CHAPTER 2
BASIC THEORY

2.1. LITERATURE REVIEW

2.1.1. Previous Research

This research on the existing bridge planning has been done by many academics before. This provides many references for planning to be carried out. This planning of the research refers to the planning and similar research that has been done before, including the following:

1. Witriatna, Cahya., dkk.2018. "Comparison Analysis of I Girder Bridge Module and Steel Box Girder as a Function of Road Bridge"

   Bridges are part of transportation infrastructures that serve as a road link that is interrupted by obstacles (rivers, lakes, seas, valleys, other transportation infrastructures). This calculation analysis aims to optimize the use of girder I with a height of 200 cm or 200 cm high box girder with 41,15 meters bridge size. the load used is the highway bridge load, namely the weight of the girder, additional dead load, and life load, additional dead load analyzed, namely the load of the concrete plate, asphalt and diaphragm, while for the live load with the function of the highway is a "D" load consisting of load distribution (load distribution) and Knife Edge Load (KEL) load based on "Loading for SNI Bridge 1725-2016". From the calculation results between the bridge girder module I and the steel girder box span 41,15 m for the highway bridge with 200 cm girder height, it was concluded that for the 200 cm girder height on the highway bridge is more effective using steel box girder type based on SNI material that is quite capable withstand road traffic loads according to standards. Based on the results of research on the analysis of the calculation of loading for bridges 41.15 m span size using SNI 1725 2016 (new standard), it is known that there is a difference in wind load and seismic load of (30-40)% towards RSNI T-02 2005

2. Propika, Jaka and Septiarsilia, Yanisfa. 2020. “Re-Design THP Bridge with segmental box girder system”

   Surabaya Bridge is commonly known by Surabaya people as THP Kenjeran Bridge. It was built above the sea or Kenjeran Beach for connecting Jl, Raya Pantai Lama (North Side) and Jl. Sukolilo Lor (South Side). Since it is a new bridge and becomes the icon of Surabaya City, many visitors from other places visit it. It was designed by using precast concrete structure in which I-Girder beam became the main girder, Pier Head as the girder pedestal, concrete pillar as the buffer, and foundation of pilling for supporting the top structure, of the bridge. As the bridge span is not too long, only 32 meters and requires many pillars, then the concrete needed by Surabaya Bridge becomes big and less efficient. For this reason, the researcher redesigned the bridge by modifying the bridge with box girder segmental system having span 48 meters for optimizing the total pier heads and pillars so as to be more efficient. This research was begun by collecting data of plans and literature through journals, reference books, and other sources. In this context, the researcher referred to SNI 1725-2016, SNI 2833-2016, and RSNI T-02-2005 which were specifically intended for planning the structure of bridge. The final results of this research were the shape and dimension of box girder cross section by 3,2 meter in height 16 meter in width, total prestress 18 tendons with 24 strands for each, and reduction total pear from 7 to 5 with the same concrete volume like the previous one.

3. Nusantoro, Agung., dkk.2022 “Redesign of the superstructure of the bridge in Hargorojo village using PCI girder”.

The bridge in Hargorojo, Bagelen District, Purworejo Regency is the main access for the village in carrying out activities, both vehicles and pedestrians to enter and leave the village so that the damage to the bridge disrupts the course of these activities. Therefore, it is necessary to build a bridge again to connect the two access roads in Hargorojo efficiently. In this study, the bridge will be planned with a span length of 16 meters and a width of 7 meters with PCI girder type of post-tensioned prestressed concrete. The planning stages in this study include girder dimensioning, loading with the Loading rules for SNI 1725-2016 Bridge, tendon layout, calculation of prestressing loss, calculation of stress that occurs, deflection control, PCI girder reinforcement and drawing. The results showed that the girder used had a concrete quality of K-500 (fc' = 41.5 MPa), 0.9 meters high with 2 tendons. The first tendon consists of 7 strands and the second tendon consists of 12 strands with a strand diameter of 12.7 mm VSL specifications. The initial prestressing force obtained is 2080,651 kN, with an effective prestressing force of 1759,921 kN with a total prestress loss of 28,10%. The value of the concrete stress at the initial state in the upper fiber is 0.447 MPa which experiences tensile stress that does not exceed the allowable tensile stress of 1.44 MPa and the lower fiber is -13.847 MPa which experiences compressive stress that does not exceed the compressive allowable stress of -19.92 MPa so that it does not crack occurs. The value of concrete stress at the final state in the top fiber of the slab is -0,107 MPa, the top fiber of the beam is -1,623 MPa and the bottom fiber of the beam is - 8,447 MPa which experiences compressive stress that does not exceed the allowable compressive stress of -18.68 MPa so that no cracks occur. The ultimate moment due to the largest combination of loading (Mu) is 2140,380 kNm which is safe against the ultimate moment of prestressing beam ($\emptyset Mn$) of 2268,381 kNm. The total deflection that occurs on the girder is 0.0191 meters (deflection) is smaller than the allowable deflection of 0.0533 m so it is safe against deflection.

2.1.2. Research Now

The result of previous reviews and research can provide a general overview for this research, including the following:

1. The superstructure of the bridge is planned to use prestressed concrete girders of type I. it is necessary to analyze the stress loss, stress during transfer, shear force, deflection control, and stress control that occurs due to loads acting on the bridge
2. Reference for bridge planning suing standard regulations for bridge loading SNI 1725:2016
3. Structure analysis process using Microsoft Excel 2010 and MIDAS Civil
4. The substructure of the bridge including abutments and foundations needs to be safe against overturning moments and shear forces

2.1.3. Research Authenticity

Based on references from previous research on bridge re-planning, this research is optimizing the Ciledug wetan bridge design using I-section girders. In this planning, the standard loading regulations of SNI 1725:2016.

Table 2.1 Research differences

Researcher Name	Kharisma Syarif D	Witriatna Cahya	Jaka P and Yanisfa S	Agung Nusantoro and friends
Years	2022	2018	2020	2022
Type of bridge	Prestressed Concrete	Prestressed Concrete and Steel Beams	Prestressed Concrete	Prestressed Concrete
Location	Ciledug		Surabaya	Purworejo
Profile	I girder	I girder and Steel box girder	Box girder	I girder
Span	36 m	41.15 m	32 m	16 m
Regulation	SNI 1725:2016	SNI 1725:2016	SNI 1725:2016	SNI 1725:2016

On this bridge it crosses the Cisanggarung river and connects two divide places, in the planning of his bridge referring to several literature studies the bridge is planned with a span 36 m using an upper construction, namely prestressed concrete with a section I. this planning refers to the loading SNI, namely SNI 1725:2016 with the help of Midas software to analyze it.

[1]Siswanto (1993), "The elements contained in a bridge are divided into four parts" accessed from https://karetmalang.worpress.com/2019/04/25/bagian-bagian-jembatan/, on may 29, 2022 at 08:00

2.2. BRIDGE

The bridge is a construction that is used to continue the road where there are obstacle in the form of rivers, valleys and other obstacles. The elements contained in a bridge are divided into four parts, namely the bottom structure, the upper structure, oprit, and the safety building. The superstructure of the bridge is the part of the bridge that is directly intended to receive loads which include vehicle traffic loads, and others

Bridge components are generally divided into 2 components, namely:

1. Upper structure

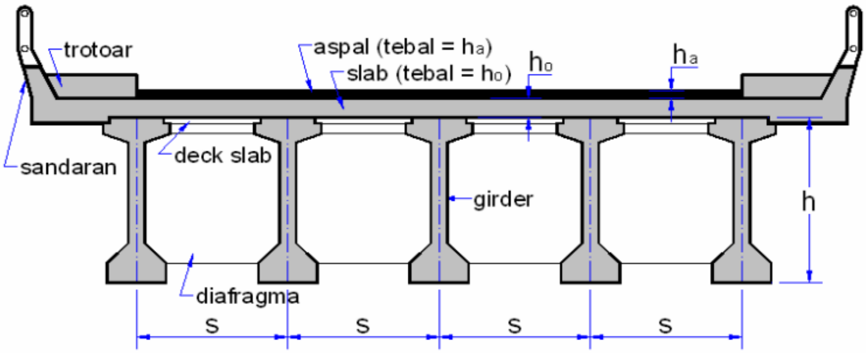
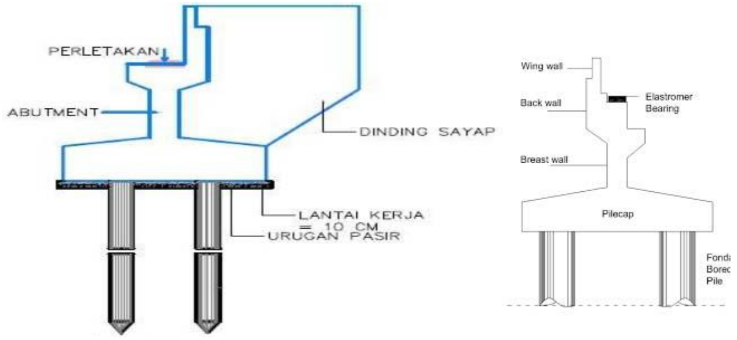


Figure 2.1 Upper Structure

The superstructure of the bridge is a construction design that is intended to transfer the load received by the bridge floor to the placement. The function of the bridge floor is the part that directly receives the load vehicular and pedestrian traffic, the superstructure of this bridge consists of several structural elements, including:

a. Backrest wall
b. Sidewalk
c. Slab bridge
d. Girder
e. Diaphragm beam
f. Bearing pad

2. Bottom structure



(Source: https://www.pengadaan.web.id/2020/10/abutment-jembatan.html)

Figure 2.2 Bottom Structure

For the bottom structure of the bridge, it is used to withstand the loads transmitted from the superstructure of the bridge:

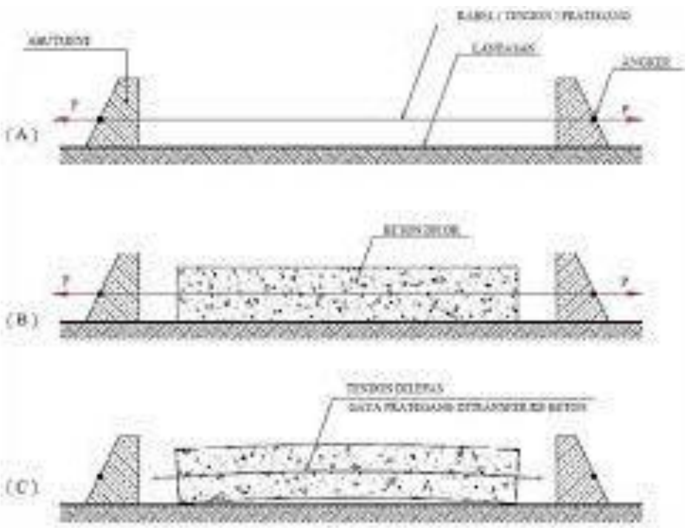
a. Abutment
b. Abutment foundation

[2]Hendi Prasetyo, thesis: “optimalization design of buntung bridge in sleman yogyakarta using pci girder with concrete quality variation and height of girder” (Yogyakarta: UII, 2018), page 11.

2.3. BASIC PRINCIPLE OF PRESTRESSED CONCRETE

Basically same the reinforced concrete, prestressed concrete is also a composite structure between two materials, namely concrete and steel but with high quality, the use of steel in prestressed concrete is often called tendons, these tendons are grouped so that they become strand cable.

The pulling of steel causes stressing of the surrounding concrete, so that the concrete becomes able to withstand higher loads before experiencing cracking.



(Source: https://eprints.umm.ac.id/45922/3/BAB%20II.pdf)

Figure 2.3 Prestress Concrete

In the world of restressed concrete bridge construction, there are several types of cross-sectional bridges used for bridge construction, including:

1. Cross sectional I (PCI girder)

   The girder is in the form of a letter I, often called a PCI girder, the material for making this PCI girder is made of composite or non-composite, depending on the use and designation for the type of strength required for the bridge construction.
2. Box girder

   The main girder consists of several hollow beam segments made of high quality concrete which are joined by steel wires which are often tendons, so that they are able to withstand bending, shearing and torsion effectively.
3. Cross section of T and U girder

   The T and U cross sections are basically the same as the I girder sections, but only different from the shape of the cross section

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[3]Yoffi Indityana Sari, thesis: “re-design struktur pci girder pada overpass kranggan (sta. 72+237) proyek jalan tol semarang – solo ruas salatiga – kartasura” (Jakarta: STT-PLN, 2018), page 8.

2.3.1. Prestressing Steel Pulling System

1. Pre-Tensioning

In this system, the prestressing force is applied to the tendon steel reinforcement before the concrete is placed, in the process of applying the prestressing force at the factory, the steel tendon reinforcement is given a tensile force and then temporarily held in place at a certain abutment. At the time of removing/cutting tendon steel reinforcement, a shortening phenomenon usually occurs which will cause some of the prestressing force to disappear, usually this is done on girder beams that have a large enough span so that it cannot be done in the factory due to limited space. Transfer of compressive stresses from the tendons to the concrete, wherein the tendons are attached to the earth anchor construction. In the lay out method, the tendons can be made straight or broken.

2. Post-Tensioning

In this post-tensioning method, the prestressing force is applied to tendon steel reinforcement after the concrete has been cast, hardened, until it reaches an qualify strength/hardness. In this method/system, the first thing that must be done is placing the concrete in a certain area that has been calculated using a tube or metal sheathe. Steel reinforcement or tendon cables are then inserted into the channel that has been made when the concrete has reached qualify strength/hardness, after which it is attached to the anchors at both ends (anchorage wedges).

The space in the channel that has not been filled is then filled with cement through grouting. The prestressing force is then applied to the steel reinforcement or tendon cable using jacking tool, which is carried out from one side of the anchor, such an anchor is commonly referred to as live anchor.

2.3.2. Prestressed Concrete Concept

Prestressed concrete is a composite structure between two different materials, namely between concrete and steel, the same thing as reinforced concrete.

1. Prestressing system to convert concrete into elastic

   This concept is the thought of Eugene Freyssinet who visualizes prestressed concrete as concrete that is transformed from a fragile into an elastic material by prioritizing (prestressing) the material.

2. Prestressing system to achieve balance

   In the overall design of prestressed concrete structures, the effect of prestressing is seen as a self-weight balance so that structural elements that experience bending such as slabs, beams, and girders will not experience bending stresses under the loading conditions that occur.

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[4]T.Y.Lin (1993) "(tendon) with high tensile strength. There are three different concept that can be." https://docplayer.info/70565372-Tendon-dengan-kekuatan-tarik-tinggi-ada-tiga-konsep-yang-berbeda-yang-dapat-ketiga-konsep-tersebut-adalah-sebagai-berikut-t-y-lin-1993.html, on may 30, 2022 at 09:00

[5]Hendi Prasetyo, thesis: "optimalization design of buntung bridge in sleman yogyakarta using pci girder with concrete quality variation and height of girder" (Yogyakarta: UII, 2018), page 13

3. Prestressing system for the combination of high-strength steel with concrete

This concept considers prestressed concrete as a combination steel and concrete as in reinforced concrete.

2.3.3. Loading Stage

At this stage of loading it is different from that of reinforced concrete, in this prestressed concrete at each stage of loading there must be a check on the stressed or pulled part in each cross section. There are two loading stage, namely:

1. Initial stage

At this stage, when the concrete has dried, it is necessary to remove the prestressed steel, usually at this stage, only dead loads work

2. Final stage

At this stage is the most crucial period for the service life because of the loss of prestressing force. So it is assumed that the prestressing value has reached the smallest value

2.4. MATERIAL CONCRETE PRESTRESSED

2.4.1. Concrete

Concrete is a combination of several mixed materials, namely mixing sand, cement, water, and aggregate if needed, you can use additional materials such as admixture. Prestressed concrete in which steel reinforcement is pulled or tensioned against the concrete.

Based on SNI 2847-2013 the allowable stress is determined as follows:

a. Allowable stresses of concrete after transfer of prestressing force or during transfer conditions
   - Compressive stress : $f_{compressive} = 0{,}6.fci$
   - Tensile stress : $f_{tensile} = 0{,}25.\sqrt{fci}$

b. Allowable stress of concrete after loss of prestressing force or service condition.

- Compressive stress : $f_{compressive}$ = 0,45.fci
- Tensile stress : $f_{tensile}$ = 0,62.$\sqrt{fci}$

With:

fci = the compressive strength at the time of transfer of the prestressing force taken is 65% - 80% of fc' (MPa)

fc' = compressive strength of concrete at service conditions (MPa)

Modulus of elasticity Ec = 4700$\sqrt{fc'}$

Density in concrete determined based on table 2.1 in accordance SNI 1725-2016 article 7.1:

Table 2.2 density for dead load

No	Material	Fill Weight (kN/m^2)	Mass Dendity (kg/m^2)
1	Bituminous wearing surface	22	2245
2	Cast iron	71	7240
3	Compacted sand, silt or clay	17.2	1755
4	Rolled gravel, macadam or ballast	18.8-22.7	1920-2315
5	Asphalt concrete	22	2245
6	Low density	12.25-19.6	1250-2000
7	Concrete f'c<35 Mpa	22-25	2320
	35<f'c<105 Mpa	22+0.022f'c	2240+2.29f'c
8	steel	78.5	7850

9	wood	7.8	800
70	Hard wood	11	1125

(Source: SNI 1725-2016 page 13)

2.4.2. Prestressed Steel

Steel used as a prestressing agent in concrete is steel used with very high quality up to 1862 MPa or higher. Such high grade steel can compensate for prestress losses and have residual stress levels that can withstand the required prestressing forces. High strength steel for prestressing systems is usually one of three forms of wire, single wire, strand, bar.

1. Wire is usually used for prestressed steel in prestressed concrete with a pretension system.
2. Strand is a group of wires, strung around their longitudinal axis, Estrand < Ewire. Usually used for prestressed steel in prestressed concrete with a post tension system.
3. Bars are usually used for prestressing steel in prestressed steel in prestressed concrete with a pretension system.

2.5. ABUTMENT

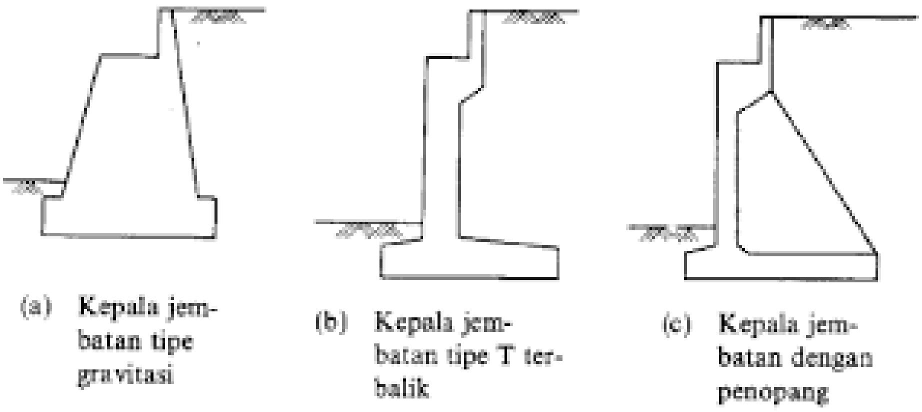

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Figure 2.4 Abutments

Abutments are a combination of the function of pillars and retaining walls with the function of supporting the ends of the bridge and providing lateral support for the soil or rock around the bridge.

Abutments are substructures located at the ends of the bridge span to support the superstructure. Bridge abutment planning according to the directorate general of highway in the bridge engineering planning book is necessary pay attention to the following matters.

1. Has economical dimensions
2. Strong to withstand the load of superstructure, traffic load, wind load, and load earthquake.
3. Strong to withstand the pressure of flowing water, the impact of drifting objects, collisions ship, and vehicle collision.

2.6. FOUNDATION

The foundation is an important aspect of every building, as well as the bridge structure, the foundation plays an important role in channeling the load on the superstructure to the top layer. Therefore the planning of the foundation must be carefully planned, for the laying of the foundation must be in an area with hard soil so that it can carry the load properly.

The failure of a bridge construction in the form of settlement, settlement, shift, and collapse of abutments and pillars can be caused by excessive loads, water scouring, earthquakes, and others, as well as the carrying capacity of the soil that does not allow or does not meet the level or hardness. Therefore, to minimize a collapse and subsidence there must be an investigation on the soil including the standard penetration test (SPT)

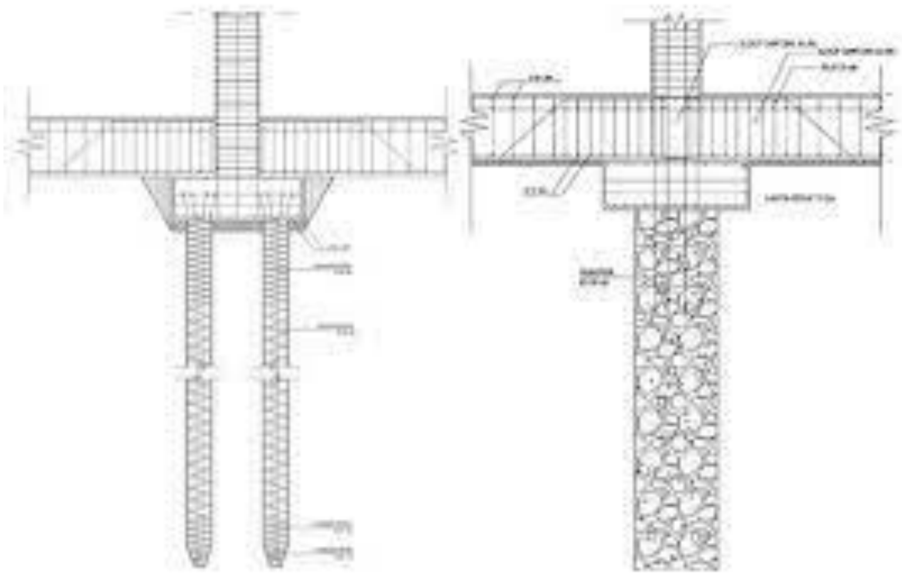

Figure 2.5 Foundation

2.7. LOADING

Loading is an important factor in planning the building structure. Therefore, in planning the structure it is necessary to identify the loads acting on the structural. The loads acting on a structure are generated in a direct direction by natural and man-made force (Schueller, 2001)

Regulatory standard:

1. Structure Bina Marga Bridge Management System (BMS) 1992
2. Other applicable regulations and in according with the existing condition of loading on the bridge structure based on SNI 1725-2016

2.7.1. Dead Load

Dead load is all loads originating from the weight of the bridge itself or the part of the bridge being reviewed, including all additional fixed elements which are considered to be a unit with the bridge (Sumantri, 1989:63)

1. Self-Load (MS)

   Self-load is from other structural elements that are carried, including in this case the weight of the bridge itself, both from structural elements, and added to non-structural elements considered.

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[6]Teknik sipil (2016) “Construction Bridge” https://www.google.com/amp/s/tekniksipil411.wordpress.com/2016/17/first-blog-post/amp/?espv=1 on may 30, 2022 at 12:00

Table 2.3 Load factor for self-load

Type of Load	Load Factor (γMS)			
	Service limit condition ($\gamma^{S} MS$)		Limit State ($\gamma^{U} MS$)	
	Material		Normal	Reduce
Permanent	Steel	1,00	1,10	0,90
	Aluminum	1,00	1,10	0,90
	Precast Concrete	1,00	1,20	0,85
	Concrete cast in situ	1,00	1,30	0,75
	Wood	1,00	1,40	0,70

(Source: SNI 1725:2016 page 14)

2. Additional Dead Load (MA)

   Additional dead load is the weight of all materials that make up a load on the bridge which is a non-structural element, and its measure can change over the life of the bridge.

Table 2.4 Load factor for additional dead load

Type of Load	Load Factor (γMA)			
	Service limit condition ($\gamma^{S} MA$)		Limit State ($\gamma^{U} MA$)	
	Material		Normal	Reduce
Permanent	General	1,00(1)	2,00	0,70
	Special (trawasi)	1,00	1,40	0,80
Note1): service load vector of 1,3 is used for utility weight				

(Source: SNI 1725:2016 page 14)

2.7.2. Live Load

Live load is a load that works on a bridge construction but is not fixed such as traffic loads or others load.

a. Traffic loads

Traffic load is all vertical and horizontal loads due to vehicle action on the bridge including relationship with dynamic effects, but excluding collisions. Traffic load for bridge design consist of lane "D" load and truck load "T".

1. Lane load "D"

Lane load is the traffic lane load part of the vehicle floor used by a series of vehicles.

Table 2.5 Load factor due to lane load "D"

Period of time	Load factor (γ_{TD})	
	Service limit condition (γ_{TD}^{S})	Ultimate limit condition (γ_{TD}^{U})
Transient	1,0	1,8

(*Source: SNI 1725:2016 page 39*)

"D" lane loads consist evenly distributed loads (BTR) combined with line loads (BGT).

Table 2.6 Number of lanes of traffic plan

Bridge Type (1)	Bridge net width (m) (2)	Number of lanes of traffic plan (n)
One lane	3000 ≤ w < 5250	1
Two-way, no median	5250 ≤ w < 7500	2
	7500 ≤ w < 10,000	3
	10,000 ≤ w < 12,500	4
	12,500 ≤ w < 15,250	5
	W ≥ 15,250	6

Two-way, with median	5500 ≤ w < 8000 8250 ≤ w < 10,750 11,000 ≤ w < 13,500 13,750 ≤ w < 16,250 W ≥ 16,500	2 3 4 5 6
Note (1)	For other type of bridges, of planned traffic lanes must be determined by the competent authority	
Note (2)	Vehicle lane width is the minimum distance between curbs or obstacles for one direction or the distance between curbs / obstacles / medians and medians for multiple direction.	

(*Source: SNI 1725:2016 page 38*)

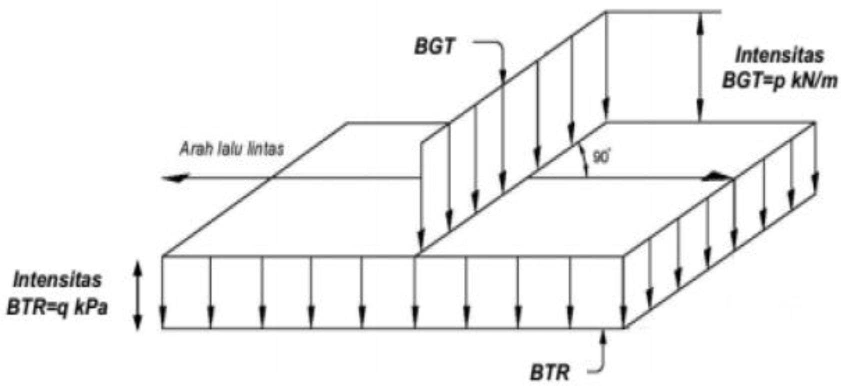


Figure 2.6 Lane load details

2. Truck load

Truck load "T" is the load of the entire width of the bridge section used to accept the load from vehicular traffic. Dynamic load factor (FDB) is the result of the interaction between moving vehicles and the bridge, which means that the "T" truck load needs to be multiplied by the dynamic load factor (FDB) and distribution factor. For loading trucks "T"

FDB is taken at 30%. The calculated FDB price is used for all parts of the building that are above ground level.

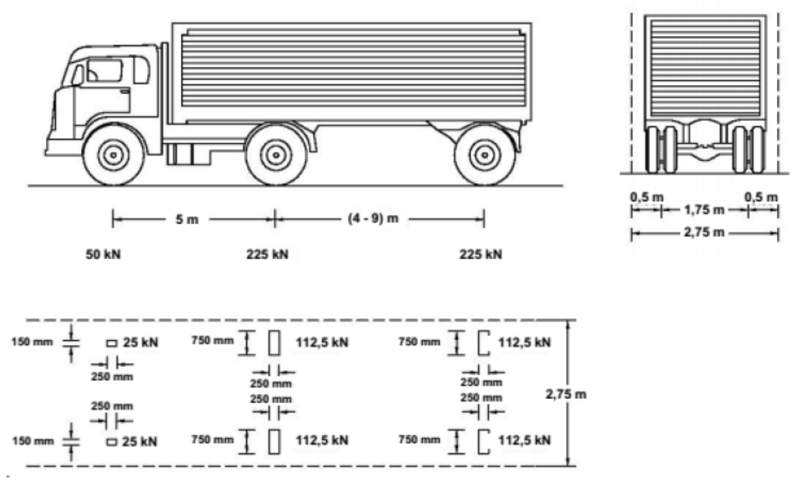


Figure 2.7 Truck loading "T" (500 kN)

3. Break style

The action of the longitudinal forces of the bridge, due to brake and traction forces, must be considered for both direction of traffic. This effect is calculated to be equivalent to a break force of 5% of the "D" lane load which is assumed to exist on all traffic lanes, without being multiplied by the dynamic load factor and in one direction. The break force is considered to work horizontally in the direction of the bridge axis with a catch point as high as 1,8 m above the vehicle floor surface. The magnitude of the brake forces depends on the total length of the bridge as follows:

For $L \leq 80$ m

Break style, T_{TB} = 250 kN

For $80 < L < 180$ m

Break stye, T_{TB} = 250 kN + 2,5 . (L-80) kN

For $L \geq 180$

Break style, T_{TB} = 500 kN

Arm to center of girder view

$Y = Y_{Tc} + t_a + 1,8$

2.7.3. Gravity Load

Gravity loads are those caused by the weight of an object on and the self-load of the bridge. Such loads are both permanent, transient and applied in a downward direction.

a. Permanent loads

   Permanent loads are those that remain on the bridge for an extended period of time, maybe for the entire service life.

b. Transient loads

   The principal load effect is the gravity load of truck, but other effects are significant and must be considered. Such effect includes impact (dynamic effect), braking forces, centrifugal force, and the effects of other trucks at the same time present.

2.7.4. Environmental Load

For this environmental load greatly affects the construction of a bridge, the loads include:

a. Temperature effect

   Temperature effect difference is a set according to the local temperature development data.

Table 2.7 Nominal mean bridge temperature

Superstructure Type	Minimum average bridge temperature	Maximum average bridge temperature
Concrete floors on concrete girder or beams	15°c	40°c
Concrete floors on girders, beams or steel frames	15°c	40°c
Steel slab floors on girders, bemas or steel frames	15°c	40°c
Note	The minimum mean bridge temperature can be reduced by 5°c for locations located at an altitude greater than 500 m above sea level.	

(*Source: SNI 1725:2016 page 49*)

b. Wind load

In the design of this bridge, the wind load is very influential so it must be taken into account. The design wind direction shall be assumed to be horizontal, unless otherwise specified in 9.6.3. in the absence of more precise data, the design wind pressure can be determined using the following equation:

$$V_{DZ} = 2{,}5\, V_o \left(\frac{V_{10}}{V_B}\right) \ln\left(\frac{Z}{Z_0}\right)$$

Description:

V_{DZ} = Design wind speed at design elevation, Z(Km/h)

V_{10} = Wind speed at an elevation of 10000 mm above ground level or above design water level

V_B = The design wind speed is 90 to 126 km/h at an elevation of 1000 mm, on the lower building it must be calculated based on a basic wind pressure of 0,0019 Mpa. Vertical upward wind force of $9{,}6\times10^{-4}$ Mpa times the width of the bridge, including parapet and pavement

Z = Elevation of the structure from the above ground level or from the water level where the wind load is calculated (Z>10000 mm)

V_o = Wind friction speed, which is a meteorological characteristic, as specified in table 2.8, for various surface types upstream of the bridge (km/h)

Z_o = The friction length upstream of the bridge, which is a meteorological characteristic, is determined in table 2.8 (mm)

V_{10} can be obtained from:

a. Basic wind speed chart for different return periods
b. Wind survey at bridge site
c. In the absence of better data, the planner can assume that $V_{10} = V_B$ = 90 to 126 km/h

Table 2.8 V_0 and Z_0 values for various upstream surface condition

Condition	Open field	Sub-urban	City
Vo (km/h)	13,2	17,6	19,3
Zo (km/h)	70	1000	2500

(source: SNI 1725:2016 page 56)

For the design wind pressure formula:

$$P_D = P_B \left(\frac{V_{DZ}}{V_B}\right)^2$$

Description:

P_D = Design wind pressure (Mpa)

P_B = Design water pressure (Mpa)

Table 2.9 Base water pressure

Superstructure components	Wind pressure	Suction wind
Frame, Column and arches	0,0024	0,0012
Beams	0,0024	N/A
Flat surface	0,0019	N/A

(Source 1725:2016 page 56)

c. Earthquake load

Depending on location of the bridge site, the anticipated earthquake effect can be inconsequential or they can govern the design of the lateral load resistance system.

The minimum seismic design load is obtained from the following formula:

$$E_Q = \frac{Csm}{Rd} \times W_t$$

Description:

E_Q = Static horizontal earthquake force (kN)

Csm = Elastic earthquake response coefficient

Rd = Response modification factor

wt = Total weight of structure consisting of dead load and corresponding live load (kN)

Calculation of the effect of earthquakes on bridges including earthquake loads, analysis methods, earthquake maps, and structural details refers to the RSNI 2833:2010 earthquake resistance planning standard for bridge.

Table 2.10 Response modification factor (Rd) for the column and the relationship to the substructure

<table>
<tr><th rowspan="2"></th><th rowspan="2">Column or Pier</th><th colspan="3">Superstructure connection bridge on</th></tr>
<tr><th>Bridge head</th><th>Column, Pier or Pillar</th><th>Connection dilated</th></tr>
<tr><td>Abutment (a)</td><td>2 (Strong axis)
3 (Strong axis)</td><td rowspan="4">0,8</td><td rowspan="4">1,0</td><td rowspan="4">0,8</td></tr>
<tr><td>Single column</td><td>3-4</td></tr>
<tr><td>Compound column</td><td>5-6</td></tr>
<tr><td>Concrete pile cap</td><td>2-3</td></tr>
<tr><td colspan="5">Note:
a. The abutments can be planned as a single column in the direction of the weak axis of the pillar
b. For single-span bridges a factor of 2,5 is used for the connection to the bridge head
c. Alternative the column connections can be designed for the maximum force developed by the column plastic hinges</td></tr>
</table>

(Source: RSNI 2833:2010)

2.7.5. Load Combination

Based on SNI 2847 – 2013 and SNI 1725 – 2016 or RSNI 2833 – 2010, planning and evaluation of reinforced concrete structures for important category bridges must use the following ultimate loading combination:

1. **Normal Loading Combination**
   - Strong 1 (D) = 1,3 MS + 2 MA + 1,25 TA + 1,8 TD
   - Strong 1 (T) = 1,3 MS + 2 MA + 1,25 TA + 1,8 (TT + TB)
   - Strong 2 (D) = 1,3 MS + 2 MA + 1,25 TA + 1,4 TD
   - Strong 2 (T) = 1,3 MS + 2 MA + 1,25 TA + 1,4 (TT + TB)
   - Strong 3 = 1,3 MS + 2 MA + 1,25 TA
   - Strong 4 = 1,3 MS + 2 MA + 1,25 TA
   - Strong 5 = 1,3 MS + 2 MA + 1,25 TA
2. **Earthquake Loading Combination**
   - Extreme 6 = 1,3 MS + 2MA + 1,25 TA + EQX + 0,3 EQY
   - Extreme 7 = 1,3 MS + 2MA + 1,25 TA + 0,3 EQX + EQY

As for evaluating the bearing capacity of the foundation, it must use a combination of permit loading (service limit) as follows:

1. **Normal Loading Combination**
   - Service 1 (D) = 1 (MS + MA + TA) + 1 TD
   - Service 1 (T) = 1 (MS + MA + TA) + 1 (TT + TB)
   - Service 2 (D) = 1 (MS + MA + TA) + 1,3 TD
   - Service 2 (T) = 1 (MS + MA + TA) + 1,3 (TT + TB)
2. **Earthquake Loading Combination**
   - Service 3 = 1 (MS + MA + TA) + 0,7 EQX + 0,21 EQY
   - Service 4 = 1 (MS + MA + TA) + 0,21 EQX + 0,7 EQY

Where:

MS = Dead load due to own weight

MA = Superimposed dead load

TT = Truck live load

TD = Distribution load due to traffic lane load, divided by:

BGT = Centralized line live load

BTR = Live load is evenly distributed

TA = Earth Pressure, divide by:

EP = Active earth pressure due to the weight of the embankment

EPBTR = Active earth pressure due to the load being evenly distributed over the embankment soil.

EPW = Active earth pressure due to water in embankment

EQx = Earthquake load x direction

a. For pier had and column used R =3
b. For pier had, column, pile cap and foundation used R=1

EQy = Earthquake load y direction

a. For pier had and column used R = 3
b. For pier had, column, pile cap, and foundation used R = 1

2.8. BRIDGE UPPER STRUCTURE DESIGN

For the upper structure of the bridge, it is very important to pay attention to because of the upper structure, most of the external loads are the first to work and these loads will be transferred to the lower structure of the bridge.

2.8.1. Barrier Planning Design

Barrier is a bridge safety construction so that users don't cross the area of a bridge construction so as not to cause an accident, the barrier used here uses a concrete barrier that can withstand collisions in the event of an accident so that it doesn't fall off the bridge.

Figure 2.8 Barrier

In general, the barrier is planned with a height of 0,9-1,0 meters from the pavement surface. The planning of the barrier is calculated as follows.

1. Barrier loading

To calculate the load on a barrier using the following and steps: Ultimate design shear force calculation:

H = W'.L

V = K

Calculation of the ultimate moment of the plan:

M = H.y

M_U = K.M

With:

W' = Ultimate horizontal design load on barrier

L = Barrier viewing distance

y = Arm against the underside of the barrier

H = Horizontal force on the barrier

M = Moment on barrier

K = Ultimate load factor

2. Barrier reinforcement design

In the calculation of the barrier reinforcement by using the following formulas.

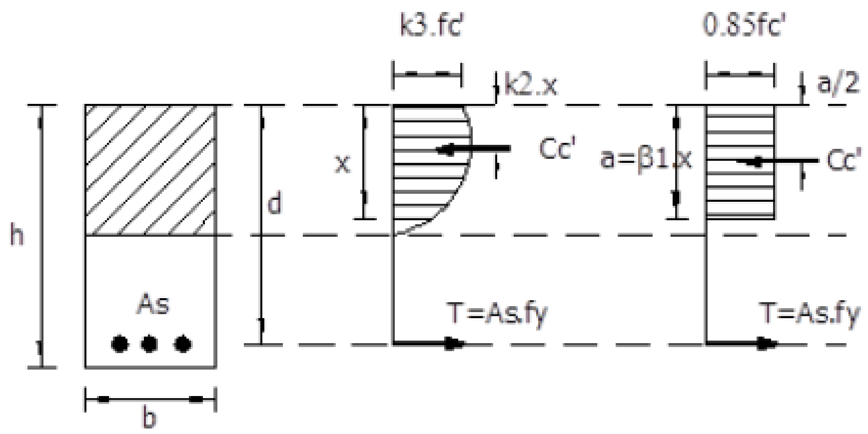


Figure 2.9 Cross-section stress distribution

After getting the formula as before, the nominal moment is calculated using the following formula:

$$M_n = \frac{M}{\emptyset}$$

After obtaining the nominal (M_n), then look for the moment resistance factor with the following formula:

$$R_n = \frac{Mn}{(b.d)^2}\ , Rn < Rmax$$

With maximum moment resistance factor:

$R_{max} = 0{,}75.\rho b.fy\left(1 - \frac{0{,}5.0{,}75.\rho b.fy}{0{,}85.f'c}\right)$

And reinforcement ratio that provide balance strain conditions:

$\rho b = \frac{0{,}85.fc'}{fy}.\left(\frac{600}{600+fy}\right)$

Required reinforcement ratio:

$\rho = 0{,}85.\frac{f'c}{fy}.\left(1 - \sqrt{1 - \frac{2.Rn}{(0{,}85.f'c)}}\right)$

The ratio of the reinforcement to be used must be greater than or equal to ρmin and must be less than or equal to ρmax.

Minimum reinforcement ratio $\rho min = \left(\frac{1{,}4}{fy}\right)$

Maximum reinforcement ratio $\rho max = 0{,}75.\rho b$

Used reinforcement ratio $\rho min < \rho need < \rho max$

After obtaining the reinforcement ratio that meets the requirements, the area of the reinforcement can be calculated.

Area of reinforcement used, $As = \rho.b.d$

After knowing the area of the used reinforcement, the required amount of reinforcement (n) can be found by dividing the area of the used reinforcement (As) by specified area of reinforcement and if (n) is rounded up to largest value.

Amount of reinforcement required $n = \frac{A_S}{\frac{1}{4}\pi D^2}$

With:

f’c = Compressive strength of concrete

fy = Steel yield stress

b = Barrier width

d = Effective barrier thickness

D = Diameter of reinforcement used

3. Barrier shear reinforcement design

The shear reinforcement in this barrier is used to bind the flexible reinforcement and withstand the barrier so that it is not damaged by shear forces, here is the formula:

Ultimate shear style

$Vu = \frac{Mu}{L}$

Nominal shear strength of concrete

$Vc = \frac{\sqrt{f'c}}{6} b.d$

${}^{1}/_{2}\, \varphi Vc < Vu$ need shear reinforcement

${}^{1}/_{2}\, \varphi Vc < Vu$ doesn't require shear reinforcement

If you need shear reinforcement on the supporting pile elements, then continue with finding the shear strength that must be resisted by the shear reinforcement steel.

$Vs = \frac{Vu}{\varphi} - Vc$

Area of shear reinforcement

$Av = n.\frac{\pi}{4}.D^2$

Required shear reinforcement distance

$s = Av.fy.\frac{d}{vs}$

With:

Vu = Ultimate shearing style

f'c = Compressive strength of concrete

fy = Steel yield stress

b = Barrier width

d = Effective barrier thickness

D = Diameter of reinforcement used

2.8.2. Bridge Slab Plan

The function of this bridge floor is a traffic floor. The floor plate of this bridge uses a one-way plate, namely a plate that is only supported on two opposite sides, or a plate that is supported on all four side but Ly/Lx > 2.

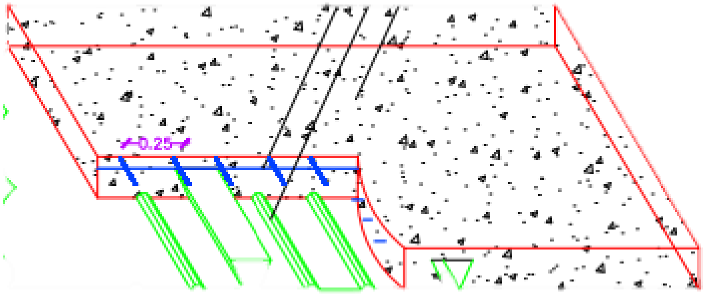


Figure 2.10 Slab

1. Loading slab

Calculation of the ultimate moment of the vehicle slab plan using the following formula.

$Mu = K_{MS} + K_{MA} + K_{IT}$

With:

MA = Moments caused by self-weight

MS = Moment due to additional dead load

TT = Moment caused by truck load

K = Ultimate load factor

2.8.3. Design of Prestressing Girder Section

The design of this prestressed concrete beam is based on the work load, allowable stress and assumptions based on the RSNI T-12-2004 regulation, and for strands of wire or often referred to as tendons, refer to the ASTM A-416 specification which a limit strength of 1720 Mpa or 1860 Mpa. The specialty of the 7-wire strand is that it has a larger wire than the outer six wires that wrap it.

Table 2.11 7 wire strand properties (ASTM A-416)

Nominal diameter	Breaking strength	Nominal area of strand
*Degrees 1720 Mpa		
63,5	40	23,22
7,94	64,5	37,42
9,53	89	51,61
11,11	120,1	69,68
12,7	160,1	92,9
15,24	240,2	139,35
*Degrees 1860 Mpa		
9,53	102,3	54,84
11,11	137,9	74,19
12,7	183,7	98,71
15,24	260,7	140

(Source: ASTM A-416)

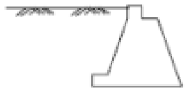
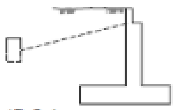
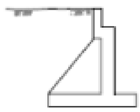
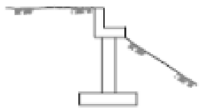
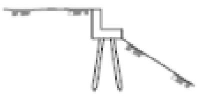
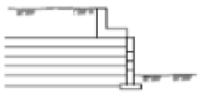
2.9. BRIDGE BOTTOM STRUCTURE DESIGN

In the design of the substructure bridge, it plays an important role in withstanding the loads received from the superstructure of the bridge, so that the planning of a substructure must be calculated and planned as well as possible so that there is no construction failure.

2.9.1. Abutments

These abutments are located at each end of the bridge and are used to receive loads from the superstructure and are channeled to the foundation and provide lateral support to the soil around the bridge.

Table 2.12 Type of abutments

JENIS PANGKAL		TINGGI TIPIKAL (m) 0 10 20 30
PANGKAL TEMBOK PENAHAN GRAVITASI		3 4
PANGKAL TEMBOK PENAHAN KANTILEVER	 Optional Tie-Back	8
PANGKAL TEMBOK PENAHAN KONTRAFORT		6 8
PANGKAL KOLOM SPILL-TROUGH		
PANGKAL BALOK CAP TIANG SEDERHANA		
PANGKAL TANAH BERTULANG		5 15

(Source: Bridge engineering planning, DJBM PU 1992)

Calculate the moment about rolling

Safety rolling value

$$SF = \left(\frac{\sum Mp}{\sum M}\right) > 1{,}5$$

Calculate of rolling

$$\sum Mp = P.\frac{Bx}{2}.(1 + k)$$

With:

$\sum Mp$ = Overturning moment

Bx = Abutment width X direction

P = Number of vertical direction forces

$\sum M$ = Sum of moments for horizontal load

k = percent of allowable overload

Calculate the moment about shear

$SF = \left(\frac{\sum Hp}{\sum M}\right) > 1{,}5$

Withstand shear force

$\sum Hp = \left(C.B_x.B_y + P\ tan\theta\right).(1 + k)$

With:

$\sum Hp$ = Withstand shear force

C = Soil cohesion

Bx = Foundation width x direction

By = Foundation width y direction

P = Abutment loading

k = percent of allowable overload

Calculate ground stress

$\sigma_{max} = \frac{\sum V}{A} + \frac{\sum M}{\frac{1}{6}b.h^2} < \sigma_{ijin}\ soil$

With:

b = Foundation width

A = Base area of foundation pila cap

$\sum V$ = Nominal of vertical direction force

$\sum H$ = Nominal of Horizontal direction force

2.9.2. Pile cap

This pile cap is a construction that can withstand the load given form the superstructure to the foundation, this pile cap collects several foundations so that they can withstand the load optimally and can spread the load not only to one foundation but to several foundations.

Figure 2.11 Pile cap planning

Pile cap rolling stability

$Mgl = (0{,}5.Bx.P) + Mv\ tot$

With:

Bx = Width of the pile cap longitudinal direction of the bridge

P = Total vertical load

Mv tot = Total of vertical moments of the force generated by the structure

Mgl = Moment withstand rolling

Pile cap shear stability

$Hp = (C.Bx.By) + (P.tan\Phi)$

With:

C = Soil cohesion at the bridge site (form soil investigation)

Bx = width of the pile cap longitudinal direction of the bridge

By = width of the pile cap transverse direction of the bridge

P = Total vertical load

Φ = Soil friction angle (from soil investigation)

Stress that occurs at the base of the pile cap due to axial force and moment (Qmax)

$$Q_{max} = \frac{P}{Bx.By} + \frac{Mh\ tot}{L.B_x^2 + \frac{1}{6}}$$

With:

Bx = width of the pile cap longitudinal direction of the bridge

By = width of the pile cap transverse direction of the bridge

P = Total vertical load

Mh tot = Total horizontal load

L=By = width of the pile cap transverse direction of the bridge

2.9.3. Pile Foundation

The foundation is a construction that can withstand the loads of the superstructure and transmit these to the soil. In this study using a pile foundation because the location is crossed by a river and can save time on foundation work.

This pile foundation planning uses the static method (using the principles of classical soil mechanics). For the static method using triaxial data, N-SPT and sondir. The essence of this formula is the calculation of the pile bearing capacity to determine the end resistance of the soil (Qe) and frictional resistance or soil bonding to the pile (Qs).

a. Based on data N-SPT method Luciano Decourt (1987)

$$Qu = \left(As \times \left(\frac{Ns}{3}\right) + 1\right) + Ae \times Ne \times K$$

b. According to Meyerhof

$$Qu = 40Ne.Ae + 0,2\ Ns.As$$

Where:

Qu = Ultimate bearing capacity of pile foundation (ton)

Ne = The value of N-SPT at the end of the pile

Ae = Cross-sectional area at the end of the pile (m^2)

As = Area on pile blanket (m^2)

Ns = Average N-SPT value

SF = Factor of safety, taken 3 or 5

c. According to US Army Corps

Ultimate end resistance (Qe)

Qb = Ae qe

qe = Pe' Nq

Skin friction resistance (Qs)

Qs = As qs

$qs = K_d \times tg\delta$

d. According to Briand et al (1985)

Frictional resistance unit (Qs)

$Qs = fs.As$

$fs = 0{,}224\ \sigma r(N'_{60})^{0,29}$

Ultimate end resistance (Qe)

$Qe = fe.As$

$fe = 19{,}7\ \sigma r(N'_{60})^{0,36}$