by prestressing steel are depend on the tension forces which is given to the cables (*Po*), eccentricity form the central weight of the cables to the central weight of the structure (*e*) and the curvature of the cable layout (Eqs 3.1)

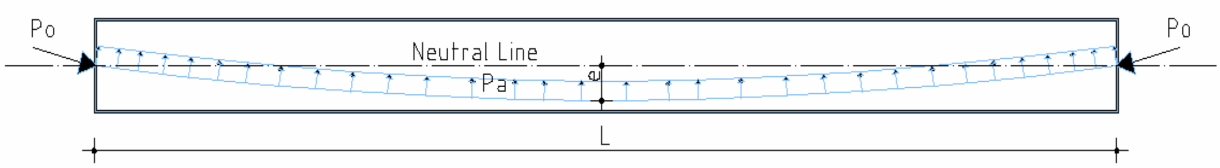


Figure 3.2 *Uplift force due to prestressing*

$$Po.e = \frac{1}{8}.Pa.L^2 \quad \text{.....(3.1)}$$

where:

Po : prestressing force (kN)

e : eccentricity (m)

Pa : compressive force in the concrete as an uplift force (kN)

L : length of the structure (m)

The idea of prestressing is by using its effect to create a structure that has more compression zone than tension zone in the structure and less deflection at service life due to the upward bend of the structure.

The typical bending moment of simple beam structure is a curve, which is bigger at the middle span and smaller at the end. Therefore, uplift forces, which are necessary all over the length, are not the same. Thus, the pre-stress cables form a curve. Maximum eccentricity is placed at the middle of the span where the maximum moment is.

There are two methods for prestressed concrete: pretensioning and posttensioning. The differences between them are at the construction methods.

In pretensioning, the cables are stressed before the concrete is placed. High-strength steel tendons are placed between two abutments and stressed around 70 to 80 percent of their ultimate strength. Concrete is poured into the moulds around the tendons and allowed to cure. Typical products for pretensioned concrete are roof slabs, piles, poles, bridge girder, wall panels, and railroad ties.

In posttensioning, the cables are stressed after the concrete reaches the certain strength. Concrete is cast around but not in contact with un-stressed cables. Once the concrete has hardened to require strength, the steel tendons are installed and stressed. There are two types of anchorage, live anchorage and dead anchorage. It can be one live anchorage, a place where tendons are tensioned, versus dead anchorage at the other side or both side with a live anchorage. Both live anchorages will reduce the direct losses of prestressing forces due to the distance between the jacking and the end.

A prestressing force at a distance *x* from the active end at a time *t* can be expressed as:

$$P(x,t) = P_0 - \Delta P(x,t_0) - \Delta P(x,t_\infty) \quad \text{.........(3.1)}$$

Where P_0 is a jacking force, $\Delta P(x,t_0)$ is the immediate losses and $\Delta P(x,t_\infty)$ is the time-dependent losses.

3.2.3 Losses

Losses of pre-stress can be characterized as that due to instantaneous losses and time-dependent losses. Losses due to anchorage set, friction and elastic shortening are instantaneous. Losses due to creep, shrinkage and relaxation are time dependent.

3.2.3.1 Friction

Friction during the tensioning of cables is the most important aspect regarding the direct losses of the prestressing force. The frictions depend on the curvature of the cable layout, the angle changing in the cable layout, the length of the cable from the live anchorage, and the Wobble effect.

In The Netherlands' code (NEN 6720 art 4.1.1.5), the losses due to the friction is:

$$\Delta F_{PF} = P_0(1 - e^{-\mu(\phi+\phi 1.x)}) \qquad (3.2)$$

where:

ΔF_{pF} = curvature coefficient (radians)

Φ = the sum of absolute values of angle change in the prestressing steel layout from jacking end (radians)

$\Phi 1$ = the wobble friction coefficient (radians/m)

x = the length of a prestressing tendon from the jacking end to the point considered (m)

μ = friction coefficient

According to the regulation from Rijkwaterstaat (The Netherlands Directorate for Public Works and Water Management), the maximum and minimum values for determining the friction in prestressing are:

The maximum value μ = 0.23 and $\Phi 1$ = 0.009 (ROBK art 16.5.1);

The minimum value for μ = 0.13 and $\Phi 1$=0.003 (ROBK art 16.5.1).

3.2.3.2 Anchorage Set

At the anchorage side, the high compression during the tensioning of the cables effected the settlement of the concrete. The concrete at the jacking side shorten a little bit hence, the cables shall loss the tension forces. The anchorage set only give the influence in prestressing losses up to a certain distance from the jacking side.

The formula to calculate the losses of prestressing force due to anchorage set is:

$$\Delta F_{pA} = 2.w.\Delta p \quad \text{(3.3)}$$

where:

$$\Delta P = \frac{P_0 - P_{pF}}{L_c} \quad \text{(3.4)}$$

$$w = \sqrt{\frac{E_p.A_p.L_{pA}}{\Delta P}} \quad \text{(3.5)}$$

L_{pA} = the thickness of anchorage set

E_p = modulus of elasticity of the prestressing steel

W = the length influenced by anchorage set

L_c = length of the cables

According to the regulation from Rijkwaterstaat (Directorate for Public Works and Water Management), ROBK art 16.5.2, the thickness of the anchorage set that is allowed is 7 mm.

The typical curve of the direct losses occurring in the prestressing system is as shown in **Figure 3.3**.

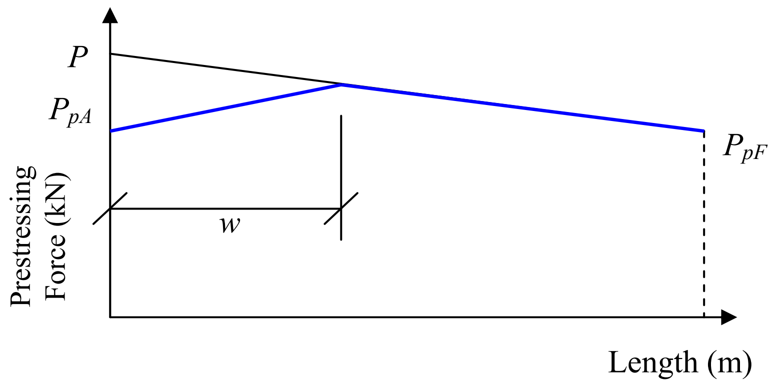


Figure 3.3 *The typical curve of direct losses*

3.2.3.3 Creep

Concrete experiences volume changes throughout its service life. When sustain ably loaded, concrete experiences a slow inelastic deformation called creep. Creep can be divided into two components, basic creep and drying creep. Basic creep is time-dependent increase in strain under sustained constant load of a concrete which is sealed or if there is no moisture exchange between the concrete. Drying creep is the creep occurring in concrete exposed to the environment and allowed to dry.

The creep of concrete depends on many factors other than time, such as: volume content of hydrated cement paste, relative humidity of the environment, the age of the concrete at the time of loading, the duration the concrete is stressed, and the geometry of the structure.

In the Netherlands' code (NEN-6720 art 6.1.5); the maximum value of creep coefficient is defined based on the strength of concrete and the relative humidity (Eqs.3.6).

$$\phi = k_c.k_d.k_b.k_h.k_t < \phi_{max} \qquad (3.6)$$

where

k_c = the factor, which depends on relative humidity. See Appendix **Table 4**

k_d = the factor, which depends on quality of the concrete and the phase age. See **ANNEX 6-Table 5** (NEN 6720-VBC 1995 art.6.1.5)

k_b = the factor, which depends on the strength of the concrete as cylinder shape (f'_{ck}). See **ANNEX 6-Table 6** (NEN 6720-VBC 1995 art.6.1.5)

k_h = the factor, which depends on the fictive height of the cross section of the structure (h_m). See **ANNEX 6-Table 7** (NEN 6720-VBC 1995 art.6.1.5)

$$h_m = \frac{2.A_c}{O} \qquad (3.7)$$

A_c = cross section area of the concrete structure

O = outer line of the concrete structure

k_t = the factor, which depends on the time of applied load in day (t).

$$k_t = \frac{t}{t + 0.04\sqrt{h_m^3}} \quad \text{.......(3.8)}$$

ϕ_{max} = the maximum value of creep coefficient based on the strength of concrete and the relative humidity. See **ANNEX 6-Table 8** (NEN 6720-VBC 1995 art.6.1.5)

3.2.3.4 Shrinkage

Shrinkage is defined as a concrete volume change occurring due to the loss of moisture and the changing of paste's internal structure. These volume changes are often attributed to the drying of the concrete over a long time period.

Shrinkage depends on many factors, including water-cement ratio, moisture, relative humidity of the environment, ambient temperature, aggregate properties, and size and shape of the structural member.

The basic shrinkage factor that has to be considered in concrete design according to the Netherlands' code (NEN-6720 art 6.1.6) is as shown in Eqs.3.9.

$$\varepsilon'_r = \varepsilon'_c .k_b .k_h .k_p .k_t < \varepsilon'_{max} \quad \text{.......(3.9)}$$

where

ε'_c = basic shrinkage factor. See **ANNEX 6-Table 9** (NEN 6720-VBC 1995 art.6.1.6)

k_b = the factor, which depends on the strength of the concrete as cylinder shape (f'_{ck}). See **ANNEX 6-Table 6** (NEN 6720-VBC 1995 art.6.1.6)

k_h = the factor, which depends on the fictive height of the cross section of the structure (h_m). See **ANNEX 6-Table 10** (NEN 6720-VBC 1995 art.6.1.6)

k_p = the factor, which depends on the percentage of reinforcement.

$$k_t = \frac{1}{1 + 0.2.\omega_o} \quad \text{.......(3.10)}$$

k_t = the factor, which depends on the time of applied load in day (t)

$$\Delta\sigma_{pS} = \varepsilon'_r .E_p \quad (\text{kN/m}^2) \text{.......(3.11)}$$

3.2.3.5 Relaxation

According to the Netherlands' code (NEN-6720 art 4.1.4.5b), the formula to predict the relaxation of prestressing steel after certain time is:

$$\Delta\sigma_{pR} = 3.\Delta_{p,1000}\left(1 - 2\frac{\Delta\sigma_{pS+p\varphi}}{\sigma_{p,0}}\right) \text{ (kN/m}^2\text{)} \quad (3.12)$$

where

$\Delta_{p,1000}$ = the maximum relaxation, which happen after 1000 hours. See **ANNEX 6-Table 14** (NEN 6720-VBC 1995 art.6.3.6)

$\Delta\sigma_{pS+p\varphi}$ = prestressing losses due to creep and shrinkage (kN/m^2)

3.2.4 The Cable Layout

A cable is a group of prestressing tendon and the centre of gravity of all prestressing reinforcement. It is a general principle that the maximum eccentricity of prestressing tendons should occur at the location of maximum moment. The structure is a continuous support, thus there are positive and negative moments, which have to be considered in the design. The upward forces generated by prestressing forces are needed to counteract positive moments and at the other side especially at the middle support, the downward forces are needed to counteract the negative moment. To manage those aspects, the layout of the cable must provide at least two curves per span.

The layout of the cable can be approached as two parabolas, which intersect each other. Those parabolas have their own radius but mostly the radius of the first parabola is far bigger than the second one (**Figure 3.4**).

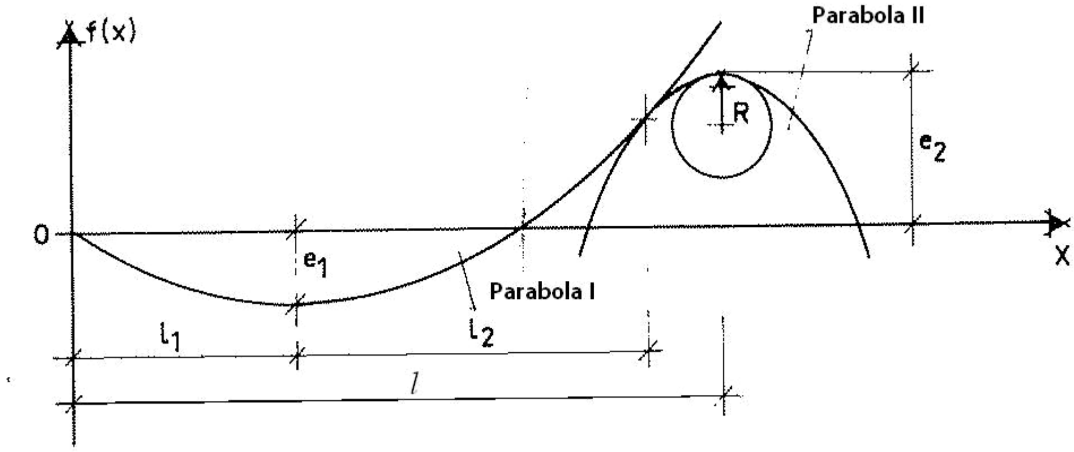


Figure 3.4 *The parabolic layout of the cable*

The general formula for 2nd grade parabola is:

$$f(x) = ax^2 + bx + c \quad (3.13)$$

Parabola I

The starting point of the parabola is (0, 0) thus c=0, then the formula will be:

$$f(x) = \frac{e_1}{l_1^2}x^2 - \frac{2e_1}{l_1}x \quad (3.14)$$

Parabola II

$$g(x) = -\frac{1}{2R}x^2 + \frac{1}{R}x + e_2 - \frac{l^2}{2R} \quad (3.15)$$

If those two parabolas intersect each other in a certain position, thus we can say that:

$$f(x) = g(x) \quad (3.16a)$$

Then the equation can be simplified as:

$$\left(\frac{e_1}{l_1^2} + \frac{1}{2R}\right)x^2 - \left(\frac{2e_1}{l_1} + \frac{1}{R}\right)x - \left(e_2 - \frac{l^2}{2R}\right) = 0 \quad (3.16b)$$

$$b^2 - 4ac = 0 \quad (3.16c)$$

afterwards the length of l_1 can be determined by using:

$$\left(\frac{e_2}{e_1}\right)l_1^2 + (2.l)l_1 + 2R(e_1 + e_2) - l^2 = 0 \quad (3.16d)$$

and the length of l_2 can be determined by using:

$$l_2 = \frac{l - l_1}{1 + \frac{2e_1 R}{l_1^2}} \quad \text{......(3.17)}$$

where,

e_1 : eccentricity of the first parabola to the neutral line of the structure (m)

e_2 : eccentricity of the second parabola to the neutral line of the structure (m)

l : the total length of the structure (m)

R : radius of the second parabola (m)

3.2.5 Ducts

The ducts for post-tensioned tendon shall be located and constructed so that:

- The concrete can be safely poured without damaging the ducts;
- The concrete can resist the forces from the ducts in the curved parts during and after stressing;
- No grout will leak during grouting process.

The minimum spacing between ducts is shown in **Figure 3.5**

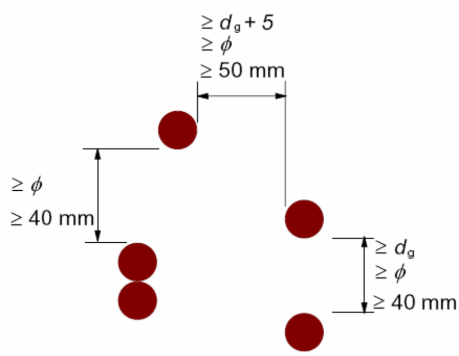


Figure 3.5 *Minimum spacing between ducts*
(Source: Eurocode EN 1992-1-1:2004)

3.3 Railway Track Systems

The track is a fundamental part of the railway infrastructure and represents the primary distinction between this form of land transportation and all others because it provides a fixed guidance system. The traditional railway system is characterized by rail tracks on cross beam made from concrete or wood, supported on a ballast bed (**Figure 3.6**). There are three main parts of the railway construction. They are rails, sleepers, and ballast bed.

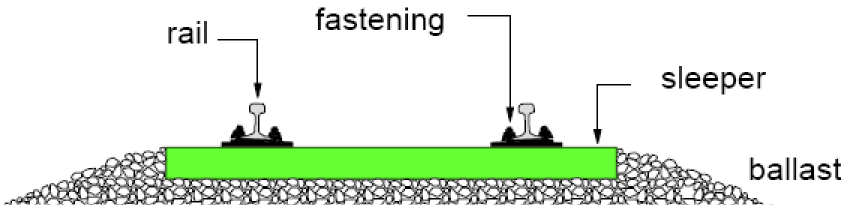
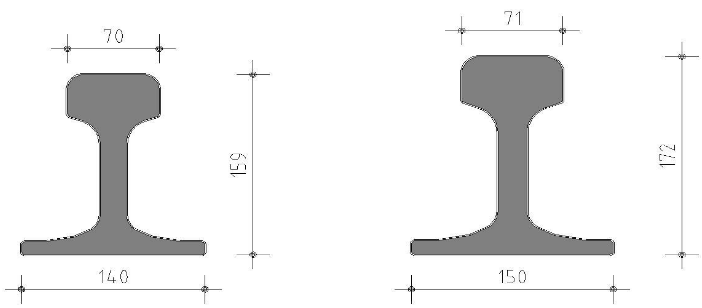


Figure 3.6 *Railway construction*

3.3.1 Rails

The rails can be seen as the main part and most important component of the railway track structure. The main function of the rail is guiding the train wheels in the lateral direction as well as horizontal transverse direction. The rail profiles, used very widely in Europe, are UIC 54 and UIC 60 (**Figure 3.7**). Generally, the track gauge is defined as a measure of the distance between the inside of two head rails. The standard gauge, which is commonly used in Europe, is 1435 mm.



(a) (b)
Figure 3.7 (a) *UIC 54 profile* (b) *UIC 60 profile* (unit in mm)

3.3.2 Sleeper

Sleeper is a beam underneath the rail that provides supporting and transferring forces to the ballast bed as uniformly as possible. Rails are fastened on the sleeper. Another function of the sleeper is to ensure that the track gauge is constant along the route. The differentiation in the track gauge is dangerous for the train and it can cause derailment.

There are two common materials of sleepers. They are wood and concrete. However, concrete is the most popular material used. Concrete sleepers give a better move resistance because concrete sleepers are much heavier than wooden ones. They work well in most conditions. Climatological influences only give a little effect. Thus, the use of concrete sleepers is preferable due to the durability for a long period.

Concrete sleepers also have the disadvantage that they cannot be cut to size for switch and special crossing work. They offer less flexibility and are alleged to crack more easily under heavy loads with stiff ballast.

Sleeper, rails and the fastening together form the built-up portion of the track superstructure (**Figure 3.8**).

Figure 3.8 *Rails, fastenings, and sleepers*
(Source: http://www.railway-technical.com)

3.3.3 Ballast Bed

A ballast bed is a layer of gravel or stones that lay underneath and between the track superstructures (**Figure 3.6**). The function of a ballast bed is to provide support and lateral resistance for the track super structure. The interlocking among the gravel creates structures that have sufficient bearing strength, stability. The ballast bed distribute the loads uniformly.

The train loads are transferred from the rail through the sleeper and from the sleeper through the ballast bed and eventually the stress that the support has to carry is less.

The advantages of using a ballast bed are:

1. Relatively low cost construction;
2. High elasticity;
3. Good maintainability;
4. Good absorb functioning of noise;
5. Track realignments are allowed.

The disadvantages of using a ballast bed are:

1. Require high construction thus the weight of the structure is heavy;
2. The damage of ballast leads to tracks "pumping" as a train passes and, eventually, rail or sleeper damage will occur.
3. Need more maintenance due to the possibility of displacement, and deterioration caused by heavy loading and the change of the weather;
4. Ballast has to be temped, replaced and renewed after a few years.

Research and development in the track systems realizes other possible design instead of using the ballast bed. One of the non-ballasted track designs is by using a concrete slab as a base. The rails are directly fastened to the slab.

The advantages of concrete slab track are:

1. Less construction depth compared to ballasted track;
2. Less maintenance, because there is no settlement and possibility of deterioration is less than a ballast bed;
3. Relatively low weight;
4. Easy to clean because of no dust from the structure;
5. The hazard of track buckling either vertically or horizontally is eliminated.

The disadvantages of concrete slab tracks are:

1. High costs of the investment and much time needed because of the high degree of precision in constructing.

2. Realignment is limited. Thus, in construction period, the accurate finishing is required and very important. Any changes at later stage are very difficult to implement.
3. Vibration and noise reduction is not very good.

CHAPTER IV

CHAPTER IV
THE BRIDGE DESIGN

4.1 Supporting Type

The total length of the approach bridge that will be built is approximately 626.5 meter. A forty-meter long from support to support divide those long bridges into a number of spans.

First, it is necessary to determine what kind of support that used for further design. It will have influences on construction methods, time, costs, and many design considerations. In this bridge design, I propose a continuous slab over three spans. Thus, it is total 120 m long in one design of bridge. One hinge support and three roll supports are a suitable choice for this situation. The supporting type is as shown on **Figure 4.1**.

Because there are five unknowns forces (V_A, V_B, V_C, V_D *and* H_A) but only three equilibrium equations ($\Sigma M=0$, $\Sigma V=0$, $\Sigma H=0$), this system of simultaneous equations cannot be solved. The structure is therefore classified as a statically indeterminate structure. A structure can be characterized as statically indeterminate when the equilibrium equations are not sufficient for determining the internal forces and reactions on the structure. To solve this problem, material properties and compatibility in deformations should be taken into account. I use *Alp 2000* for determining internal forces in the structure.

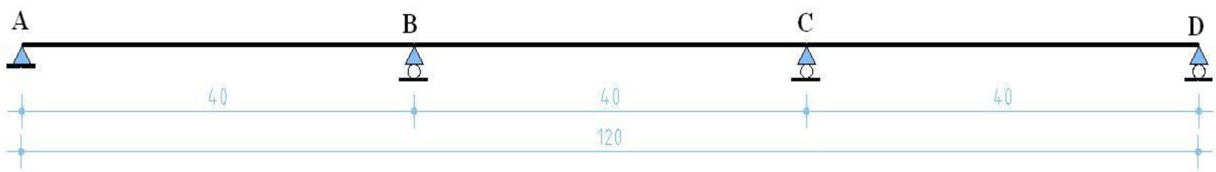


Figure 4.1 *Supporting type of the bridge (unit in m)*

The advantages of using a continuous system are:

1. The structure is monolithic.
2. The positive moment is distributed into the intermediate support, thus the positive moments are less, compared to the positive moment if a simple beam system is used.

3. The deflection can be reduced due to the reduction of the maximum moment.

The disadvantages of using a continuous system are:

1. It is difficult to do maintenance in continuous span than simple span, in case the bearing has to be changed after some years.
2. The negative moments, which occur at intermediate supports, have to be taken into account. Since the negative moment has an anti-gravity direction.

4.2 Cross Section of the Bridge

The width of the deck must provide sufficient area for a double railway track. The spaces for the traffic envelope of the train, drainage, electricity, footpath for maintenance have to be taken into account to determine the proper width of the deck.

The free clearance of the trains has to be provided and it is important for safely travelling. It is a fictive area at both sides and top of the train where obstacles are prohibited. Moreover, the train has a small movement perpendicular to its direction during travelling. That can be caused by side-wind, super elevation of the track, or the shock breaker movement during the high speed. To provide the free clearance between two trains, the minimum track distance is 4.250 m centre to centre. The total railway construction on top of the bridge is shown in **Figure 4.2**.

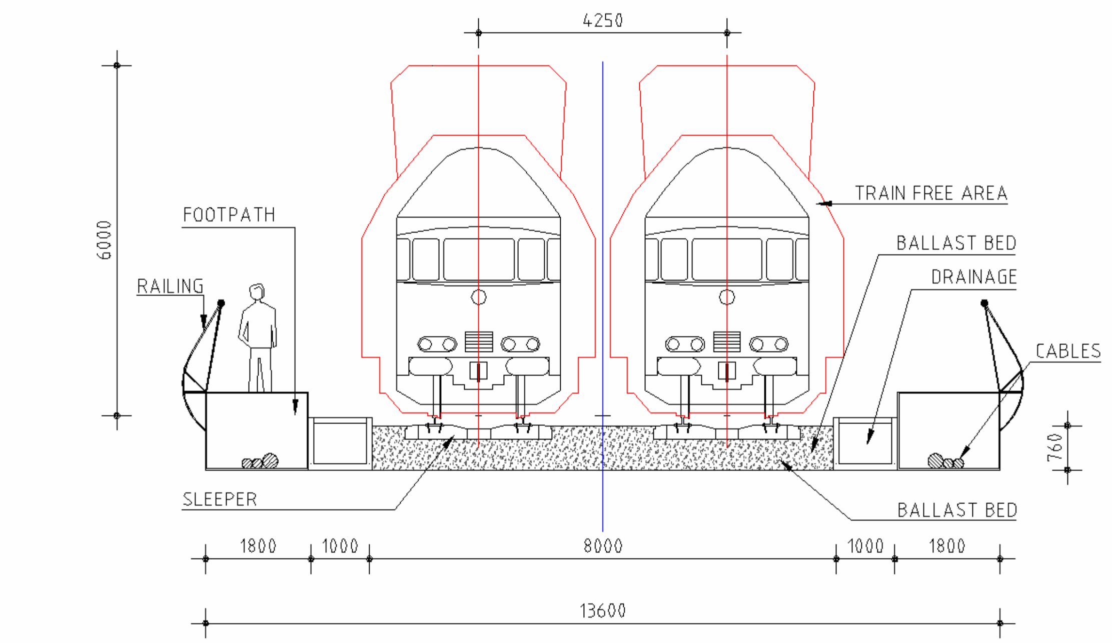


Figure 4.2 *Railway constructions* (unit in mm)

After studying and finding the effective shape of the slab, the preliminary design of the bridge cross section is as shown in **Figure 4.3.** The dimension of the bridge cross section is got after trying several calculations. The shape has to become efficient to reduce the self-weight.

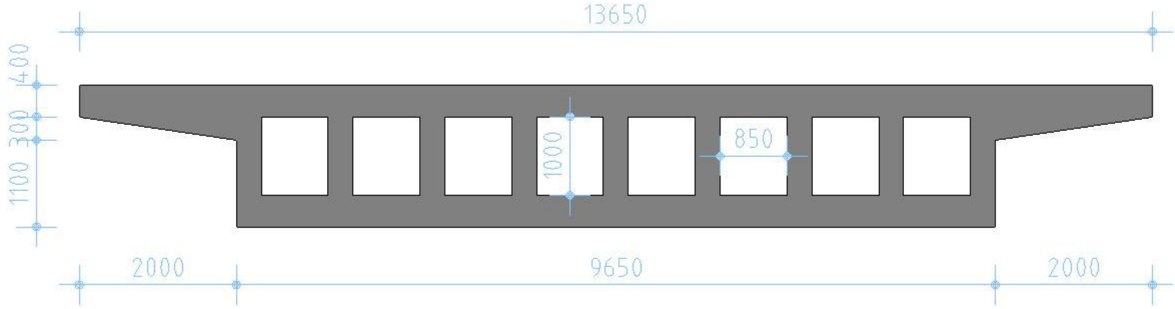


Figure 4.3 *The assumed cross-section* (unit in mm)

4.3 Material Properties

The two main parts of the structure are concrete steels and prestressing cables. The type of concrete that is used in the design is concrete *C53/65*. In the pre-stress system, high quality concrete is necessary to react against high forces of prestressing cables. For the prestressing cables, strands with the strength of 1860 N/mm^2 are used in the design. That is the common type of prestressing cables, which are used in the construction.

Materials, used in the design, are shown in **Table 4.2**

Material	Type of material	Strength (MPa)	Density (kN/m^3)	Modulus elasticity (MPa)
Concrete	C53/65	65*	25	38500
Pre-stress cable	FeP 1860	1860	78.5	200000

Table 4.1 *The material properties*

* The compressive strength of the cube shape of concrete specimen

Permanent structures on the top of the bridge are the railway system including rails, sleepers, cables for electricity and piping. The materials, which are used, are described further on.

1. The rails

   The rails used in The Netherlands are the standard rail, *UIC 54*, with the weight of the steel rail, γ_{rails} is 0.54 kN/m'.

2. Sleeper

   Sleepers, which are used, are concrete sleepers instead of wooden sleepers. Concrete sleeper is more durable, strong and easy in maintenance compared with wooden sleeper. The density of concrete sleepers ($\gamma_{concrete}$) is 24.5 kN/m'.

3. Ballast bed

   This railway bridge uses a conventional railway system to support trainloads. Ballast bed which are laid to support sleeper and rails are preferred than concrete ballast. Ballast bed consists of the layer of aggregate or small stones, which create interlocking among them. Moreover, the composition of ballast bed is important so that the movement in the ballast structure can be minimalized and the structures are strong enough for distributing and spreading the loads from the railway tracks to the superstructure. According to NEN-6723:1995, the density of gravel for the ballast bed ($\gamma_{ballast}$) is 18 kN/m^3.

4. Railing

   The weight of the railing steel is assumed 5 kN/m'.

5. Cables and pipe

   The weight of the cables and pipes is assumed 3 kN/m'.

6. The electrical installation

   The weight of electrical installation is assumed 1 kN/m'.

4.4 Load Cases

Determining loads are the important part in designing structures. The structure should be able to withstand certain loading, which are possibly present during either the construction period or service life period. In this bridge design, there are three types of loading that give many influences in the structure behaviour; they are dead loads, live loads, and prestressing loads.

4.4.1 Dead Loads

Dead load is defined as a load that is permanently applied to a structure. It is applied to the structure as long as the structure is still functioned. In the railway bridge, dead loads consist of weight of the structure itself, railway structure, and any attachments it may carry. For designing bridges, dead loads are critical aspect to be considered because usually the weight of the bridge structure itself is much higher than the traffic load applied to it.

Dead loads, which are used for designing Railway Bridge, are:

1. Railway structure
   a. Rails
   b. Sleeper
   c. Ballast bed
2. Self-weight of the structure
3. Railing
4. Utilities
   a. Cables and pipe
   b. Electricity

The permanent loads applied on the structure are as seen in **Figure 4.4.** For the calculation of dead loads, see **ANNEX 2**.

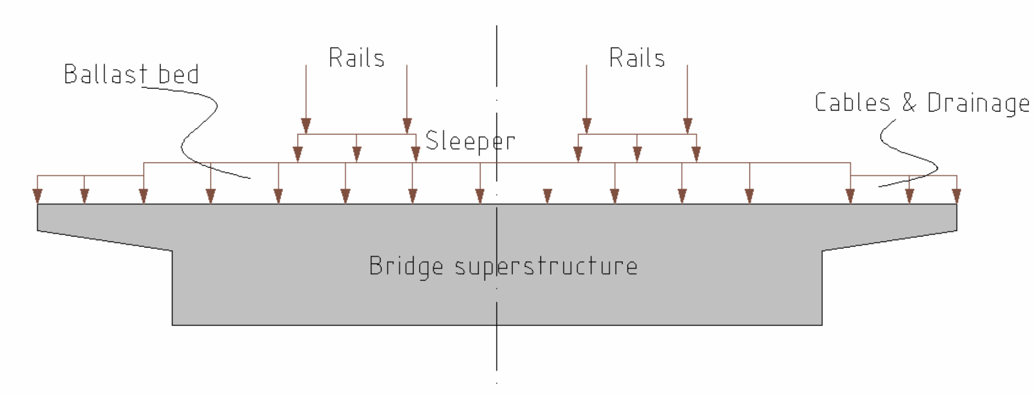


Figure 4.4 *The applied dead loads in cross section*

4.4.2 Live Loads

Live loads are the loads, which temporarily acted, depend on the function of structure and vary with time and space during the lifetime of the structure. According to the Netherlands' code NEN 6723, the distribution of the trainloads, which is commonly used for railway bridge designing, is as shown in **Figure 4.5**. It consists of 80 kN/m' of uniformly distributed loads and 150 kN of point loads, which are represent train axles.

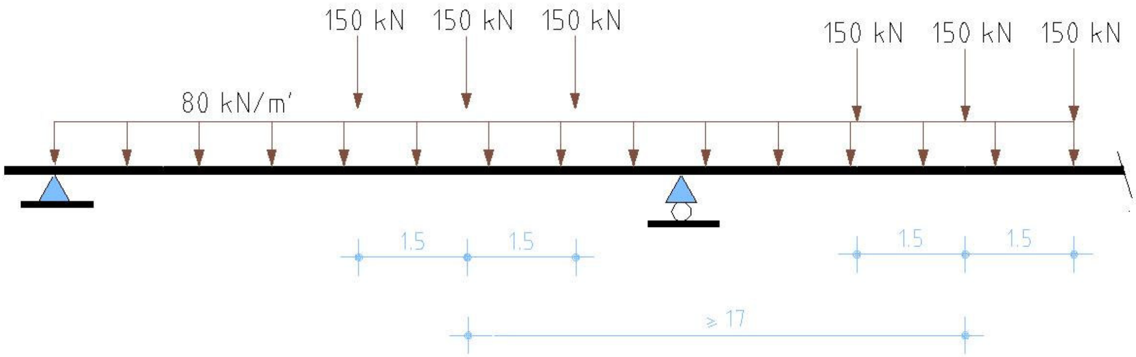


Figure 4.5 *The applied trainloads for one track in longitudinal direction (NEN 6723:1995)*

4.4.3 Load Combinations

A variety of loads can be applied to the structure at any time depend on in which phase the loads are. It can be at the same time or only some of them. The combinations of the loads are intended to find a possible combination, which give a critical value. The values of internal forces in the structure are used to design and verify if the design is good or not.

The load combinations I used in this design are based on the loads, which possibly occur in every phase. It is better to check the internal forces in every phase, from the construction phase to the service load phase. For example, in the day of 28^{th} after the concrete are cured, normally permanent loads such as railway structures, railings, and cables are not applied yet. The load combinations, which are taken into account in this design, are shown in **Table 4.2.**

Combination	Types of the load	Factors	Days
1	Dead Loads	1.2	-
2	Mobile Loads	1.5	-

3	- Self weight of the structure - Prestressing (with direct losses)	1.2 1.0	28
4	- Self weight of the structure - Permanent loads (cables, railway structure, piping) - Prestressing (with direct losses)	1.2 1.2 1.0	42
5 (ULS ∞)	- Self weight of the structure - Permanent loads (cables, railway structure, piping) - Prestressing (with direct losses + time dependent losses) - Mobile loads	1.2 1.2 1.0 1.5	∞
6 (ULS ∞)	- Self weight of the structure - Permanent loads (cables, railway structure, piping) - Prestressing (with direct losses+ time dependent losses) - Mobile loads - Settlement (10 mm at first support)	1.2 1.2 1.0 1.5 1.5	∞
7 (ULS ∞)	- Self weight of the structure - Permanent loads (cables, railway structure, piping) - Prestressing (with direct losses+ time dependent losses) - Mobile loads - Settlement (10 mm at the second support)	1.2 1.2 1.0 1.5 1.5	∞

8 (SLS ∞)	- Self weight of the structure - Permanent loads (cables, railway structure, piping) - Prestressing (with direct losses+ time dependent losses) - Mobile loads	1.0 1.0 1.0 1.0	∞
9 (SLS ∞)	- Self weight of the structure - Permanent loads (cables, railway structure, piping) - Prestressing (with direct losses+ time dependent losses) - Mobile loads - Settlement (10 mm at the second support)	1.0 1.0 1.0 1.0 1.0	∞

Table 4.2 *Load combinations*

4.5 Design Considerations

Limit state is defined as a limiting condition of acceptable performance of structures. In order to achieve the objective for safety, verification of the structure is necessary to prevent failures and to ensure that the structure is able to withstand within its lifetime. In this bridge design, I used the terms of Ultimate Limit States, Service Limit States and Fatigue Limit States for verifying the structure. The structure is checked using those terms by either software or hand calculation.

4.5.1 Ultimate Limit States

The structure should satisfy the strength based on Ultimate Limit States (ULS). The structures which are being designed are shown to be safe when the factored loads are less than their factored resistance. The structure must satisfy Eqs(4.1).

$$M_D < M_U \qquad (4.1)$$

where M_D is a factored moment due to load combination and M_U is the moment that the structure can resist.

4.5.2 Service Limit States

Service limit states correspond to the restrictions on cracking width and deformation under the lifetime. They are intended to ensure that the bridge will behave and perform acceptably.

The maximum deflection that occur in the middle of span should not more than 0.001 times the length of the span Eqs(4.2).

$$\sigma < 0.001.L \quad \text{.......................................(4.2)}$$

The vertical deflection of the bridge due to the effect of dead loads, mobile loads and settlement are calculated during the design process by using computer analysis program.

Cracking may occur in the tension zone in the concrete due to the low tensile strength of concrete. The cracks can be controlled by distributing reinforcement over the tension zone. In addition, the use of prestressing system is a good way to minimize tensile force in the concrete. Usually, prestressing will create a structure more in compression. By limiting the tensile stresses in the concrete, cracks that could occur are less.

The allowable tensile stress in the concrete is depending on the quality of the concrete. The maximum tensile stress of concrete is as shown in **Table 3.1.**

4.5.3 Fatigue Limit States

Cyclic loads, which are subjected to the structure, can cause fatigue damage. The fluctuation of stresses in the structure makes the material, especially steel, loss its strength. The fatigue was identified as one of the causes of distress in steel bridges.

Fatigue limit stress is used to limit the stress in steel reinforcements to control concrete crack growth under repetitive mobile loads. Fatigue can cause crack in the structure and cracks could become worst after certain number of cycles of loading even if the maximum fatigue loading is less then static strength of member.

According to The Netherlands code, NEN, the railway bridge has an adequate fatigue resistance if Eqs(4.3) is satisfied.

$$\Delta\sigma_{VOSB} \leq \Delta\sigma_{toel} \quad \text{.......................................(4.3)}$$

$$\Delta\sigma_{VOSB} = \sigma_{\max} - \sigma_{\min} \quad \text{.......................................(4.4)}$$

$$\Delta\sigma_{toel} = \frac{\Delta f_{ak}.k_A.k_N}{\gamma_{fat}}.\frac{1}{\lambda_\tau.\beta_\tau} \qquad (4.5)$$

where:

Δf_{ak} = the different stress characteristic of steel

k_A = the reduction factor due to bended steel and welding

k_N = the coefficient of the loads changing

γ_{fat} = safety factor

λ_τ = the coefficient due to the length of the span

β_τ = the factor for double tracks railway

4.6 The Result

4.6.1 Internal Forces

Load combinations, in Table 4.2, are put into *Alp 2000* program. Every stage, either in construction period or in the service life period, are designed and calculated for ensuring that the structure is safe. Internal forces, deflection due to the combination shall be used for analysing the structure.

1. Construction stage (ULS)

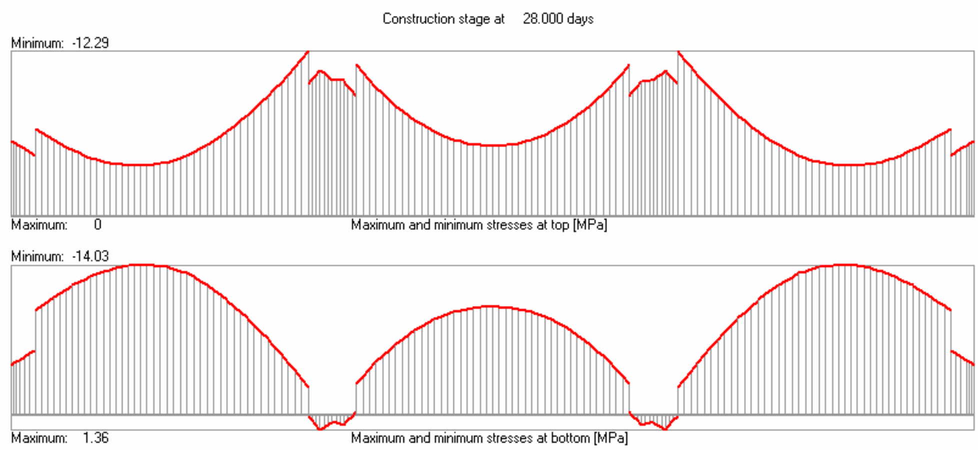


Figure 4.6a *Maximum and minimum stresses at construction stage (Combination 3- construction stage)*

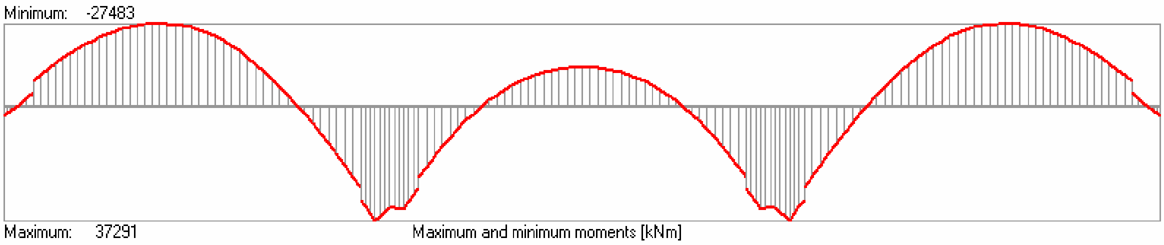


Figure 4.6b *Maximum and minimum bending moment (Combination 3- construction stage)*

When the concrete reaches the age of 28 days, prestressing cables are installed and tensioned. The tensile stresses in the cables are translated into a compressive stress in the concrete and they create uplift forces. That uplift forces make the structure bended upwards. In the **Figure 4.6b,** it shows that bending moments, which occur at construction period, are in the opposite direction with normal bending moment. That it happens because not all the permanent loads are there, only self-weight of the bridge whereas upward forces due to the prestressing force are high enough to make the structure bended upwards. Even though the negative moment occurs in the middle of the span but the behaviour of the structure is still reasonable. The stress diagram (**Figure 4.6a**) shows that the whole structures are in compression particularly in middle of the span.

2. Service life (SLS)

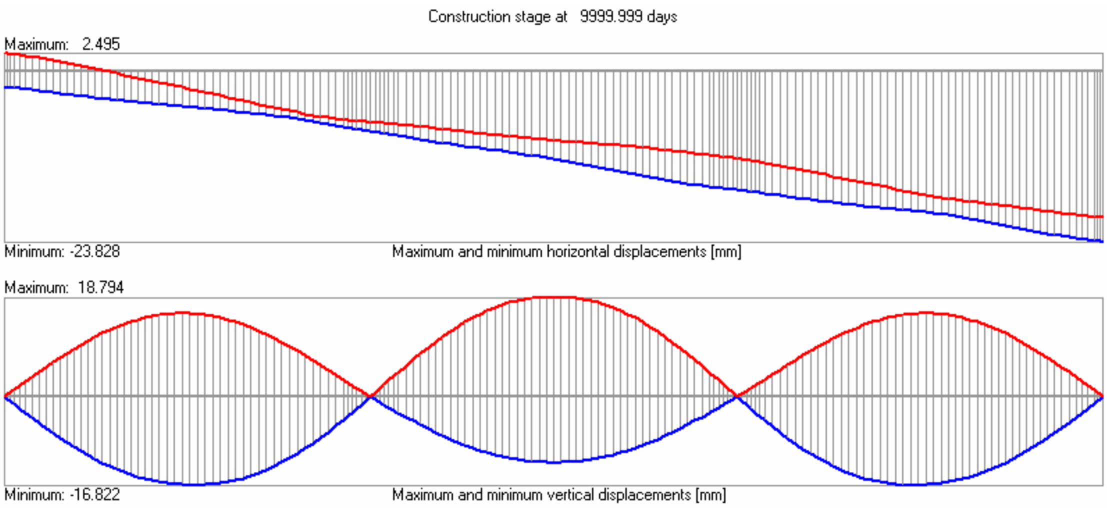


Figure 4.7a *Maximum and minimum displacement (Combination 8-Service Limit States)*

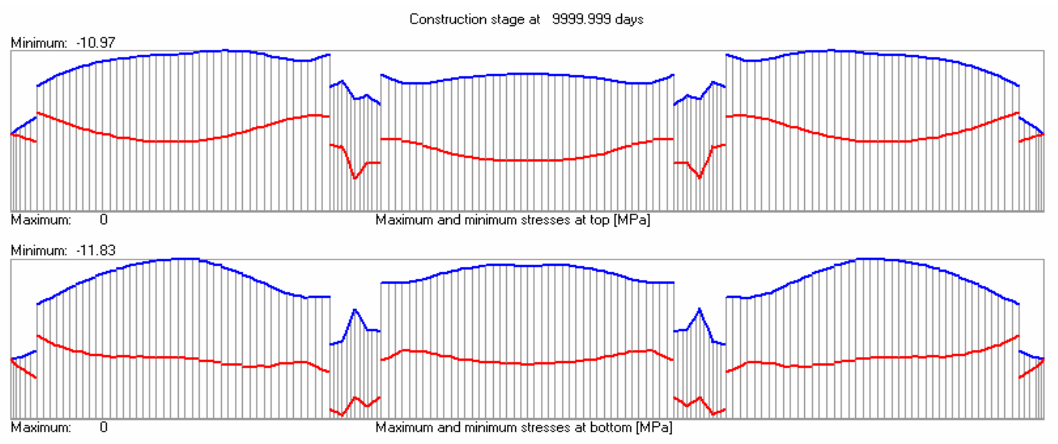


Figure 4.7b *Maximum and minimum stresses (Combination 8-Service Limit States)*

In the service life period, the mobile loads from the train are applied to the bridge. As trainloads pass the bridge, the structure swings up and down in average of 18 mm (**Figure4.7a**). Even though there are stress changes due to the mobile loads, the stress diagram (**Figure 4.7b**) shows that the whole structures are in compression. The horizontal displacements that occur is maximum 24 mm (**Figure 4.7a**)

In Service Limit States, factor of one is used for all loadings. It represents the actual load that subjected to the structure. The loading combination, which is used, is shown in **Table 4.2.**

3. Service life (ULS)

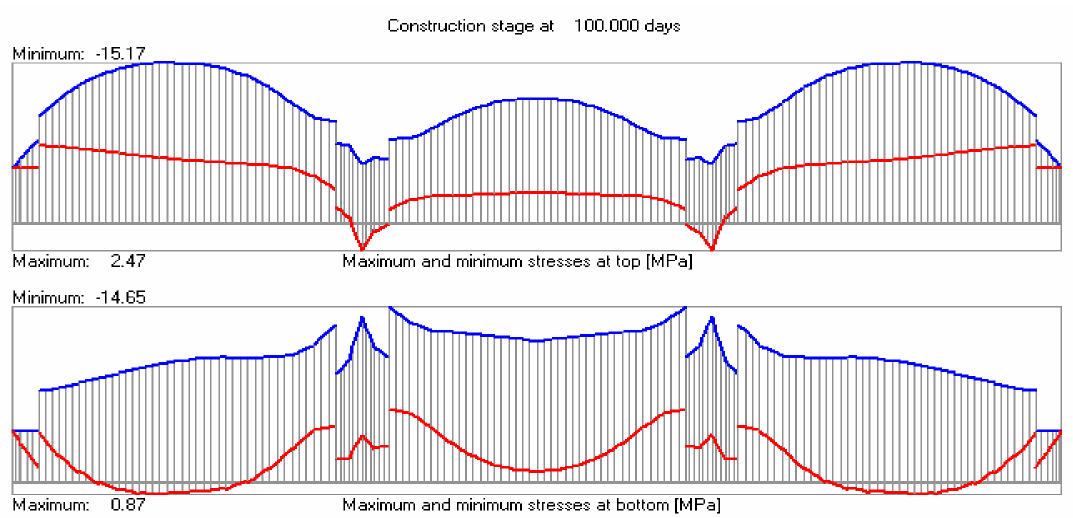


Figure 4.8a *Maximum and minimum stresses (Combination 5-Ultimate Limit States)*

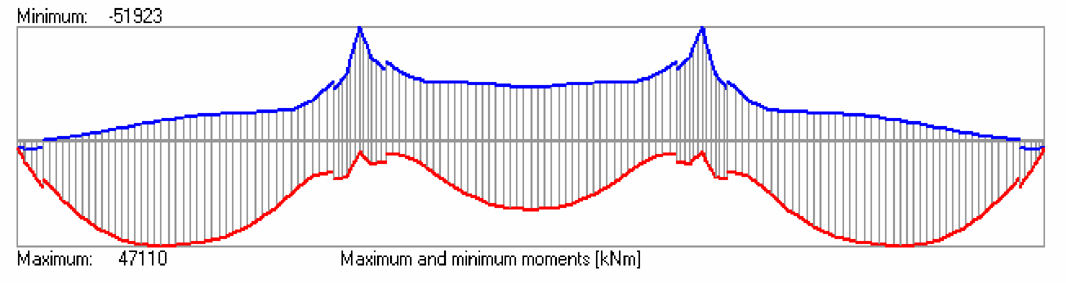


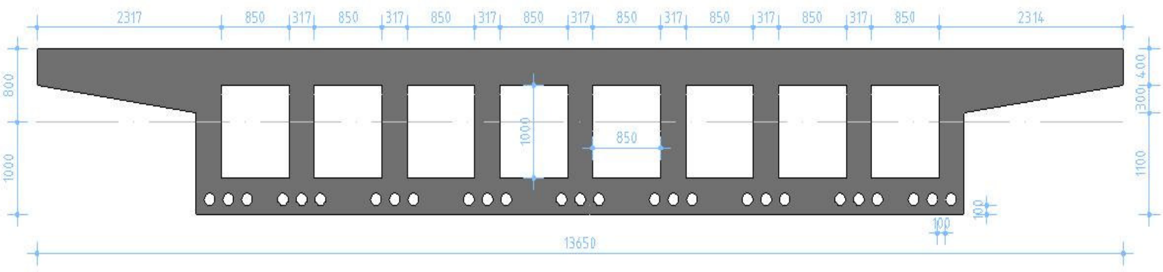
Figure 4.8b *Maximum and minimum bending moment (Combination 5-Ultimate Limit States)*

In the Ultimate Limit States, the loading factor in the load combination is varying depend on the type of the loads. The loading combination, which is used, is shown in **Table 4.1.**

Stresses occurring at the bottom of the cross section of the structure are in tension. In the place where maximum positive moment occurs, the tension stress is 0.87 MPa and it occurs at the bottom side of the bridge cross section. In the place where maximum negative moment occurs, the tension stress is 2.47 MPa and it is still less than maximum tension allowed of the chosen quality of concrete (**Figure 4.8a**). It is still less than maximum tension allowed for the chosen quality of concrete. The allowed tension stress for concrete quality C53/65 is 4.3 MPa thus the structure is safe against the crack failure. The structure is vulnerable for cracking if there are high-tension stresses.

4.6.2 The Bridge Cross Section

These following results are based on hand calculations.



A	=	12.770 m^2
y_a	=	0.800 m
y_b	=	1.000 m
I	=	4.889 m^4
W_a	=	6.112 m^3
W_b	=	4.889 m^3
ka	=	0.383 m
kb	=	0.479 m
q_{DL}	=	319.250 kN/m

Compressive strength of concrete : 65 MPa

For complete hand calculations, see **ANNEX 2**.

Prestressing:

- The type of the cables : 5-31
- The maximum tensioned forces : 5766 kN
- Number of cables needed : 27 Cables
- Both side post-tensioned

For cable properties, see **ANNEX 5.**

4.6.3 Verification

1. Ultimate Limit States

a. At construction stage

Maximum stress occurring at compression area = 14.52 < 39 MPa O.K

Maximum stress occurring at tension area = 0.00 < 4.04 MPa O.K

At service-life stage

Maximum stress occurring at compression area = 14.09 < 39 MPa O.K

Maximum stress occurring at tension are = 0.00 < 4.04 MPa O.K

Ultimate moment

$M_d < M_u$

37948.59 kNm < 131537.69 kNm O.K

2. Service Limit States

a. Deflection at the service-life (Output from ALP2000 with factor 1.0)

δ = 16.82 mm < 0.001 L m

16.82 mm < 40.00 mm O.K

b. Deflection at the service-life (Output from ALP2000 with factor 1.0 and settlement 10mm at the second support)

d = 24.67 mm < 0.001 L m

24.67 mm < 40.00 mm O.K

3. Fatigue Limit States

$\Delta\sigma_{vosb} \leq \Delta\sigma_{toel}$

24.9 < 197.80 O.K

4. Prestressing losses

a. Direct losses

- The anchorage set losses (ΔF_{pA}) = 516.73 kN per cable

- The maximum losses due to the friction losses and the Wobble effect (ΔF_{pF})

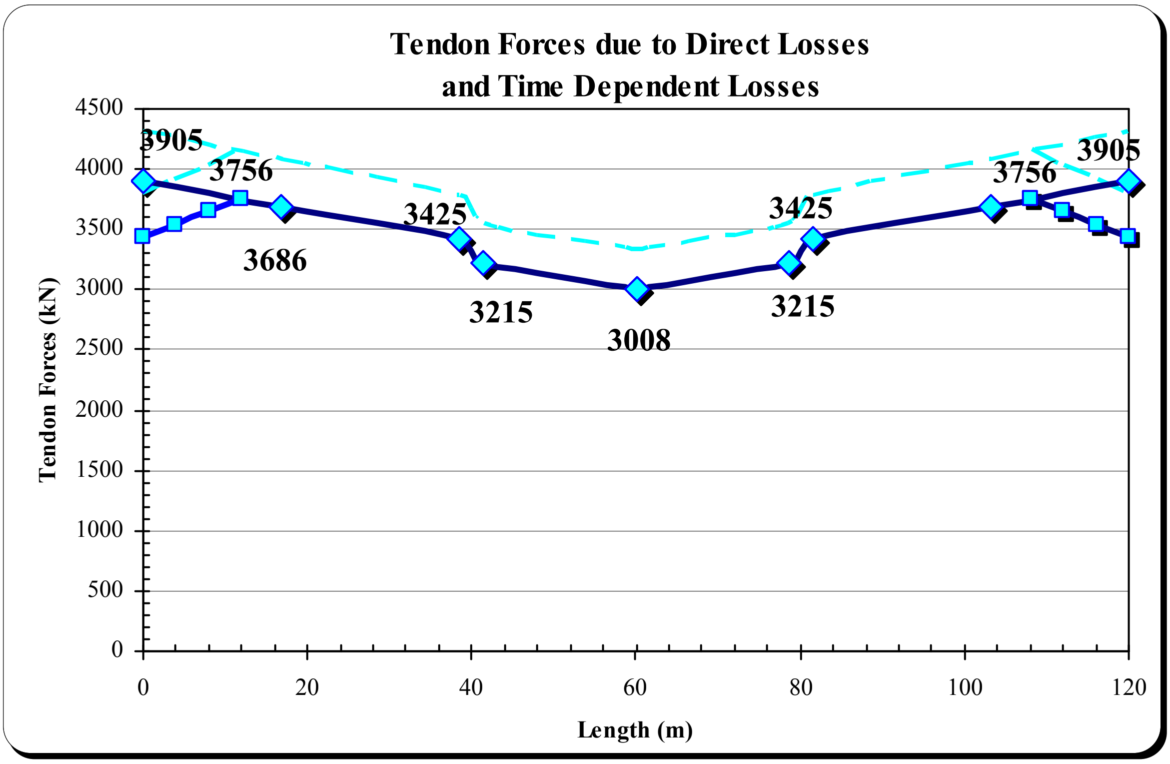
ΔF_{pF} = 993 kN

b. Time-dependent losses

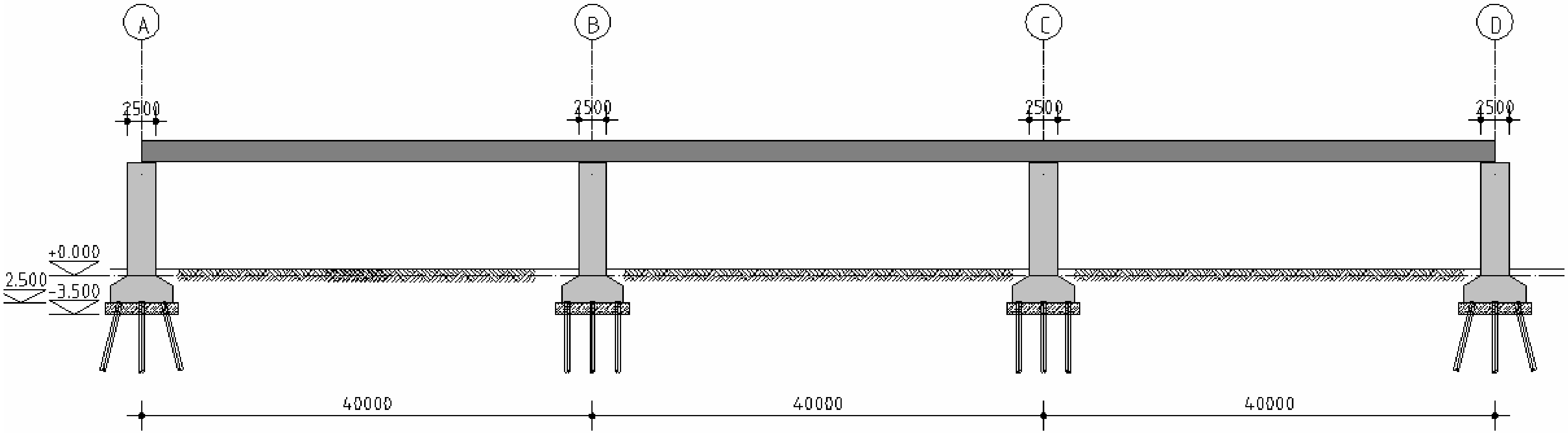
- Losses because of creep $\Delta\sigma_{p\varphi}$ $= 27200.62\ kN/m^2 = 27.23\ MPa$
- Losses because of shrinkage $\Delta\sigma_{pS}$ $= 18375.00\ kN/m^2 = 18.38\ MPa$
- Losses because of relaxation $\Delta\sigma_{pR}$ $= 89976.70\ kN/m^2 = 89.97\ MPa$

c. Percentage of losses due to time dependent losses =

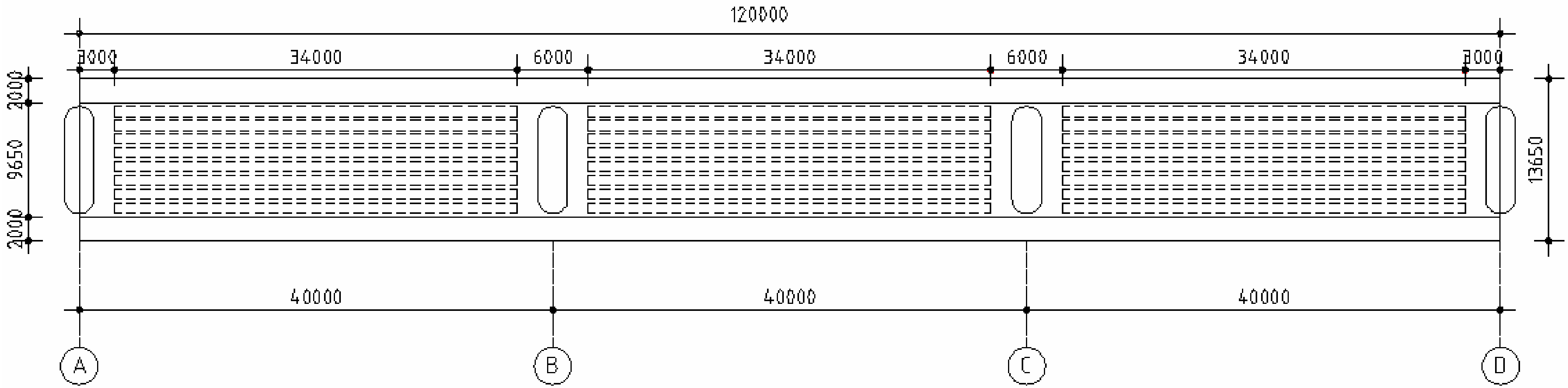
$$= \frac{27.23 + 18.38 + 89.97}{1395.16} * 100\% = 9.7\ \% < 20\ \% \qquad \text{O.K}$$



For complete hand calculations, see **ANNEX 2.**



SIDE VIEW OF THE BRIDGE



TOP VIEW OF THE BRIDGE

CHAPTER V

CHAPTER V
CONSTRUCTION METHOD

After the design stage, it is also important how the designed bridge can be constructed at the site. The construction methods are influenced by the type of the bridge, the area where the bridge is situated, the span of the bridge and the obstacles that are present in the construction area.

The construction methods, which will be executed, have to be designed and calculated in advance to avoid failures during the construction. The structure has to accommodate the possible bending moments that will occur due to the certain construction method. For instance in the segmental bridge, the distribution of bending moments during erection are different with the final situation and it has to be taken into account. The structure requires reinforcements only for a short period during the lifting of the segment.

For concrete cast in situ bridges, it is necessary to reduce the self-weight for longer span. The shape has to become efficient to reduce the self-weight. Therefore, voids are introduced in the slabs. The voids are usually located at the mid-depth of the slab, thereby having the effect of reducing the self-weight without significantly reducing the inertia of the section.

In this bridge design, slab bridges require greater quantities of steel and concrete than beams, but are easier to construct and requires less formwork. Slab bridges also have less height of construction than beam bridges, which can be advantageous with regard to the aesthetic and the quantity of earthwork required in the approach embankment.

The construction stages of the bridge are divided into two main parts. They are the constructions of sub-structure such as earthwork, foundations, pier and the constructions of superstructure such as bridge deck including the structure on top of it.

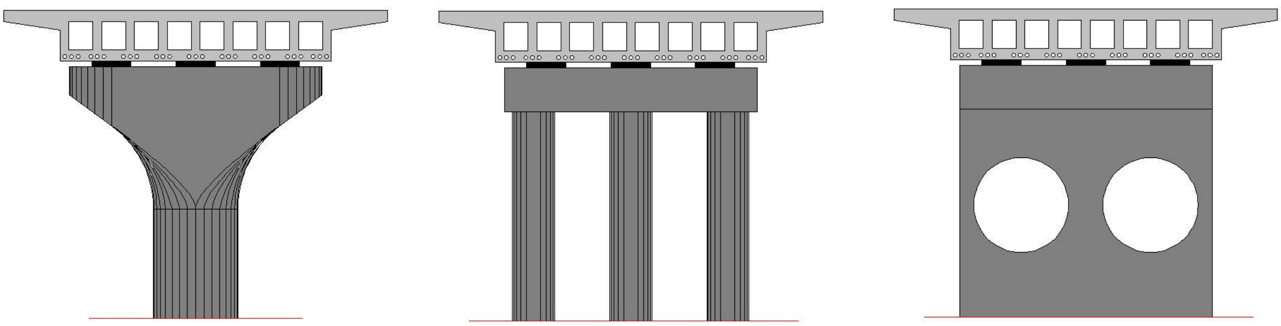
5.1 Substructure Works

Because the topic of this final thesis is only about the bridge superstructure, the sub-structure of the bridge will not be discussed in detail. Only general considerations will be given in this chapter. The sub-structure of the bridge consists of foundations and piers.

A bridge foundation is a part of the bridge sub-structure connecting the bridge to the ground. All loads are distributed to the ground because of that, foundations have to be supported by high bearing capacity of the soil.

Pier is the structure of the bridge that has functions to transfer vertical loads from the superstructure to the foundation and to resist horizontal forces acting to the bridge. Although piers are usually design to resist vertical loads, it is becoming more common that piers are also able to resist high lateral loads such as seismic loads. A pier should be design to withstand the overturning, sliding forces applied from superstructure. In the design, Piers is subjected to combined forces of axial, bending and shear.

Types of pier can be distinguished by its framing configuration. They are single or multiple column bent, hammerhead and solid wall pier (**Figure 5.1**). Selection of the type of piers for a bridge should be based on functional, structural and geometric requirements. Aesthetic is also important factor since nowadays bridges are also part of city's landscape.



(a) *Hammerhead pier* (b) *Multiple column pier* (c) *Solid wall pier*

Figure 5.1 *Typical pier types of the bridge concrete*

Most of the time, piers are constructed in site. After foundations have been installed, the stage can be followed by placing reinforcements and formworks for pier. After that, concrete is placed and because of that, piers and foundations become a monolithic structure, which transfers the loads from super structures to the ground.

5.2 Superstructure Works

The voided slab bridge in this design will be constructed by cast in situ construction method. Cast in situ construction means the bridge decks are constructed at the final place of the bridge. Thus, equipments for erecting and transporting the segments are not needed in this method. The investment is in constructing the temporary support and the formwork at the site thus the bridge deck is constructed directly in the final place.

Stages of construction in super structure are:

1. Installation of the falseworks

The construction on falseworks can be an economic execution in the following situations:

a. The height of the structure is relatively close to the ground.
b. The condition of the ground is good, so that settlement of soil due to the self-weight of the structure is expected only a little.
c. No obstacles, such as traffics, cross to the falsework.
d. Suitable for span-by-span construction.

This one hundred twenty-meter span bridge can be categorized as a long bridge for this type of construction method. The cost of providing overall falseworks and the problem associated with placing large volume of concrete in a single pour become the things that have to be considered. It is therefore more usual to construct such bridge in a series of stages.

The number of stages will be dependent upon the length and the configuration of the structure. The most common sequence is to construct these bridges on a span-by-span basis, although it is also possible to construct two or three spans in a single stage.

Because the bridge is monolithic and consists of three spans of forty meter long, it is better to construct the falseworks for three spans in one stage.

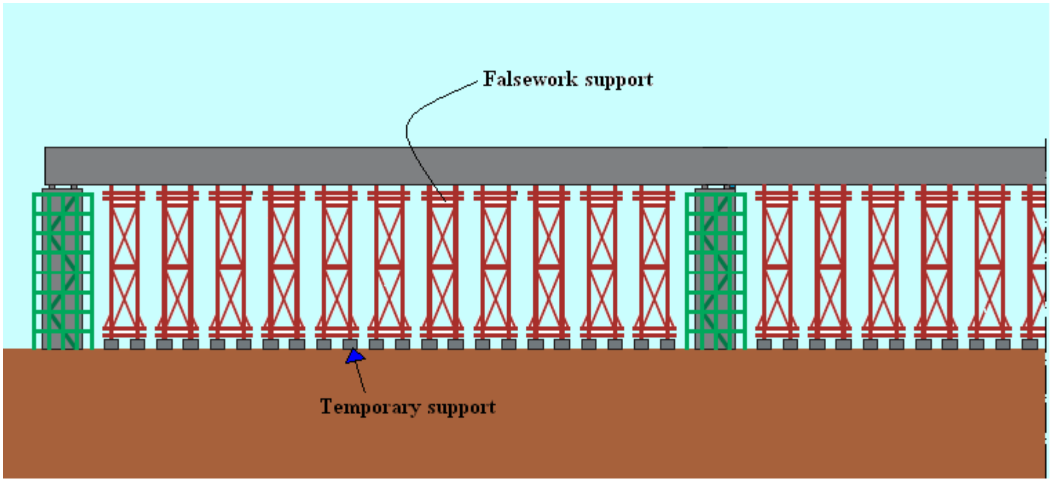


Figure 5.2 *Falseworks as temporary support*

In this bridge design, the entire structure, 120-meter long bridge, is supported on stationary falseworks (**Figure 5.2**). The stationary falseworks are used as a support for the formwork and the self-weight of the bridge until the bridge is strong enough. Because they are temporary used, the falseworks can be reuse again afterwards in another span of the bridge.

Formworks of the slab then are installed in the proper elevation on the top the falseworks. The height of the false works has to be adjusted by a jack to get a correct elevation of the bridge.

2. The installation of reinforcements

The next stage after installing the falseworks is to place reinforcements at the formwork. Normally, there are two types of reinforcement in prestressing design. They are the normal reinforcement and the prestressing cables.

This design of bridge is a fully prestressing system, but in the real implementation, we still need normal reinforcements. The normal reinforcement consists of reinforcements for shear, torsion, and the reinforcements that hold the prestressing cables. The present of normal reinforcements, obviously makes the structure more strong as well as increases the safety factor. Shear forces are very high especially near and at the support. Concrete only could resist at certain shear forces and the rest shall be held by reinforcements. Reinforcements, which are needed for tension and shear force, have to be designed and put together in the structure.

The prestressing ducts then are placed at the slab formwork. In the post-tensioned system, the prestressing cables will be installed after the concrete are strong enough. Thus in the early stage, only the cable ducts are installed including other complements such as pipes for grouting, place for live anchorage, tendon supports, etc. The layout of the cable ducts have to follow curvatures, which have been designed before. It has to be as accurate as possible to get the expected force. Reinforcements are used to hold the elevation of the cable ducts in every certain distance. The recommended spacing between tendon supports according to VSL is 0.8 to1.2 meter for standard steel ducts and 0.6 to 1.0 meter for plastic PT-Plus ducts. They have to be strong enough so that in the time of pouring the concrete into the formwork, the positions of the cable will not move. The installation of reinforcements, tendons at formwork can be seen in **Figure 5.3.** Post-tensioned cast in place system is used by Grontmij for constructing a double track railway bridge, *Oosterheemlijn project*.

Figure 5.3 *Post tensioned cast in place**

Notes:
* Photo is taken from *Oosterheemlijn Project* designed by Grontmij

Recently, VSL Company has developed the cable ducts, which are made by plastic. The corrugated plastic duct provide a number of important advantages when compare with conventional steel ducts. The plastic ducts are fully encapsulated and watertight therefore they offer superb corrosion protection. The use of plastic ducts improves the tendon fatigue resistance where in the railway bridge, fatigue loading is one of the problems.

3. Pouring the concrete

After reinforcements and other necessary complements have been placed at the formwork, then the concrete is ready to be poured in.

During concreting, the voided slabs require more attention in the case of floatation of the void-former due to the upward pressure of the fresh concrete. The water coming up during the hardening, so called bleeding, can cause the upward force.

Moreover, the water that comes up during the hardening of the concrete have to be considered that it does not enter the void. Normally, the surfaces of formwork are coated before with some kind of waterproof film. The use of those films is intended to get good and smooth surface of the concrete. In addition, Formworks are easier to uninstall because the concrete do not stick to the formwork.

4. Stressing the cables

The tendons cannot be tensioned until the concrete has attained a compressive strength equal to the strength at the time of initial prestressing shown on the design plan. Normally, cables are tensioned after the age of the concrete has reached 28 days but for speeding up the construction time, it also possible that cables are firstly only be tensioned for 50% of the design forces in the 14^{th} day after the concrete are poured.

The cable ducts shall be blown out or flushed immediately prior to installation of the steel. After that, high strength cables are place in the cable ducts at the structure. Then anchor head and wedges are placed in the live anchor side (**Figure 5.4a**). All prestressing steel are tensioned by means of hydraulic jacks. The jacks are positioned so that the cables can be tensioned with the force that should not be less than the value shown on the plans (**Figure 5.4b**).

Afterwards, the cables are tensioned by using a hydraulic forces from the jack (**Figure 5.4c**). The average working stress in the prestressing steel shall not less than 60 percent of the specified minimum ultimate tensile strength of the prestressing steel. Moreover, the maximum temporary tensile stress (jacking stress) in prestressing steel shall not exceed 75 percent of the specified minimum ultimate tensile strength of the prestressing steel.

Each jack used to stress tendons has to be equipped with either a pressure gage or a load cell for determining the jacking stress. If the pressure gage used, it must have an accurately reading dial at least six (6) inches or 15 centimetres in diameter each jack and been accompanied by a certified calibration chart.

The cables are anchored at both end by seating of wedges and soon after that cables release the tensioned force as compressive force to the concrete. Steel wedges grip each strand and seat firmly in a wedge plate (**Figure 5.4d**).

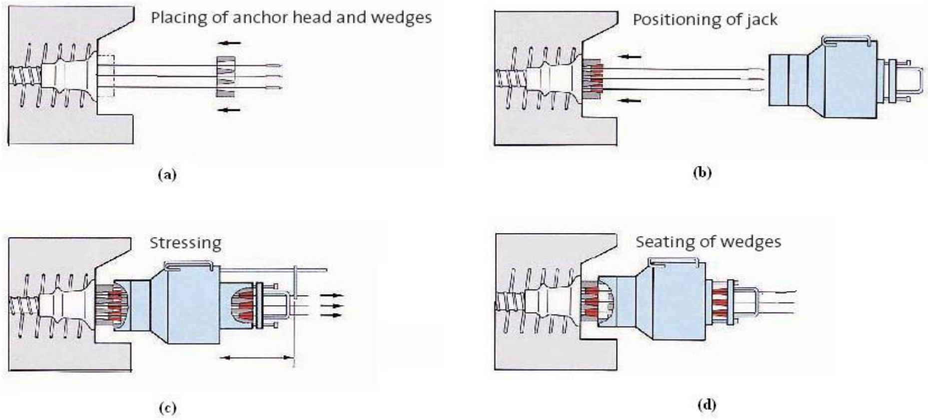


Figure 5.4 *Execution methods for prestressing* (Source: VSL-System)

All prestressing steels have to be protected against physical damage and rust or other results of corrosion at either construction period or service period. Grouting is a key element of the overall corrosion protection strategy in the bonded tendon. The principle objective of grouting is to fill in the free space in the tendon with the grout, which provides an alkaline encapsulation of the tendon. It provides an effective corrosion protection system and also minimizes voids in the completed structure. To achieve an effective bond between the tendon and the surrounding concrete, it is therefore essential that grouting be carried out in a carefully monitored and controlled manner.

The key design feature of bonded systems is the hardened grout that locks the movement of the post-tensioning strands to that of the surrounding concrete, hence the force in a bonded strand is a function of the movement of the surrounding concrete. Therefore, bonded systems offer a significant design advantage which leads to life cycle saving.

For final protection, after grouting, a cap of high quality grout contained covers an anchorage.

5. Relocating falseworks

After the structure reaches its strength, formworks are safely to be relocated. Because approach bridges are designed with a constant shape, formworks can be reused again in the other spans of the bridge, which have not been constructed. That is one of the advantages of using falseworks. The falseworks are then moved forward to prepare for the construction of the next stage. The process of concreting, prestressing and moving falseworks continue until the structure is complete.

CHAPTER VI

CHAPTER VI
CONCLUSION AND SUGGESTIONS

6.1 Conclusions

Introducing concrete bridge for railway bridges could be a reasonable alternative. The span of forty meter long is quite long for the slab bridge where usually slab bridges suitable for spans up to 20 meter. For longer span, it is necessary to reduce the self-weight of the bridge. The shape has to become efficient to reduce the self-weight. Therefore, voids are introduced in the slabs. The voids are usually located at the mid-depth of the slab, thereby having the effect of reducing the self-weight without significantly reducing the inertia of the section.

After studying and analyzing this bridge design, it can be concluded that, some advantages of this design are as following. Void slab bridge system requires less formwork when constructed by in situ method. It is easy in design. And height of the structure is relatively low, which gives the advantage for total construction height and aesthetic aspect. The use of high quality concrete in the structure followed by good construction at the site could reduce the volume changes in concrete such as creep and shrinkage. High strength concrete not only has high compression strength but also has little improvement in tensile resistance.

The fatigue problems that usually occur in bridges could be reduced by limitating the stress fluctuation due to the high cycle of mobile loads. Fully prestressed concrete or no cracked existing bridge shall experience less tension and less stress differentiation, thus the fatigue problem can be reduced. The use of plastic ducts has been investigated that it improves the fatigue resistance in prestressing system.

In prestressed bridge, the structure is designed to have more compression than tension. It is better for concrete bridge because the problem because of cracks and deflection can be reduced. Less cracks means less maintenance needed afterwards in the structure. It also means that the structure is more durable within its lifetime.

Reinforcements that are necessary in prestressed bridges are:

1. Prestressing tendons;
2. Reinforcements for shear and torsion;
3. Tendon supports;
4. Reinforcements at anchorage.

Beside the advantages, the designed bridge, obviously, has some disadvantages. In the fact that more volume of material needed, void slab bridges are still heavier than steel bridges. The eccentricity of the prestressing cables is limited due to the less height of the structure and because of that, the number of cables that are necessary increase. Moreover, the use of voids at the middle of the structure makes the layout of the cables becomes difficult to be executed in the construction. The cables need more curvature especially in horizontal direction in order to be fit in the structure hence the prestressing losses due to the curvature and friction become higher.

Losses in prestressing system are important aspects that we should take into account, because losses that possibly occur influence much in the prestressing force. Losses in prestressing system are:

a. Direct losses
- Friction losses;
- Anchorage set losses.

b. Time-dependent losses
- Creep;
- Shrinkage
- Relaxation.

6.2 Suggestions

After all things that I have made, I believe this report is far from perfect. Due to the limited time, there are still some aspects that I did not take into account. Therefore, I would suggest for further bridge design to consider about:

1. Checking the slab deck in three-dimensional model gives a better overview about what will happen in the structure, and also gives better moments and stresses distribution.

2. It is also good to consider about if there will be a replacement of bridge bearings after some years. Are bridge structures able to withstand during the replacement process.
3. In the case that the bridge located in the seismic area, for instance my home country Indonesia, the decks of the bridge have to be design so that the horizontal loads can be well transferred to the bearing and to the foundations. We must prevent as much as possible the bridge failure due to the seismic loads.
4. Since my report only based on static loads, it is better to check what the effects of dynamic loads in the structure are.

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Sorgenfrei, D.F. and Marianos, W.R.Jr. Railroad Bridges. in: Chen, Wai-Fah and Duan Lian. (2000) *Bridge Engineering Handbook*. United States of America:CRC Press.

HOGESCHOOL UTRECHT

ANNEX 1
LOADING CALCULATION AND COMBINATIONS

Grontmij

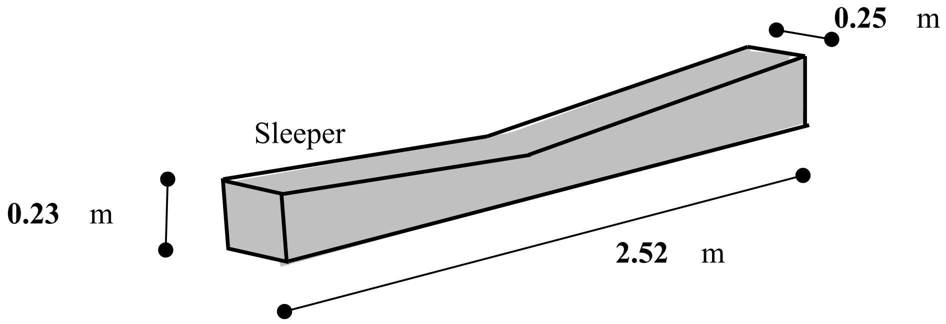
STEP I : LOADS CALCULATIONS

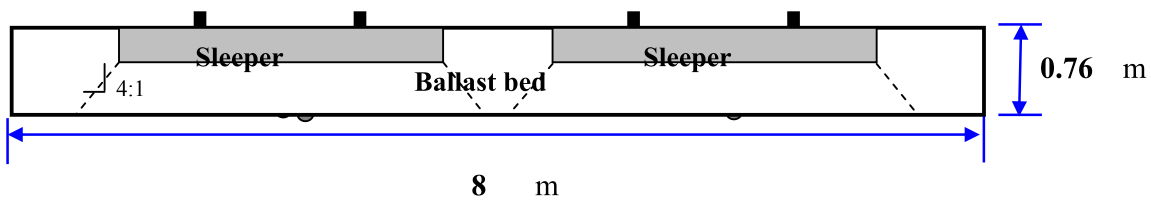
1.1 Parameters

γ *c max*	=	**25**	kN/m^3			
γ *c min*	=	**24.5**	kN/m^3			
γ *ballast bed max*	=	**18**	kN/m^3			
γ *Rails*	=	**0.54**	kN/m			
E_c	=	**3.80E+04**	Mpa	=	3.80E+07	KN/m^2
E_p	=	**2.10E+05**	Mpa	=	2.10E+08	KN/m^2
fc' (strength of concrete)	=	**65**	Mpa			
Number of tracks	=	**2**	tracks			
Length of the spans (l)	=	**40**	m			

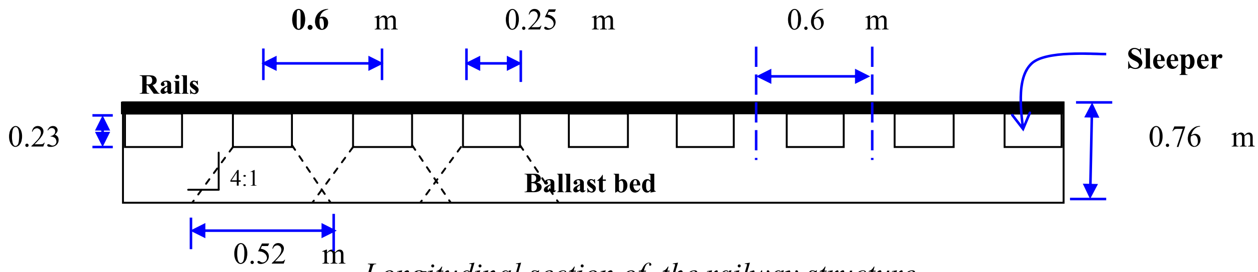
1.2 Calculation of dead loads

1. Railway structure





Cross section of the railway structure



Longitudinal section of the railway structure

a. Rails (point loads)

$W_1 = \gamma_{Rails}$ * Length of influence (m) * Quantity

$= 0.54 * 0.6 * 4$

$= 1.30$ kN

The weight spreads due to the use of ballast bed

$W_1' = \frac{1.30}{0.52}$

$= 2.52$ kN/m'

b. Ballast bed (uniformly loads)

$W_2 = \gamma_{ballast\ bed} * B\ (m) * H\ (m)$

$= 18 * 8 * 0.76$

$= 109.44$ kN/m'

c. Sleeper (uniformly loads)

$W_3 = \gamma_{c\ min} * B\ (m) * H\ (m)$ * Quantity

$= 24.5 * 2.52 * 0.23 * 2$

$= 28.40$ kN/m'

The weight spreads due to the use of ballast bed

$W_3' = \frac{28.40}{0.52} * 0.25$

$= 13.787$ kN/m'

2. Self weight of bridge (uniformly loads)

$W_4 = \gamma_{c\ max}$ * Cross section area (m^2)

$= 25 * 12.77$

$= 319.25$ kN/m'

3. Railing (steel)
   Railing load is 5 kN/m
   W_5 = 5 kN/m'

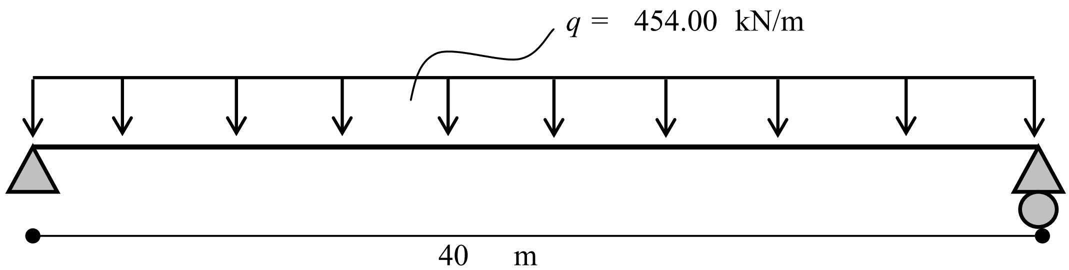
4. Cables and pipe loads
   Cables and pipe load is 3 kN/m
   W_6 = 3 kN/m'

5. Electrical Installation
   Electrical installation is 1 kN/m
   W_7 = 1 kN/m'

The total of dead loads

$W_{DL} = W_1' + W_2 + W_3' + W_4 + W_5 + W_6 + W_7$

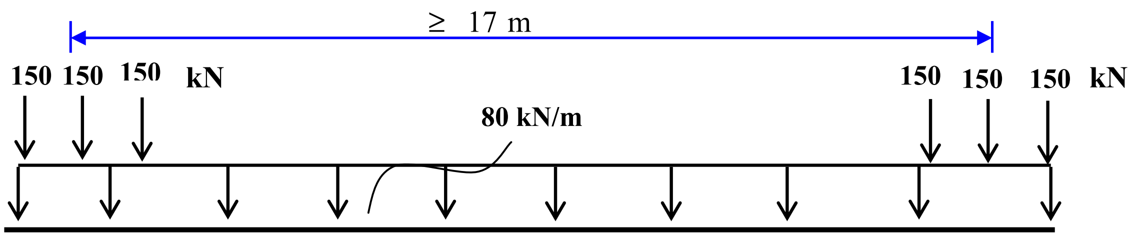
$= \underline{\underline{454.00}}$ kN/m'



The total uniformly dead loads in longitudinal direction

1.3 Calculation of Live Loads

a. Train loads



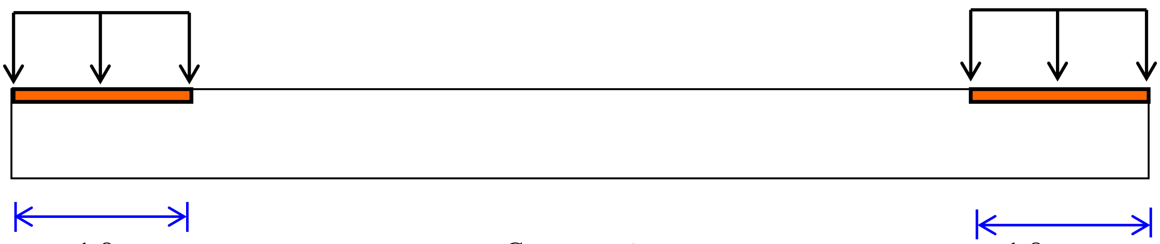
Configuration of train loads (NEN 6723:1995)

b. Footpath loads

Pedestrian, general maintenance should be represented by a uniformly distributed loads

q_{fk} = **5** kN/m'

The width of footpath = **1.8** m

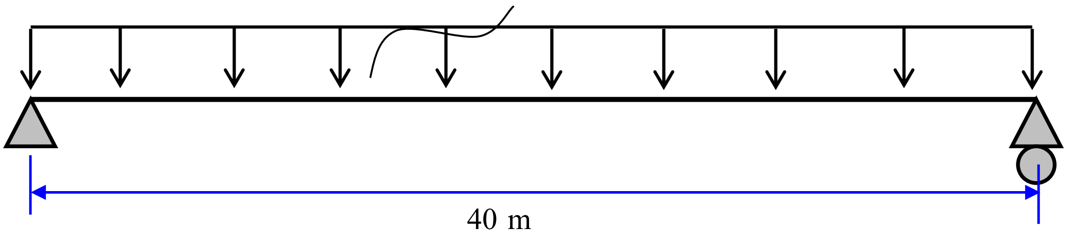


Cross section

the loads in the longitudinal direction

q_{fk} = (5 * 1.8) * 2

= 18 kN/m'



Footpath loads in longitudinal direction

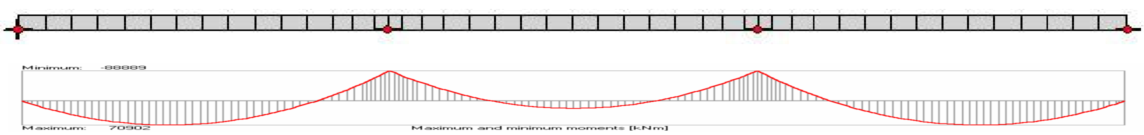
1.4 Load Combinations

a. Output from Alp 2000

Combinations, which are considered in hand calculation are:

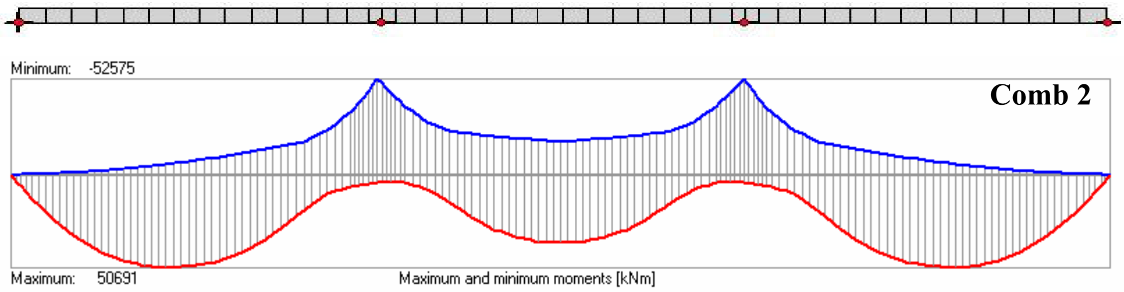
1. Combination 1

   1.2 M_{DL} (+) = **70902** kNm



2. Combination 2

   1.5 M_{LL} (+) = **50691** kNm



3. Combination 3

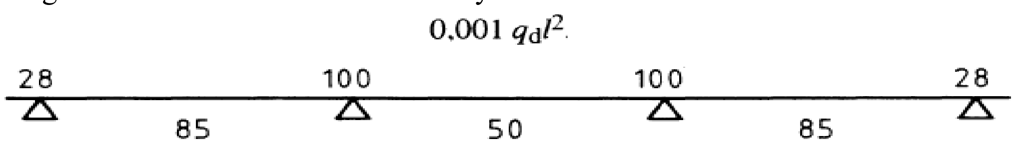
   1.2 M_{DL} + 1.5 M_{LL} = 70902 + 50691

   = 121593.00 kNm

* Maximum Bending Moments (+) are located at **17** m and **103** m from the hinge support

b. Hand Calculation

Bending moment due to the dead loads only

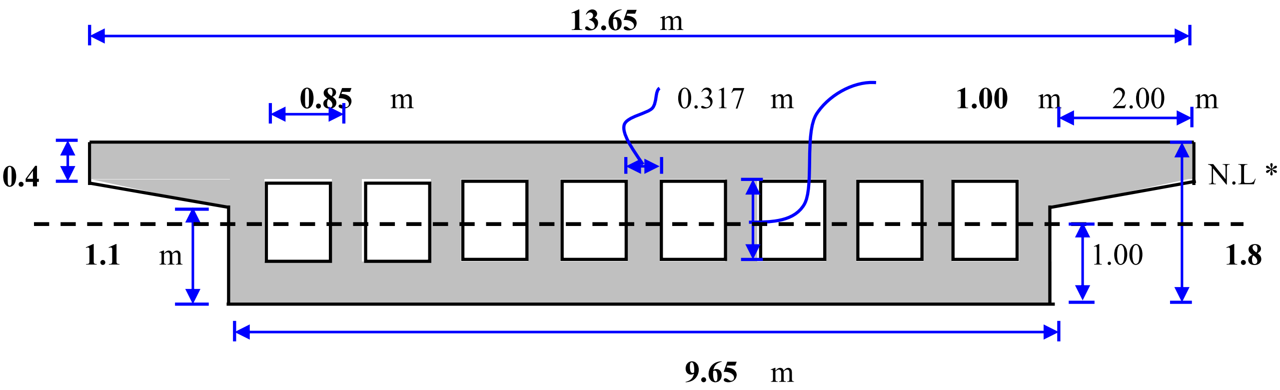


coefficient	q (kN/m)	l	$0.001*q.l^2$ (kNm)	1.2 M_{DL} (kNm)
85	454.00	40	61744	74092.8
100	454.00	40	-72640	-87168
50	454.00	40	36320	43584
100	454.00	40	-72640	-87168
85	454.00	40	61744	74092.8

ANNEX 2
VOID SLAB CALCULATION

STEP II : PRE-LIMINARY DESIGN OF BRIDGE CROSS SECTION

2.1 The Bridge Cross Section



* N.L : Neutral line

2.2 Calculation of The Cross Section Ares

1. Roof : 13.65 * 0.4 = 5.46
2. Floor : 9.65 * 0.4 = 3.86
3. Middle wall : 0.3167 * 1 * 9 = 2.85
4. Chamfer : $\left(\frac{2 * 0.3}{2}\right) * 2 = 0.60$ +

$A_c = 12.770 \text{ m}^2$

2.3 Calculation of The Centre of Weight

Total height of the structure *(h)* : 1.8 m

$$y_b = \frac{5.46 * 1.6 + 3.86 * 0.2 + 2.85 * 0.9}{12.770} + \frac{0.60 * 1.3}{12.770}$$

$$y_b = \frac{12.853}{12.770} = 1.00 \text{ m} \qquad y_a = 0.80 \text{ m}$$

2.4 Calculation of The Moment of Inertia

$$I \; : \; \frac{1}{12} * b * h^3 + A * d^2$$

1. Roof $= \frac{1}{12} * 13.65 * 0.064 + 5.46 * 0.36 = 2.0384 \; m^4$
2. Floor $= \frac{1}{12} * 9.65 * 0.064 + 3.86 * 0.64 = 2.5219 \; m^4$
3. Middle wall $= \frac{1}{12} * 0.3167 * 1 + 0.3167 * 0.01 = 0.0296 \; m^4$

   $= 0.0296 * 9$

   $= 0.266 \; m^4$
4. Chamfer $= \frac{1}{36} * 2 * 0.027 + 0.3 * 0.09 = 0.0285 \; m^4$

   $= 0.0285 * 2$

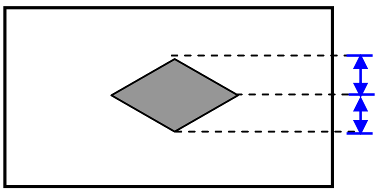
   $= 0.0570 \; m^4$

Moment Inertia of the Structure

$$I = 2.0384 + 2.5219 + 0.2660 + 0.0570$$
$$= \underline{\underline{4.8833}} \; m^4$$

$$W_a = \frac{I}{y_a} = \frac{4.883}{0.80} = 6.104 \qquad W_b = \frac{I}{y_b} = \frac{4.883}{1.00} = 4.883$$

- $k_a = \frac{W_b}{A_c} = \frac{4.883}{12.770} = 0.382 \; m$



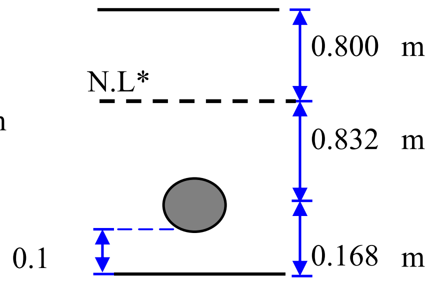
$k_a = 0.382 \; m$

$k_b = 0.478 \; m$

- $k_b = \frac{W_a}{A_c} = \frac{6.104}{12.770} = 0.478 \; m$

STEP III : PRESTRESSING CABLE DESIGN

3.1 Concrete Cover & Eccentricity



Space of concrete at the bottom of the tendon = **0.100** m

eccentricity *(e)* = **0.832** m

* Neutral Line

3.2 Determining The Number of Cables

Diameter of strand = 12.9 mm

No	Number of strand	Area (mm^2)	F (kN)	75% F (kN)	65%F (kN)	55%F (kN)
1	7	700	1302	977	847	717
2	12	1200	2223	1668	1445	1223
3	19	1900	3534	2651	2298	1944
4	31	3100	5766	4325	3748	3172

- Cable choosen : **31** strand per cable

- In this design, effective force for 1 cable is by using 75 %
- 75 % F : 4325 kN

  Area : 3100 mm^2
- Stress ($\sigma_{p,0}$) : $\frac{4325}{0.0031}$ = 1395161 kN/m^2 = 1395 N/mm^2

- Number of cable:

$$P \;*\; e \;=\; M_{DL+LL} \;*\; 70\%$$

$$P = \frac{121593.00}{0.832} * 0.7$$

$$= 102301.81 \text{ kN}$$

The number of cables needed:

$$x = \frac{P}{F_{cable}}$$

$$x = \frac{102301.81 \text{ kN}}{4325 \text{ kN}} = 24 \text{ cables} \longrightarrow \text{The number of cables} = \mathbf{27} \text{ cables}$$

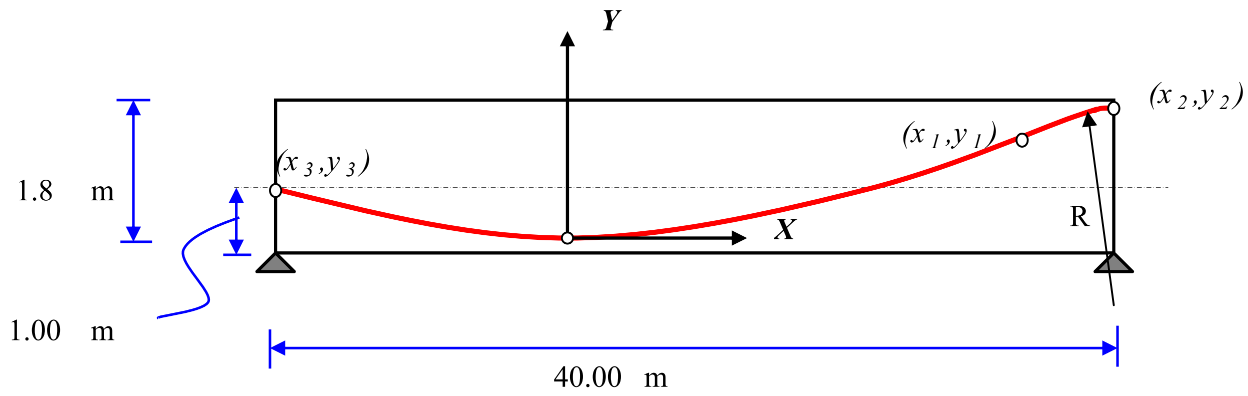
Total stressing force (P) that will be applied :

$$P_0 = x * 0.75 F_{cable}$$

$$= 27 * 4325 = 116775 \text{ kN}$$

3.3 The Calculation of Cable Layout

a. The layout from the end support to the middle support



R	=	**12**	m	F_{cable}	=	4325	kN
L	=	40	m				
ap	=	0.168	m				

$$y_2 = 1.8 - 2 * 0.168 = 1.464 \text{ m}$$

$$y_3 = 1.00 - 0.168 = 0.832 \text{ m}$$

$$x_2 = \frac{L \pm \sqrt{\left[\left(L^2 + 2.R.y_3\right).\frac{y_3}{y_2} - 2.R.y_3\right]}}{\left(1 - \frac{y_3}{y_2}\right)}$$

$$x_2 = \frac{40 \pm \sqrt{\left(40^2 + 2 * 12 * 0.832 * \frac{0.832}{1.464}\right) - 2 * 12 * 0.832}}{1 - \frac{0.832}{1.464}}$$

x_2 = 162.18 or 23.139 m

x_2 = 23.139 m

$$x_3 = x_2 - L$$

x_3 = 23.139 - 40.000 = -16.861 m

$$x_1 = \left(-2.R.\frac{y_2}{x_2}\right) + x_2$$

$$x_1 = -2 * 12 * \frac{1.464}{23.139} + 23.139 = 21.620 \text{ m}$$

Parabola I

$$f(x) = C_1.x^2$$

Parabola II

$$g(x) = C_2 x^2 + C_3.x + C_4$$

$$C_1 = \frac{-(21.620 - 23.139)}{2 * 12 * 21.620} = 0.0029$$

$$C_2 = -\frac{1}{2.R}$$

$$C_2 = \frac{-1}{2 * 12} = -0.042$$

$$C_3 = +\frac{x_2}{R}$$

$$C_3 = \frac{23.1387}{12} = 1.9282$$

$$C_4 = y2 - \left(\frac{x_2^2}{2.R}\right)$$

$$C_4 = 1.464 - \frac{535.400}{2 * 12} = -20.844$$

$$g(x) = -\frac{1}{2.R}(x_1 - x_2)^2 + y_2$$

$$y_1 = \frac{-1}{2* 12} * (21.620 - 23.139)^2 + 1.464$$

$$= 1.368 \text{ m}$$

$$f(x) = C_1.x^2$$

$$y_1 = 0.00293 * 21.620^2 = 1.37$$

O.K

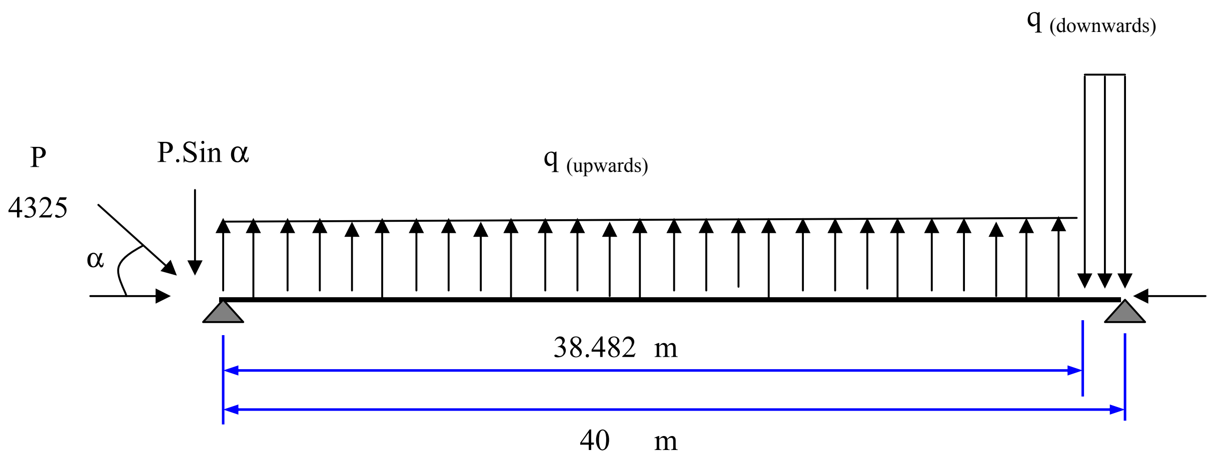
$$R_2 = \frac{1}{y''}$$

$$y = C_1 * x^2 = 0.0029 * x^2$$

$y' = 0.00585 * x$

$y'' = 0.00585$

$R_2 = \frac{1}{0.00585} = 170.86 \text{ m}$



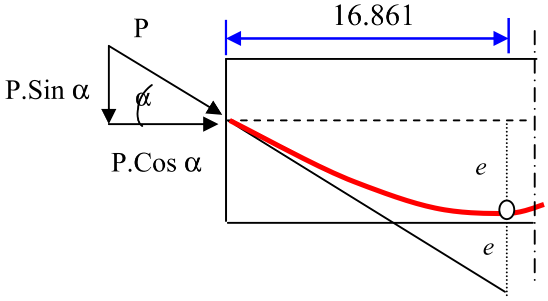
$$q = \frac{P}{R}$$

$q_{(upwards)} = \frac{4325}{170.856} = 25.31 \text{ kN/m'}$

$q_{(downwards)} = \frac{4325}{12} = 360.42 \text{ kN/m'}$

$F_{(upwards)} = 25.314 * (16.861 + 21.620) = 974.12 \text{ kN}$

$F_{(downwards)} = 360.42 * (23.139 - 21.620) = 547.29 \text{ kN}$



P (↓) = sin α * P

$$\tan \alpha = \frac{2 \ * \ 0.832}{16.861} = 0.0987$$

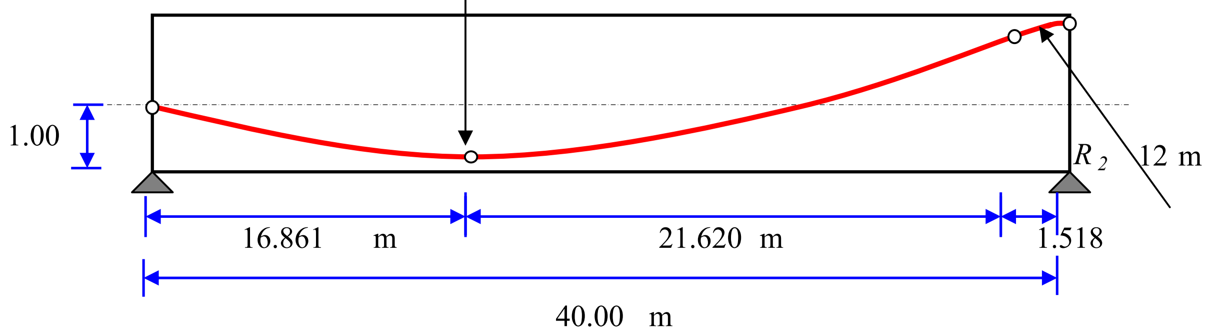
α = 5.636

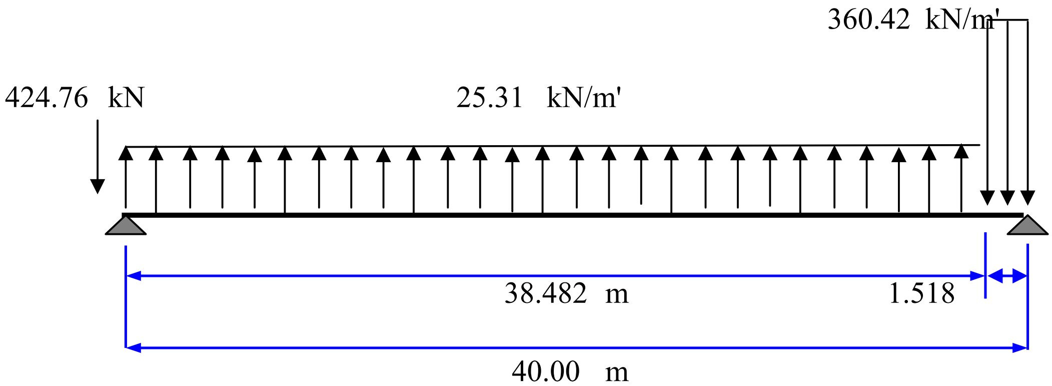
P (↓) = 0.09821 * 4325 = 424.76 kN

Checking, Σ Fv = 0

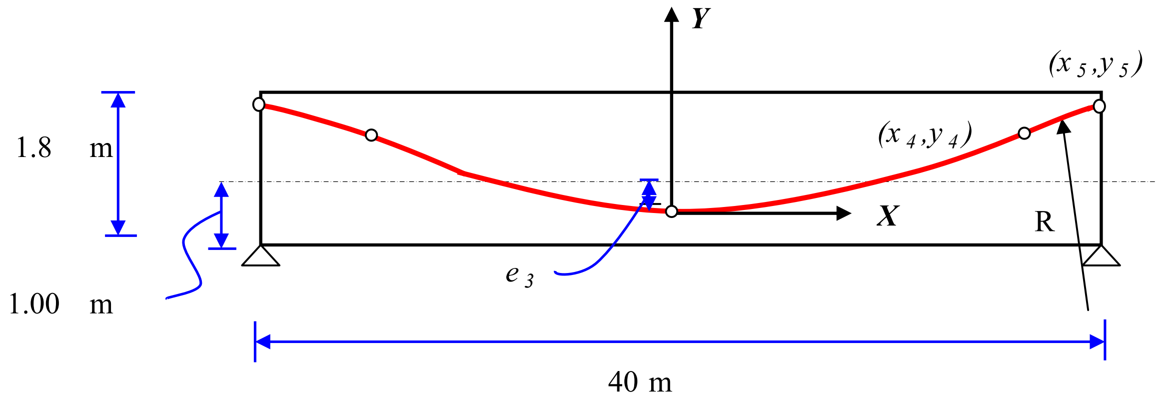
$F_{(upwards)}$ - ($F_{(downwards)}$ + P (↓))

974.12 - (547.29 + 424.76) = 2.07 kN





b. The layout from the middle support to the middle support



e_3 = **0.593** m

$$x_5 = \frac{40}{2} = 20$$

y_5 = 1.23

$$x_4 = \left(-2.R.\frac{y_5}{x_5}\right) + x_5$$

$$x_4 = -2 * 12 * \frac{1.225}{20} + 20 = 18.53$$

$$C_1 = \frac{-(x_4 - x_5)}{2.R.x_4}$$

$$C_1 = \frac{-(18.53 - 20)}{2 * 12 * 18.53} = 0.00331$$

$$C_2 = -\frac{1}{2.R}$$

$$C_2 = \frac{-1}{2 * 12} = -0.0417$$

$$C_3 = +\frac{x_5}{R}$$

$C_3 = \frac{20}{12} = 1.6667$

$$C_4 = y_5 - \left(\frac{x_5^2}{2.R}\right)$$

$C_4 = 1.225 - \frac{400}{2 * 12} = -15.44$

$$g(x) = -\frac{1}{2.R}(x_4 - x_5)^2 + y_5$$

$y_4 = \frac{-1}{2* 12} * (18.530 - 20)^2 + 1.225$

$= 1.135$ m

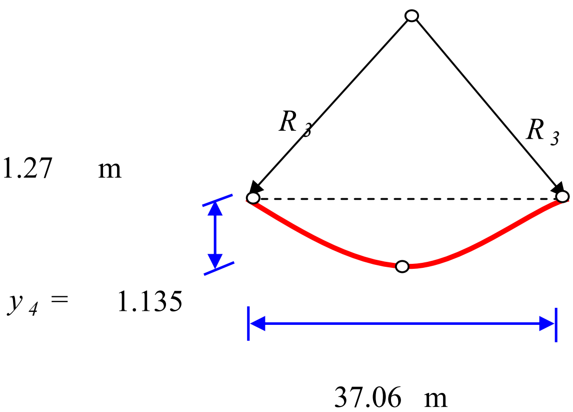
$$f(x) = C_1.x^2$$

$y_4 = 0.00331 * 18.530^2 = 1.135$

→ **O.K**

$R_3 = \frac{l^2}{8 * y_4}$

$= \frac{1373.444}{8 * 1.135} = 151.27$ m



$$q = \frac{P}{R}$$

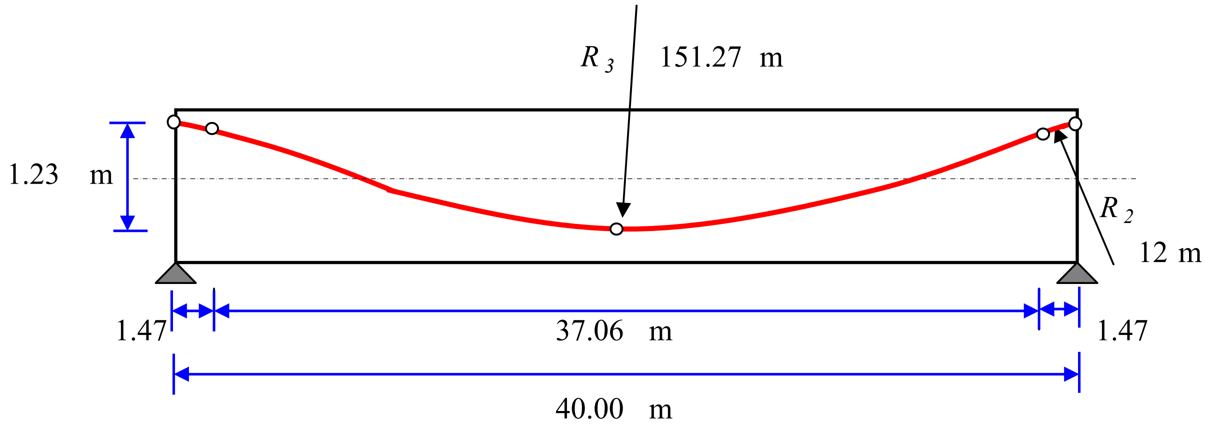
q (upwards)	=	$\frac{4325}{151.26531}$	=	28.59	kN/m'
q (downwards)	=	$\frac{4325}{12}$	=	360.42	kN/m'

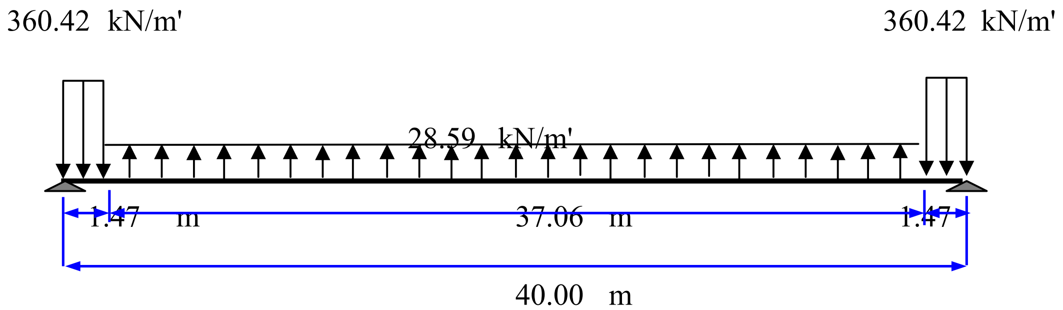
F (upwards)	=	28.593 * (37.060)	=	1059.66	kN
F (downwards)	=	360.42 * (2 * 1.470)	=	1059.63	kN

Checking, $\Sigma Fv = 0$

F (upwards) - F (downwards)

1059.66 - 1059.63 = 0.03





STEP IV : DETERMINING INTERNAL FORCES

4.1 The Stress Diagram in The Construction Phase (dead loads only)

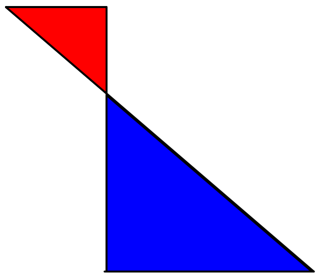
- Stresses diagram due to the prestressing forces

$$f_{top} = -\frac{P_0}{A_c} + \frac{M_c * y_a}{I}$$

$$= -\frac{P_0}{A_c} + \frac{P_0 * e * y_a}{I}$$

$$= -\frac{116775}{12.770} + \frac{116775 * 0.83 * 0.80}{4.8833}$$

$$= 6772 \text{ kN/m}^2 = 6.77 \text{ MPa}$$



P_0

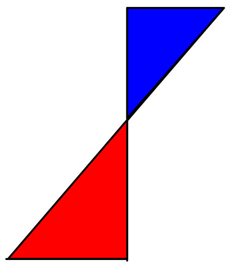
$$f_{bott} = -\frac{P_0}{A_c} - \frac{P_0 * e * y_b}{I}$$

$$= -\frac{116775}{12.770} - \frac{116775 * 0.83 * 1.00}{4.8833}$$

$$= -29040 \text{ kN/m}^2 = -29.04 \text{ MPa}$$

- Stresses diagram due to dead loads

$$M_{Design} = 1.2\,M_{DL} = 70902 \text{ kNm}$$



$1.2\,M_{DL}$

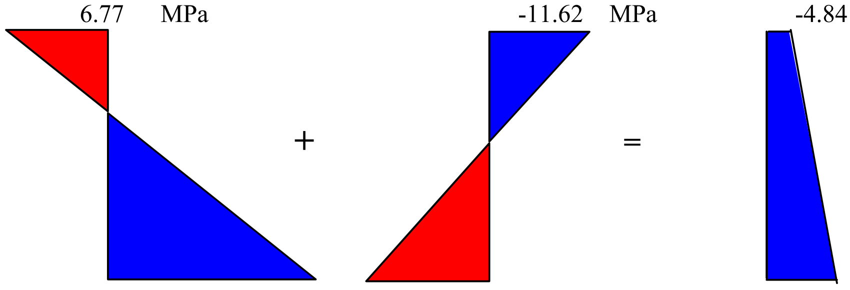
$$f_{top} = -\frac{M_{DL} * y_a}{I}$$

$$= -\frac{70902 * 0.80}{4.8833}$$

$$= -11615.503 \text{ kN/m}^2 = -11.62 \text{ MPa}$$

$$f_{bott} = \frac{M_{DL} * y_b}{I} = \frac{70902 * 1.00}{4.8833}$$

$$= 14519 \text{ kN/m}^2 = 14.52 \text{ MPa}$$



4.2 Simultaneous Losses

a. Friction losses

$$\Delta F_{pF} = P_0 \left(1 - e^{-\mu(\Phi + \Phi_1 . x)}\right)$$

μ = the curvature coefficient (rad)

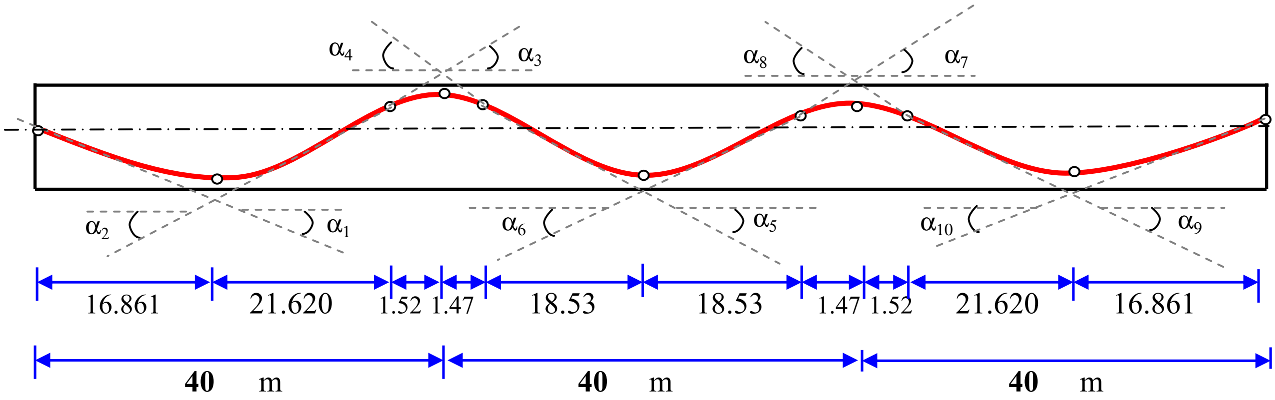
Φ = the sum of of absolute values of angle change in the pre-stressing steel path from jacking end

Φ_1 = the wobble friction coefficient (rad/m)

x = the length of a pre-stressing tendon from the jacking end to the point considered (m)

According to ROBK version 5 art 16.5.1

- The maximum values are:
  μ = 0.23 Φ_1 = 0.009
- The minimum values are:
  μ = 0.13 Φ_1 = 0.003



$$\alpha_1 = \tan^{-1}\left(\frac{2 * 0.832}{16.861}\right) = 0.098 \text{ radians}$$

$$\alpha_2 = \tan^{-1}\left(\frac{2 * 1.368}{21.620}\right) = 0.126 \text{ radians}$$

$$\alpha_3 = \tan^{-1}\left(\frac{2 * 0.096}{1.518}\right) = 0.126 \text{ radians}$$

$$\alpha_4 = \tan^{-1}\left(\frac{2 * 0.090}{1.470}\right) = 0.122 \text{ radians}$$

$$\alpha_5 = \tan^{-1}\left(\frac{2 * 1.135}{18.530}\right) = 0.122 \text{ radians}$$

$$\alpha_6 = \alpha_5 = 0.122 \text{ radians}$$

$$\alpha_7 = \alpha_4 = 0.122 \text{ radians}$$

$$\alpha_8 = \alpha_3 = 0.126 \text{ radians}$$

$$\alpha_9 = \alpha_2 = 0.126 \text{ radians}$$

$$\alpha_{10} = \alpha_1 = 0.098 \text{ radians}$$

Total rotation

$$\Sigma\Phi = 0.098 + 0.126 + 0.126 + 0.122 + 0.122 + 0.122 + 0.122 + 0.126 + 0.126 + 0.098$$

$$\Sigma\Phi = 1.1878 \text{ radians}$$

- Maximum friction losses

μ * Φ = 0.23 * 1.1878 = 0.2732

μ * Φ_1 * x = 0.23 * 0.009 * **120** = 0.2484 +

= 0.5216

$e^{-0.5216}$ = 0.5936

Pre-stressing forces after the friction losses effect

P_{pF} = P_0 * 0.5936

= 4325 * 0.5936 = 2567 kN

ΔP_{pF} = 4325 - 2567.2

= 1758 kN

x (m)	Φ	Φ_1	μ	P_{pF} (kN)
0	0	0.009	0.23	4325
16.861	0.098	0.009	0.23	4083
38.482	0.224	0.009	0.23	3793
41.470	0.472	0.009	0.23	3561
60.000	0.594	0.009	0.23	3332

2. Anchorage set loss

$$\Delta F_{pA} = 2 * w * \Delta p$$

$$\Delta p = \frac{P_0 - P_{pF}}{L_c}$$

$$w = \sqrt{\frac{Ep\ (Ap)\ L_{pA}}{\Delta p}}$$

L_{pA} = the thickness of anchorage set = **7** mm = 0.007 m

E_p = modulus elasticity of pre-stressing steel

w = the length influenced by anchorage set

L_c = horizontal length of the cables

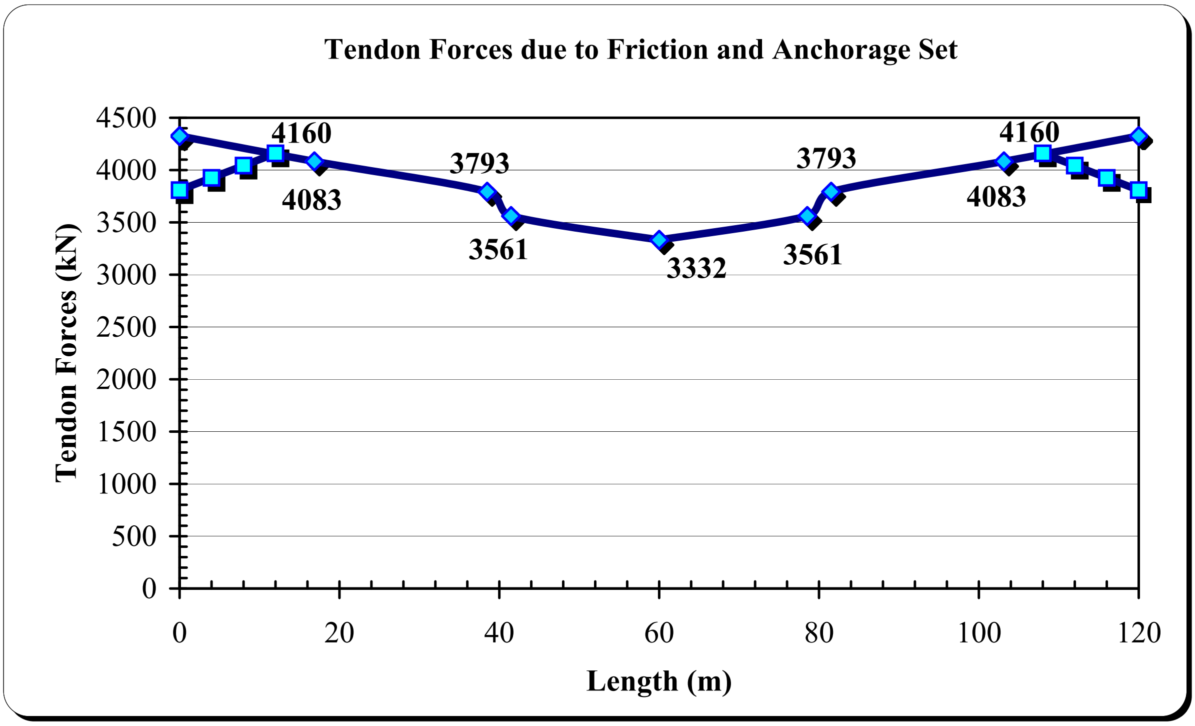
$$\Delta p = \frac{4325 - 2567.21}{\mathbf{120}} = 14.65 \text{ kN/m}$$

$$w = \sqrt{\frac{2.10E+08 \quad * \quad 0.0031 \quad * \quad 0.007}{14.65}}$$
$$= \quad 17.64 \quad m$$

$$\Delta F_{pA} = 2 \quad * \quad 17.64 \quad * \quad 14.65$$
$$= \quad 516.73 \quad kN$$

$$P_{pA} = P_0 \quad - \quad \Delta F_{pA}$$
$$= \quad 4325 \quad - \quad 516.73$$
$$= \quad 3808 \quad kN$$

Span	x/l	ΔP_{pA} (kN)
1	0	516.73
	0.1	399.54
	0.2	282.36
	0.3	165.17
	0.4	47.98
	0.5	0.00
	0.6	0.00
	0.7	0.00
	0.8	0.00
	0.9	0.00
	1	0.00


Tendon Forces due to Friction and Anchorage Set
Tendon Forces (kN)
Length (m)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
20
40
60
80
100
120
4160
4083
3793
3561
3332
3561
3793
4160
4083

4.3 Time-Dependent Losses

a. Losses because of creep

$$\Delta\sigma_{p\varphi} = (\varepsilon'_{\varphi 1} - \varepsilon'_{\varphi 2}) * E_p$$

$$\varepsilon'_{\varphi 1} = \frac{\sigma'_{b1}}{E_c} * \phi_1$$

$$\phi_t = k_c * k_d * k_b * k_h * k_t$$

$$\varepsilon'_{\varphi 2} = \frac{\sigma'_{b1} - \sigma'_{b2}}{E_c} * \phi_2$$

Parameters		Values	Table (NEN-6720)
k_c	= Humidity, outside (60-85%)	**1.4**	4
k_d	= hardening concrete after 14 days, concrete class B	**0.9**	5
k_b	= Quality of concrete B 65	**0.7**	6
k_h	$h_m = \frac{2\ A_c}{O} = \frac{2 * 12.770}{29.345} = 0.871 = 871$ mm	**0.7**	7
k_t	= t = ∞	**1.0**	

Note: see the table in ANNEX 6

$$\phi_1 = k_c * k_d * k_b * k_h * k_t$$
$$= 1.4 * 0.9 * 0.7 * 0.7 * 1.0$$
$$= 0.6 < 1.2 \quad \text{(table 8 NEN 6720)}$$

$$\sigma'_{b1} = -\frac{P_0}{A_c} - \frac{(P_0\ e - M_{DL}) * e}{I}$$

$$= -\frac{116775}{12.770} - \frac{(116775 * 0.83 - 70902) * 0.83}{4.8833}$$

$= -9144.5 - 4473.2$

$= -13618 \quad KN/m^2$

hardening concrete after 90 days, concrete class B $\quad k_d = \mathbf{0.5}$

$\phi_2 = k_c * k_d * k_b * k_h * k_t$

$= 1.4 * 0.5 * 0.7 * 0.7 * 1.0$

$= 0.35$

$$\sigma'_b = \frac{M_{LL} * e}{I}$$

$$= \frac{50691 * 0.83}{4.88327} = 8637 \quad kN/m^2$$

$\sigma'_{b2} = \sigma'_{b1} + \sigma'_b$

$= -13617.71 + 8636.6 = -4981 \quad kN/m^2$

Modulus elasticity of concrete $\quad E_c = 3.80E+07 \quad kN/m^2$

safety factor $\longrightarrow \quad = 1.1 * 3.80E+07 = 4.18E+07 \quad kN/m^2$

$$\boxed{\Delta\sigma_{p\varphi} = (\varepsilon'_{\varphi 1} - \varepsilon'_{\varphi 2}) * E_p}$$

$$\varepsilon'_{\varphi 1} = \frac{13617.7131}{4.18E+07} * 0.62 = 2.02E-04$$

$$\varepsilon'_{\varphi 2} = \frac{13617.7131 - 4981.1}{4.18E+07} * 0.35 = 7.23E-05$$

$\Delta\sigma_{p\varphi} = (2.02E-04 - 7.23E-05) * 2.10E+08$

$= \underline{\underline{27231}} \quad kN/m^2$

b. Losses because of shrinkage

$$\Delta\sigma_{pS} = \varepsilon'_r * E_p$$

$$\varepsilon'_r = \varepsilon'_c * k_b * k_h * k_p * k_t$$

Parameters	Values	Table (NEN-6720)
ε'_r =	**2.50E-04**	9
k_b = Quality of concrete B 65	**0.7**	6
k_h $h_m = \frac{2 A_c}{O} = \frac{2 * 13.828}{29.345} = 0.943 = 943$ mm	**0.5**	10
k_p =	**1.0**	
k_t = t = ∞	**1.0**	

Note: see the table in ANNEX 6

$\varepsilon'_r = \varepsilon'_c * k_b * k_h * k_p * k_t$
= 2.50E-04 * 0.7 * 0.5 * 1.0 * 1.0
= 8.75E-05 < 0.00023 (see **Table 11**) ⟶ **O.K**

so,
$\Delta\sigma_{pS} = \varepsilon'_r * E_p$
= 8.75E-05 * 2.10E+05
= 18.38 N/mm^2 = 18375 kN/m^2

c. Losses because of relaxation

$$\Delta\sigma_{pR} = 3\Delta\sigma_{p,1000} \left(1 - 2\frac{\Delta\sigma_{pS+\varphi}}{\sigma_{p,0}}\right)$$

$\Delta\sigma_{p,1000}$ = 0.023 * $\sigma_{p,0}$
= 0.023 * 1395161.3 = 32088.71 kN/m^2

Thus,

$$\Delta\sigma_{pR} = 3 * 32088.71 \left(1 - 2 * \frac{27230.50 + 18375.00}{1395161.3} \right)$$

$$= 96266.13 \quad (0.93462333)$$

$$= 89973 \quad kN/m^2$$

d. Total prestressing due to time-dependent losses

$$\Delta\sigma = \Delta\sigma_{p\varphi} + \Delta\sigma_{pS} + \Delta\sigma_{pR}$$

$$= 27230.50 + 18375.00 + 89972.58$$

$$= \underline{\underline{135578}} \quad kN/m^2$$

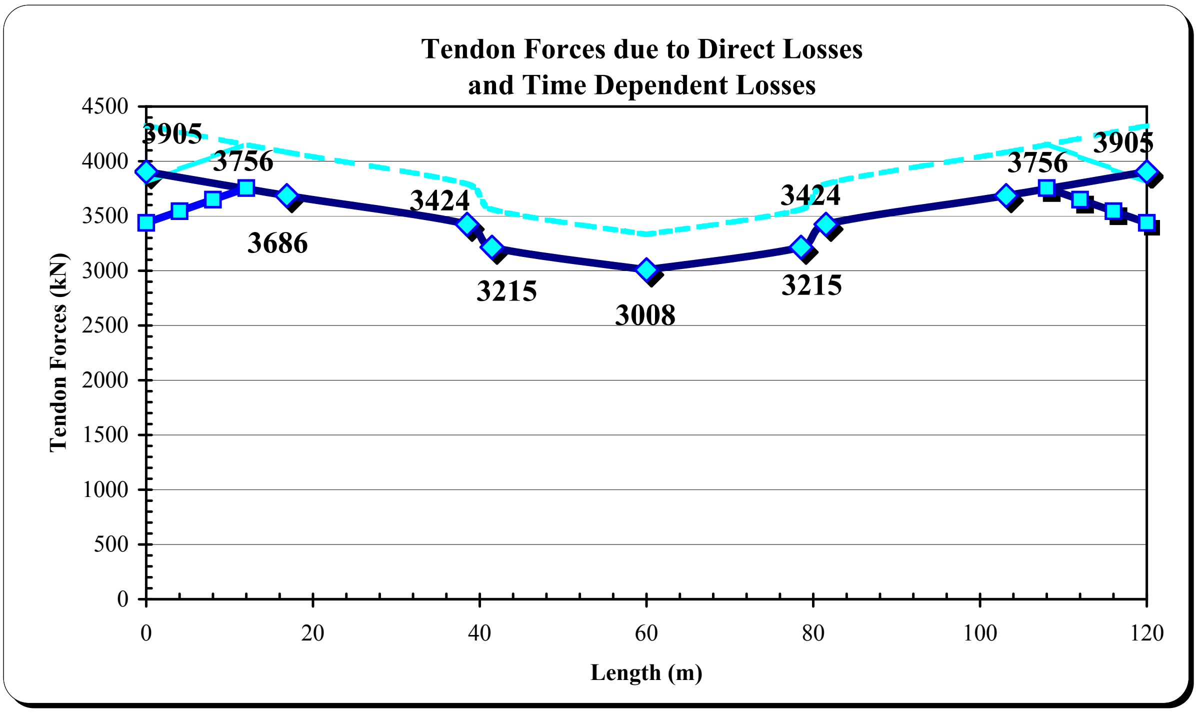
$$\sigma_{p,0} = 1395161 \quad kN/m^2$$

$$\sigma_{p,\infty} = 1395161 - 135578 = 1259583 \quad kN/m^2$$

The percentage of losses due to time dependent losses

$$\frac{\Delta\sigma}{\sigma_{p,0}} = \frac{135578}{1395161} * 100\% = 9.72 \% < 20 \%$$

Losses which happen are less than 20 %, the design is good


Tendon Forces due to Direct Losses
and Time Dependent Losses
Tendon Forces (kN)
Length (m)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
20
40
60
80
100
120
3905
3756
3686
3424
3215
3008
3215
3424
3756
3905

4.4 The Stress Diagram in The Service Life

- Prestress force after losses

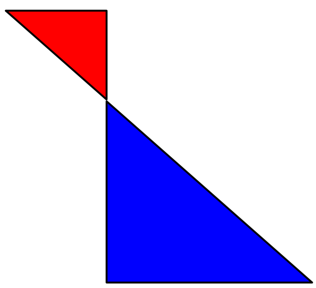
  Prestressing force equal to prestessing force at the beginning minus direct losses and time dependent losses. Stresses diagram which is checked in this hand calculation is at the maximum positif moment.

$$P_{\infty} = P_0 - (\Delta P_{pF} + \Delta P_{pF}) - (\Delta\sigma * A_P)$$
$$= 116775 - (181.22) * 27 - (135578.08 * 0.0031) * 27 \text{ cables}$$
$$= 100534 \text{ kN}$$

- Stresses diagram due to stressing force

$$f_{top} = -\frac{P_{\infty}}{A_c} + \frac{M_c * y_a}{I}$$
$$= -\frac{P_{\infty}}{A_c} + \frac{P_{\infty} * e * y_a}{I}$$
$$= -\frac{100534}{12.770} + \frac{100534 * 0.83 * 0.8000}{4.8833}$$
$$= 5830 \text{ kN/m}^2 = 5.8303 \text{ MPa}$$

$$f_{bott} = -\frac{P_{\infty}}{A_c} - \frac{P_{\infty} * e * y_b}{I}$$
$$= -\frac{100534}{12.770} - \frac{100534 * 0.83 * 1.0000}{4.8833}$$
$$= -25001 \text{ kN/m}^2 = -25 \text{ MPa}$$



- Stresses diagram due to dead loads and live loads

$M_{Design} = 1.2\ MDL + 1.5\ MLL$

$M_{Design} = 121593 \quad \text{kNm}$

$$f_{top} = -\frac{M * y_a}{I}$$

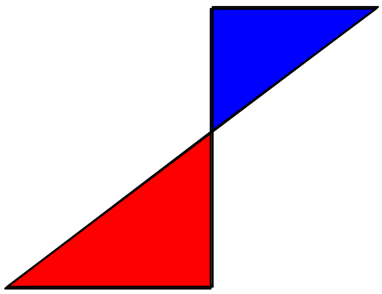
$$= -\frac{121593 * 0.8}{4.8833}$$

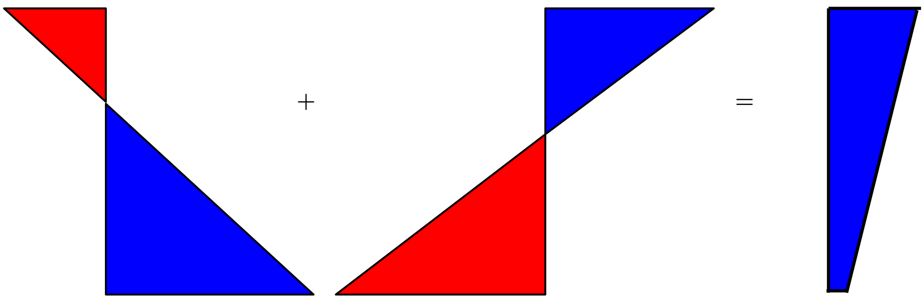
$$= -19920 \quad \text{KN/m}^2 = -19.92 \quad \text{MPa}$$

$$f_{bott} = \frac{M * y_b}{I}$$

$$= +\frac{121593 * 1}{4.8833}$$

$$= 24900 \quad \text{KN/m}^2 = 24.9 \quad \text{MPa}$$





STEP V : THE VERIFICATION

5.1 The Ultimate Limit State

Stress in the cables after losses

$$\sigma_\infty = \frac{P_\infty}{A_p}$$

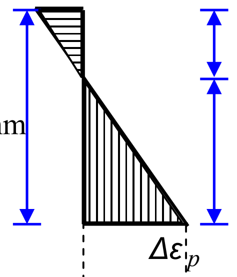
$$= \frac{100534150}{83700} = 1201 \quad N/mm^2$$

Strain in the cables after losses

$$\varepsilon_\infty = \frac{\sigma_\infty}{E_p}$$

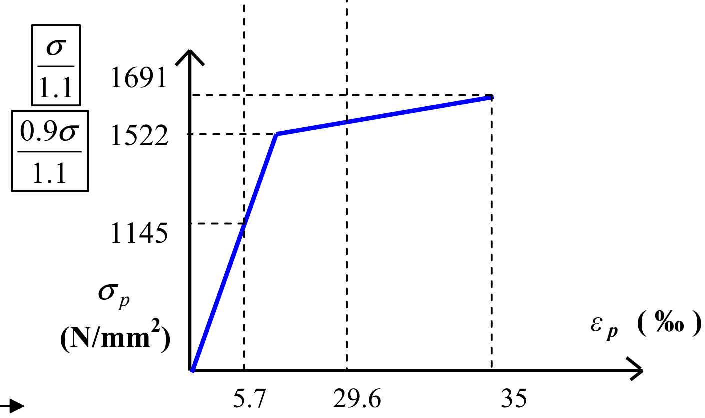
$$= \frac{1201.12}{2.10E+05} = 5.72E-03$$

try, x_u = 208.506 mm



$$\frac{0.0035}{208.51} = \frac{\Delta\varepsilon_p}{1423.5} \qquad h = 1632.0 \text{ mm}$$

$$\Delta\varepsilon_p = 2.39E-02$$



$$\varepsilon_p = \varepsilon_\infty + \Delta\varepsilon_p$$

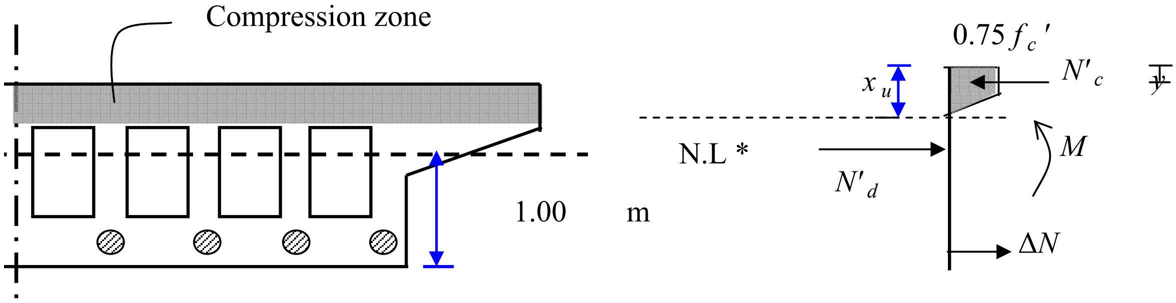
$$= 5.72E-03 + 2.39E-02$$

$$= 2.96E-02 \qquad \sigma_p = 1657.7 \ N/mm^2$$

$\Delta\sigma_p$ = 1657.67 - 1201.12 = 456.55 N/mm^2

ΔN_p = 456.55 * 3100 * 27 cables
= 38213224.3 N = 38213.22 kN

y = 0.389 * 208.51
= 81.11 mm



N'_d = P_∞

* Neutral Line

Ultimate moment of the structure is :

M_u = N'_d $(h - y_b - y)$ + $\Delta N_p\,(d_p - y)$
= 100534.15 * (1.80 - 1.000 - 0.081) + 38213.22 *
(1.80 - 0.168 - 0.081)
= 131538 kNm

Controlling the total horizontal forces

$N'_d - (N'_c - \Delta N_p)$ = 0

N'_c = 0.8 * f_c' * *Area of concrete*
N'_c = 0.8 * 65 * 208.51 * 13650 = 138747 kN

$N'_d - (N'_c - \Delta N_p)$ = 0
100534.15 - (138747.38 - 38213.22) = 0
-0.004 = 0

Maximum moment which is occur at the service life

M_d = 1.2 M_{DL} + 1.5 M_{LL} -1.0 M_P
= 70902 + 50691 - 83644
= 37949 kNm

Controlling the strength of the structure in transverse direction

$M_d \leq M_u$

37949 ≤ 131538 ⟶ **O.K**

5.2 The Stress Verification

Maximum stress (σ) allowed at compression area $= 0.6 * f_c'$

$= 0.6 * 65$ MPa

$= 39$ Mpa

Maximum stress (σ) allowed at tension area $= 0.5 * \sqrt{f_c'}$

$= 0.5 * 8$ MPa

$= 4.04$ MPa

Maximum stress occurring at compression area = 14.52 < 39 MPa ⟶ **O.K**

Maximum stress occurring at tension area = 0.00 < 4.04 MPa ⟶ **O.K**

5.3 Fatigue Verification

$$\Delta\sigma_{VOSB} \leq \Delta\sigma_{toel}$$

$$\Delta\sigma_{VOSB} = \sigma_{\max} - \sigma_{\min}$$

$$\Delta\sigma_{toel} = \frac{\Delta f_{ak}.k_A.k_N}{\gamma_{fat}} \cdot \frac{1}{\lambda_\tau.\beta_\tau}$$

Δf_{ak} = **180** N/mm^2 (NEN-ANNEX 6 Chapter 6 art.2.3.2.1)

k_A = **1.00** (NEN-ANNEX 6 Chapter 6 art.2.3.2.2)

γ_{fat} = **1.5** (NEN-ANNEX 6 Chapter 6 art.2.3.2.3)

k_N = **0.9** (NEN-ANNEX 6 Chapter 6 art.2.3.2.4)

λ_τ = **0.7** (NEN-ANNEX 6 Chapter 6 art.2.3.2.5)

β_τ = **0.78** (NEN-ANNEX 6 Chapter 6 art.2.3.2.6)

$$\Delta\sigma_{toel} = \frac{180 * 1.00 * 0.9}{1.5} * \frac{1}{0.7 * 0.78}$$

$$= 197.80 \ \text{N/mm}^2$$

- Based on the calculation from DBET

  Maximum stresses of the pre-stressing steel due to the mobile loads = **1231.9** N/mm^2

  Minimum stresses of the pre-stressing steel due to the mobile loads = **1205.9** N/mm^2

$$\Delta\sigma_{VOSB} = 1231.9 - 1205.9$$

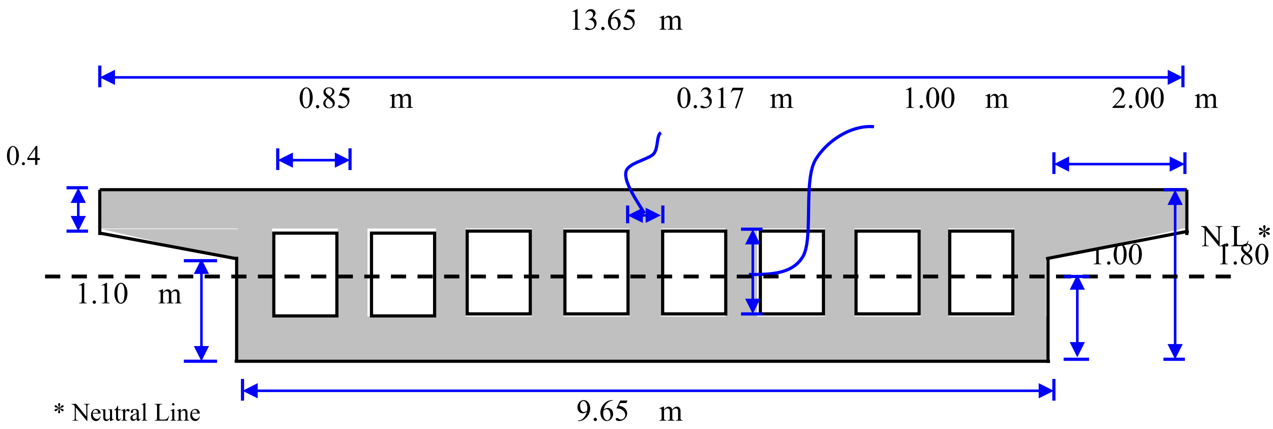
$$= 26 \ \text{N/mm}^2$$

Controlling the fatigue resistance of the pre-stressing steels

$$\Delta\sigma_{vosb} \leq \Delta\sigma_{toel}$$

$26 \leq 197.80$ ⟶ **O.K**

THE RESULTS



Cross section

A	=	12.770 m^2
y_a	=	0.800 m
y_b	=	1.000 m
I	=	4.883 m^4
W_a	=	6.104 m^3
W_b	=	4.883 m^3
k_a	=	0.382 m
k_b	=	0.478 m
q_{DL}	=	319.250 kN/m

- Number of cables needed = 27 Cables
- Type of cable = 5 - 31
- Area per cable = 3100 mm^2
- Type of concrete = C53/65

Verification

<u>Ultimate Limit States</u>

1. At construction stage

Maximum stress occurring at compression area	=	14.52	<	39	MPa	→	**O.K**
Maximum stress occurring at tension area	=	0.00	<	4.04	MPa	→	**O.K**

2. At service-life stage

Maximum stress occurring at compression area	=	14.09	<	39	MPa	→	**O.K**
Maximum stress occurring at tension area	=	0.00	<	4.04	MPa	→	**O.K**

Ultimate moment

$M_d \leq M_u$

37948.59 ≤ 131537.69 ⟶ **O.K**

<u>Service Limit States</u>

1. Deflection at the service-life (Output from ALP2000 with factor 1.0)

δ =	**16.82**	mm	≤	0.001 L	m		
	16.82	mm	≤	40.00	mm	→	**O.K**

2. Deflection at the service-life (Output from ALP2000 with factor 1.0 and settlement 10mm at the second support)

δ =	**24.67**	mm	≤	0.001 L	m		
	24.67	mm	≤	40.00	mm	→	**O.K**

<u>Fatigue Limit States</u>

1. $\Delta\sigma_{vosb} \leq \Delta\sigma_{toel}$

   26 ≤ 197.80 ⟶ **O.K**

<u>Pre-stressing losses</u>

1. Direct losses
   - The ancorage set losses (ΔF_{pA}) = 516.73 kN per cable
   - The maximum losses due to the friction losses and the Wobble effect (ΔF_{pF}) = 993 kN
2. Time-dependent losses
   - Losses because of creep $\Delta\sigma_{p\varphi}$ = 27230.50 kN/m^2 = 27.23 Mpa
   - Losses because of shrinkage $\Delta\sigma_{pS}$ = 18375.00 kN/m^2 = 18.38 Mpa
   - Losses because of relaxation $\Delta\sigma_{pR}$ = 89972.58 kN/m^2 = 89.97 Mpa

3. Percentage of losses due to time-dependent losses

$$= \frac{27.23 + 18.38 + 89.97}{1395.16} * 100 \%$$

$$= 9.72 \% < 20 \% \longrightarrow \textbf{O.K}$$

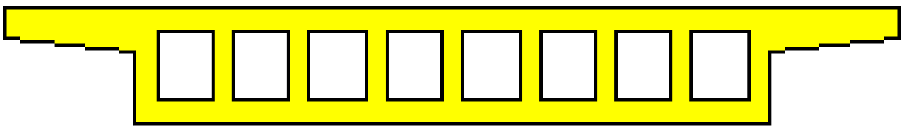
Conclusion

Based on the hand calculation, it can be concluded that :

1. Stresses which occur either at compression zone or tension zone are below the maximum allowed values.
2. Losses in the prestressing system are important aspetcs that we should take into account because losses that possibly occur influence much in the prestressing force.
   Losses in prestressing system are:
   a. Direct losses
      - Friction losses;
      - Anchorage set losses.
   b. Time-dependent Losses
      - Creep;
      - Shrinkage;
      - Relaxation.
3. Since the structure is very long for prestressing system, losses due to friction and curvature of the cable are relatively high.
4. Losses due to time-dependent are still below 20%. The prestressing forces after losses are adequate enough to react against dead loads and mobile loads.
5. Appllying both live end in tensioning method can reduce friction losses which occur in the structure
6. The structure experiences compression more than tension. The advantages of that are:
   - Less crack, due to limitating the tension stress;
   - The fatigue problem could be reduced;
   - Better for concrete structure. Since concrete is very strong at in compression forces.
7. Reinforcements that are intoduced in the structure are:
   - Prestressing cables;
   - Reinforcements for shear and torsion;
   - Tendon supports;
   - Reinforcements at anchorage.

ANNEX 3
ALP 2000 CALCULATION

Cross Section of the Bridge - Section 1
Alternative of A Double Track Railway Bridge
designed by Suwanda



Section 1 (Macro type 12)

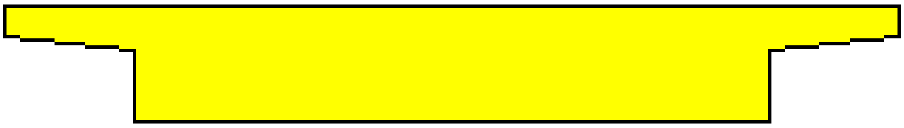
B A S I C   S E C T I O N S

Section: 1   Construction Height: 1800 [mm]

Macro topic:	Value: [mm]
b	13650
b1l	2000
b2l	742
b1r	2000
b2r	742
h	1800
h1l	500
h2l	1100
h1r	500
h2r	1100
h3	400
d	1000
c	850
n (number)	8
s	0
fl * 1000	1000
fr * 1000	1000

Section no	Subsection no	H [mm]	Y-top [mm]	e_top [mm]	Area [m2]	Ixx [m4]
1	1	1800	1800	789.5	1.2970e+01	4.8968e+00

Cross Section of the Bridge - Section 2
Alternative of A Double Track Railway Bridge
designed by Suwanda



Section 2 (Macro type 12)

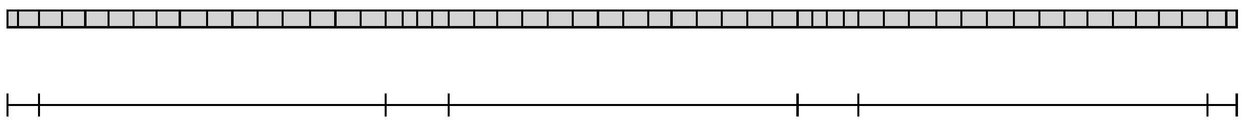
B A S I C   S E C T I O N S

Section: 2   Construction Height: 1800 [mm]

Macro topic:	Value: [mm]
b	13650
b1l	2000
b2l	742
b1r	2000
b2r	742
h	1800
h1l	500
h2l	1100
h1r	500
h2r	1100
h3	400
d	800
c	850
n (number)	0
s	0
fl * 1000	1000
fr * 1000	1000

Section no	Subsection no	H [mm]	Y-top [mm]	e_top [mm]	Area [m2]	Ixx [m4]
2	1	1800	1800	827.5	1.9770e+01	5.5180e+00

Longitudinal Section of the Bridge
Alternative of A Double Track Railway Bridge
designed by Suwanda



B A S I C   B E A M S
=====================

Beam no	X_left [mm]	X_Right [mm]	Length [mm]	Section at left no	Section at right no
1	0	3000	3000	2	2
2	3000	37000	34000	1	1
3	37000	43000	6000	2	2
4	43000	77000	34000	1	1
5	77000	83000	6000	2	2
6	83000	117000	34000	1	1
7	117000	120000	3000	2	2

Beam no	Subbeam no	Kn factor [-]	Ks Factor [-]	Material	Concreted at [days]	Deshuttered at [days]	Removed at [days]
1	1	1.000	1.000	C53.3/65.0	0	28.00	10000.00
2	1	1.000	1.000	C53.3/65.0	0	28.00	10000.00
3	1	1.000	1.000	C53.3/65.0	0	28.00	10000.00
4	1	1.000	1.000	C53.3/65.0	0	28.00	10000.00
5	1	1.000	1.000	C53.3/65.0	0	28.00	10000.00
6	1	1.000	1.000	C53.3/65.0	0	28.00	10000.00
7	1	1.000	1.000	C53.3/65.0	0	28.00	10000.00

Longitudinal Section of the Bridge
Alternative of A Double Track Railway Bridge
designed by Suwanda

G E N E R A T E D   C R O S S   S E C T I O N S

Section no	Subsection no	H [mm]	Y-top [mm]	Y-bottom [mm]	Area [m2]	Sxx [m3]	Ixx [m4]
1	1	1800	0	-1800	1.9770e+01	-1.6360e+01	1.9056e+01
2	1	1800	0	-1800	1.9770e+01	-1.6360e+01	1.9056e+01
3	1	1800	0	-1800	1.9770e+01	-1.6360e+01	1.9056e+01
4	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
5	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
6	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
7	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
8	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
9	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
10	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
11	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
12	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
13	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
14	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
15	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
16	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
17	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
18	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
19	1	1800	0	-1800	1.9770e+01	-1.6360e+01	1.9056e+01
20	1	1800	0	-1800	1.9770e+01	-1.6360e+01	1.9056e+01
21	1	1800	0	-1800	1.9770e+01	-1.6360e+01	1.9056e+01
22	1	1800	0	-1800	1.9770e+01	-1.6360e+01	1.9056e+01
23	1	1800	0	-1800	1.9770e+01	-1.6360e+01	1.9056e+01
24	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
25	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
26	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
27	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
28	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
29	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
30	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
31	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
32	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
33	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
34	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
35	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
36	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
37	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
38	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
39	1	1800	0	-1800	1.9770e+01	-1.6360e+01	1.9056e+01
40	1	1800	0	-1800	1.9770e+01	-1.6360e+01	1.9056e+01
41	1	1800	0	-1800	1.9770e+01	-1.6360e+01	1.9056e+01
42	1	1800	0	-1800	1.9770e+01	-1.6360e+01	1.9056e+01
43	1	1800	0	-1800	1.9770e+01	-1.6360e+01	1.9056e+01
44	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
45	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
46	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
47	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
48	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
49	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
50	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
51	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
52	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
53	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
54	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
55	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
56	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
57	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
58	1	1800	0	-1800	1.2970e+01	-1.0240e+01	1.2981e+01
59	1	1800	0	-1800	1.9770e+01	-1.6360e+01	1.9056e+01
60	1	1800	0	-1800	1.9770e+01	-1.6360e+01	1.9056e+01
61	1	1800	0	-1800	1.9770e+01	-1.6360e+01	1.9056e+01

G E N E R A T E D   B E A M   P A R T S

Part no	X_left [mm]	X_Right [mm]	Length [mm]	Gen. Sect. at left no	Gen. Sect. at right no
1	0	1000	1000	1	2
2	1000	3000	2000	2	3
3	3000	5310	2310	4	5
4	5310	7620	2310	5	6
5	7620	9930	2310	6	7
6	9930	12240	2310	7	8
7	12240	14550	2310	8	9
8	14550	16861	2311	9	10
9	16861	19378	2517	10	11
10	19378	21895	2517	11	12
11	21895	24412	2517	12	13
12	24412	26929	2517	13	14
13	26929	29446	2517	14	15
14	29446	31963	2517	15	16
15	31963	34480	2517	16	17
16	34480	37000	2520	17	18
17	37000	38482	1482	19	20
18	38482	40000	1518	20	21
19	40000	41470	1470	21	22
20	41470	43000	1530	22	23
21	43000	45429	2429	24	25
22	45429	47858	2429	25	26
23	47858	50287	2429	26	27
24	50287	52716	2429	27	28
25	52716	55145	2429	28	29
26	55145	57574	2429	29	30
27	57574	60000	2426	30	31
28	60000	62429	2429	31	32
29	62429	64858	2429	32	33
30	64858	67287	2429	33	34
31	67287	69716	2429	34	35
32	69716	72145	2429	35	36
33	72145	74574	2429	36	37
34	74574	77000	2426	37	38
35	77000	78530	1530	39	40
36	78530	80000	1470	40	41
37	80000	81518	1518	41	42
38	81518	83000	1482	42	43
39	83000	85517	2517	44	45
40	85517	88034	2517	45	46
41	88034	90551	2517	46	47
42	90551	93068	2517	47	48
43	93068	95585	2517	48	49
44	95585	98102	2517	49	50
45	98102	100619	2517	50	51
46	100619	103139	2520	51	52
47	103139	105449	2310	52	53
48	105449	107759	2310	53	54
49	107759	110069	2310	54	55
50	110069	112379	2310	55	56
51	112379	114689	2310	56	57
52	114689	117000	2311	57	58
53	117000	119000	2000	59	60
54	119000	120000	1000	60	61

S U P P O R T S

Support no	X [mm]	Y [mm]	Horizontally fixed	Vertically fixed	Rotation fixed	Placed at [days]	Removed at [days]
1	0	-1800	True	True	False	0	10000.00
2	40000	-1800	False	True	False	0	10000.00
3	80000	-1800	False	True	False	0	10000.00
4	120000	-1800	False	True	False	0	10000.00

Support no	Spring X [kN/mm]	Spring Y [kN/mm]	Spring M [kNm/rad]
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0

P E R M A N E N T   L O A D S

UDL no	X-left [mm]	X-right [mm]	Q-left [kN/m]	Q-right [kN/m]	From [days]	Until [days]
1	0	120000	-2.520	-2.520	60	10000
2	0	120000	-109.440	-109.440	60	10000
3	0	120000	-13.787	-13.787	60	10000
4	0	120000	0	0	60	10000
5	0	120000	-5.000	-5.000	60	10000
6	0	120000	-3.000	-3.000	60	10000
7	0	120000	-1.000	-1.000	60	10000

M O B I L E   L O A D S

Trains VBB95 A.2.2.a

UDL [kN/m]	S	B
0	1.000	1.000

Span no	X-left [mm]	X-right [mm]	Length [mm]	K1 [-]	K2 [-]
1	0	40000	40000	1.000	1.000
2	40000	80000	40000	1.000	1.000
3	80000	120000	40000	1.000	1.000

Trains VBB95 A.2.2.b

UDL [kN/m]	S	B
0	1.000	1.000

Span no	X-left [mm]	X-right [mm]	Length [mm]	K1 [-]	K2 [-]
1	0	40000	40000	1.000	1.000
2	40000	80000	40000	1.000	1.000
3	80000	120000	40000	1.000	1.000

Trains VBB95 A.2.2.c

UDL [kN/m]	S	B
0	1.000	1.000

Span no	X-left [mm]	X-right [mm]	Length [mm]	K1 [-]	K2 [-]
1	0	40000	40000	1.000	1.000
2	40000	80000	40000	1.000	1.000
3	80000	120000	40000	1.000	1.000

T E M P E R A T U R E   G R A D I E N T S

Case:	Top [oC]	Bottom [oC]
Opwarmen	3.98	-4.23
Afkoelen	-1.92	2.04
OpwarmeB	7.24	-7.69
AfkoelenB	-2.90	3.08

T E M P E R A T U R E   J U M P S

Case:	Subbeam no	Temperature [oC]

S E T T L E M E N T S

Case:	Support No	Settlement [mm]
Settlement 1	1	-10.000
Settlement 2	2	-10.000

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C O L L E C T I O N pre-stressing G R O U P 1

G R O U P P R O P E R T I E S

Number of Tendons	:	27
Area of one Tendon	:	3100 [mm2]
Limit stress at tensioning	:	1450 [MPa]
Limit stress after blocking	:	1305 [MPa]
Applied tensioning stress	:	1351 [MPa]
Relaxation	:	6.00 [%]
Additional loss: low	:	0 [%]
average	:	0 [%]
high	:	0 [%]
Tensioning method	:	first at left second at right
Tensioned at	:	28.00 [days]
Removed at	:	10000.00 [days]
Modulus of elasticity	:	200000 [MPa]
Friction coefficient: low	:	0.130000
average	:	0.180000
high	:	0.230000
Wobble effect: low	:	0.003000 [rad/m]
average	:	0.006000 [rad/m]
high	:	0.009000 [rad/m]

B A S I C T O P O L O G I C A L D A T A

GIVEN POINTS IN VERICAL PLANE XY

Point no	X [mm]	Y [mm]	Tan(Alfa-V) [-]		Line Type
1	0	-800	-0.093164	<Fixed>	
2	1000	-893	-0.093164	<Fixed>	Left End
3	16861	-1632	0	<Fixed>	Left End
4	38482	-264	0.126500	<Fixed>	Left End
5	40000	-168	0	<Fixed>	Left End
6	41470	-258	-0.122500	<Fixed>	Middle
7	60000	-1393	0	<Fixed>	Middle
8	78530	-258	0.122500	<Fixed>	Middle
9	80000	-168	0	<Fixed>	Middle
10	81518	-264	-0.126500	<Fixed>	Right End
11	103139	-1632	0	<Fixed>	Right End
12	119000	-893	0.093164	<Fixed>	Right End
13	120000	-800	0.093164		Right End

GIVEN POINTS IN HORIZONTAL PLANE XY

Point no	X [mm]	Y [mm]	Tan(Alfa-H) [-]	Line Type
1	0	168	0	
2	120000	168	0	3rd order

C O M P U T E D D A T A

1. Total length	:	120277 [mm]
2. Total rotation	:	1.17677 [rad]
3. Minimum radius in vertical plane	:	12.000 [m]
4. Minimum radius in horizontal plane	:	0 [m]

(Friction and wobble)		Low	Average	High	
5. Slip influence length left end	:	30383	22392	17770	[mm]
6. Slip influence length right end	:	30386	22391	17767	[mm]
7. Left elongation at stressing	:	737	689	635	[mm]
8. Left elongation after blocking	:	730	682	628	[mm]
9. Right elongation at stressing	:	41	64	89	[mm]
10. Right elongation after blocking	:	34	57	82	[mm]

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COMPUTED TOPOLOGY

Point no	X [mm]	Y-V [mm]	Y-H [mm]	Tan(Alfa-V) [-]	Tan(Alfa-H) [-]	Fhi [rad]	S [mm]
1	0	-800	168	-0.093164	0	0	0
2	250	-823	168	-0.093164	0	0	251
3	500	-847	168	-0.093164	0	0	502
4	750	-870	168	-0.093164	0	0	753
5	1000	-893	168	-0.093164	0	0	1004
6	1500	-939	168	-0.090227	0	0.002912	1506
7	2000	-983	168	-0.087290	0	0.005826	2008
8	2500	-1026	168	-0.084353	0	0.008742	2510
9	3000	-1068	168	-0.081416	0	0.011659	3012
10	3578	-1114	168	-0.078024	0	0.015029	3591
11	4155	-1158	168	-0.074632	0	0.018402	4170
12	4733	-1200	168	-0.071240	0	0.021776	4749
13	5310	-1240	168	-0.067848	0	0.025152	5328
14	5888	-1278	168	-0.064456	0	0.028529	5907
15	6465	-1315	168	-0.061064	0	0.031908	6486
16	7043	-1349	168	-0.057672	0	0.035288	7064
17	7620	-1381	168	-0.054280	0	0.038669	7643
18	8198	-1412	168	-0.050887	0	0.042052	8221
19	8775	-1440	168	-0.047495	0	0.045436	8799
20	9353	-1466	168	-0.044103	0	0.048821	9377
21	9930	-1491	168	-0.040711	0	0.052207	9955
22	10508	-1513	168	-0.037319	0	0.055594	10533
23	11085	-1534	168	-0.033927	0	0.058982	11111
24	11663	-1553	168	-0.030535	0	0.062370	11689
25	12240	-1569	168	-0.027143	0	0.065760	12267
26	12818	-1584	168	-0.023751	0	0.069150	12844
27	13395	-1597	168	-0.020358	0	0.072540	13422
28	13973	-1607	168	-0.016966	0	0.075931	14000
29	14550	-1616	168	-0.013574	0	0.079322	14577
30	15128	-1623	168	-0.010181	0	0.082715	15155
31	15706	-1628	168	-0.006787	0	0.086109	15733
32	16283	-1631	168	-0.003394	0	0.089502	16310
33	16861	-1632	168	0	0	0.092896	16888
34	17490	-1631	168	0.003683	0	0.096579	17517
35	18120	-1627	168	0.007366	0	0.100262	18147
36	18749	-1622	168	0.011049	0	0.103944	18776
37	19378	-1613	168	0.014732	0	0.107627	19405
38	20007	-1603	168	0.018415	0	0.111309	20035
39	20637	-1590	168	0.022098	0	0.114990	20664
40	21266	-1575	168	0.025781	0	0.118671	21293
41	21895	-1558	168	0.029464	0	0.122351	21923
42	22524	-1538	168	0.033146	0	0.126030	22553
43	23154	-1516	168	0.036829	0	0.129708	23182
44	23783	-1492	168	0.040512	0	0.133386	23812
45	24412	-1465	168	0.044195	0	0.137062	24442
46	25041	-1436	168	0.047878	0	0.140737	25072
47	25671	-1405	168	0.051561	0	0.144411	25702
48	26300	-1371	168	0.055244	0	0.148083	26332
49	26929	-1335	168	0.058926	0	0.151754	26962
50	27558	-1297	168	0.062609	0	0.155423	27592
51	28188	-1257	168	0.066292	0	0.159091	28223
52	28817	-1214	168	0.069975	0	0.162756	28854
53	29446	-1169	168	0.073657	0	0.166420	29485
54	30075	-1121	168	0.077340	0	0.170082	30116
55	30705	-1071	168	0.081023	0	0.173742	30747
56	31334	-1019	168	0.084705	0	0.177399	31378
57	31963	-965	168	0.088388	0	0.181055	32010
58	32592	-908	168	0.092071	0	0.184708	32642
59	33222	-849	168	0.095753	0	0.188358	33274
60	33851	-787	168	0.099436	0	0.192006	33906
61	34480	-724	168	0.103119	0	0.195651	34538
62	35110	-657	168	0.106806	0	0.199298	35172
63	35740	-589	168	0.110493	0	0.202942	35806
64	36370	-518	168	0.114180	0	0.206583	36440
65	37000	-445	168	0.117867	0	0.210221	37074
66	37371	-401	168	0.120035	0	0.212359	37447
67	37741	-356	168	0.122203	0	0.214496	37820
68	38112	-310	168	0.124371	0	0.216632	38193
69	38482	-264	168	0.126540	0	0.218766	38567
70	38862	-222	168	0.094875	0	0.250045	38949
71	39241	-192	168	0.063250	0	0.281471	39329
72	39621	-174	168	0.031625	0	0.313023	39709
73	40000	-168	168	0	0	0.344637	40089
74	40368	-174	168	-0.030625	0	0.375252	40456
75	40735	-191	168	-0.061250	0	0.405811	40824

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76	41103	-219	168	-0.091875	0	0.436255	41193
77	41470	-258	168	-0.122500	0	0.466530	41562
78	41853	-304	168	-0.119971	0	0.469022	41948
79	42235	-350	168	-0.117443	0	0.471515	42333
80	42618	-394	168	-0.114914	0	0.474010	42718
81	43000	-438	168	-0.112385	0	0.476507	43103
82	43607	-505	168	-0.108371	0	0.480473	43714
83	44215	-569	168	-0.104356	0	0.484442	44325
84	44822	-631	168	-0.100342	0	0.488415	44935
85	45429	-691	168	-0.096327	0	0.492391	45545
86	46036	-748	168	-0.092313	0	0.496370	46155
87	46644	-803	168	-0.088299	0	0.500352	46765
88	47251	-856	168	-0.084284	0	0.504337	47374
89	47858	-906	168	-0.080270	0	0.508325	47984
90	48465	-953	168	-0.076255	0	0.512315	48593
91	49073	-998	168	-0.072241	0	0.516307	49202
92	49680	-1041	168	-0.068226	0	0.520302	49810
93	50287	-1081	168	-0.064212	0	0.524299	50419
94	50894	-1119	168	-0.060197	0	0.528298	51027
95	51502	-1154	168	-0.056183	0	0.532299	51636
96	52109	-1187	168	-0.052168	0	0.536301	52244
97	52716	-1218	168	-0.048154	0	0.540306	52852
98	53323	-1246	168	-0.044139	0	0.544312	53460
99	53931	-1271	168	-0.040125	0	0.548319	54067
100	54538	-1294	168	-0.036110	0	0.552328	54675
101	55145	-1315	168	-0.032096	0	0.556337	55283
102	55752	-1333	168	-0.028081	0	0.560348	55890
103	56360	-1349	168	-0.024067	0	0.564360	56498
104	56967	-1363	168	-0.020053	0	0.568373	57105
105	57574	-1374	168	-0.016038	0	0.572386	57713
106	58181	-1382	168	-0.012029	0	0.576394	58319
107	58787	-1388	168	-0.008019	0	0.580404	58926
108	59394	-1392	168	-0.004010	0	0.584413	59532
109	60000	-1393	168	0	0	0.588422	60139
110	60607	-1392	168	0.004014	0	0.592437	60746
111	61215	-1388	168	0.008029	0	0.596451	61353
112	61822	-1382	168	0.012043	0	0.600465	61960
113	62429	-1373	168	0.016058	0	0.604479	62568
114	63036	-1363	168	0.020072	0	0.608492	63175
115	63644	-1349	168	0.024087	0	0.612505	63782
116	64251	-1333	168	0.028101	0	0.616516	64390
117	64858	-1315	168	0.032116	0	0.620527	64997
118	65465	-1294	168	0.036130	0	0.624537	65605
119	66073	-1271	168	0.040145	0	0.628546	66213
120	66680	-1246	168	0.044159	0	0.632553	66821
121	67287	-1217	168	0.048174	0	0.636559	67428
122	67894	-1187	168	0.052188	0	0.640563	68036
123	68502	-1154	168	0.056203	0	0.644566	68645
124	69109	-1119	168	0.060217	0	0.648567	69253
125	69716	-1081	168	0.064232	0	0.652566	69861
126	70323	-1041	168	0.068246	0	0.656563	70470
127	70931	-998	168	0.072260	0	0.660557	71079
128	71538	-953	168	0.076275	0	0.664550	71688
129	72145	-905	168	0.080289	0	0.668540	72297
130	72752	-855	168	0.084304	0	0.672527	72906
131	73360	-803	168	0.088318	0	0.676512	73515
132	73967	-748	168	0.092333	0	0.680494	74125
133	74574	-691	168	0.096347	0	0.684473	74735
134	75181	-631	168	0.100357	0	0.688444	75345
135	75787	-569	168	0.104366	0	0.692412	75954
136	76394	-505	168	0.108376	0	0.696377	76564
137	77000	-438	168	0.112385	0	0.700338	77174
138	77383	-394	168	0.114914	0	0.702835	77559
139	77765	-350	168	0.117443	0	0.705330	77944
140	78148	-304	168	0.119971	0	0.707823	78330
141	78530	-258	168	0.122500	0	0.710315	78715
142	78898	-219	168	0.091875	0	0.740590	79084
143	79265	-191	168	0.061250	0	0.771034	79453
144	79633	-174	168	0.030625	0	0.801592	79821
145	80000	-168	168	0	0	0.832208	80188
146	80380	-174	168	-0.031625	0	0.863822	80568
147	80759	-192	168	-0.063250	0	0.895374	80948
148	81139	-222	168	-0.094875	0	0.926800	81329
149	81518	-264	168	-0.126500	0	0.958039	81710
150	81889	-310	168	-0.124332	0	0.960174	82084
151	82259	-356	168	-0.122165	0	0.962309	82457
152	82630	-401	168	-0.119997	0	0.964445	82830
153	83000	-445	168	-0.117829	0	0.966582	83203
154	83629	-518	168	-0.114148	0	0.970215	83837

155	84259	-589	168	-0.110467	0	0.973850	84470
156	84888	-657	168	-0.106786	0	0.977488	85103
157	85517	-723	168	-0.103105	0	0.981129	85736
158	86146	-787	168	-0.099424	0	0.984773	86368
159	86776	-848	168	-0.095743	0	0.988419	87000
160	87405	-907	168	-0.092063	0	0.992067	87633
161	88034	-964	168	-0.088382	0	0.995718	88264
162	88663	-1019	168	-0.084702	0	0.999371	88896
163	89293	-1071	168	-0.081021	0	1.003026	89527
164	89922	-1121	168	-0.077341	0	1.006684	90159
165	90551	-1168	168	-0.073661	0	1.010343	90790
166	91180	-1213	168	-0.069981	0	1.014004	91420
167	91810	-1256	168	-0.066301	0	1.017667	92051
168	92439	-1297	168	-0.062621	0	1.021332	92682
169	93068	-1335	168	-0.058941	0	1.024998	93312
170	93697	-1371	168	-0.055262	0	1.028665	93942
171	94327	-1404	168	-0.051582	0	1.032334	94573
172	94956	-1436	168	-0.047903	0	1.036005	95203
173	95585	-1465	168	-0.044224	0	1.039676	95832
174	96214	-1491	168	-0.040545	0	1.043349	96462
175	96844	-1516	168	-0.036866	0	1.047022	97092
176	97473	-1538	168	-0.033187	0	1.050697	97722
177	98102	-1558	168	-0.029508	0	1.054372	98351
178	98731	-1575	168	-0.025829	0	1.058048	98981
179	99361	-1590	168	-0.022151	0	1.061724	99610
180	99990	-1603	168	-0.018472	0	1.065401	100240
181	100619	-1613	168	-0.014794	0	1.069079	100869
182	101249	-1621	168	-0.011111	0	1.072761	101499
183	101879	-1627	168	-0.007428	0	1.076443	102129
184	102509	-1631	168	-0.003746	0	1.080125	102759
185	103139	-1632	168	-0.000064	0	1.083808	103389
186	103717	-1631	168	0.003392	0	1.087263	103966
187	104294	-1628	168	0.006784	0	1.090655	104544
188	104872	-1623	168	0.010176	0	1.094047	105121
189	105449	-1616	168	0.013568	0	1.097439	105699
190	106027	-1608	168	0.016961	0	1.100830	106277
191	106604	-1597	168	0.020353	0	1.104221	106854
192	107182	-1584	168	0.023745	0	1.107611	107432
193	107759	-1569	168	0.027137	0	1.111001	108010
194	108337	-1553	168	0.030529	0	1.114391	108587
195	108914	-1534	168	0.033921	0	1.117779	109165
196	109492	-1513	168	0.037313	0	1.121167	109743
197	110069	-1491	168	0.040705	0	1.124554	110321
198	110647	-1466	168	0.044097	0	1.127940	110899
199	111224	-1440	168	0.047489	0	1.131325	111477
200	111802	-1412	168	0.050882	0	1.134709	112055
201	112379	-1381	168	0.054274	0	1.138092	112633
202	112957	-1349	168	0.057666	0	1.141473	113212
203	113534	-1315	168	0.061058	0	1.144853	113790
204	114112	-1278	168	0.064450	0	1.148232	114369
205	114689	-1240	168	0.067842	0	1.151609	114948
206	115267	-1200	168	0.071236	0	1.154987	115527
207	115845	-1158	168	0.074629	0	1.158362	116106
208	116422	-1114	168	0.078023	0	1.161736	116686
209	117000	-1068	168	0.081416	0	1.165108	117265
210	117500	-1026	168	0.084353	0	1.168025	117767
211	118000	-983	168	0.087290	0	1.170940	118269
212	118500	-939	168	0.090227	0	1.173854	118771
213	119000	-893	168	0.093164	0	1.176767	119273
214	119250	-870	168	0.093164	0	1.176767	119524
215	119500	-847	168	0.093164	0	1.176767	119775
216	119750	-823	168	0.093164	0	1.176767	120026
217	120000	-800	168	0.093164	0	1.176767	120277

The Layout of Prestressing Cables
Alternative of A Double Track Railway Bridge
designed by Suwanda

COMPUTED TENDON FORCES (One after blocking without relaxation and losses)

	Low Friction				Average Friction				High Friction			
Point no	F [kN]	Fx [kN]	Fy-V [kN]	Fy-H [kN]	F [kN]	Fx [kN]	Fy-V [kN]	Fy-H [kN]	F [kN]	Fx [kN]	Fy-V [kN]	Fy-H [kN]
1	3906	3889	-362	0	3805	3788	-353	0	3705	3689	-344	0
2	3906	3889	-362	0	3806	3790	-353	0	3707	3691	-344	0
3	3907	3890	-362	0	3807	3791	-353	0	3709	3693	-344	0
4	3907	3890	-362	0	3808	3792	-353	0	3711	3695	-344	0
5	3907	3890	-362	0	3809	3793	-353	0	3713	3697	-344	0
6	3910	3894	-351	0	3814	3798	-343	0	3720	3705	-334	0
7	3912	3897	-340	0	3818	3804	-332	0	3727	3713	-324	0
8	3915	3901	-329	0	3823	3809	-321	0	3735	3721	-314	0
9	3917	3904	-318	0	3827	3815	-311	0	3742	3729	-304	0
10	3920	3908	-305	0	3832	3821	-298	0	3750	3739	-292	0
11	3922	3912	-292	0	3837	3827	-286	0	3758	3748	-280	0
12	3925	3915	-279	0	3843	3833	-273	0	3766	3757	-268	0
13	3928	3919	-266	0	3848	3839	-260	0	3774	3766	-255	0
14	3931	3923	-253	0	3853	3845	-248	0	3782	3775	-243	0
15	3934	3926	-240	0	3858	3851	-235	0	3791	3784	-231	0
16	3936	3930	-227	0	3863	3857	-222	0	3799	3792	-219	0
17	3939	3933	-213	0	3868	3862	-210	0	3807	3801	-206	0
18	3942	3937	-200	0	3873	3868	-197	0	3815	3810	-194	0
19	3945	3940	-187	0	3878	3874	-184	0	3823	3819	-181	0
20	3947	3944	-174	0	3883	3880	-171	0	3831	3827	-169	0
21	3950	3947	-161	0	3888	3885	-158	0	3839	3836	-156	0
22	3953	3950	-147	0	3893	3891	-145	0	3847	3844	-143	0
23	3956	3953	-134	0	3899	3896	-132	0	3855	3853	-131	0
24	3958	3957	-121	0	3904	3902	-119	0	3863	3861	-118	0
25	3961	3960	-107	0	3909	3907	-106	0	3871	3869	-105	0
26	3964	3963	-94	0	3914	3913	-93	0	3879	3878	-92	0
27	3967	3966	-81	0	3919	3918	-80	0	3887	3886	-79	0
28	3969	3969	-67	0	3924	3923	-67	0	3895	3894	-66	0
29	3972	3972	-54	0	3929	3928	-53	0	3902	3902	-53	0
30	3975	3975	-40	0	3934	3934	-40	0	3910	3910	-40	0
31	3978	3978	-27	0	3939	3939	-27	0	3918	3918	-27	0
32	3980	3980	-14	0	3944	3944	-13	0	3926	3926	-13	0
33	3983	3983	0	0	3949	3949	0	0	3934	3934	0	0
34	3986	3986	15	0	3954	3954	15	0	3942	3942	15	0
35	3989	3989	29	0	3960	3959	29	0	3941	3941	29	0
36	3992	3992	44	0	3965	3965	44	0	3932	3932	43	0
37	3995	3995	59	0	3970	3970	58	0	3924	3923	58	0
38	3998	3997	74	0	3976	3975	73	0	3915	3915	72	0
39	4001	4000	88	0	3981	3980	88	0	3907	3906	86	0
40	4004	4003	103	0	3987	3985	103	0	3899	3897	100	0
41	4007	4005	118	0	3992	3990	118	0	3890	3888	115	0
42	4010	4008	133	0	3995	3992	132	0	3882	3880	129	0
43	4013	4010	148	0	3989	3986	147	0	3873	3871	143	0
44	4016	4012	163	0	3984	3981	161	0	3865	3862	156	0
45	4019	4015	177	0	3978	3975	176	0	3857	3853	170	0
46	4022	4017	192	0	3973	3969	190	0	3849	3844	184	0
47	4025	4019	207	0	3968	3963	204	0	3840	3835	198	0
48	4027	4021	222	0	3963	3956	219	0	3832	3826	211	0
49	4030	4023	237	0	3957	3950	233	0	3824	3817	225	0
50	4033	4025	252	0	3952	3944	247	0	3816	3808	238	0
51	4036	4027	267	0	3947	3938	261	0	3807	3799	252	0
52	4039	4029	282	0	3941	3932	275	0	3799	3790	265	0
53	4042	4031	297	0	3936	3925	289	0	3791	3781	278	0
54	4045	4033	312	0	3931	3919	303	0	3783	3772	292	0
55	4045	4031	327	0	3925	3913	317	0	3775	3763	305	0
56	4042	4027	341	0	3920	3906	331	0	3767	3753	318	0
57	4039	4023	356	0	3915	3900	345	0	3759	3744	331	0
58	4036	4019	370	0	3910	3893	358	0	3751	3735	344	0
59	4033	4015	384	0	3904	3887	372	0	3743	3726	357	0
60	4030	4010	399	0	3899	3880	386	0	3735	3716	370	0
61	4027	4006	413	0	3894	3874	399	0	3727	3707	382	0
62	4024	4002	427	0	3889	3867	413	0	3719	3697	395	0
63	4021	3997	442	0	3884	3860	427	0	3711	3688	408	0
64	4018	3993	456	0	3878	3853	440	0	3703	3679	420	0
65	4016	3988	470	0	3873	3847	453	0	3695	3669	432	0
66	4014	3985	478	0	3870	3843	461	0	3690	3664	440	0
67	4012	3983	487	0	3867	3839	469	0	3685	3658	447	0
68	4010	3980	495	0	3864	3835	477	0	3681	3652	454	0
69	4009	3977	503	0	3861	3831	485	0	3676	3647	461	0
70	3992	3974	377	0	3838	3821	362	0	3647	3630	344	0
71	3975	3967	251	0	3815	3807	241	0	3618	3610	228	0
72	3958	3956	125	0	3791	3790	120	0	3589	3587	113	0
73	3941	3941	0	0	3768	3768	0	0	3560	3560	0	0

74	3925	3923	-120	0	3746	3744	-115	0	3532	3531	-108	0
75	3909	3902	-239	0	3724	3717	-228	0	3505	3498	-214	0
76	3893	3877	-356	0	3702	3687	-339	0	3478	3463	-318	0
77	3877	3848	-471	0	3681	3653	-448	0	3451	3425	-420	0
78	3875	3848	-462	0	3678	3651	-438	0	3446	3422	-410	0
79	3874	3847	-452	0	3674	3649	-429	0	3441	3418	-401	0
80	3872	3846	-442	0	3671	3647	-419	0	3437	3414	-392	0
81	3870	3846	-432	0	3668	3645	-410	0	3432	3411	-383	0
82	3867	3844	-417	0	3663	3642	-395	0	3425	3405	-369	0
83	3864	3843	-401	0	3658	3638	-380	0	3417	3399	-355	0
84	3861	3842	-385	0	3653	3635	-365	0	3410	3393	-340	0
85	3858	3840	-370	0	3648	3631	-350	0	3402	3387	-326	0
86	3855	3839	-354	0	3643	3627	-335	0	3395	3380	-312	0
87	3852	3837	-339	0	3638	3624	-320	0	3387	3374	-298	0
88	3849	3836	-323	0	3633	3620	-305	0	3380	3368	-284	0
89	3847	3834	-308	0	3628	3616	-290	0	3373	3362	-270	0
90	3844	3833	-292	0	3623	3612	-275	0	3365	3356	-256	0
91	3841	3831	-277	0	3618	3609	-261	0	3358	3349	-242	0
92	3838	3829	-261	0	3613	3605	-246	0	3351	3343	-228	0
93	3835	3827	-246	0	3608	3601	-231	0	3343	3337	-214	0
94	3832	3825	-230	0	3603	3596	-216	0	3336	3330	-200	0
95	3829	3823	-215	0	3598	3592	-202	0	3329	3324	-187	0
96	3826	3821	-199	0	3593	3588	-187	0	3322	3317	-173	0
97	3823	3819	-184	0	3588	3584	-173	0	3314	3311	-159	0
98	3820	3817	-168	0	3583	3580	-158	0	3307	3304	-146	0
99	3818	3814	-153	0	3578	3575	-143	0	3300	3297	-132	0
100	3815	3812	-138	0	3573	3571	-129	0	3293	3291	-119	0
101	3812	3810	-122	0	3568	3567	-114	0	3286	3284	-105	0
102	3809	3807	-107	0	3564	3562	-100	0	3279	3277	-92	0
103	3806	3805	-92	0	3559	3558	-86	0	3271	3270	-79	0
104	3803	3802	-76	0	3554	3553	-71	0	3264	3264	-65	0
105	3800	3800	-61	0	3549	3548	-57	0	3257	3257	-52	0
106	3797	3797	-46	0	3544	3544	-43	0	3250	3250	-39	0
107	3794	3794	-30	0	3539	3539	-28	0	3243	3243	-26	0
108	3792	3792	-15	0	3534	3534	-14	0	3236	3236	-13	0
109	3789	3789	0	0	3529	3529	0	0	3229	3229	0	0
110	3792	3792	15	0	3534	3534	14	0	3236	3236	13	0
111	3794	3794	30	0	3539	3539	28	0	3243	3243	26	0
112	3797	3797	46	0	3544	3544	43	0	3250	3250	39	0
113	3800	3800	61	0	3549	3548	57	0	3257	3257	52	0
114	3803	3802	76	0	3554	3553	71	0	3264	3264	66	0
115	3806	3805	92	0	3559	3558	86	0	3271	3271	79	0
116	3809	3807	107	0	3564	3562	100	0	3279	3277	92	0
117	3812	3810	122	0	3568	3567	115	0	3286	3284	105	0
118	3815	3812	138	0	3573	3571	129	0	3293	3291	119	0
119	3818	3815	153	0	3578	3575	144	0	3300	3297	132	0
120	3820	3817	169	0	3583	3580	158	0	3307	3304	146	0
121	3823	3819	184	0	3588	3584	173	0	3315	3311	159	0
122	3826	3821	199	0	3593	3588	187	0	3322	3317	173	0
123	3829	3823	215	0	3598	3592	202	0	3329	3324	187	0
124	3832	3825	230	0	3603	3597	217	0	3336	3330	201	0
125	3835	3827	246	0	3608	3601	231	0	3344	3337	214	0
126	3838	3829	261	0	3613	3605	246	0	3351	3343	228	0
127	3841	3831	277	0	3618	3609	261	0	3358	3349	242	0
128	3844	3833	292	0	3623	3612	276	0	3366	3356	256	0
129	3847	3834	308	0	3628	3616	290	0	3373	3362	270	0
130	3850	3836	323	0	3633	3620	305	0	3380	3368	284	0
131	3852	3837	339	0	3638	3624	320	0	3388	3374	298	0
132	3855	3839	354	0	3643	3628	335	0	3395	3381	312	0
133	3858	3840	370	0	3648	3631	350	0	3402	3387	326	0
134	3861	3842	386	0	3653	3635	365	0	3410	3393	340	0
135	3864	3843	401	0	3658	3638	380	0	3417	3399	355	0
136	3867	3844	417	0	3663	3642	395	0	3425	3405	369	0
137	3870	3846	432	0	3668	3645	410	0	3432	3411	383	0
138	3872	3846	442	0	3671	3647	419	0	3437	3414	392	0
139	3874	3847	452	0	3674	3649	429	0	3442	3418	401	0
140	3875	3848	462	0	3678	3651	438	0	3446	3422	411	0
141	3877	3848	471	0	3681	3653	448	0	3451	3425	420	0
142	3893	3877	356	0	3702	3687	339	0	3478	3463	318	0
143	3909	3902	239	0	3724	3717	228	0	3505	3498	214	0
144	3925	3923	120	0	3746	3744	115	0	3532	3531	108	0
145	3941	3941	0	0	3768	3768	0	0	3560	3560	0	0
146	3958	3956	-125	0	3791	3790	-120	0	3589	3587	-113	0
147	3975	3967	-251	0	3815	3807	-241	0	3618	3610	-228	0
148	3992	3974	-377	0	3838	3821	-362	0	3647	3631	-344	0
149	4009	3977	-503	0	3861	3831	-485	0	3676	3647	-461	0
150	4011	3980	-495	0	3864	3835	-477	0	3681	3653	-454	0
151	4012	3983	-487	0	3867	3839	-469	0	3685	3658	-447	0
152	4014	3985	-478	0	3870	3843	-461	0	3690	3664	-440	0

153	4016	3988	-470	0	3873	3847	-453	0	3695	3669	-432	0
154	4018	3993	-456	0	3878	3853	-440	0	3703	3679	-420	0
155	4021	3997	-442	0	3884	3860	-426	0	3711	3688	-407	0
156	4024	4002	-427	0	3889	3867	-413	0	3719	3697	-395	0
157	4027	4006	-413	0	3894	3874	-399	0	3727	3707	-382	0
158	4030	4010	-399	0	3899	3880	-386	0	3735	3716	-369	0
159	4033	4015	-384	0	3904	3887	-372	0	3743	3726	-357	0
160	4036	4019	-370	0	3910	3893	-358	0	3751	3735	-344	0
161	4039	4023	-356	0	3915	3900	-345	0	3759	3744	-331	0
162	4042	4027	-341	0	3920	3906	-331	0	3767	3753	-318	0
163	4045	4031	-327	0	3925	3913	-317	0	3775	3763	-305	0
164	4045	4033	-312	0	3931	3919	-303	0	3783	3772	-292	0
165	4042	4031	-297	0	3936	3925	-289	0	3791	3781	-279	0
166	4039	4029	-282	0	3941	3932	-275	0	3799	3790	-265	0
167	4036	4027	-267	0	3947	3938	-261	0	3807	3799	-252	0
168	4033	4025	-252	0	3952	3944	-247	0	3816	3808	-238	0
169	4030	4023	-237	0	3957	3950	-233	0	3824	3817	-225	0
170	4028	4021	-222	0	3962	3956	-219	0	3832	3826	-211	0
171	4025	4019	-207	0	3968	3963	-204	0	3840	3835	-198	0
172	4022	4017	-192	0	3973	3969	-190	0	3849	3844	-184	0
173	4019	4015	-178	0	3978	3975	-176	0	3857	3853	-170	0
174	4016	4012	-163	0	3984	3981	-161	0	3865	3862	-157	0
175	4013	4010	-148	0	3989	3986	-147	0	3873	3871	-143	0
176	4010	4008	-133	0	3994	3992	-132	0	3882	3880	-129	0
177	4007	4005	-118	0	3992	3990	-118	0	3890	3888	-115	0
178	4004	4003	-103	0	3987	3985	-103	0	3898	3897	-101	0
179	4001	4000	-89	0	3981	3980	-88	0	3907	3906	-87	0
180	3998	3997	-74	0	3976	3975	-73	0	3915	3915	-72	0
181	3995	3995	-59	0	3970	3970	-59	0	3924	3923	-58	0
182	3992	3992	-44	0	3965	3965	-44	0	3932	3932	-44	0
183	3989	3989	-30	0	3960	3959	-29	0	3941	3940	-29	0
184	3986	3986	-15	0	3954	3954	-15	0	3942	3942	-15	0
185	3983	3983	0	0	3949	3949	0	0	3934	3934	0	0
186	3980	3980	14	0	3944	3944	13	0	3926	3926	13	0
187	3978	3978	27	0	3939	3939	27	0	3918	3918	27	0
188	3975	3975	40	0	3934	3933	40	0	3910	3910	40	0
189	3972	3972	54	0	3929	3928	53	0	3902	3902	53	0
190	3969	3969	67	0	3924	3923	67	0	3895	3894	66	0
191	3967	3966	81	0	3919	3918	80	0	3887	3886	79	0
192	3964	3963	94	0	3914	3913	93	0	3879	3878	92	0
193	3961	3960	107	0	3909	3907	106	0	3871	3869	105	0
194	3958	3957	121	0	3904	3902	119	0	3863	3861	118	0
195	3956	3953	134	0	3898	3896	132	0	3855	3853	131	0
196	3953	3950	147	0	3893	3891	145	0	3847	3844	143	0
197	3950	3947	161	0	3888	3885	158	0	3839	3836	156	0
198	3947	3944	174	0	3883	3880	171	0	3831	3827	169	0
199	3945	3940	187	0	3878	3874	184	0	3823	3819	181	0
200	3942	3937	200	0	3873	3868	197	0	3815	3810	194	0
201	3939	3933	213	0	3868	3862	210	0	3807	3801	206	0
202	3936	3930	227	0	3863	3857	222	0	3799	3792	219	0
203	3934	3926	240	0	3858	3851	235	0	3791	3784	231	0
204	3931	3923	253	0	3853	3845	248	0	3782	3775	243	0
205	3928	3919	266	0	3848	3839	260	0	3774	3766	255	0
206	3925	3915	279	0	3843	3833	273	0	3766	3757	268	0
207	3922	3912	292	0	3837	3827	286	0	3758	3748	280	0
208	3920	3908	305	0	3832	3821	298	0	3750	3738	292	0
209	3917	3904	318	0	3827	3815	311	0	3742	3729	304	0
210	3915	3901	329	0	3823	3809	321	0	3735	3721	314	0
211	3912	3897	340	0	3818	3804	332	0	3727	3713	324	0
212	3910	3894	351	0	3814	3798	343	0	3720	3705	334	0
213	3907	3890	362	0	3809	3793	353	0	3713	3697	344	0
214	3907	3890	362	0	3808	3792	353	0	3711	3695	344	0
215	3907	3890	362	0	3807	3791	353	0	3709	3693	344	0
216	3906	3889	362	0	3806	3790	353	0	3707	3691	344	0
217	3906	3889	362	0	3805	3788	353	0	3705	3689	344	0

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COMPUTED CURVATURE FORCES IN VERTICAL PLANE (Total without relaxation and losses)

Part	Low Friction		Average Friction		High Friction	
	Ql	Qr	Ql	Qr	Ql	Qr
no	[kN/m]	[kN/m]	[kN/m]	[kN/m]	[kN/m]	[kN/m]
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	611.7	612.2	596.4	596.8	581.3	581.8
6	612.6	613.0	597.5	598.0	582.9	583.3
7	613.4	613.9	598.7	599.1	584.5	584.9
8	614.2	614.7	599.8	600.3	586.0	586.4
9	615.1	615.6	601.0	601.5	587.5	588.0
10	616.0	616.5	602.3	602.7	589.3	589.8
11	616.9	617.4	603.5	604.0	591.0	591.5
12	617.8	618.2	604.8	605.2	592.8	593.2
13	618.7	619.1	606.0	606.4	594.5	594.9
14	619.5	619.9	607.2	607.6	596.1	596.5
15	620.4	620.7	608.4	608.8	597.8	598.2
16	621.2	621.5	609.6	609.9	599.4	599.8
17	622.0	622.3	610.7	611.1	601.1	601.4
18	622.7	623.0	611.9	612.2	602.7	603.0
19	623.5	623.8	613.0	613.3	604.2	604.5
20	624.2	624.5	614.1	614.3	605.8	606.0
21	624.9	625.2	615.1	615.4	607.3	607.5
22	625.6	625.8	616.2	616.4	608.8	609.0
23	626.3	626.5	617.2	617.4	610.3	610.5
24	626.9	627.1	618.2	618.4	611.8	611.9
25	627.5	627.7	619.2	619.3	613.2	613.4
26	628.1	628.3	620.1	620.3	614.6	614.7
27	628.7	628.8	621.1	621.2	616.0	616.1
28	629.2	629.3	622.0	622.1	617.4	617.5
29	629.8	629.9	622.9	623.0	618.7	618.8
30	630.3	630.3	623.8	623.8	620.0	620.1
31	630.8	630.8	624.6	624.6	621.3	621.4
32	631.2	631.3	625.4	625.4	622.6	622.6
33	629.5	629.4	624.0	624.0	621.7	621.7
34	629.9	629.9	624.9	624.8	623.0	623.0
35	630.3	630.3	625.7	625.6	622.7	622.6
36	630.7	630.7	626.5	626.4	621.3	621.2
37	631.1	631.0	627.2	627.1	619.9	619.7
38	631.5	631.3	628.0	627.8	618.4	618.3
39	631.8	631.6	628.7	628.5	616.9	616.8
40	632.1	631.9	629.4	629.2	615.5	615.3
41	632.4	632.1	630.0	629.8	613.9	613.7
42	632.6	632.4	630.2	630.0	612.4	612.2
43	632.8	632.6	629.1	628.8	610.9	610.6
44	633.0	632.7	628.0	627.7	609.3	609.0
45	633.2	632.9	626.9	626.5	607.7	607.4
46	633.3	633.0	625.7	625.4	606.1	605.7
47	633.4	633.1	624.5	624.1	604.4	604.1
48	633.5	633.1	623.3	622.9	602.8	602.4
49	633.6	633.2	622.1	621.7	601.1	600.7
50	633.6	633.2	620.8	620.4	599.4	599.0
51	633.6	633.2	619.6	619.1	597.7	597.3
52	633.6	633.1	618.3	617.8	596.0	595.5
53	633.6	633.0	616.9	616.4	594.2	593.7
54	633.5	633.0	615.6	615.1	592.5	591.9
55	632.9	632.3	614.2	613.7	590.7	590.1
56	631.8	631.2	612.9	612.3	588.9	588.3
57	630.8	630.2	611.5	610.8	587.0	586.5
58	629.7	629.1	610.0	609.4	585.2	584.6
59	628.6	627.9	608.6	607.9	583.3	582.7
60	627.5	626.8	607.1	606.4	581.5	580.8
61	626.3	625.6	605.6	604.9	579.6	578.9
62	625.2	624.4	604.1	603.4	577.7	577.0
63	624.0	623.2	602.6	601.9	575.7	575.0
64	622.8	622.0	601.0	600.3	573.8	573.1
65	621.5	621.0	599.5	599.0	571.8	571.4
66	620.8	620.3	598.6	598.1	570.7	570.2
67	620.0	619.5	597.6	597.1	569.5	569.1
68	619.3	618.8	596.7	596.2	568.3	567.9
69	-8851.5	-8877.1	-8525.3	-8549.9	-8116.7	-8140.1
70	-8861.9	-8928.2	-8519.7	-8583.5	-8095.6	-8156.2
71	-8890.5	-8930.5	-8531.5	-8569.9	-8091.1	-8127.5
72	-8892.6	-8906.0	-8517.9	-8530.7	-8062.4	-8074.5
73	-8868.1	-8855.7	-8478.8	-8466.9	-8009.7	-7998.4

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74	-8819.2	-8782.2	-8417.0	-8381.7	-7936.3	-7902.9
75	-8746.1	-8685.2	-8332.4	-8274.3	-7841.6	-7786.9
76	-8649.6	-8565.8	-8225.8	-8146.1	-7726.7	-7651.9
77	676.8	677.4	642.5	643.1	602.4	602.9
78	677.1	677.7	642.5	643.1	602.1	602.6
79	677.3	677.9	642.5	643.1	601.8	602.3
80	677.6	678.2	642.5	643.1	601.5	602.0
81	677.9	678.8	642.5	643.4	601.2	602.0
82	678.2	679.1	642.5	643.3	600.7	601.4
83	678.6	679.4	642.4	643.2	600.1	600.8
84	678.9	679.7	642.3	643.1	599.5	600.2
85	679.2	680.0	642.2	642.9	598.9	599.6
86	679.4	680.2	642.0	642.7	598.3	598.9
87	679.7	680.4	641.8	642.5	597.6	598.3
88	679.8	680.5	641.6	642.2	597.0	597.5
89	680.0	680.6	641.3	641.9	596.2	596.8
90	680.1	680.7	641.1	641.6	595.5	596.0
91	680.2	680.8	640.8	641.3	594.7	595.2
92	680.3	680.8	640.4	640.9	593.9	594.4
93	680.3	680.8	640.0	640.5	593.1	593.6
94	680.3	680.8	639.6	640.1	592.3	592.7
95	680.3	680.7	639.2	639.6	591.4	591.8
96	680.2	680.6	638.7	639.1	590.5	590.8
97	680.1	680.5	638.2	638.6	589.6	589.9
98	679.9	680.3	637.7	638.0	588.6	588.9
99	679.8	680.1	637.2	637.5	587.6	587.9
100	679.6	679.8	636.6	636.8	586.6	586.8
101	679.3	679.6	636.0	636.2	585.6	585.8
102	679.1	679.3	635.3	635.5	584.5	584.7
103	678.8	678.9	634.6	634.8	583.4	583.6
104	678.4	678.6	633.9	634.1	582.3	582.4
105	678.1	678.2	633.2	633.3	581.2	581.3
106	677.7	677.7	632.4	632.5	580.0	580.1
107	677.2	677.3	631.6	631.7	578.8	578.8
108	676.8	676.8	630.8	630.8	577.6	577.6
109	676.3	676.3	630.0	630.0	576.4	576.3
110	676.8	676.7	630.8	630.8	577.6	577.6
111	677.2	677.1	631.6	631.6	578.8	578.7
112	677.7	677.5	632.4	632.3	580.0	579.9
113	678.1	677.9	633.2	633.1	581.2	581.1
114	678.4	678.2	633.9	633.8	582.3	582.2
115	678.8	678.5	634.7	634.5	583.4	583.3
116	679.1	678.8	635.3	635.1	584.5	584.3
117	679.3	679.1	636.0	635.7	585.6	585.3
118	679.6	679.3	636.6	636.3	586.6	586.4
119	679.8	679.4	637.2	636.9	587.6	587.3
120	679.9	679.6	637.7	637.4	588.6	588.3
121	680.1	679.7	638.3	637.9	589.6	589.2
122	680.2	679.7	638.7	638.3	590.5	590.1
123	680.3	679.8	639.2	638.8	591.4	591.0
124	680.3	679.8	639.6	639.2	592.3	591.8
125	680.3	679.8	640.0	639.5	593.1	592.7
126	680.3	679.7	640.4	639.9	594.0	593.5
127	680.2	679.6	640.8	640.2	594.8	594.2
128	680.1	679.5	641.1	640.5	595.5	595.0
129	680.0	679.3	641.4	640.7	596.3	595.7
130	679.9	679.2	641.6	640.9	597.0	596.4
131	679.7	678.9	641.8	641.1	597.7	597.0
132	679.4	678.7	642.0	641.3	598.3	597.6
133	679.2	678.4	642.2	641.4	598.9	598.2
134	678.9	678.1	642.3	641.5	599.5	598.8
135	678.6	677.7	642.4	641.6	600.1	599.4
136	678.2	677.4	642.5	641.6	600.7	599.9
137	677.9	677.3	642.5	642.0	601.2	600.7
138	677.6	677.0	642.5	642.0	601.5	601.0
139	677.3	676.7	642.5	642.0	601.8	601.3
140	677.1	676.5	642.5	641.9	602.1	601.5
141	-8531.0	-8614.5	-8098.7	-8178.0	-7593.1	-7667.4
142	-8649.7	-8710.4	-8225.9	-8283.6	-7726.9	-7781.1
143	-8746.2	-8783.1	-8332.5	-8367.6	-7841.7	-7874.8
144	-8819.3	-8831.7	-8417.1	-8429.0	-7936.4	-7947.6
145	-8868.2	-8854.9	-8478.9	-8466.2	-8009.8	-7997.8
146	-8892.7	-8852.9	-8518.0	-8479.9	-8062.5	-8026.4
147	-8890.6	-8824.6	-8531.7	-8468.3	-8091.2	-8031.1
148	-8862.0	-8770.6	-8519.9	-8431.9	-8095.8	-8012.2
149	618.4	618.9	595.6	596.1	567.0	567.5
150	619.1	619.6	596.5	597.0	568.2	568.6
151	619.9	620.3	597.5	597.9	569.4	569.8
152	620.6	621.1	598.4	598.8	570.5	570.9

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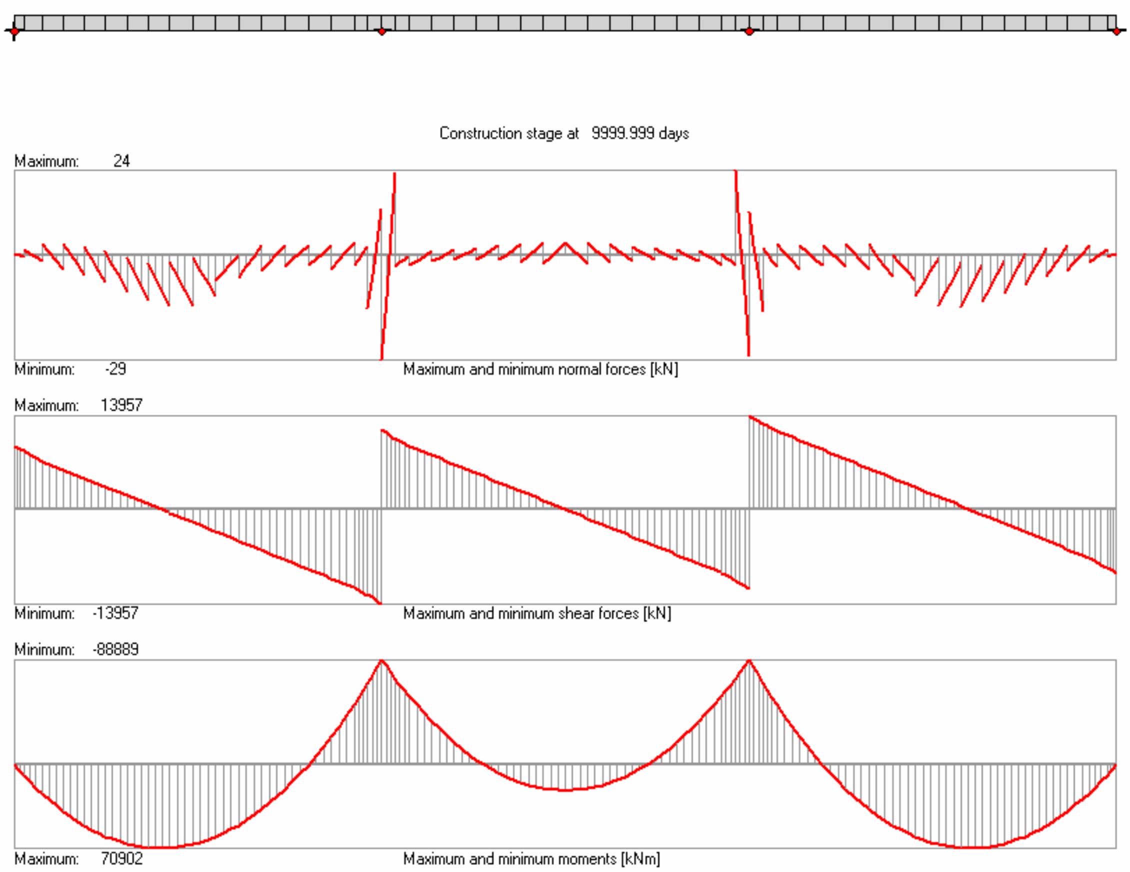
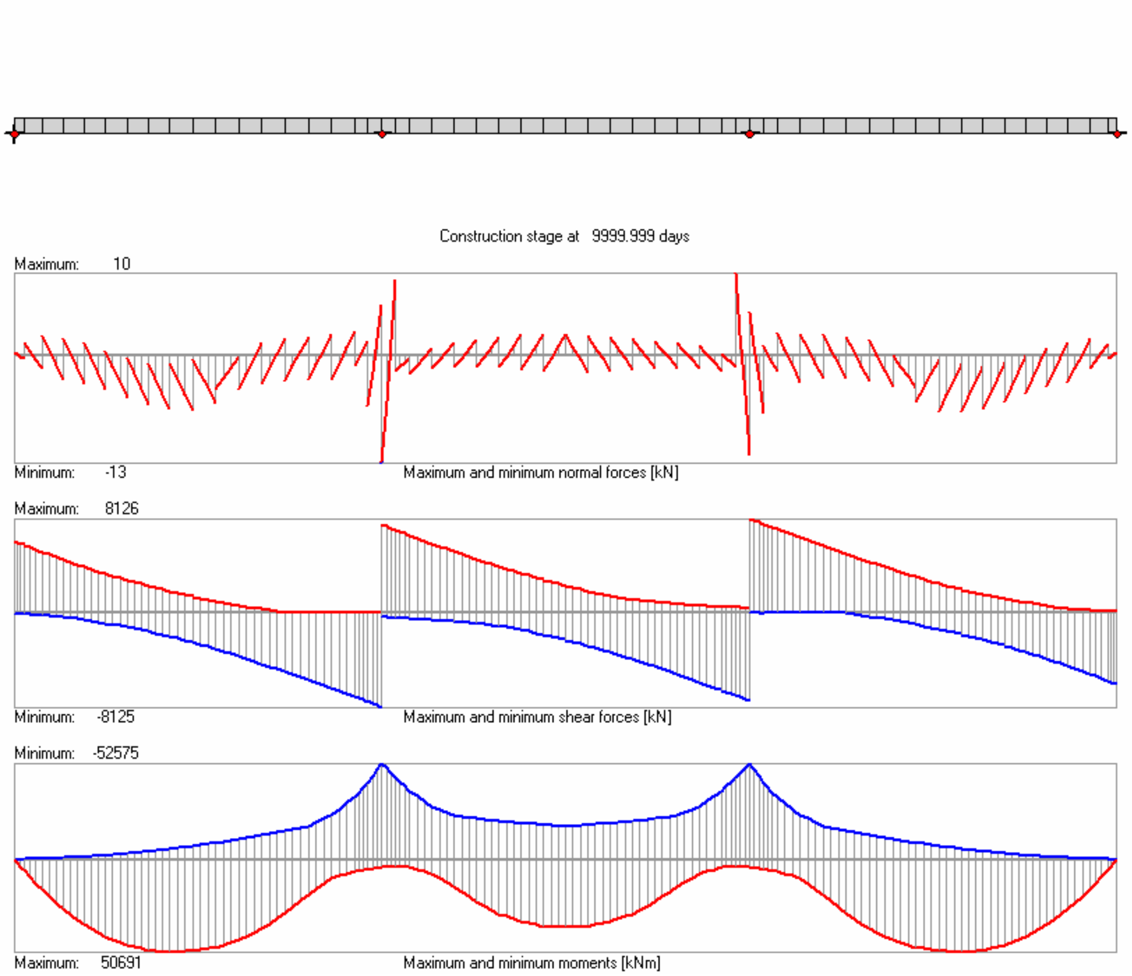
153	621.3	622.1	599.3	600.0	571.7	572.4
154	622.5	623.3	600.8	601.6	573.6	574.3
155	623.7	624.5	602.4	603.1	575.5	576.2
156	624.9	625.6	603.9	604.5	577.4	578.1
157	626.1	626.7	605.4	606.0	579.3	579.9
158	627.2	627.8	606.8	607.5	581.2	581.8
159	628.3	628.9	608.3	608.9	583.0	583.6
160	629.4	630.0	609.7	610.3	584.9	585.4
161	630.4	631.0	611.1	611.7	586.7	587.2
162	631.5	632.0	612.5	613.0	588.5	589.0
163	632.5	633.0	613.8	614.3	590.3	590.8
164	633.1	633.6	615.2	615.7	592.0	592.5
165	633.1	633.6	616.5	617.0	593.8	594.2
166	633.1	633.6	617.8	618.2	595.5	596.0
167	633.1	633.6	619.1	619.5	597.2	597.6
168	633.1	633.5	620.3	620.7	598.9	599.3
169	633.1	633.4	621.5	621.9	600.6	601.0
170	633.0	633.3	622.7	623.1	602.2	602.6
171	632.9	633.2	623.9	624.3	603.9	604.2
172	632.7	633.0	625.1	625.4	605.5	605.8
173	632.6	632.8	626.2	626.5	607.1	607.3
174	632.4	632.6	627.3	627.6	608.7	608.9
175	632.2	632.4	628.4	628.7	610.2	610.4
176	631.9	632.1	629.5	629.7	611.7	611.9
177	631.7	631.8	629.3	629.5	613.2	613.4
178	631.4	631.5	628.6	628.8	614.7	614.9
179	631.0	631.2	627.9	628.1	616.2	616.3
180	630.7	630.8	627.2	627.3	617.6	617.7
181	630.3	630.4	626.4	626.5	619.1	619.1
182	629.9	630.0	625.7	625.7	620.5	620.5
183	629.5	629.5	624.9	624.9	621.9	621.9
184	629.1	629.1	624.0	624.0	622.2	622.2
185	679.1	608.0	673.2	602.8	670.7	600.5
186	631.2	631.2	625.4	625.4	622.6	622.6
187	630.8	630.7	624.6	624.5	621.3	621.3
188	630.3	630.2	623.8	623.7	620.0	620.0
189	629.8	629.7	622.9	622.8	618.7	618.6
190	629.2	629.1	622.0	621.9	617.4	617.3
191	628.7	628.5	621.1	620.9	616.0	615.9
192	628.1	627.9	620.1	620.0	614.6	614.5
193	627.5	627.3	619.2	619.0	613.2	613.0
194	626.9	626.7	618.2	618.0	611.8	611.6
195	626.3	626.0	617.2	617.0	610.3	610.1
196	625.6	625.3	616.2	615.9	608.8	608.6
197	624.9	624.6	615.1	614.9	607.3	607.0
198	624.2	623.9	614.1	613.8	605.8	605.5
199	623.5	623.2	613.0	612.7	604.2	603.9
200	622.7	622.4	611.9	611.5	602.7	602.3
201	622.0	621.6	610.7	610.4	601.1	600.7
202	621.2	620.8	609.6	609.2	599.4	599.1
203	620.4	620.0	608.4	608.0	597.8	597.4
204	619.5	619.1	607.2	606.8	596.1	595.7
205	618.7	618.2	606.0	605.6	594.5	594.1
206	617.8	617.3	604.8	604.3	592.8	592.3
207	616.9	616.4	603.5	603.1	591.0	590.6
208	616.0	615.5	602.3	601.8	589.3	588.8
209	615.1	614.6	601.0	600.5	587.5	587.1
210	614.2	613.8	599.8	599.4	586.0	585.6
211	613.4	612.9	598.7	598.2	584.5	584.0
212	612.6	612.1	597.5	597.1	582.9	582.4
213	0	0	0	0	0	0
214	0	0	0	0	0	0
215	0	0	0	0	0	0
216	0	0	0	0	0	0

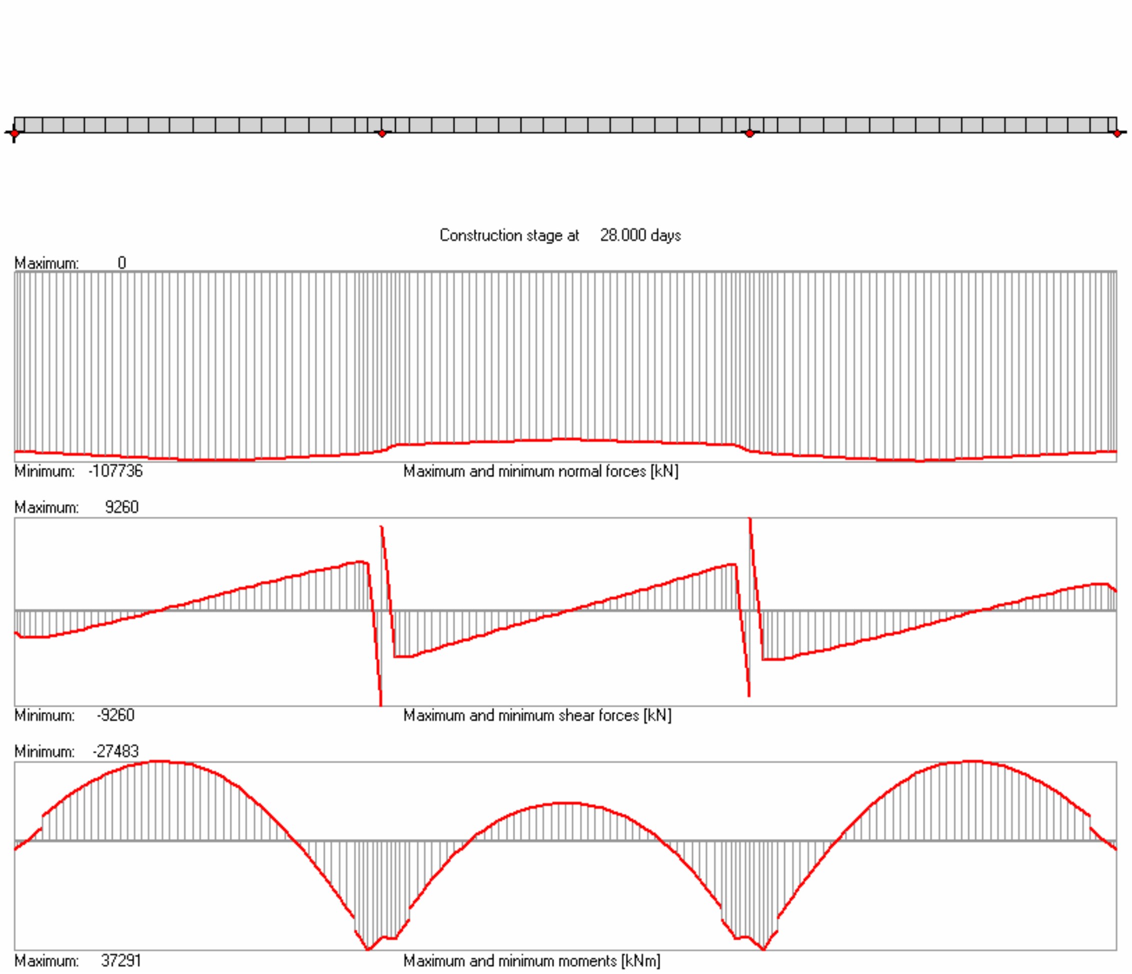
Combination	Types of the load	Factors	Days
1	- Dead Loads	1.2	∞

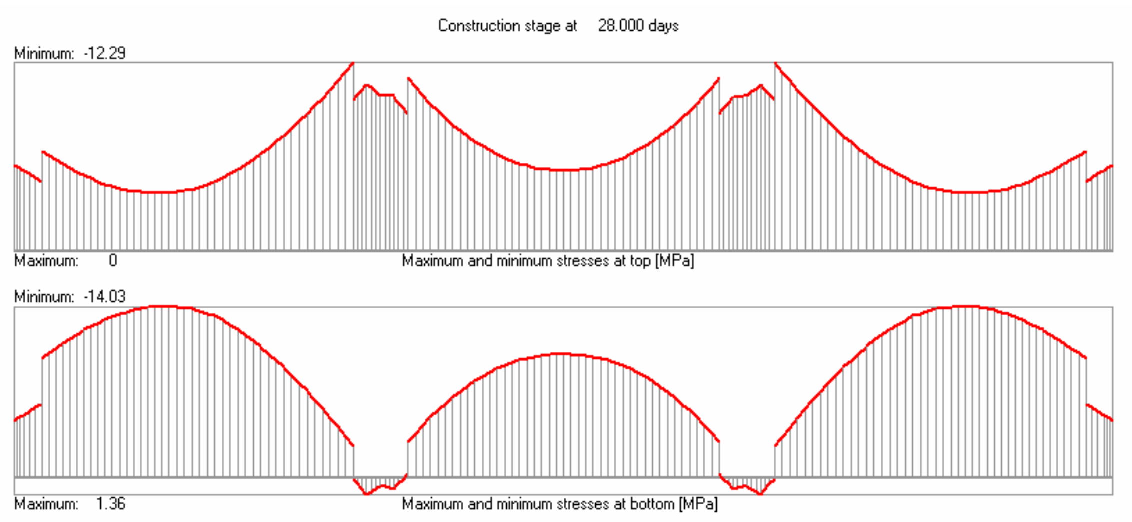


Combination	Types of the load	Factors	Days
2	- Mobile Loads	1.5	∞

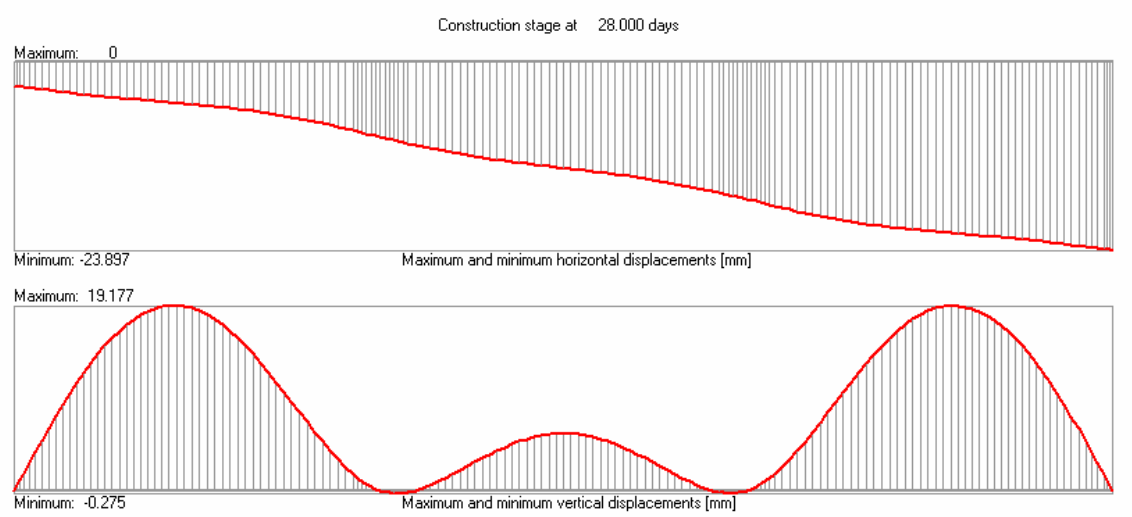


Combination	Types of the load	Factors	Days
3	- Self weight of the structure - Prestressing (with direct losses)	1.2 1.0	28



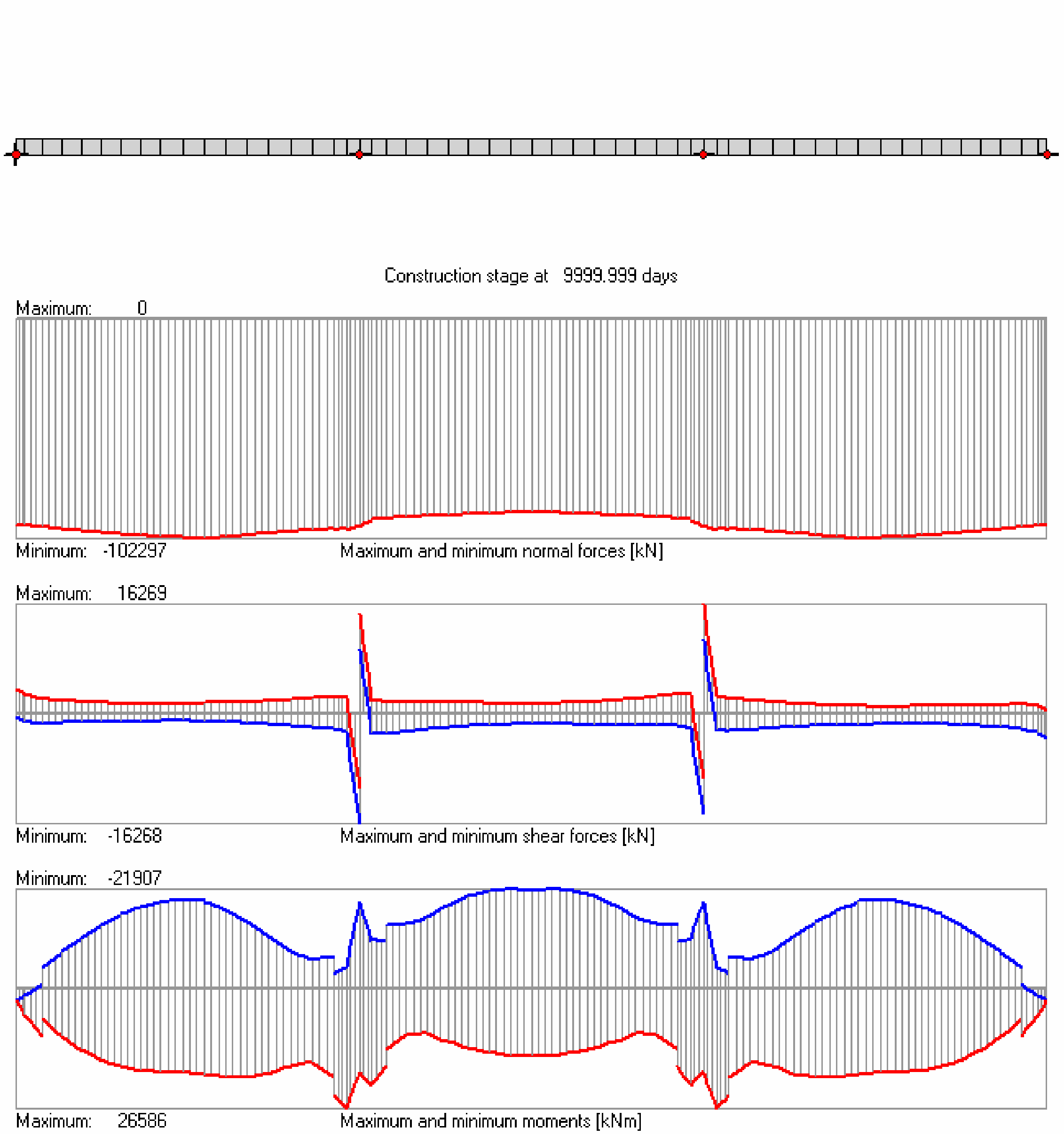


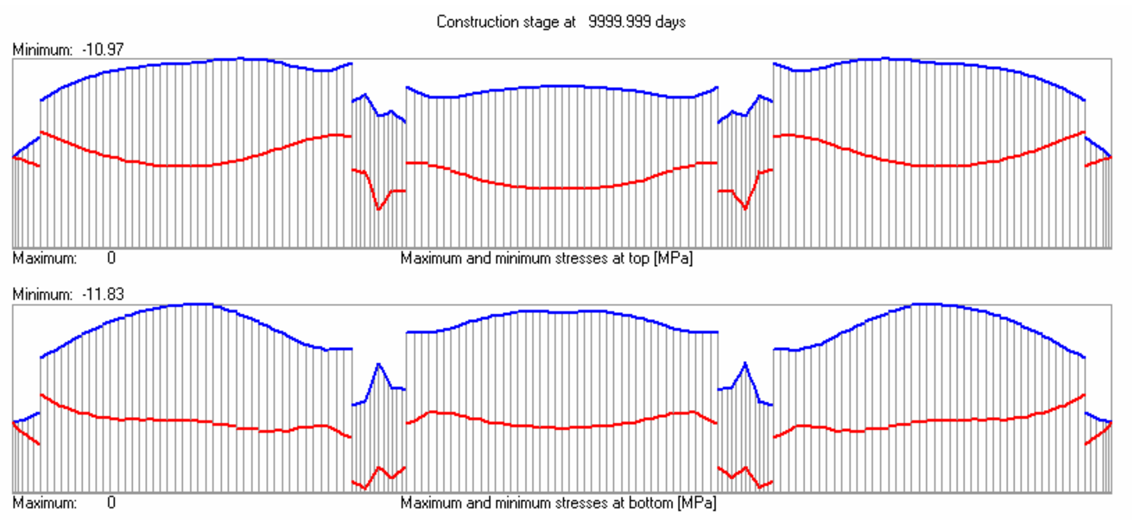
Construction stage at 28.000 days
Minimum: -12.29
Maximum: 0
Maximum and minimum stresses at top [MPa]
Minimum: -14.03
Maximum: 1.36
Maximum and minimum stresses at bottom [MPa]

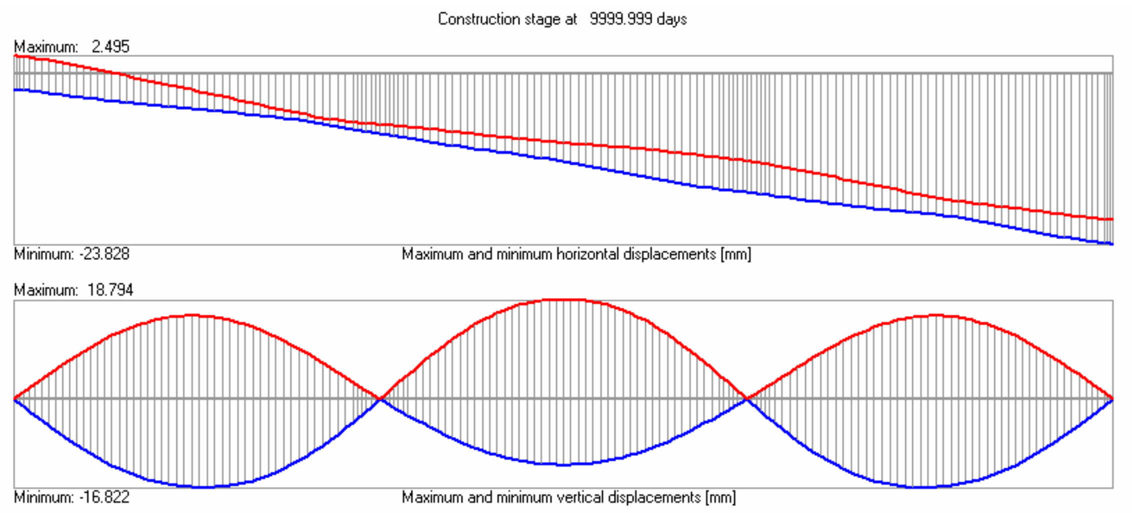


Construction stage at 28.000 days
Maximum: 0
Minimum: -23.897
Maximum and minimum horizontal displacements [mm]
Maximum: 19.177
Minimum: -0.275
Maximum and minimum vertical displacements [mm]

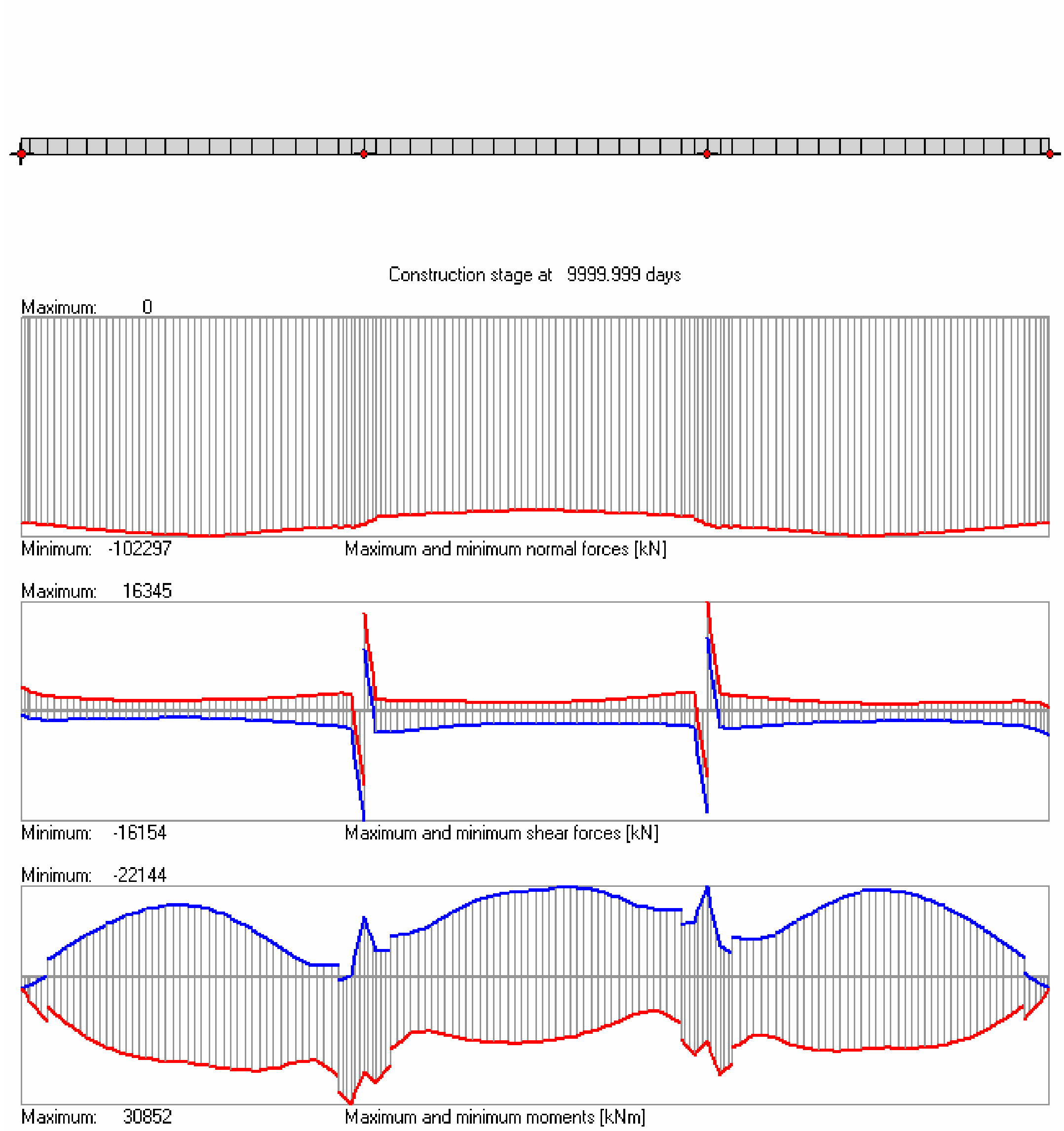
Combination	Types of the load	Factors	Days
8 (SLS ∞)	- Self weight of the structure - Permanent loads (cables, railway structure, piping) - Prestressing (with direct losses+ time dependent losses) - Mobile loads (Trains)	1.0 1.0 1.0 1.0	∞

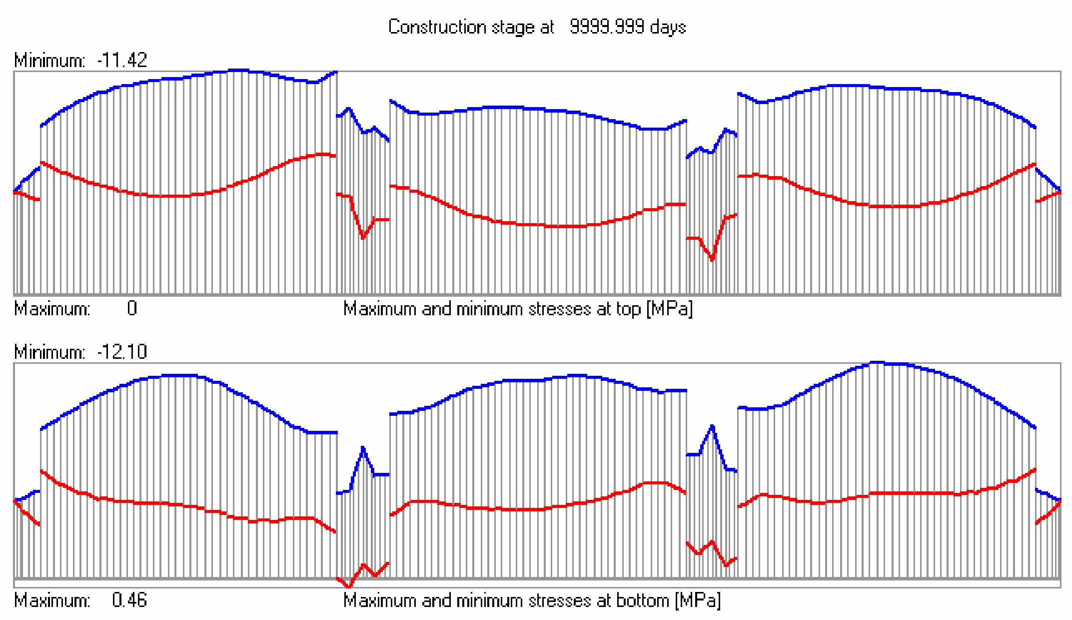


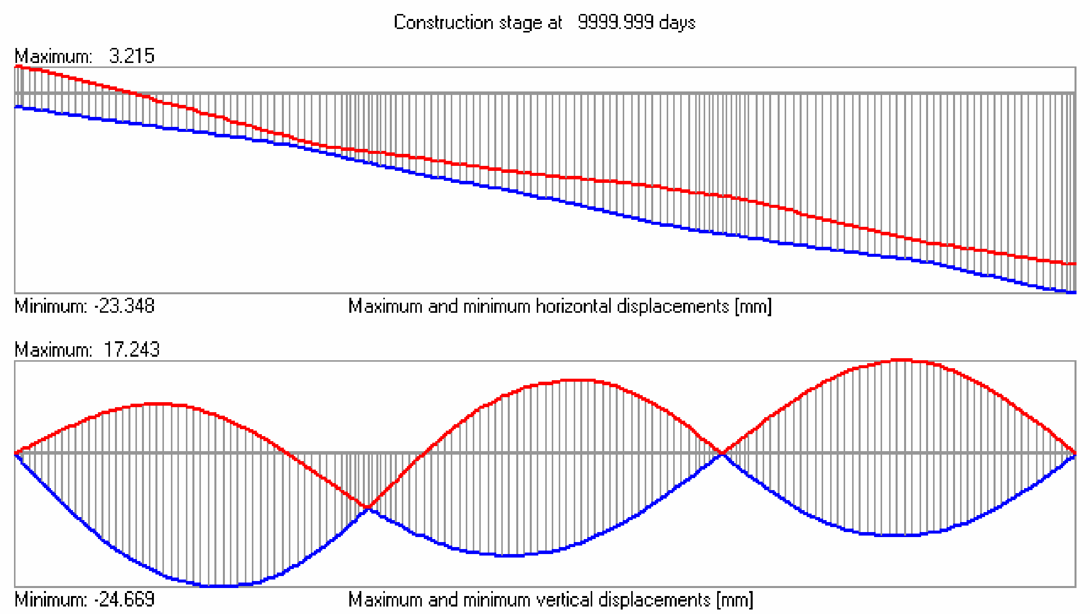

Construction stage at 9999.999 days
Minimum: -10.97
Maximum: 0
Maximum and minimum stresses at top [MPa]
Minimum: -11.83
Maximum: 0
Maximum and minimum stresses at bottom [MPa]


Construction stage at 9999.999 days
Maximum: 2.495
Minimum: -23.828
Maximum and minimum horizontal displacements [mm]
Maximum: 18.794
Minimum: -16.822
Maximum and minimum vertical displacements [mm]

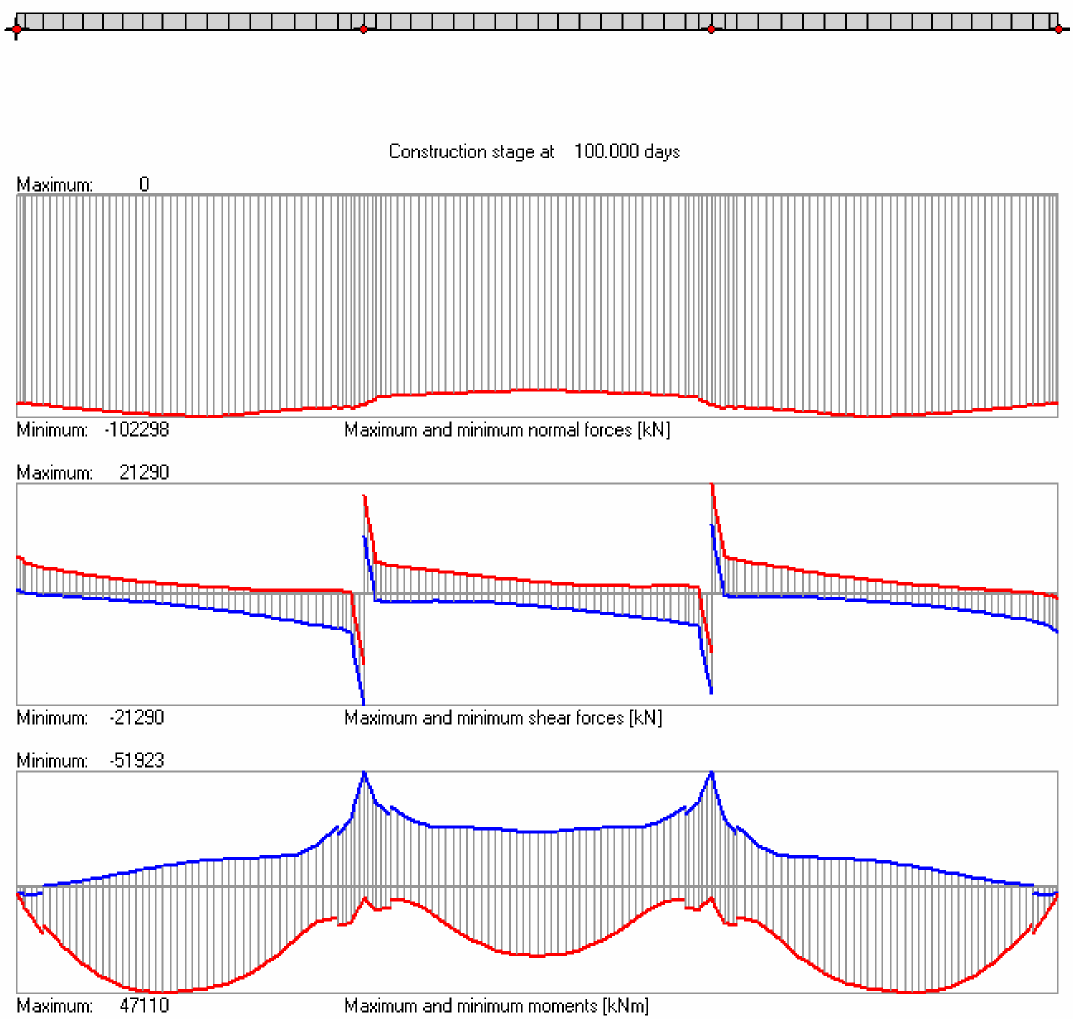
Combination	Types of the load	Factors	Days
9 (SLS ∞)	- Self weight of the structure - Permanent loads (cables, railway structure, piping) - Prestressing (with direct losses+ time dependent losses) - Mobile loads - Settlement (10 mm at the second support)	1.0 1.0 1.0 1.0 1.0	∞

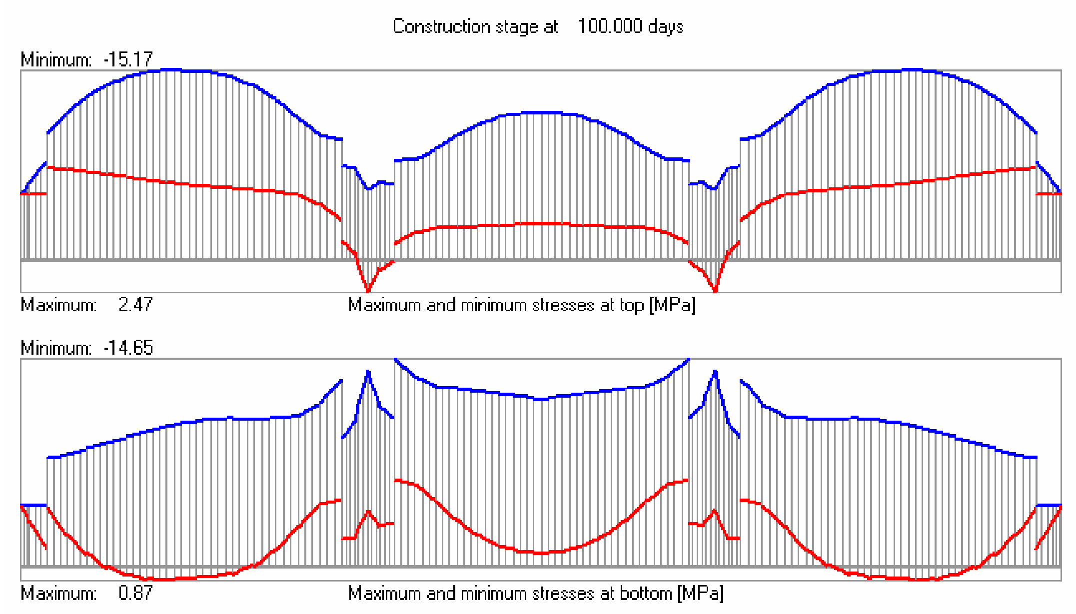



Construction stage at 9999.999 days
Minimum: -11.42
Maximum: 0
Maximum and minimum stresses at top [MPa]
Minimum: -12.10
Maximum: 0.46
Maximum and minimum stresses at bottom [MPa]


Construction stage at 9999.999 days
Maximum: 3.215
Minimum: -23.348
Maximum and minimum horizontal displacements [mm]
Maximum: 17.243
Minimum: -24.669
Maximum and minimum vertical displacements [mm]

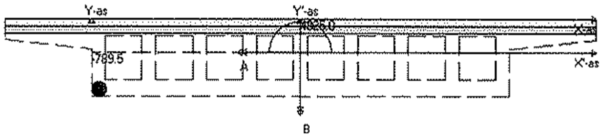
Combination	Types of the load	Factors	Days
5 (ULS ∞)	- Self weight of the structure - Permanent loads (cables, railway structure, piping) - Prestressing (with direct losses + time dependent losses) - Mobile loads	1.2 1.2 1.0 1.5	∞




Construction stage at 100.000 days
Minimum: -15.17
Maximum: 2.47
Maximum and minimum stresses at top [MPa]
Minimum: -14.65
Maximum: 0.87
Maximum and minimum stresses at bottom [MPa]

ANNEX 4
DEBT VERIFICATION

Ultimate Limit States
Alternative of A Double Track Railway Bridge
designed by Suwanda



Toegepast Voorschrift VBC 1995.

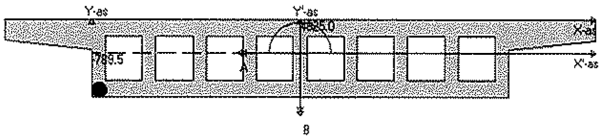
TOETSING UITERSTE GRENSTOESTAND (Drsn. balk: 8 rechts)

Toetsingen uitgevoerd waarbij met voorspanning met gemiddelde wrijving is rekening gehouden.

Situatie met gegeven verlies van voorspanning
Belastinggeval: ULS ~
Positie assenstelsel: Y = -789.49

Belastinggegevens	N[kN]	M(A)[kNm]
Permanent:	-100221.7	-14066.6
Verschil:	-1168.6	61151.1
	---------	---------
Belasting:	-101390.3	47084.6

VBC 8.1.1: Bezwijkmoment
»OK«, doorsnede op betonstuk bezweken.
Md 47084.6 [kNm]   Mu 116190.4 [kNm]
VBC 8.1.3: Hoogte betondrukzone
»OK«, hoogte betondrukzone voldoet.
Geen drukwapening
Mu = 116190.4 [kNm]
B = 0   f. = 496.6 [MPa]
xu = 335.5 [mm]   d = 1616.3 [mm]
xu/d = 0.208   kxmax = 0.502
VBC 9.9.2.1: Scheurmoment
»OK«, scheurmoment is kleiner dan bezwijkmoment.
Mu = 116190.4 [kNm]   Mr = 79554.2 [kNm]   1.25 Md = 58855.7 [kNm]



Toegepast Voorschrift VBC 1995.

TOETSING GEBRUIKSTOESTAND/SCHEURVORMING (Drsn. balk: 8 rechts)

Spanningsincrementen van voorspanstaal worden berekend vanaf het 0 vlak.
De gemiddelde betonspanning wordt berekend volgens de VBC.
Toetsing uitgevoerd voor voorspanning met gemiddelde wrijving.

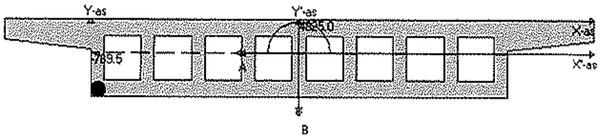
Situatie met gegeven verlies van voorspanning
Belastinggeval: SLS~
Positie assenstelsel: Y = -789.49

Belastinggegevens	N[kN]	M(A)[kNm]
Permanent:	-100221.7	-14066.6
Verschil:	-1165.6	32622.0
	---------	---------
Belasting:	-101387.4	18555.4

```
Toetsingscriteria:
   Sigb =  -4.86 =<    4.21 = fbm  [MPa]
   Advies: Onvolledig scheurenpatroon VBC 8.7.3
   As =          0  [mm2] ;  Ap =         0  [mm2]
   ka =          0 <  0.5
   Advies: Geen toetsing met betonspanningen

VBC 8.7.2:  Volledig ontwikkeld scheurenpatroon
  Gekozen voorspanning: Diameter = 326.5 mm   X = 168.0 mm   Y =      -1616.3 mm
VBC 8.7.3:  Onvolledig ontwikkeld scheurenpatroon
  Bij het bepalen van ssr is alleen Ma gevarieerd.
  Gekozen voorspanning: Diameter = 326.5 mm   X = 168.0 mm   Y =      -1616.3 mm
  »FOUT«, kenmiddellijn te groot
  k1     =  1250         k3    = 20000        kc =   1.000       ksi=   0.500
  h      = 1.800 m       kr    = 0.500        ssr=   18.19 MPa   ss =        0 MPa
  Ø_km   =326.45 mm      Ø_lim =  50.0  mm    eis:   Ø_km < Ø_lim
VBC 8.7.4a: Ongescheurd veronderstelde doorsnede met scheurbeperkende wapening
  »OK« maximale betonspanning voldoet
  k4    =    0.6         k5    =   0.3        ksi=   0.500       h  =  1800.0 mm
  ssbm  =   8.11 MPa     ep    = -40.5 mm     ho =   970.0 mm    zp =  1010.5 mm
  dssbm =      0 MPa     ka    =     0        ke =   0.890       fbm=    4.21 MPa
  ss_op = -4.86 MPa      ss_lim=  7.69 MPa    eis:     ss_op < ss_lim
VBC 8.7.4b: Ongescheurd veronderstelde doorsnede zonder scheurbeperkende wapening
  »OK« maximale betonspanning voldoet
  k6    =      0         k7    =   0.2        fbm =  4.21 MPa
  ssbm  =   8.11 MPa     dssbm =      0 MPa
  ss_op = -4.86 MPa      ss_lim=  1.62 MPa    eis:     ss_op < ss_lim
```

The Fatigue Verification
Alternative of A Double Track Railway Bridge
designed by Suwanda



TOETSING VERMOEIING, TOETS VBB 8.6.2 (Drsn. balk: 8 rechts)

Toetsing uitgevoerd voor voorspanning met gemiddelde wrijving.

Situatie met gegeven verlies van voorspanning
Belastinggeval: SLS~
Positie assenstelsel: Y = -789.49

Belastinggegevens	N[kN]	M(A)[kNm]
Permanent:	-100221.7	-14066.6
Verschil:	-1161.9	-5118.0
	---------	---------
Belasting A:	-101383.6	-19184.6
Permanent:	-100221.7	-14066.6
Verschil:	-1165.6	32622.0
	---------	---------
Belasting B:	-101387.4	18555.4

Doorsnede gescheurd verondersteld.

VBB 8.6.6.2.b (meest getrokken betonvezel, n=1.000e+08)
Toetsing niet uigevoerd, beton is gescheurd.
TOETS VBB 8.6.6.2.a (meest gedrukte betonvezel, n=1.000e+08)
»OK« meest gedrukte betonvezel voldoet

beta =	1.0 MPa	R =	0.398 MPa
ss_bdmin =	4.88 MPa	f_bdv =	33.6 MPa
ss_bdmax =	12.25 MPa	f_bduv =	12.77 MPa

TOETS VBB 8.6.3 (meest getrokken voorspanelement, n=1.000e+08)
»OK« meest getrokken voorspanelement voldoet

m =	4.0 MPa	jj_m =	1.1
dss_prep =	95.0 MPa	dss_pnrep =	53.4 MPa
ss_pdmin =	1205.9 MPa		
ss_pdmax =	1231.9 MPa	ss_pu =	1254.4 MPa

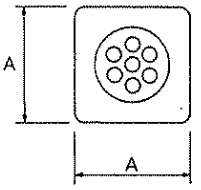
ANNEX 5
PRESTRESSING CABLE PROPERTIES

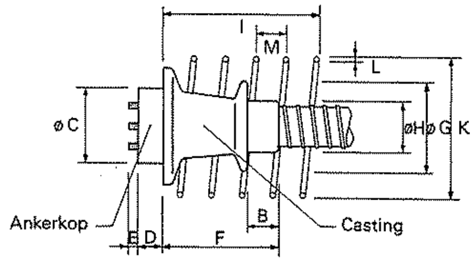
Spanverankeringen

Zie ook opmerkingen op blz. III

Type Ec

Betonklasse:*
- f'ckj ≥ 30 N/mm^2 (B 37.5)
- f'ckj ≥ 36 N/mm^2 (B 45)





Afmeting Verankering

Type Ec	5-4	5-7	5-12	5-19	5-22	5-31	5-37	5-42	6-4	6-7	6-12	6-19	6-31	6-37
A	135	165	215	270	290	340	370	395	150	190	250	310	390	430
B	50	55	55	55	60	65	75	75	60	55	60	65	70	80
C	95	110	150	180	190	230	240	260	110	135	170	200	260	270
D	50	55	60	75	85	95	105	110	55	60	75	95	120	135
E	30	30	30	30	30	30	30	30	30	30	30	30	30	30
F	125	155	215	285	335	365	360	380	155	170	245	305	350	450
G	100	125	160	200	220	255	275	295	115	145	190	235	295	320
H	65	77	96	115	120	135	155	165	77	96	115	135	165	175

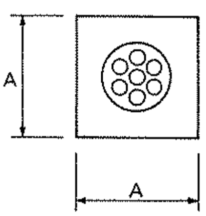
Afmeting Wapening (FeB 400**) per Betonklasse

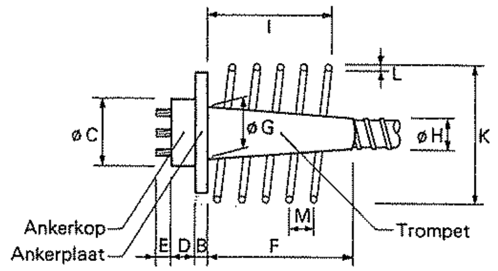
		5-4	5-7	5-12	5-19	5-22	5-31	5-37	5-42	6-4	6-7	6-12	6-19	6-31	6-37
• Betonklasse B 37.5 (f'ckj ≥ 30 N/mm^2)															
a) Spiraal-wapening 	I	145	210	285	345	380	440	475	540	210	260	345	440	540	605
	K	160	200	270	350	370	440	480	510	200	250	330	400	510	550
	L	10	12	14	16	20	20	22	22	12	14	16	20	22	22
	M	45	50	55	55	60	60	65	65	50	50	55	60	65	65
b) Orthogonaal-wapening 	I	145	210	285	345	380	440	475	540	210	260	345	440	540	605
	K	160	200	270	350	370	440	480	510	200	260	330	420	540	600
	L	10	12	14	16	20	20	22	22	12	14	16	20	22	22
	M	45	50	55	55	60	60	65	65	50	50	55	60	65	65
• Betonklasse B 45 (f'ckj ≥ 36 N/mm^2)															
a) Spiraal-wapening	I	145	210	285	345	380	440	475	540	210	260	345	440	540	605
	K	160	200	270	350	370	440	480	510	200	250	330	400	510	550
	L	10	12	14	16	18	20	22	22	12	14	16	18	22	22
	M	45	50	55	55	60	60	65	65	50	50	55	60	65	65
b) Orthogonaal-wapening	I	145	210	285	345	380	440	475	540	210	260	345	440	540	605
	K	140	170	230	290	320	370	410	440	160	210	275	345	440	490
	L	10	12	14	16	20	20	22	22	12	14	16	20	22	22
	M	45	50	55	55	60	60	65	65	50	50	55	60	65	65

* De Ec - verankering kan, buiten komo-attest, toegepast worden voor betonklasse B 30 (f'ckj ≥ 24 N/mm^2).
** De spiraal - of orthogonaal-wapening kan uitgevoerd worden in staalkwaliteit FeB 220, mits de totale breukkracht gehandhaafd blijft.

Type E

Betonklasse:
- f'ckj ≥ 20 N/mm^2 (B 30)
- f'ckj ≥ 28 N/mm^2 (B 37.5)
- f'ckj ≥ 36 N/mm^2 (B 45)





Afmetingen Ankerkop en Trompet

Type E	5-1	5-3	5-4	5-7	5-12	5-16	5-19	5-22	5-31	5-37	5-42	5-55
C	42	90	95	110	150	180	180	190	230	240	260	290
D	45	50	50	55	60	75	75	85	95	105	110	130
E	30	30	30	30	30	30	30	30	30	30	30	30
F	70	190	190	190	240	400	400	480	550	490	540	680
G	15	50	55	74	104	135	135	150	172	188	201	230
H	30	48	53	60	75	85	90	95	110	130	140	153

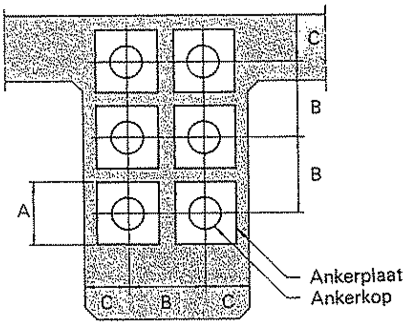
Type E	6-1	6-2	6-3	6-4	6-7	6-12	6-19	6-31	6-37	6-42	6-55
C	53	90	95	110	135	170	200	260	270	290	320
D	50	50	50	55	60	75	95	120	135	145	160
E	30	30	30	30	30	30	30	30	30	30	30
F	70	190	190	190	190	370	530	690	830	890	950
G	18	50	56	65	84	118	150	192	215	232	255
H	35	48	54	53	70	90	110	140	153	163	183

Technische Gegevens

Konstruktie details

Plaatsing van de verankeringen
Minimale afstanden, Supporten voor de kabels

Plaatsing van de verankeringen



Betonklasse: B 30 ⟶ f'ck = 30.0 N/mm²
B 37.5 ⟶ f'ck = 37.5 N/mm²
B 45 ⟶ f'ck = 45.0 N/mm²

B: h.o.h. afstand van de verankering
C: randafstand
Maten in mm.

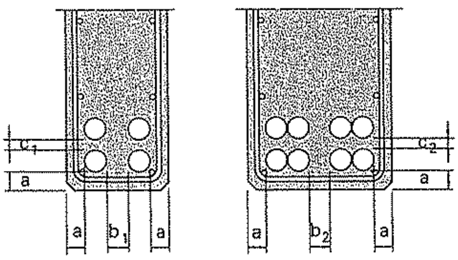
Ankertype Ec			5-4	5-7	5-12	5-19	5-22	5-31	5-37	5-42
B 37.5	Spiraal	B	180	230	300	380	420	490	530	565
		C	110	155	190	230	250	315	335	355
	Orthogonale wapening	B	180	230	300	380	420	490	530	565
		C	110	155	190	230	250	315	335	355
B 45	Spiraal	B	180	220	290	370	390	460	500	530
		C	110	150	185	225	235	300	320	335
	Orthogonale wapening	B	160	200	260	330	360	420	460	500
		C	100	140	170	205	220	280	300	320

Ankertype Ec			6-4	6-7	6-12	6-19	6-31	6-37
B 37.5	Spiraal	B	220	290	370	470	600	660
		C	130	185	225	305	370	400
	Orthogonale wapening	B	220	290	370	470	600	660
		C	130	185	225	305	370	400
B 45	Spiraal	B	220	270	350	420	530	570
		C	130	175	215	280	335	355
	Orthogonale wapening	B	180	240	315	395	500	550
		C	110	160	200	270	320	345

Ankertype E		5-1	5-3	5-4	5-7	5-12	5-16	5-19	5-22	5-31	5-37	5-42	5-55
B 30	B	110	190	220	290	380	440	480	515	610	670	710	815
	C	75	115	130	185	230	260	280	300	375	405	425	480
B 37.5	B	100	165	190	250	330	380	415	450	530	580	620	710
	C	70	105	115	165	205	230	250	265	335	360	380	425
B 45	B	90	150	175	230	300	350	380	410	485	530	565	650
	C	65	95	110	155	190	215	230	245	315	335	355	395

Ankertype E		6-1	6-2	6-3	6-4	6-7	6-12	6-19	6-31	6-37	6-42	6-55
B 30	B	135	190	235	270	355	465	585	750	820	870	1000
	C	90	115	140	155	220	275	365	445	480	505	570
B 37.5	B	120	165	205	235	310	405	510	650	710	760	870
	C	80	105	125	140	195	245	325	395	425	450	505
B 45	B	110	150	185	215	285	370	465	600	650	695	795
	C	75	95	115	130	185	225	305	370	395	420	470

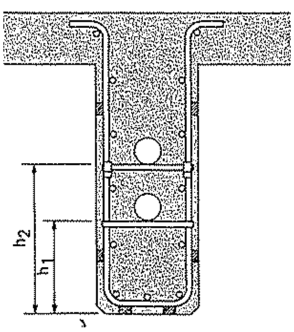
Minimale afstanden



Minimale afstanden in mm bij grindbeton

		milieu	droog	vochtig	agressief
NEN 3880	a	vloer	25	35	40
		wand	25	35	40
		balk	35	40	45
		kolom	40	45	50
NEN 3866	$b_1 = b_2$ $c_1 = c_2$	ø trilnaald ≥ 0.5 ø uitw. omhulling ≥ nominal korrel van het toeslagmaterial ≥ 25			

Supporten voor de kabels



Supportafstanden in m (afhankelijk van ø omhulling)

- geprefabriceerde kabels 0,80 - 1,20 m
- kabels waarbij de strengen voor of na het betonneren in de omhulling gebracht worden 0,80 - 1,20 m

Om een eenvoudige en preciese plaatsing van de kabel-ondersteuningen te bewerkstelligen, moet men het kabelverloop op de tekening vanaf de bovenkant van de vloerbekisting aangeven.

Technische Gegevens
Kenmerken van de voorspankabels
13 mm (0.5") strengen

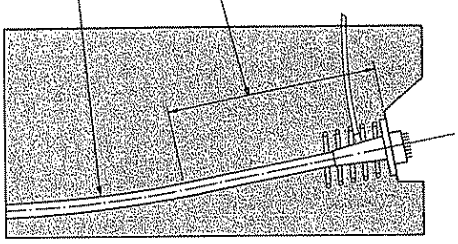
Eenheid	Strengen	Omhulling		Excentriciteit (mm)**		Karakteristieke Breukkracht		Vijzeltype***
		minimum* Ø (mm)	normaal Ø (mm)	Omhulling minimum	Omhulling normaal	normaal (kN)	super (kN)	
5–1	1	20/25	25/30	3	6	173	186	ZPE-30
	2	35/40	40/45	8	11	346	372	ZPE-60
5–3	3	35/40	40/45	6	9	519	558	
5–4	4	40/45	45/50	7	10	692	744	
	5	45/50	50/55	8	11	865	930	ZPE-7 A
	6	45/50	50/55	6	9	1038	1116	
5–7	7	50/55	55/60	7	10	1211	1302	
	8	55/60	60/67	9	12	1384	1488	ZPE-12/St 2
	9	55/60	60/67	8	11	1557	1674	
	10	60/67	65/72	10	13	1730	1860	
	11	60/67	65/72	9	12	1903	2046	
5–12	12	60/67	65/72	8	11	2076	2232	
	13	65/72	70/77	9	12	2249	2418	ZPE-19
	14	65/72	70/77	8	11	2422	2604	
	15	70/77	75/82	9	12	2595	2790	
	16	70/77	75/82	9	12	2768	2976	
	17	75/82	80/87	11	14	2991	3162	
	18	75/82	80/87	10	13	3114	3348	
5–19	19	75/82	80/87	9	12	3287	3534	
	20	80/87	85/92	10	13	3460	3720	ZPE-460/31 ZPE-500
	21	80/87	85/92	9	12	3633	3906	
5–22	22	80/87	85/92	8	11	3806	4092	
	23	85/92	90/97	12	15	3979	4278	
	24	85/92	90/97	11	14	4152	4464	
	25	90/97	95/102	14	17	4325	4650	
	26	90/97	95/102	13	16	4498	4836	
	27	95/102	100/107	15	18	4671	5022	
	28	95/102	100/107	14	17	4843	5208	
	29	95/102	100/107	13	16	5076	5394	
	30	95/102	100/107	12	15	5189	5580	
5–31	31	95/102	100/107	11	14	5362	5766	
5–37	37	110/117	120/127	16	22	6400	6882	ZPE-1000 ZPE-1250
5–42	42	120/127	130/137	19	25	7265	7812	
5–55	55	130/137	140/150	17	23	9514	10230	

* Voor korte kabels.
** Afstand tussen de zwaartepunten van de strengenbundel en van de omhulling.
*** Bij het spannen tot max. 82,5% van de breukkracht van de kabel.

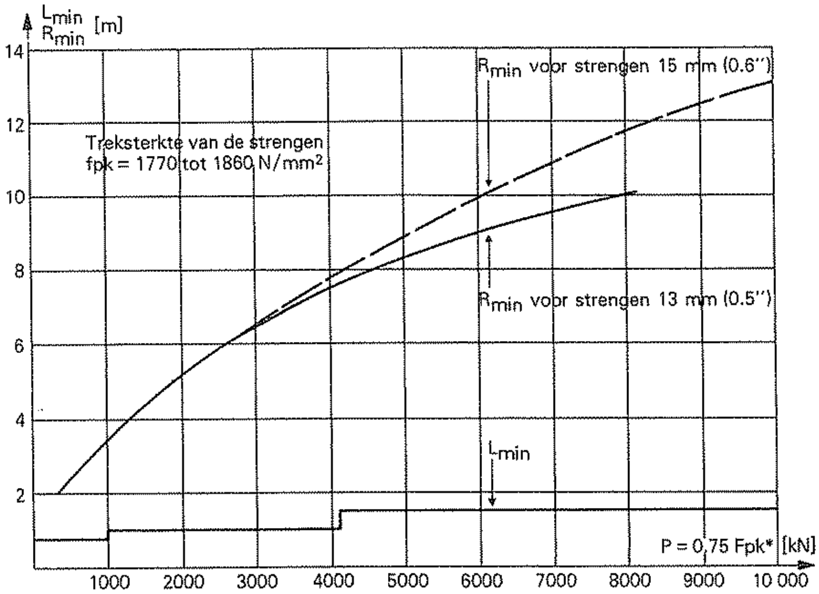
Streng	normaal	super	Dimensie
Diameter	12.5	12.9	mm
Opp. v/d doorsnede	93	100	mm²
Gewicht	0.73	0.79	kg
0,1 – rekgrens	1620	1620	N/mm²
Kar. treksterkte	1860	1860	N/mm²

Volgens NEN 3868

Minimale kromtestraal van de kabels

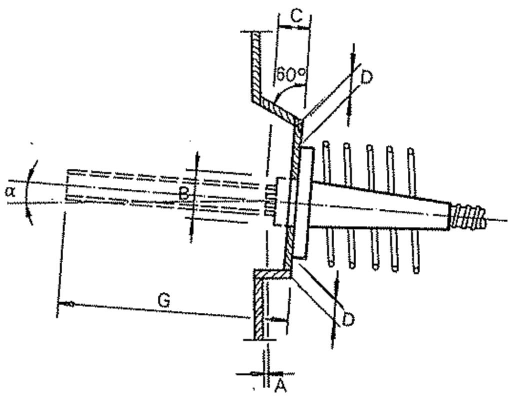


De, in nevenstaand diagram, aangegeven kromtestralen kunnen gereduceerd worden, mits de plaatselijke betonsterkte en de door de kromming veroorzaakte extra staalspanningen gekontroleerd worden.



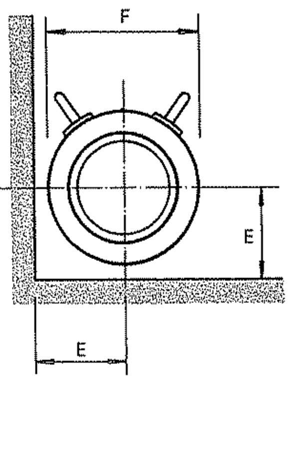
*F_{pk} = karakteristieke breukkracht van de kabel

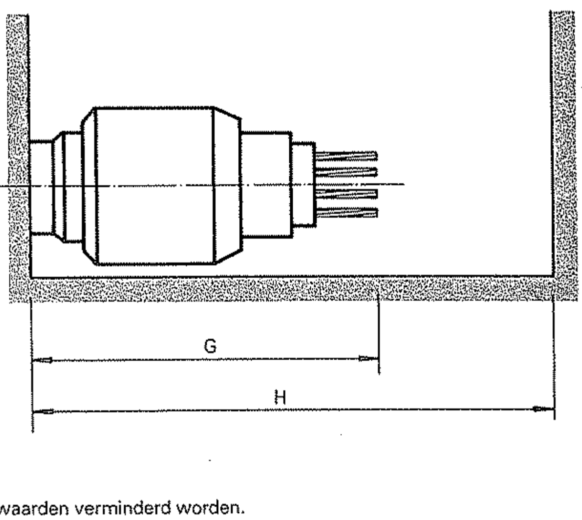
Sparingen en benodigde ruimte voor de vijzels



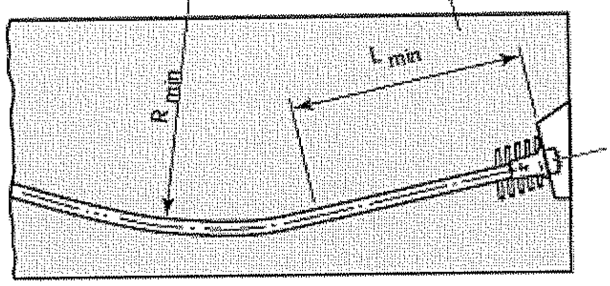
Vijzeltype	Dmin	E	F	G	H
ZPE-20FJ	–	90	112	300	1200
ZPE-30	30	100	140	600	1100
ZPE-60	30	140	180	650	1100
ZPE-7A	30	200	280	650	1200
ZPE-12/St 2	50	200	310	670	1300
ZPE-19	50	250	390	850	1500
ZPE-460/31	60	300	485	700	1500
ZPE-500	80	330	550	1150	2000
ZPE-1000	80	450	790	1300	2200
ZPE-1250	90	375	620	1350	2250
ZPE-1400	100	500	850	1500	2400

A: betondekking volgens NEN 3880, min. 25 mm
B en C zijn in de tabellen van bladzijde I en II te vinden.





Opmerking: voor speciale gevallen kunnen de bovengenoemde waarden verminderd worden.



Tendon Unit	R min. ft.	R min. m	L min. ft.	L min. m
5-7	9.8	3.0	2.6	0.8
5-12	13.5	4.1	3.3	1.0
5-19	17.7	5.4	3.3	1.0
5-27	21.0	6.4	3.3	1.0
5-31	22.3	6.8	4.9	1.5
5-37	24.0	7.3	4.9	1.5
5-43	25.9	7.9	4.9	1.5
5-55	29.5	9.0	4.9	1.5

Tendon Unit	R min. ft.	R min. m	L min. ft.	L min. m
6-7	12.8	3.9	3.3	1.0
6-12	16.4	5.0	3.3	1.0
6-19	20.7	6.3	4.9	1.5
6-22	22.6	6.9	4.9	1.5
6-31	26.4	8.1	4.9	1.5
6-37	28.2	8.6	4.9	1.5
6-43	30.8	9.4	4.9	1.5
6-55	34.8	10.6	4.9	1.5

Minimum Radius of the Tendons (Source: VSL)

HOGESCHOOL UTRECHT

ANNEX 6
REGULATION
NEN-6720-VBC 1995

Grontmij

Tabel 4 – Waarden van de factor k_c als functie van de relatieve vochtigheid

RV %	k_c
0 – 60 (droge lucht)	2,6
60 – 85 (buitenlucht)	1,9
85 – 100 (zeer vochtig)	1,4
100 (in water)	1,0

Tabel 5 – Waarden van de factor k_d als functie van de ouderdom bij belasten en de sterkteklasse van het cement

t_c	k_d	
dagen	sterkteklassen 32,5 en 32,5 R	sterkteklassen 42,5 en 42,5 R, 52,5 en 52,5 R
1	1,8	1,7
3	1,6	1,4
7	1,4	1,1
14	1,2	0,9
28	1,0	0,7
90	0,8	0,5
≥ 365	0,5	0,3

Tabel 6 – Waarden van de factor k_b als functie van f'_{ck}

f'_{ck} N/mm^2	k_b
15	1,4
25	1,2
35	1,0
45	0,9
55	0,8
65	0,7

Tabel 7 – Waarden van de factor k_h als functie van de fictieve dikte

h_m mm	k_h
50	1,20
100	1,00
200	0,85
300	0,75
≥ 500	0,70

Tabel 8 – Maximaal aan te houden waarden van de kruipcoëfficiënt ϕ_{max}

f'_{ck} N/mm^2	RV < 60 % (in droge lucht)	60 % ≤ RV < 85 % (in buitenlucht)	85 % ≤ RV < 100 % (zeer vochtig)	RV = 100 % (in water)
15	4,2	3,1	2,3	1,7
25	3,6	2,7	2,0	1,4
35	3,2	2,4	1,8	1,2
45	2,8	2,1	1,5	1,1
55	2,4	1,8	1,3	0,9
65	2,2	1,6	1,2	0,8

6.1.6 *Krimpverkorting*

De representatieve waarde en de rekenwaarde van de specifieke krimpverkorting ε'_r moeten worden bepaald uit:

$$\varepsilon'_r = \varepsilon'_c k_b k_h k_p k_t \not> \varepsilon'_{max}$$

waarin:

ε'_c is de basiskrimp, zoals aangegeven in tabel 9;
k_b is de factor, afhankelijk van f'_{ck}, zoals aangegeven in tabel 6;
k_h is de factor, afhankelijk van de fictieve dikte h_m van de betondoorsnede, zoals aangegeven in tabel 10;
k_p is de factor, afhankelijk van het wapeningspercentage, waarvan de waarde volgt uit:

$$k_p = \frac{1}{1 + 0,2\ \bar{\omega}_o}$$

$\bar{\omega}_o$ is het laagste wapeningspercentage van de totale in de doorsnede voorkomende langswapening betrokken op de totale hoogte van de doorsnede;
k_t is de factor, afhankelijk van de ouderdom t van het beton, waarvan de waarde volgt uit:

$$k_t = \frac{t}{t + 0,04\ \sqrt{h_m^3}}$$

t is de getalwaarde van de ouderdom van het beton in dagen;
h_m is de getalwaarde van de fictieve dikte h_m van de betondoorsnede volgens 6.1.5, in mm;
ε'_{rmax} is de maximaal aan te houden rekenwaarde voor de specifieke krimpverkorting, afhankelijk van f'_{ck} en van de relatieve vochtigheid volgens tabel 11.

Tabel 9 – Waarden van de basiskrimp als functie van de relatieve vochtigheid

RV %	ε'_c ‰
0 – 60 (droge lucht)	0,4
60 – 85 (buitenlucht)	0,25
85 – 100 (zeer vochtig)	0,1
100 (in water)	0

Tabel 10 – Waarden van de factor k_h als functie van de fictieve dikte

h_m mm	k_h
50	1,20
100	1,05
200	0,80
300	0,65
400	0,55
≥ 500	0,50

Tabel 11 – Maximaal aan te houden waarden voor de specifieke krimpverkorting ε'_{rmax}, in ‰

f'_{ck} N/mm²	RV < 60 % (in droge lucht)	60 % ≤ RV < 85 % (in buitenlucht)	85 % ≤ RV < 100 % (zeer vochtig)	RV = 100 % (in water)
15	0,54	0,34	0,14	0
25	0,47	0,29	0,12	0
35	0,41	0,26	0,10	0
45	0,36	0,23	0,09	0
55	0,31	0,20	0,08	0
65	0,27	0,18	0,07	0

6.3.3 De gegeven waarde geldt slechts voor de statische berekening. Bij het bepalen van de verlengingen bij het spannen moet worden uitgegaan van de door de fabrikant in het leveringsattest op te geven waarden.

6.3.6 Voor praktisch gebruik zijn voor verschillende niveaus van de aanvangsspanning de waarden van de maximale relaxatie na 1000 h in tabel 14 samengevat:

Tabel 14 – Relaxatie voorspanstaal

aanvangsspanning als percentage van f_{purep}	$\Delta\sigma_{prel}$ als percentage van de aanvangsspanning	
	draden en strengen	staven
60	1.5	1.5
70	2.5	4.0
80	4.5	7.0

Bij een aanvangsspanning van 30 % van f_{purep} mag de relaxatie op nul worden gesteld; bij aanvangsspanningen tussen 30 % en 60 % van f_{purep} mag rechtlijnig worden geïnterpoleerd tussen 0 % en 1.5 %.

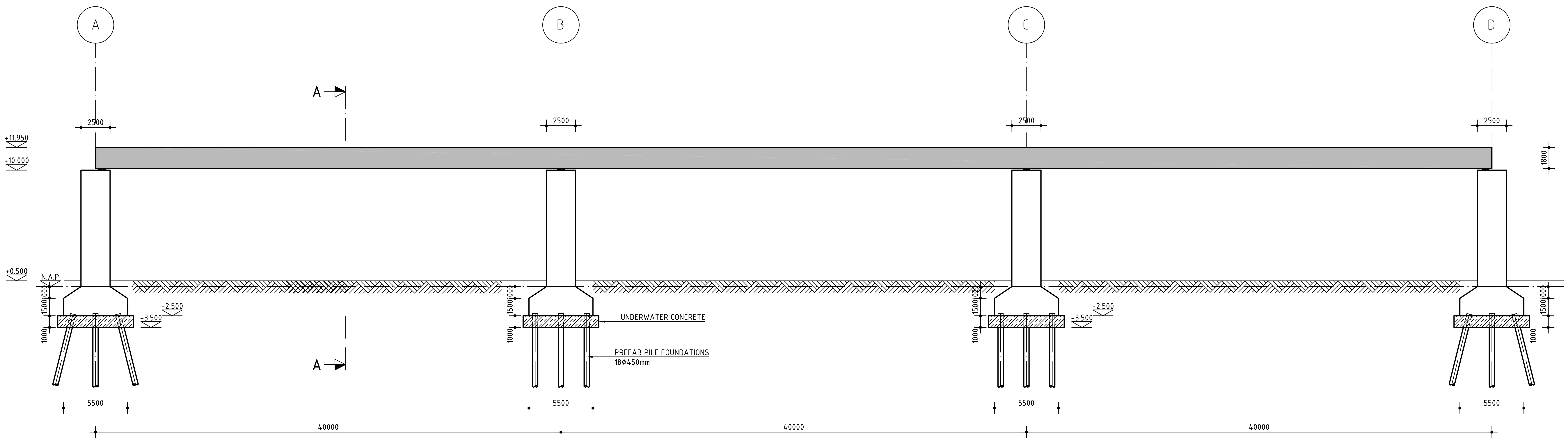
6.3.7 Zie toelichting op 6.2.5.

De knik in het σ-ε-diagram – bij $\sigma_p = 0,9 f_{pu}$ – is zodanig gekozen, dat het werkelijke kromlijnige verloop zo goed mogelijk wordt benaderd.
In het kader van het gelijkwaardigheidsbeginsel (zie ook toelichting bij 1.2) is het toegestaan het σ-ε-diagram van het voorspanstaal proefondervindelijk vast te stellen en dit diagram in de berekening te hanteren. Daarbij moet worden uitgegaan van de karakteristieke waarden, te bepalen volgens NEN 3868:1991.
Voor het verkrijgen van rekenwaarden moeten de karakteristieke waarden worden gedeeld door $\gamma_m = 1,1$. De helling van de elastische tak moet daarbij niet worden gewijzigd (deling door γ_m "evenwijdig aan elastische tak").

HOGESCHOOL UTRECHT

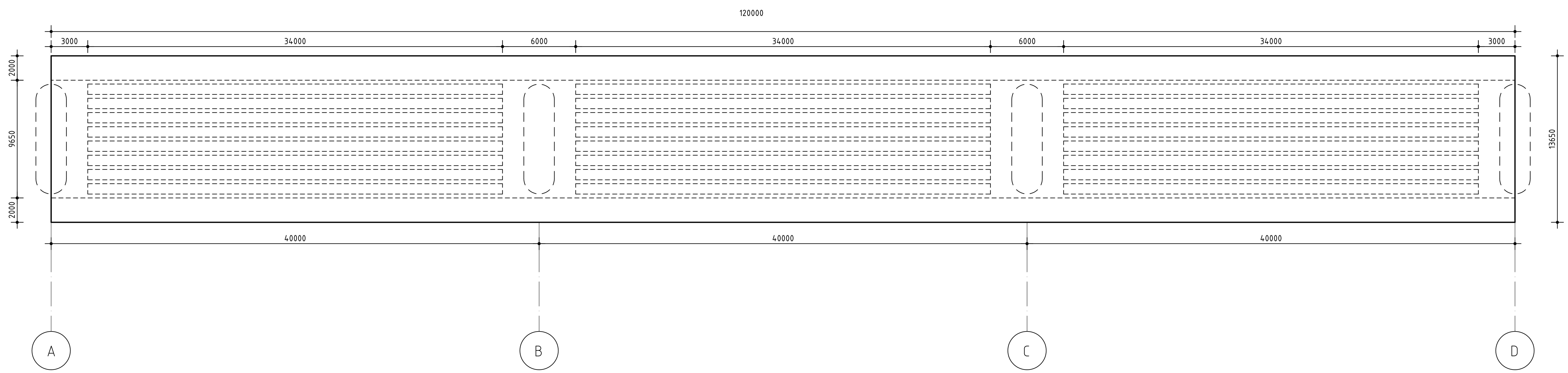
ANNEX 7
DRAWINGS

Grontmij



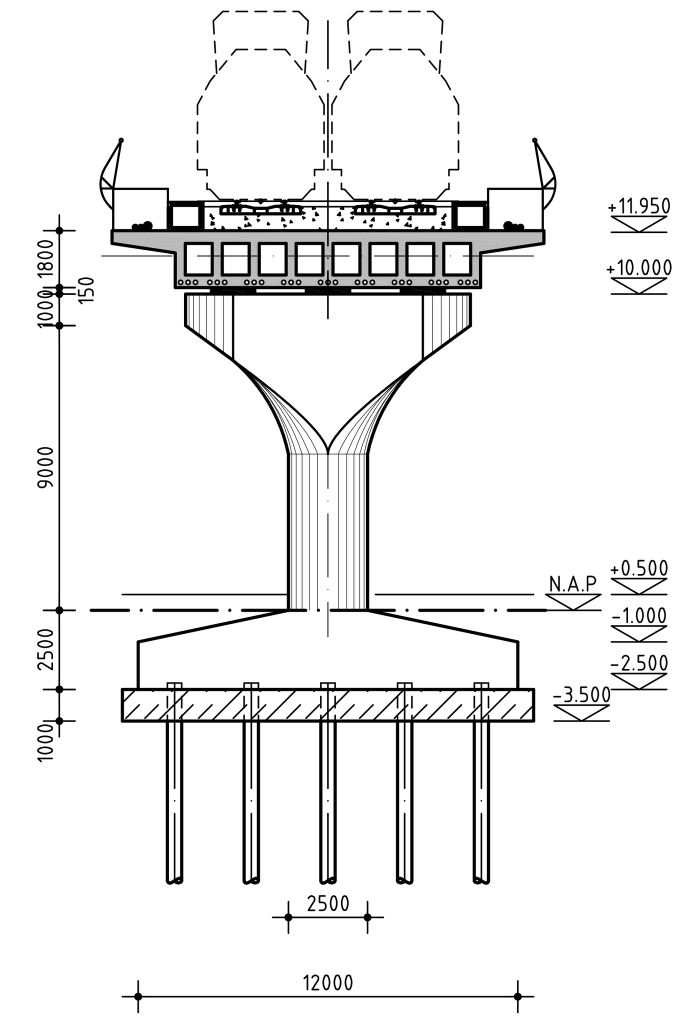
SIDE VIEW OF THE BRIDGE

SCALE 1:200



TOP VIEW OF THE BRIDGE

SCALE 1:200



CROSS SECTION A-A

SCALE 1:200

Grontmij Maunsell ICS

HOGESCHOOL UTRECHT

Projectnummer :

Documentnummer : 1

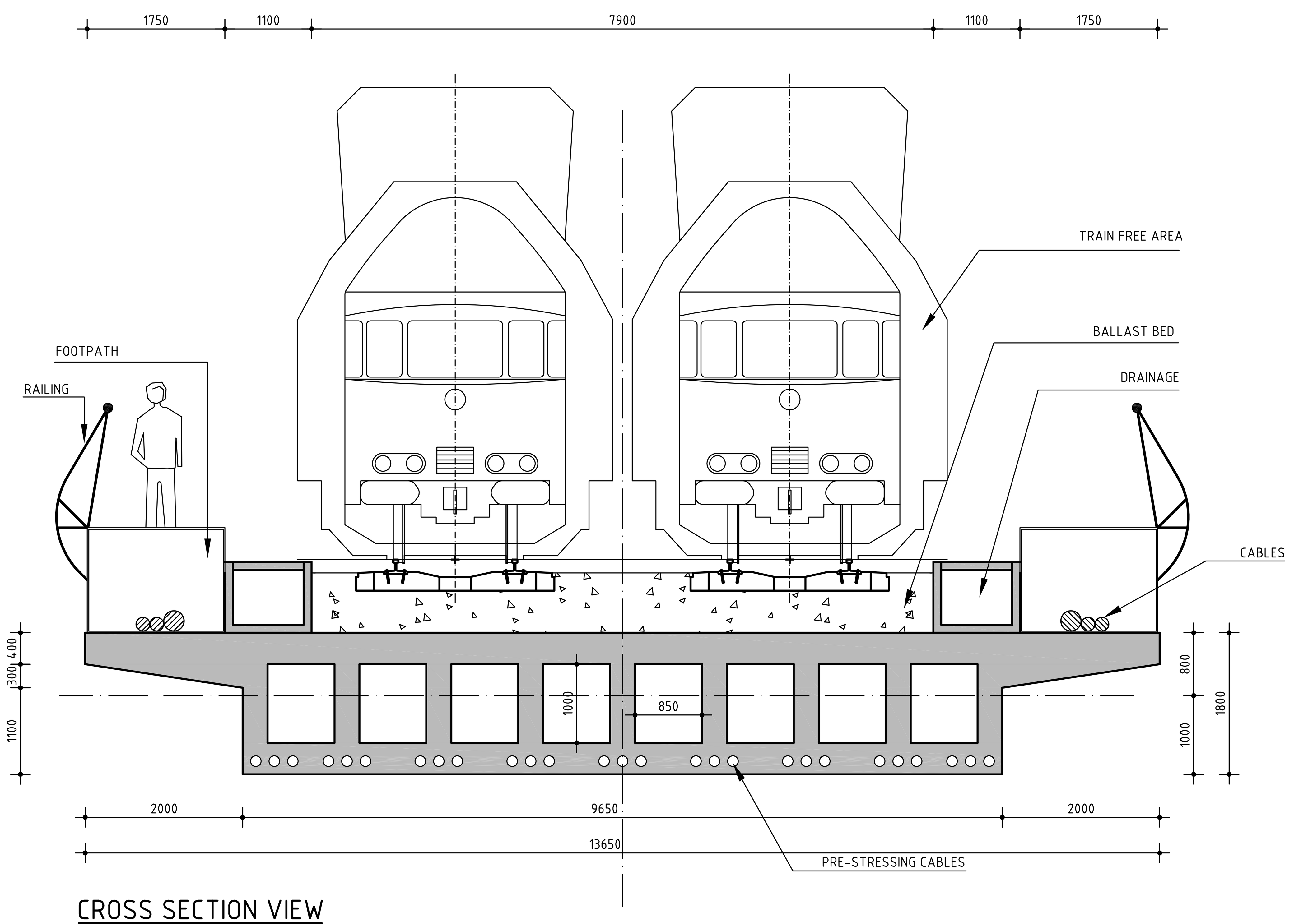
Versie	Datum	Get.	Gec.	Acc.	Opmerkingen

BRIDGE OVERVIEW
DOUBLE TRACK RAILWAY BRIDGE
FINAL THESIS PROJECT

Versie	FINAL THESIS PROJECT
Schaal	1 : 200
Formaat	A1

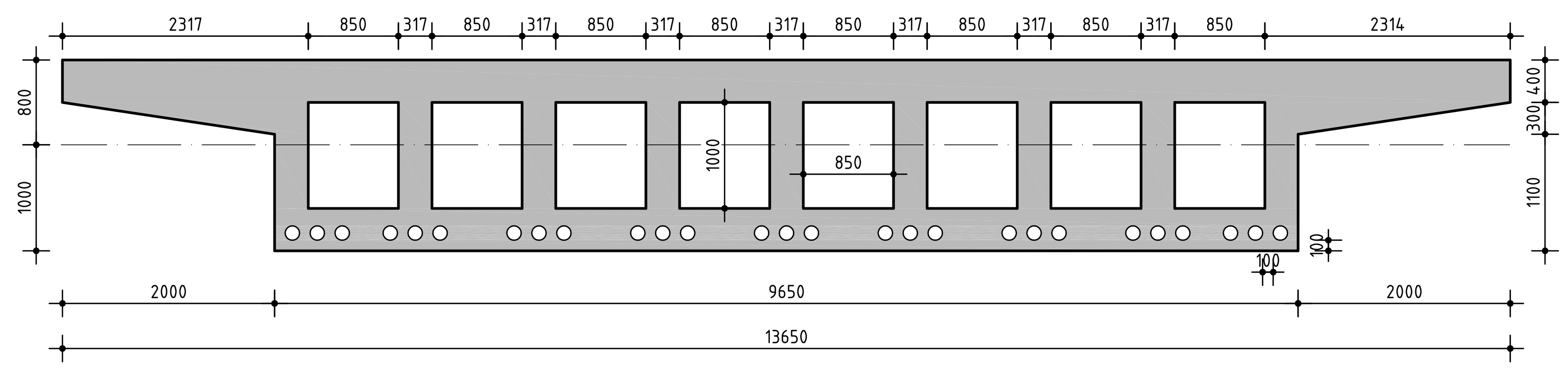
Projectnummer Haagrail:
Tekeningnummer Haagrail:
Fase:
Datum eerste uitgave: 01-06-07
Status:
Blad:

Plotdatum



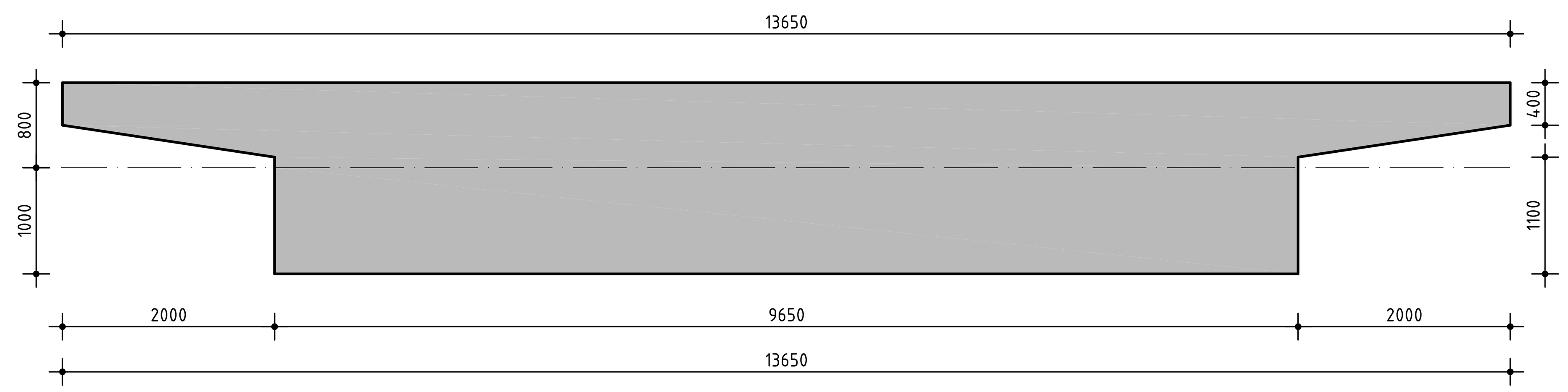
CROSS SECTION VIEW

SCALE 1:50



BRIDGE DECK TYPE 1

SCALE 1:50



BRIDGE DECK TYPE 2

SCALE 1:50

Grontmij Maunsell ICS

HOGESCHOOL UTRECHT

Projectnummer :	
Documentnummer :	2

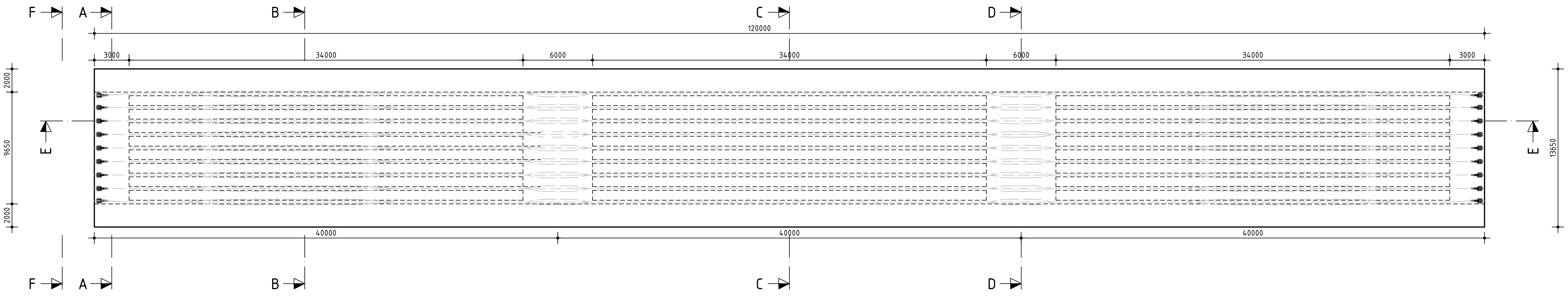
Versie	Datum	Get.	Gec.	Acc.	Opmerkingen

CROSS SECTION DETAIL
DOUBLE TRACK RAILWAY BRIDGE
FINAL THESIS PROJECT

Versie	FINAL THESIS PROJECT
Schaal	1 : 50
Formaat	A1

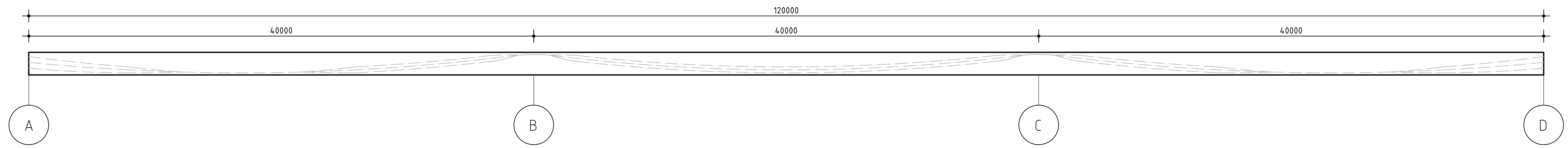
Projectnummer Haagrail:	Fase:	Status:	Blad:
Tekeningnummer Haagrail:	Datum eerste uitgave: 01-06-07		

Plotdatum



TOP VIEW OF THE CABLE LAYOUT

SCALE 1:200

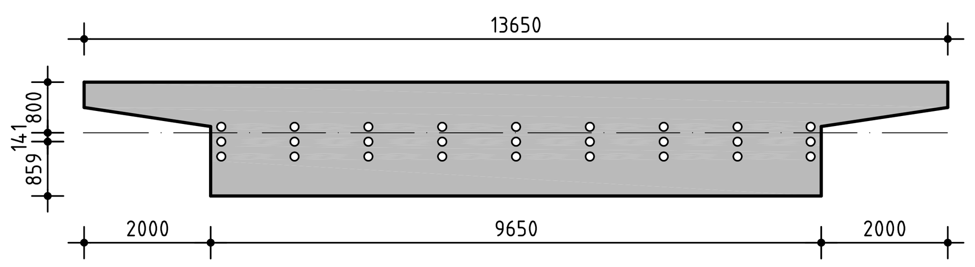


SIDE VIEW OF THE CABLE LAYOUT

SCALE 1:200

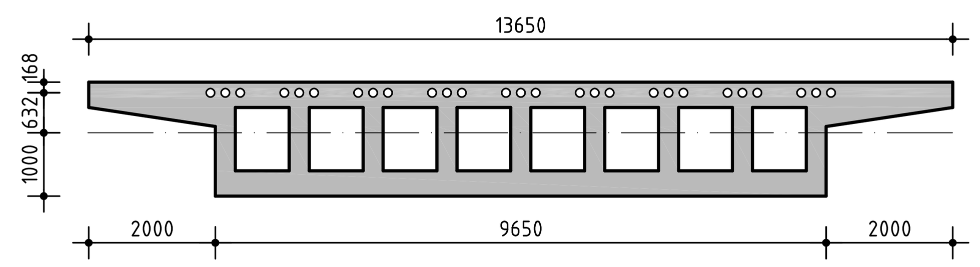
CROSS SECTION E-E

SCALE 1:100



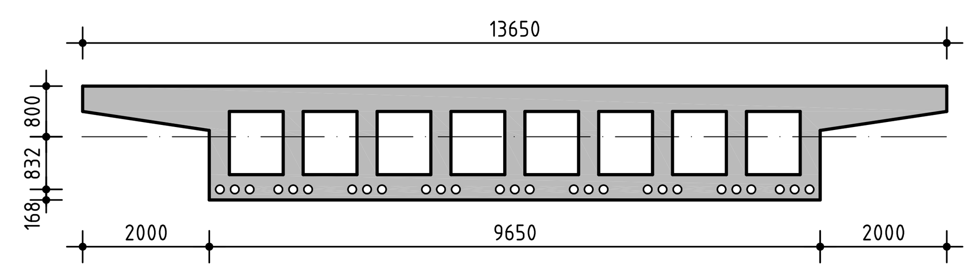
CROSS SECTION A-A

SCALE 1:100



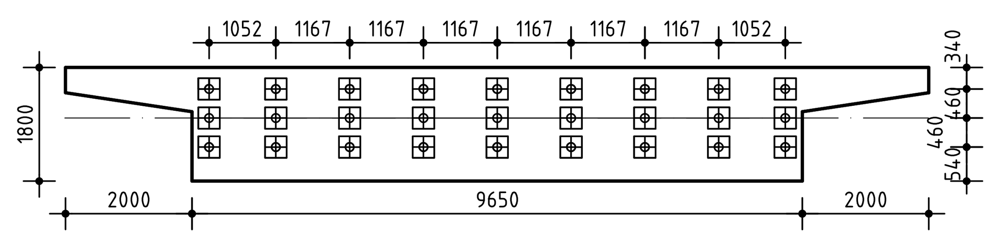
CROSS SECTION D-D

SCALE 1:100



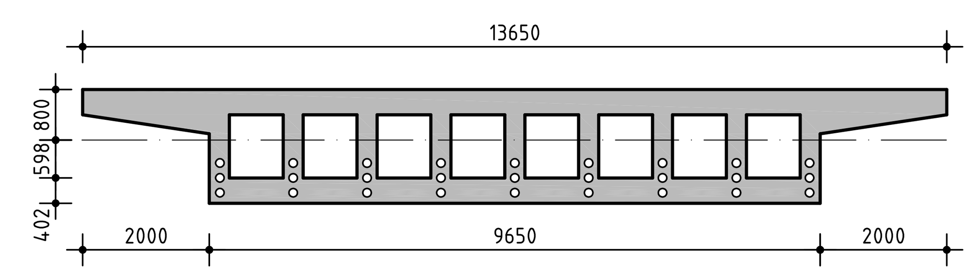
CROSS SECTION B-B

SCALE 1:100



CROSS SECTION F-F

SCALE 1:100



CROSS SECTION C-C

SCALE 1:100

Information :

Quality of the concrete	: C53/65
Type of the tendon	: 5-31
Number of the cable	: 27 cables
Tendon area	: 3100 mm2
Diameter of duct	: 135 mm

Grontmij Maunsell ICS

HOGESCHOOL UTRECHT

Projectnummer :

Documentnummer : 3

Versie	Datum	Get.	Gec.	Acc.	Opmerkingen

PRESTRESSING CABLE LAYOUT
DOUBLE TRACK RAILWAY BRIDGE
FINAL THESIS PROJECT

Versie	FINAL THESIS PROJECT
Schaal	SEE THE DRAWING
Formaat	A1

Projectnummer Haagrail:
Tekeningnummer Haagrail:
Fase:
Datum eerste uitgave: 01-06-07
Status:
Blad:

Plotdatum