ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

COMPUTER PROGRAM FOR COMPARATIVE STUDY OF THE ANALYSIS AND DESIGN OF SLAB AND T- GIRDER BRIDGES.

ABRHAM GEBRE

JULY 2006

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BY ABRHAM GEBRE

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING.

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Declaration

I the undersigned, declare that this thesis is my work and all sources of materials used for this thesis have been duly acknowledged.

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This Thesis is Dedicated to my Families

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List of Symbols

A_{di} = Area of distribution reinforcement, interior strip of a slab bridge
A_g = gross concrete area
A_{gc} = gross area of uncracked section
A_{pi} = area of steel provided for interior strip of a slab bridge.
A_{pn} = area of negative moment reinforcement
A_{pp} = area of positive moment reinforcement
A_r = shear forces at the left of support A
A_{ro}=shear forces at the right of support A
A_{rt} =reaction at support A
a_s= area of shear reinforcement
A_{s1}= area of positive moment reinforcing bars
A_{s2} = area of negative moment reinforcing bars
A_{s6}= area of reinforcement, exterior girder
A_{s7}= area of reinforcement, interior girder
A_{sti} = area of reinforcing bars provided in interior strip
b_e= effective width of the exterior girder
b_{ii}= effective width of the interior girder
b_{min} = the minimum web width
B_r = reaction at support B
B_{r1} =shear forces at the left of support B
B_{r2}=shear forces at the right of support B
b_t= Bitumen thickness
B_{t3} = negative moment at joint B
C_{ci} = depth of the Neutral axis, interior girder
C_d = additional curb depth
C_f, C_{f1} =influence segment coefficients for moment
C_s= Clear Span of the Bridge
C_w= additional curb width
d_1 = effective depth for interior strip of a slab bridge
d1t = diameter of temperature bars
db = diameter of main reinforcing bars for slab bridge and T- girders.
dd = diameter of the distribution bars used
dd1 = diameter of the distribution bars used
d_e = effective depth for edge strips of a slab bridge
d_{ig}= depth of the interior girder capable of carrying the design moment
d_{ki}= deflection due to each truck load
d_{Kt} = total live load deflection
d_{li} = diaphragm load on interior girder

d_{le} = diaphragm load on exterior girder

d_{max}= maximum permissible deflection

d_n = effective depth for negative reinforcement

d_p = effective depth for positive reinforcement

d_{pn}= effective depth of the exterior girder

d_{pp}= effective depth of the interior girder

dst= diameter of shear reinforcement

dt = diameter of the temperature bars used, for slab bridge

d_{tic}= depth required for carrying the maximum moment

d_{tl} = deflection due to tandem load

d_v= effective depth for max shear

E_c= Modulus of elasticity of steel

E_e = Edge strip width of a slab bridge

E_i = equivalent transverse strip width

E_{m1}= interior strip width of a slab bridge

E_s= Modulus of elasticity of Steel

E_w = equivalent width

F_c=Cylindrical compressive strength of concrete

F_{cten}= tensile strength of the concrete

f_f = stress range

f_{min} = minimum live load stress

F_r= modulus of rupture

F_y=Steel strength

G_s= Girder Spacing

I_{cr} = critical moment of inertia for positive reinforcement, interior strip

I_{cre} = critical moment of inertia for negative reinforcement, edge strip

I_{crt}= critical moment of inertia for the whole section of a slab bridge.

I_{eff}= effective moment of inertia exterior girder

I_{gex} = gross moment of inertia

L_1 = C/C span length of the bridge

L_{1a}= position of the wheel load

M = design maximum negative moment at support B

m_1,m_2,m_3 = Influence line coefficients for shear force due to truck loads

m_1',m_2',m_3'= Influence line coefficients for moment due to truck loads

M_{11} = positive moment at support A

M_{ad}= maximum dead load moment of a slab bridge

M_b = support moment at support B

M_{BM} = maximum negative moment at support B

M_{bp} = moment due to railings and posts at support B

M_{bw}=support moment at support B due to wearing surface

M_c = support moment at support C

M_{cp} = moment due to railings and posts at support C
M_{cr}= critical moment of the whole slab bridge
M_{crex}= critical moment for the exterior girder.
M_{cw} = support moment at support C due to wearing surface
M_{DC} = total moment due to deck slab
MD(L_{1a})= Factored design moment at L_{1a} distance, interior Strip
MDe(L_{1a})= Factored design moment at L_{1a} distance, exterior Strip
M_{dfi}, M_{dwi} = moments carried by the flanges and webs
M_{dl}= Moment due to dead load for interior strip of a slab bridge
M_{dle}= Moment due to dead load , edge strip
MDU(L_{1a})= Unactored design moment at L_{1a} distance, interior Strip
M_{DW} = total moment due to wearing surface
M_e = end moment at support A for exterior girder
M_{ew} = end moment at support A due to wearing surface for exterior girder
mg_1 = distribution factor for moment of interior beams for one lane loaded
mg_2= distribution factor for moment of interior beams for two lanes loaded
M_{gd}= Distribution factor for deflection
mgev = distribution factor for shear of exterior beams
mgv_1, mgv_2 = distribution factors for shear
M_{lld}= total moment due to dead and live load of the whole slab bridge
M_{llf} = maximum moment per meter width for fatigue
M_{maxp} = maximum positive moment
M_{mf}= maximum moment for fatigue
M_n = maximum interior negative live load moment
M_{oh} = overhang moment at support A
M_{om11}= maximum moment of interior and exterior girders.
M_{p1} = maximum positive moment at support A
M_{pn} = negative maximum moment for service limit state
M_{pp}= positive max. moment for service limit state
M_{rp} = end moment at support A due to railings and posts
M_{tml} = moment at a distance L_{1a} due to tandem and lane loads
M_{trl} =Moment at a distance L_{1a} due to truck and lane loads
M_{USe}(L_{1a})= Unfactored design moment at L_{1a} distance, exterior Strip
N= modular steel ratio
n_1, n_2 = Influence line coefficients for shear force due to tandem loads
n_1',n_2'= Influence line coefficients for moment due to tandem loads
N_g = total number of girders
NL= number of lane loaded
N_{mom} = negative moment at support A
P_1, P_2 =Truck loads
P_3 = Tandem Load

P_d= Post depth made of concrete
P_e = percentage of distribution reinforcement
P_h= Post height
P_{LL1}, P_{LL2} = the factored truck loads
P_n = total number of posts
P_s= Post spacing
P_{stl} = single concentrated tandem load
P_w= Post width of concrete
R_A = total reaction at support A
R_{a31}= reaction at support A
R_{ae1} = reaction transferred to external girders due to DL of deck slab
R_{ae2} = reaction transferred to external girders due to DL of wearing surfaces
R_{ai1}=reaction transferred to internal girders due to DL of deck slab
R_{ai2} = reaction transferred to internal girders due to DL of wearing surfaces
R_{b11} =shear force at left of support B
R_{b12} =shear force at right of support B
R_{b31} =shear force at left of support B
R_{b32} =shear force at right of support B
r_{bw}= shear force at left of support B
r_{bwo} = shear force at right of support B
R_d= Railing depth of concrete
R_{m1}= maximum reaction at support B
R_{m3} = reaction at support B
R_{min} = minimum steel ratio
R_{rm1} = reaction transferred to girders
R_{rm3} = maximum live load reaction on the exterior girder
R_w= Roadway width of the Bridge
R_{ww}= Railing width of concrete
R_{1f} , R_{2f} = reactions at right & left supports due to truck load, respectively
S_{di}= Spacing of distribution bars
S_e= Spacing of main bars
$S_{st=}$ Spacing of temperature bars for a girder bridge
S_{ti}= Spacing of temperature bars for a slab bridge
S_x = Clear spacing between girders
t_s = depth of deck slab of a girder bridge
U = Fatigue load
V_{cc}= Allowable shear stress of concrete
VD= design maximum factored shear force
V_{dl}= Shear force due to dead load for interior strip of a slab bridge
V_{dle}= Shear force due to dead load for exterior strip of a slab bridge
V_{se}= critical shear, exterior girder

V_{si}= critical shear for interior girder

V_{tml}=shear force at a distance L_{1a} due to tandem and lane loads.

V_{trl} =shear force at a distance L_{1a} due to truck and lane loads.

W_c = dead load due to curbs

W_{dc} = dead load of the deck slab

W_{dd}=total dead load of the whole Slab bridge

W_{ddc}=total dead load of the whole Slab bridge excluding load due to wearing surface

W_{ddw}=total dead load of the Slab bridge of the whole bridge due to wearing surface

W_{de} = total dead load edge strip

W_{di}= total dead load interior strip

W_{dw} = dead load due to wearing surfaces

W_{oh} = weight of the overhang slab

W_p = load due to posts

W_{ra} = dead load due to railings

W_{rs}= Support width

W_s = weight of the deck slab for a girder bridge.

W_W= own weight of the web for a girder bridge.

X_2 = neutral axis depth for the deck slab

X_{22} = neutral axis depth from top fiber, interior girder

X_{23} = neutral axis depth from top fiber, exterior girder

X_3 = neutral axis depth from top fiber, for edge strip

Y_b= Bituminous density

Y_{bt}=Neutral axis depth from the bottom of a slab bridge

Y_c= Concrete density

Y_t= location of Neutral Axis from bottom for the whole of a slab bridge.

Z= Crack width parameter

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Abstract

Ethiopia is one of the mountainous countries in Africa. This topographic condition such as rough terrain, deep gorges of the country; river crossings and other factors aggravate the difficultness of construction of roads in the country without constructing crossways which include culvert and bridges. Thus, Bridges are vital structures required during roads construction.

The type of structure in design standard is selected on the basis of openings span in which culverts span 1 to 6m, slab bridge span 6 to 15, and up to 18m with provision, while T-Girder bridge span 10 to 20m, where sometimes span up to 24m.

The site visit during this study also reveals that slab bridges up to 12m and T-Girder bridges as low as 9m span have been recorded. This lead to the requirement of the standard to narrow the span gap at the boundary for selecting slab or T-Girder in the range of 10 to 15m spans.

In line with this the thesis of this study focused on developing computer program for analysis and design of slab and T-Girder bridges, in due cause solving the design problem of economical spans for slab and T-Girder bridges.

A comparative study on the basis of cost of materials is conducted to select and identify the economical span range of slab and T-Girder bridges. The developed program is illustrated using particular example of both slab and T-Girder bridges.

The study has come with solution based on the prevailing rates of construction cost to be adopted for design Engineer’s use.

1. Introduction

1.1. Background

Bridge construction in Ethiopia was early started on Blue Nile near Alata, Almeida Bridge, where thick log is placed across the narrow rocky banks. During the period following Fassiledes (after 1667) it is said that many bridges were constructed in Gonder and Lake Tana area [6].

In Addis Ababa, the first bridge was constructed on Kebena River in 1902 by a Russian engineer after their compatriot was drowned. The second was Ras Mekonnen Bridge, arch type bridge, in 1908 [6]. Quite considerable numbers of bridges were constructed in the years 1935-1945, the years of occupations by Italians. Notable bridges have been constructed since 1970's (i.e, during the last 30 years). A bridge on Baro River with a total span of 305m is one of the longest span bridges in the country, constructed during this period [6]. Slab and T- Girder bridges made using reinforced concrete, mostly with simple supports but either single span or spans in series are the most commonly used bridges in Ethiopia.

Most of the bridges so far constructed have now been widened and replaced because their roadway widths were too restrictive for the safety of accommodating modern traffic. Moreover, due to new roads are envisaged to connect communities, corresponding new bridges are also designed and constructed whenever obstruction are encountered.

1.2. Objective

- The specific objective of this thesis is to prepare a computer program for Analysis and Design of the superstructure of Slab and T- Girder Bridges following the Ethiopian Roads Authority Bridge Design Manual, nationally accepted standard and use same in the selection of type of bridge, based on the demarcation span using cost as the basis of comparison. Thus from the result obtained, one can easily identify the demarcation span length during selection of the bridge type with a better degree of accuracy instead of giving a range of span lengths.

- The most appropriate type used or to be used can be selected with the aid of the developed program.

- The program is locally developed following the recently prepared Bridge Design Manual by Ethiopian Roads Authority (ERA), 2002 and also reference is made to Addis Ababa City Roads Authority (AACRA), 2004. It is easy to amend or modify whenever necessary as the source program is at our disposal. It is also cheaper in cost compared with imported softwares, flexible and simple to use.

1.3. Content of the Thesis

This thesis consists of seven chapters. The first chapter deals with the general background of bridge construction in Ethiopia and the objectives of the thesis, and outcome of the study.

The second chapter is devoted to discuss the literature survey carried on types and classification of bridges, how span of bridges is determined, and problems associated with selection of bridge type, especially at around the boundary.

The third chapter addresses the condition survey of selected bridges, undertaken by the researcher, which comprises of the Site Visit in aggregate and observations during the visit and discussion on findings.

The fourth chapter focused on design consideration of Slab and T-Girder bridges, with specific attention on loadings, material properties and design assumptions made. Moreover, it also addresses the design specification to be considered during analysis and design of bridges as per the standards stated in the Design Manuals and general standards. The core and specific input of the researcher is presented under this chapter, indicating all the necessary steps and calculations used in developing the program using “FORTRAN 90”. The selection criteria of bridges are also specified.

The flow charts and an Algorithm for analysis and design of the two types of bridges under considerations are presented in chapter five, Computer Program for Design of Slab and T-Girder Bridges.

Chapter six is devoted for demonstrating the application of the developed program and illustrates using practical examples. Further, summary of the outputs, cost analysis for different spans and comparisons carried are also included.

The last chapter of this thesis is made to contain the conclusions drawn from the outputs based on the developed program and the recommendations on the basis of the findings. With in demarcation span method is developed to select type of bridge on the basis of cost analysis.

1.4. Applications and Limitations

Applications

- The computer program developed will be applicable for Analysis and Design of Slab and T-Girder Bridges for any span length and also perform the selection of bridge type either Slab or T-Girder on the basis of economy.

- The program shall benefit Engineering Consultants and bridge constructors (contractors) in the checking and design review works and simplifies to look matters of optimal solution. Moreover, the department may use this for future research in line with up grading the program to handle many other aspect of bridge design.

Limitations

In developing the program the following are only taken into account.

- The cost analysis of bridges does consider only construction costs.
- The superstructure cost of the bridge is considered for economical analysis since it is assumed that the substructures are the same for both slab & T-girder bridges of having the same span length.
- For purpose of this program, bearings are not designed and locally produced steel bearings are considered.
- The program is developed for single span bridges.

2. Basics of Bridges Parameters

2.1. General

Bridge Engineering covers the planning, design, construction and operation of structures that carry facilities for the movement of humans, animals, or materials over natural or created obstacles. The obstacles may be a river, valley, road or highway. The passage may be for highway or railway traffic, pedestrian, canal or pipeline [6].

2.2. Types and Classification of Bridges

Some units of bridge construction are similar to those of building construction and serve similar purposes. These include footings, piers, caissons, walls, columns, beams, slabs, girders etc. However, the bridge designer has somewhat more freedom than the building designer in combining these units in the finished bridge structure.

2.2.1 Types of Bridges

There are numerous types of bridges where for a particular site condition, more than one type of bridge may be equally proposed on the basis of cost, time of construction or resource available. The type of bridge most suitable for a particular site can be selected after rough calculation is estimated based on costs of construction and maintenance [7].

The types of bridges for general use fall under the following category [7]:

i. Simply supported bridges, is suitable for short spans.
ii. Balanced cantilever bridges, good for increased span and are mostly of reinforced concrete and/ or pre-stressed concrete construction.
iii. Multiple but simple spans in series, used for medium or long span bridges.
iv. Continuous beams: advantageous over simple spans for reduced weight, greater stiffness (smaller deflection), and less number of bearings. Continuous spans also provide redundancy and hence greater overload capacity than simple spans.
v. Arch Bridges: suitable for large spans.
vi. Rigid frame bridges: where the horizontal deck slabs are made monolithic with the vertical abutments walls and are economically suitable for moderate-medium span lengths.

2.2.2 Classification of Bridges

Bridges can be classified on the basis of the following characteristics [10]:

1. Construction material as Steel, Concrete, Timber or combination of any two or more.
2. Span length as short, medium or large.
3. Structural forms as Slab, T-Girder, Box Girder, Arch, Suspension etc.
4. Span type as single or multi-span.

Reinforced Concrete is used extensively in highway bridges in short and medium spans because of its economy, durability, low maintenance costs, adaptability to horizontal and vertical alignments and ease of construction. The major advantage in the use of concrete bridges is the wide variation that can be achieved in form [3].

Concrete can be used in many different ways and often many different configurations are feasible. However, market forces, projects and site conditions affect the relative economy of each option and this lead to selecting the different forms of bridge as slab, T or Box Girder, Arch etc.

Slab Bridges

Single span slab bridges are perhaps the most common forms of bridges in Ethiopia. It is indicated in design manual that they can be economical for spans from 6 m to 15 m. However above 15 m they should preferably be ribbed [5]. In accordance with AACRA Bridge Design Manual of 2004 on the other hand, slab bridges are selected for a span length ranging from 6-12m [1]. Slab brides are most commonly used to short spans ranging from 10-12m [2].

Substructure costs are excessive due to the limited distance between supports. With open railings, slab spans can become a better solution for low headroom stream crossings where occasional flood inundation is expected.

The construction is much simpler and placement of concrete and steel is easy. The cost of formwork and labor is also much less.

Girder Bridges

Girder bridges are usually used for single span bridges, or non-continuous girders in multi-span bridge, simple span in series. They shall be used for span lengths between 10 – 25 m [5] and ranges from 10 – 20 m [7]. And as of AASHTO 1998, T- Girders are used for bridges spanning from about 10-25m [2].

T-beam bridges are generally more economical for spans of 12-18m [9]. In accordance with the LRFD design method, materials used are minimized when the numbers of girders/beams are less in number [2].

A closer spacing of girders results in a thin slab and number of bearings required are more. On the other hand, wider spacing between girders give thicker slab but lesser number of girders, resulting in less cost of formwork and less number of bearings. In a situation where formwork is expensive, bearings are considerably expensive and materials are relatively cheap, a wide spacing of girders shall be economical [7]. On the other hand, where formwork is cheap and materials are costly, closer spacing is desirable. Diaphragms are provided to connect main girders at suitable intervals, where maximum spacing of these cross-girders is 10m [5].

2.3. Span Determination

The span of a bridge is mainly determined on the basis of economy, hydraulic requirement, and location of the bridge site.

Economical Span

For a given linear waterway, the total cost of the superstructure increases while the total cost of the substructure decreases, with increase in the span. The most economical span length is that for which the cost of superstructure equals the cost of substructure, the point at which the total cost is the minimum [6].

The cost of a bridge is the total cost of substructure and superstructure. For small variation in span, the cost of pier will not be affected so also the cost of deck slab will be the same for any small variation in span length [7].

Clause 2.3.3 of ERA Bridge Design Manual states that the most economical bridge design depends on Structural types, span lengths, and materials selected, for this purpose these essentially characterize the overall projected cost [5].

If data for the trends in labor and material cost fluctuation are available, the effect of such trends can be projected to the time the bridge will likely be constructed.

2.4. Selection of Bridges

Typically there are 3-4 viable structure types for each span length [1]. The following guidelines have been suggested for the selection of types of bridges.

1. Bridges in which the load effects are governed by a single actual vehicle on the span can be considered as short-span bridges (up to 20m).
2. Bridges in which the maximum load effects are governed by a train of moving vehicles can be considered as medium-span bridges (20m-125m).

2.4.1. Background of Selection

In the selection of bridge type, there is no unique answer. For each span length range, there is more than one alternative bridge type that will satisfy the design requirements. The exact solution will be dependent on the various construction methods, materials and current market price adopted. There are regional differences and preferences because of available materials, skilled workers, and knowledgeable contractors.

2.4.2. Particular Problem of Selection

Design Manuals recommend span lengths to be criteria of selection of bridge types, such as Slab or T-Girder bridges.

ERA Bridge Design Manual recommends slab bridges can be economical for spans from 6 to 18 m and T–Girder bridges shall be used for span lengths between 10 – 25 m [5]. And as of AACRA Bridge Design Manual of 2004, slab bridges are used for spans from 6 to 12m and T-Girder spans from 10 to 20m [1].

Thus, there exist no clear demarcations on the selection of spans for Slab and T- Girder bridges if the span lies with in the intervals on the basis of economy. This is a serious design problem that Engineers face during selection of bridge type.

Up to recent period, bridge designers in this country have been adopting design loads and then the whole design, based on AASHTO LRFD method. However, trends have changed and demand to adopt the ERA 2002 and AACRA 2004 Bridge Design Manuals in conjunction with AASHTO as additional reference per the requirements of the projects administered by the respective Authorities. To this effect the program developed adopts the design provision of these locally developed design manuals, with special emphasis to the ERA Bridge Design Manual.

The objectives of a bridge design include safety, serviceability, economy, constructability and aesthetics. Thus, bridges can be selected essentially on the basis of safety, economy, and availability of construction materials, maintenance issues, and aesthetics. [1, 2 and 5]

2.4.3. Design Problem

The design of bridges requires the collection of extensive data and from these the selection of possible options becomes apparent [6].

A Bridge must satisfy a number of objectives which include [4]:

- Perform the function for which the bridge is intended,
- Obtain structurally soundness,
- Be economical,
- Aesthetically appealing.

For this, criteria have been set by almost all standards to serve as rule of thumb to select bridge type satisfying the above requirements. Nevertheless, there exists a situation where the designer is left with two or more alternatives especially when selecting bridge type on the basis of span length at around the boundary, in this particular work Slab versus T-girder bridges.

3. Condition Survey of Selected Bridges

3.1. Site Visit

In order appreciate the design problem, condition survey on existing bridges of concern in Addis Ababa, in its vicinity and outside Addis have been performed by means of site visit accompanied by desktop study.

Site visit area was selected arbitrarily and was conducted along the Welkite-Boterbocho road, located about 300km from Addis, southwest direction and within the vicinity of Addis Ababa.

A visit is also conducted on the road Addis to Burayo and other part of the city. But most of the bridges in the roads along Burayo are of arch type and small span slab culverts, except the Finance Bridge and a bridge near the area locally named “Enqulal Fabrica”.

During the visit, attention was given only to the two types of bridges (Slab and T-Girder Bridges), which is related to the study work, and the relevant dimensions are measured. These include bridges across the Main Gibe, Werabesa, Nano, and Kulit rivers along Welkite-Boterbocho road while in the vicinity of Addis Ababa and Addis include bridges near Civil Service College, Alem Gena, Adua Bridges and others, within Addis Ababa. Since the Adua Bridge is under construction for widening purpose, it is being surveyed two times where the first was made on the existing bridge and the second on its widened part during construction.

Brief surveyed summary and condition of each is provided underneath.

3.1.1. Main Gibe Bridge

Bridge Name: Main Gibe Bridge
Crossing: Gibe River
Bridge Location: About 300km Southwest of Addis Ababa
Bridge Type: T-Girder
Number of spans: 4
Span Length: 21m (each span)
Roadway width: 4.00m
Deck Depth: 0.20m
Girder Depth: 1.15m
Present Status: In good condition
Retaining Walls: Stone masonry

Piers: Reinforced concrete piers

Bearings Type: Not accessible

Problem observed: None

Figure 3.1 Main Gibe Bridge

3.1.2. Werabesa Bridge

Bridge Name: Werabesa Bridge

Crossing: Werabesa River

Bridge Location: About 270Km Southwest of Addis Ababa

Bridge Type: Slab

Number of spans: 1

Span Length: 9.40m

Roadway width: 5.70m

Deck Depth: 0.48m

Girder Depth: None

Present Status: In good condition

Retaining Walls: Stone masonry

Piers: None

Bearings Type: None

Problem observed: None

Figure 3.2 Werabesa Bridge

3.1.3. Nono Bridge

Bridge Name: Nono Bridge

Crossing: Nono River

Bridge Location: About 270Km Southwest of Addis Ababa

Bridge Type: Slab

Number of spans: 1

Span Length: 11.00m

Roadway width: 8.65m

Deck Depth: 0.52m

Present Status: In good in condition

Retaining Walls: Stone masonry

Piers: None

Bearings Type: None

Problem observed: None, except for less number of railings.

Figure 3.3 Nono Bridge

3.1.4. Kulit Bridge

Bridge Name: Kulit Bridge

Crossing: Kulit River

Bridge Location: About 245Km Southwest of Addis Ababa

Bridge Type: Slab

Number of spans: 3

Span Length: 8.65m

Roadway width: 4.50m

Deck Depth: 0.45m

Girder Depth: None

Present Status: In good condition

Retaining Walls: Stone masonry

Piers: made of stone masonry

Bearings Type: None

Problem observed: None

Photo: Not attached

3.1.5. Alem Gena Bridge

Bridge Name: Alem Gena Bridge

Crossing: - Alem Gena River

Bridge Location: About 15Km South of Addis Ababa

Bridge Type: T-Girder

Number of spans: 1

Span Length: 9.00m

Roadway width: 4.50m

Deck Depth: 0.20m

Girder Depth: 0.70m

Present Status: In good condition

Retaining Walls: Stone masonry

Piers: -None

Bearings Type: Steel Bearings

Problem observed: None

Figure 3.4 Alem Gena Bridge

3.1.6. Bridge near Civil Service College

Bridge Name: At present time it is known by Civil Service Bridge.

Crossing: Welgemu River

Bridge Location: Addis Ababa

Bridge Type: T-Girder

Number of spans: 2

Span Length: 9.20m

Roadway width: 10.70m

Deck Depth: 0.20m

Girder Depth: 0.68m

Present Status: In good condition, except for the bridge on the other side.

Retaining Walls: Stone masonry

Piers: - Reinforced Concrete

Bearings Type: Steel Bearings

Problem observed: opposite part of the bridge is damaged, water leaking through the expansion joint, the masonry are poorly pointed and scour problem at the foundations of the abutments.

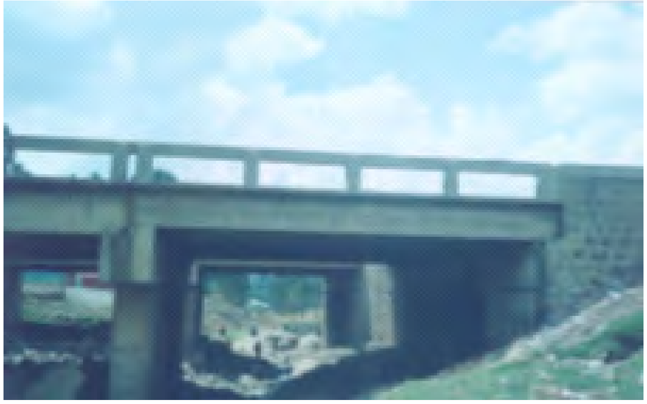


Figure 3.5 Civil Service Bridge

3.1.7. Adua Bridge (The Old one)

Bridge Name: Adua Bridge

Crossing: - Adua River

Bridge Location: Addis Ababa

Bridge Type: T-Girder

Number of spans: 1

Span Length: 16.20m

Roadway width: 9.20m

Deck Depth: 0.20m

Girder Depth: 1.10m

Present Status: In good condition

Retaining Walls: Stone masonry

Piers: - None

Bearings Type: Steel bearings

Problem observed: Some debris are accumulated at one bearing

Figure 3.6 Adua Bridge

3.1.8. Adua Bridge (Under construction)

Bridge Name: Adua Bridge

Crossing: - Adua river

Bridge Location: Addis Ababa

Bridge Type: T-Girder

Number of spans: 1

Span Length: 12.50m

Roadway width: 10.5m

Deck Depth: Not constructed

Girder Depth: Not constructed

Present Status: In good condition

Retaining Walls: Stone masonry

Piers: - None

Bearings Type: steel bearings

Problem observed: None

Figure 3.7 Steel Bearings of Adua Bridge

3.1.9. Clinic Bridge

Bridge Name: Clinic Bridge /near Lidata Tsebel /

Crossing: - Tinshwa Akake river

Bridge Location: Addis Ababa

Bridge Type: T-Girder

Number of spans: 1

Span Length: 12.00m

Roadway width: 16.70m

Deck Depth: 0.25m

Girder Depth: 0.95m

Present Status: old and damaged

Retaining Walls: Stone masonry

Piers: - None

Bearings Type: steel bearings

Problem observed: bearings have rusted, posts and railings are corroded and damaged, top reinforcement of the curbs are exposed to the atmosphere, corrosion of reinforcements, poor pointing of masonry and water leaking down through abutments.

Figure 3.8 Clinic Bridge (Lideta Tsebel)

3.1.10. Sar Bet Bridge

Bridge Name: Sar Bet Bridge

Crossing: - Samuel River

Bridge Location: Addis Ababa

Bridge Type: T-Girder

Number of spans: 1

Span Length: 15.00m

Roadway width: 20.85 (a 4 lane bridge with 1.65m of medians)

Deck Depth: 0.30m (including wearing surface)

Girder Depth: 1.10m

Present Status: In good condition

Retaining Walls: Stone masonry

Piers: - None

Bearings Type: steel bearings

Problem observed: posts and railings at one side is damaged due vehicle collision, deterioration of concrete of the curbs, leaking of water at joints.

Figure 3.9 Sar Bet Bridge

3.1.11. Coca Cola Bridge

Bridge Name: Coca Cola Bridge

Crossing: - Saris Awash river

Bridge Location: Addis Ababa

Bridge Type: Slab

Number of spans: 1

Span Length: 10.00m

Roadway width: 21m

Deck Depth: 0.50m

Present Status: New Bridge

Retaining Walls: Stone masonry

Piers: - None

Bearings Type: None

Problem observed: None (New and the other wing is under construction).

Figure 3.10 Coca Cola Bridge

3.1.12. Gordeme Bridge

Bridge Name: Gordeme Bridge

Crossing: Gordeme River

Bridge Location: within Addis Ababa

Bridge Type: Slab

Number of spans: 1

Span Length: 9.60m

Roadway width: 6.90m

Deck Depth: 0.42m

Present Status: In relatively good in condition

Retaining Walls: Stone masonry

Piers: None

Bearings Type: None

Problem observed: Corrosion of steel, the wearing surface is eroded.

Figure 3.11 Gordeme Bridge

3.1.13. Finance Bridge

Bridge Name: Finance Bridge

Crossing: -

Bridge Location: Addis Ababa

Bridge Type: T-Girder

Number of spans: 1

Span Length: 16.8m

Roadway width: 12.0m

Deck Depth: 0.20m

Girder Depth: 1.15m

Present Status: In relatively good condition

Retaining Walls: Stone masonry

Piers: - None

Bearings Type: steel bearings

Problem observed: clogging of debris which results corrosion of bearings, the girders are poorly plastered, scour at the bed of abutment.

Figure 3.12 Finance Bridge

Samples of the Standard ERA Bridge Inspection Format have been used for during condition survey where two samples are attached as Annex I.

3.2. Discussion

3.2.1 Design

During condition survey, discussion with leading bridge professional of AACRA on how designs of bridges have been carried.

1. They used their own Bridge Design Manual (AACRA Bridge Design Manual of 2002). The manual includes drawings and detailing for each type of bridge span so that they are only checking the design calculations submitted by consultants and no specific check is made regarding selection of bridge type.

2. A length of 10m is a predetermined span (demarcation point for slab and T-girder bridges) set by the authority during investigating and preparing the design manual. And no bridges were constructed by the authority of Slab Bridge having a span exceeding 10m.

3. During checking design calculations, they use empirical formulas when computing reinforcements for deck slab of a girder bridge.

4. The standard of the constructed bridges by AACRA coincides with that of the ERA standard.

5. They used approach slabs for both slab and girder bridges to minimize the effect of road settlement at the approach.

3.2.2 Discussion on Site Findings

During the visit, the followings were observed:

1. A span of 9m T-Girder bridge is constructed, at the Alem Gena river crossing and an 11m span slab bridge was constructed on Nono river. Which are both in good performance but in both cases, the stipulated design standards are not met. There is no relevant reason why these types of bridges are selected instead of the other in each case.

2. The bridge located near Civil Service College is of closely spaced ribs. Although the specification states that a 9m span length is of Slab Bridge, this constructed bridge is of T-Girder Type.

3. The newly constructed Adua Bridge, the Sar Bet Bridge, Bridge near Lideta Tsebel and the Finance Bridge are of T-Girder type, having clear span of 12m, 15m ,12m and 16.8m, respectively. These bridges have no access to observe their bottom parts. Alternatively all of these bridges could have been slab bridges and one may raise what particular criteria were set

during selection of the bridge types, as the span length lies with in the demarcation up to 15m and for the 16.8m closely spaced ribs, for the ERA standard.

4. The Bridge near Lideta Tsebel is among those with poor performance; bearings have rusted, posts and railings are corroded, top reinforcement of the curbs is exposed for damage.

5. Slab bridges rest on the abutment after an asphalted layer is coated, whereas T- Girder bridges require bearings at the locations of both interior and exterior girders on both supports.

6. Visited is also made two bridges constructed by the authority (AACRA) and those under construction. The constructed bridges are obtained in a better performance, the posts are made of Reinforced Concrete and the railings are of steel pipe except the Alem Gena Bridge, which is fully made of a reinforced concrete barrier.

7. Locally produced steel bearings for the bridges are used for their low cost.

8. No approach slab is observed for all slab bridges so far visited. Nevertheless, holes are provided for both slab and T-girder bridges for floor drains.

9. For all the bridges surveyed, the abutments are made of stone masonry due to its low cost as compared to concrete bridge and also availability of construction material.

10. Among the bridges so far constructed using AACRA Bridge Design Manual of 2002, their performances are found satisfactory.

11. The exterior girder of the Finance Bridge, T- Girder type, having a span length of 16.8m, has bulged outward and this may be due to the difficulties of erection of formwork or due to excessive vibration during placing of concrete.

From the above observations, one can realize that no clear demarcation for slab and T- Girders were set and different authorities have their own standards. Thus, there is a need of identifying a clear demarcation of span length for selecting slab types on the basis of economy.

The above data indicates that among the bridges surveyed 62% of the bridges are with in the ERA standard and 80%of the bridges are with in the AACRA and AASHTO standards.

In due course, the bridges at Lideta Tsebel and Gordeme need to be replaced by new ones and the finance bridge has to be repaired. In addition to this, the bridges have to be frequently inspected and maintained as soon as possible prior to damages leading to a completely collapsed state.

4. Analysis and Design of Slab and T-Girder Bridges

4.1. General

4.1.1. Loadings

Loadings for the purpose of computing maximum adverse effect on any structural member of a bridge in general consist of the following [7].

1. Permanent Loads: Dead and Earth Loads
2. Transient Load: Live, Water, Wind pressure
3. Dynamic Loads: Earthquake Loads
4. Force effects due to superimposed deformations
5. Friction Forces
6. Vessel Collision

In addition to the stresses caused by the above loadings, the following stresses shall be taken into account:

i. Secondary stresses
ii. Temperature stresses
iii. Erection Stresses

Secondary stresses fall in to two groups:

- Stresses which are the result of eccentricity of connections &
- Stresses, which are the result of the elastic deformation of the structure, combined with the rigidity of the joints.

The load bearing capacity of an existing bridge is determined by a classification calculation together with a field inspection to determine the condition of the bridge.

A bridge is usually constructed to fulfill a well-defined function. Bridge design loadings are directly governed by the functionality requirement

Traffic Load (Recent Events): In an Axle Load Control Survey in Ethiopia in 1998, it was found that some 22% of the heavy trucks were overloaded. One vehicle had an axle load of 275 kN (27.5 tons), which is however still less than "the ultimate limit load" (145 kN + 4.3 * 9.3 kN/m lane load) * 1.75 = 323 kN. The maximum tandem axle load for one of the trucks was 215 kN/axle, which also is less than "the ultimate limit load" (110 kN + 4.3 * 9.3 kN/m lane load) * 1.75 = 262 kN.

The axle load of the other trucks was below 201 kN (20 tons). The maximum total tandem truck weight in the same report was 320 kN (32,000 kg) plus a trailer of the same weight. This corresponds quite well with European results.

The "design tandem" for Ethiopia represents exceptional loading and is recommended as 2 nos. of 110 kN axles, excluding Dynamic Load Allowance. This results in a "safety factor" of some 45% for overloaded vehicles, which is deemed sufficient. This tandem load shall be applied for military vehicle loading, and for strategic bridges [5].

Design Truck: Design Vehicular Live Loads and Fatigue Loads, the spacing between the two 145 kN axles shall be varied between 4.3 and 9.0 m to produce extreme force effects [5].

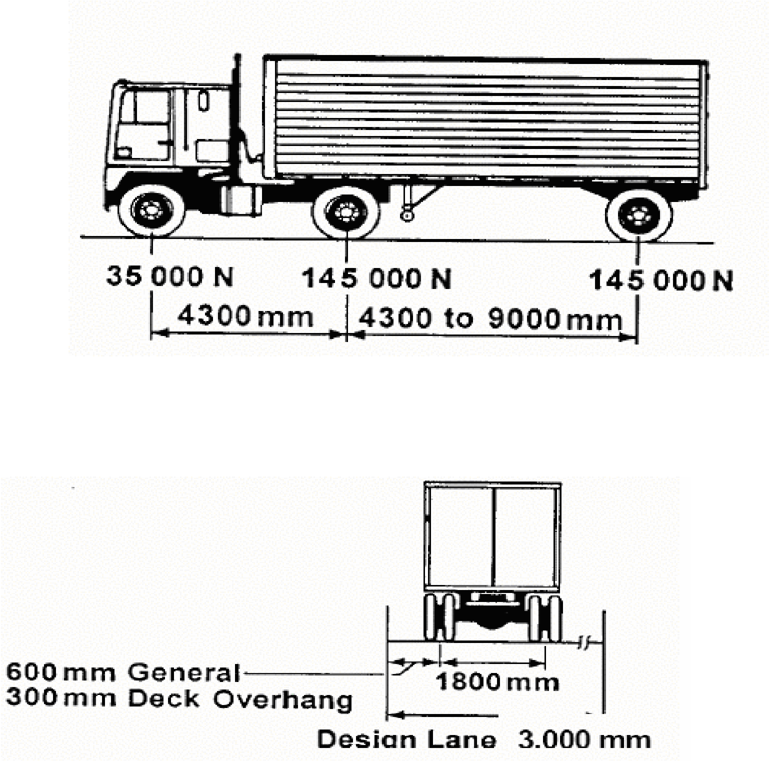


Figure 4.1 Characteristics of the Design Truck

Design Tandem: The design tandem used for Strategic Bridges shall consist of a pair of 110 kN axles spaced 1.2 m apart. The transverse spacing of wheels shall be taken as 1.8 m. A dynamic load allowance shall be considered [5].

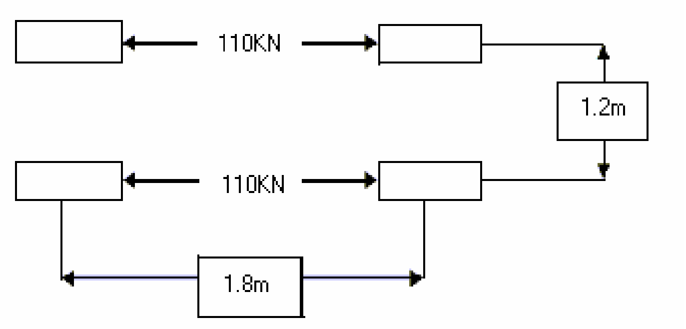


Figure 4.2 Design Tandem Load

<u>**Design Lane Load**</u>: The design lane load shall consist of a load of 9.3 kN/m uniformly distributed in the longitudinal direction. Transversely, the design lane load shall be assumed to be uniformly distributed over a 3.0-m width. The force effects from the design lane load shall not be subject to a dynamic load allowance (ERA Bridge Design Manual 2002, Clause 3.8.5).

4.1.2. Material Properties

Materials used in designing bridges of this program are as follows:

1. Steel strength of 400MPa for reinforcing bars of diameter greater than 20mm and 300MPa for less diameters.

2. The strength of the concrete is the 28th day cylindrical compressive strength of concrete. (f_c'=0.8*f_c where f_c is the150mm cube strength of same age)

3. The density of concrete is taken as 2400kg/m^3 for the computation of the modulus of elasticity of concrete, E_c, and 25kN/m^3 for dead load computations.

4. The modulus of Elasticity of Steel, E_s, is a constant and which is equal to 200GPa.

4.1.3. Assumptions

The following assumptions are made in developing the program.

1. Abutments are assumed to be the same for both slab and T-Girder bridges of the same span length. Thus, design of abutments and its associated costs are not taken into account for cost comparisons.

2. Although the dead loads of railings, curbs and posts are considered during the analysis, design and in quantity computations, it is assumed that the loads are the same for the same span of both Slab and T-Girder bridges.

3. For slab bridges of span having 10m and greater, a concrete bearing shelf is considered.

4. The cost of bearings for each T-Girder bridges is the same.

4.2. Design Specification

Span Length

The span of bridges is defined as [5]:

- For simple spans, the distance center to center of supports but needs not exceed clear span plus thickness of slab.
- For members that are not built integrally with their supports, the clear span plus the depth of the member but need not exceed the distance between centers of supports.
- Theoretical span length is the distance between the centers of bearings in the longitudinal directions.

Moreover, it is normally measured at the alignment and given as stations (or chanage).

Width of bridge deck: The width of the bridge corresponds with the roadway or carriageway width. It is to be measured between the inside of the railings or the curbs.

The clear width of bridge is defined as the distance between the inside of the outer railings including walkways, island/refuge and similar.

If the width will vary along the bridge all dimensions shall be provided. If not otherwise stated, per the ERA Geometric Design Manual-2002, a one-lane bridge shall not be less than 4.2 m wide and a two-lane bridge shall not be less than 7.0 m wide.

The dimensions for a one-lane bridge are based on the current ERA standard for Bailey bridge width as used for one-lane road.

The dimensions of 7.30m for a two-lane bridge are based on trucks of widths 2.4m, meeting with 0.7m clearances between them, and at the sides, the greater clearance allowing a higher average speed [5].

Table 4.1 Bridge Widths

Application	Width (m)
Two-lane in “urban” area	10.30
Two-lane in “rural” area	7.30
Single Lane	4.20
Pedestrian Overpass	3.0

Overall length of bridge and span length: For smaller bridges, the ground slopes at the abutments will often affect the overall length of the bridge. Therefore, it could be more economical to use some sort of retaining wall at the abutments such as stone masonry walls, gabions and reno mattresses, concrete block wall, etc. This will make the bridge shorter and, most probably, more economical.[5]

Dynamic Load Allowance: The factor to be applied to the static load shall be taken as: (1 + IM/100). The dynamic load allowance shall not be applied to pedestrian loads or to the design lane load. The table gives the Dynamic Load Allowance, IM [2 and 5].

Table 4.2 Dynamic Load Allowance, IM

Component	IM
Deck Joints – All Limit States	75%
All Other Components	
Fatigue and Fracture Limit State	15%
All Other Limit States	33%

Dynamic load allowance need not be applied to:

- Retaining walls not subject to vertical reactions from the superstructure, and
- Foundation components that are entirely below ground level.

The design specifications for different limit states per Table 3-1, ERA Bridge Design Manual, 2002, are adopted.

Load Factors and Load Combinations: In Load and Resistance Factor Design (LRFD) method, load factors per the provision of ERA 2002 Bridge Design Manual are applied to the loads and resistance factors to the internal resistances or capacities of sections [1, 2 and 5]
Moreover, the load combinations and load factors are considered accordingly.

Number of Design Lanes: Generally, the number of design lanes should be determined by taking the integer part of the ratio w/3000, where w is the clear roadway width in mm between curbs and/or barriers.
Possible future changes in the physical or functional clear roadway width of the bridge should be considered. In cases where the traffic lanes are less than 3.0 m wide, the number of design lanes shall be equal to the number of traffic lanes, and the width of the design lane shall be taken as the width of the traffic lane.

Multiple Presence of Live Load

The m-factors specified below shall not be applied in conjunction with approximate load distribution factors [2 and 5].

Table 4.3 Multiple Presence Factors "m"

Number of Loaded Lanes	1	2	3	>3
Multiple Presence Factors “m”	1.2	1.0	0.85	0.65

The value of m for a single lane was estimated at 1.2 on the basis of statistical calibration of these Specifications. When a single vehicle is on the bridge, it may be heavier than each one of a pair of vehicles and still have the same probability of occurrence.

- This provision shall not be adopted to fatigue limit state.
- Approximate methods can be also used other than the lever rule and statical method.

4.3. A step by Step Analysis and Design

4.3.1. Slab Bridges

4.3.1.1. Design Load

The loads that constitutes in the design of slab bridges are:

- Self-weight of the slab including loads due to railings, posts and curbs.
- Self-weight of the wearing surface if exists.
- Equivalent distributed live loads of vehicular loads (truck loads, lane loads and tandem loads), per meter width of strip.

4.3.1.2. Load Distribution

The above loads are distributed across the strips, both in the interior and edge strips.

4.3.1.3. Design Procedure

Depth Determination: Unless approved by ERA, the depth of a concrete deck, excluding any provision for grinding, grooving, and sacrificial surface, minimum thickness is provided as of Clause 7.4.1 of ERA Bridge Design Manual.

For durability, adequate cover shall be used as per the specification of ERA Bridge Design Manual, 2002.

The center to center distance of a bridge can be given by:

$S = (W_{rs} + C_s)*1000$

where:

S = Center to center distance of Bridge (mm)

C_s= Clear Span of the Bridge (m)

W_{rs}= Support width (m)

Minimum depth required,

$D=1.2*(S+3000)/30$ (mm) ………………………………………….... (4.1)

$d_1= D-25-0.5*db$ (mm) 25mm of concrete cover is used

$d_e= d_1+C_d$ (mm)

where:

d_1 and d_e are effective depths for interior and edge strips, respectively.

db= diameter of main reinforcing bars

Live Load Equivalent Strip Widths

The Equivalent width of longitudinal strips per lane for both shear and moment with one lane i.e., two lines of wheels and with more than one lane i.e., two lines of wheels, loaded for slab type bridges may be determined in accordance with ERA Bridge Design Specifications.

a) Interior Strip

$E = 250 + 0.42\sqrt{(S*R_{wt})}$ for one lane loaded (mm) ……………………….. (4.2)

$E_m = 2100 + 0.12\sqrt{(S*R_{wt})} \leq W/NL$ for multiple lanes loaded (mm)

Thus, Interior strip width, E_{m1}, becomes the lesser of E and E_m.

Where:

- L_1 = modified span length taken equal to the lesser of actual span length or 18m
- $R_{wt} = R_w + 2C_w \leq 9000$mm , total roadway width (m)
- NL = Number of lanes loaded = $R_{Wt}/3600$

b) Edge Strip

Longitudinal edge strip width, E_e

E_e, in mm, is the minimum of 1800mm and $(C_w+300+E_m/2)$…………………..(4.3)

Equivalent Concentrated and Distributed Loads

Interior Strip

The equivalent concentrated and distributed Loads per meter width of interior strip is given by:

Truck Load: $P_1 = 1.33 * 145/E_{m1}$; $P_2 = 1.33 * 35/E_{m1}$

(for a truck load of 145 and 35 KN, respectively)

Tandem Load: $P_3 = 1.33*110/E_{m1}$ (a tandem load of 110KN)

(1.33 is an impact factor, 33%)

Lane Load: $9.3/E_{m1}$ (a lane load of 9.3KN/m)

- in the above derivations E_{m1} is in meter.

Shear and Moment Calculations

Live Load Force Effects

i) Shear force and Moment for truck and lane loads

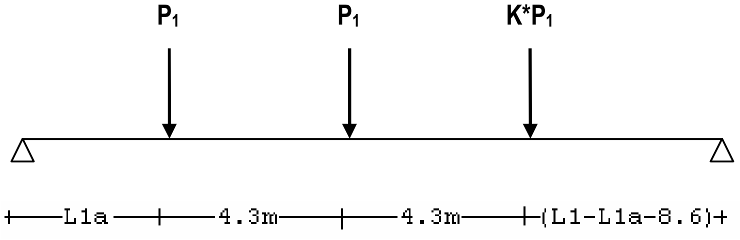


Figure 4.3 Truck moving to the right

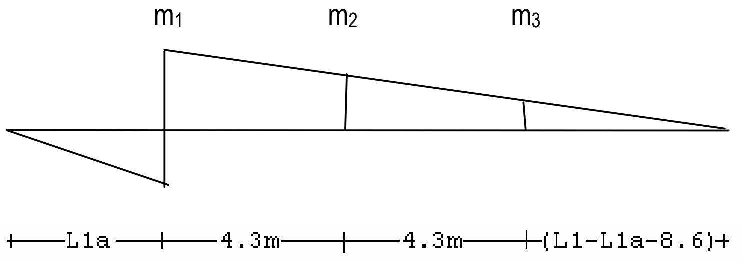


Figure 4.3.1 IL for Shear Force

Influence line coefficients for shear force

$m_1 = L_{1a}(L_1 - L_{1a})/L_1$

$m_2 = L_{1a}(L_1 - L_{1a} - 4.3)/L_1$

$m_3 = L_{1a}(L_1 - L_{1a} - 8.6)/L_1$

$K = P_2/P_1$

$V_{trl}= (P_1*m_1+P_1*m_2+K*P_1*m_3)+0.5*(L_1-L_{1a})*m_1$

$= P_1*(L_{1a}/L_1)*((L_1-L_{1a})+(L_1-L_{1a}-4.3)+K*(L_1-L_{1a}-8.6))+ 0.5*L_{1a}(L1-L_{1a})^2/L_1$

Where:

V_{trl} = shear force at a distance L_{1a} due to truck and lane loads.

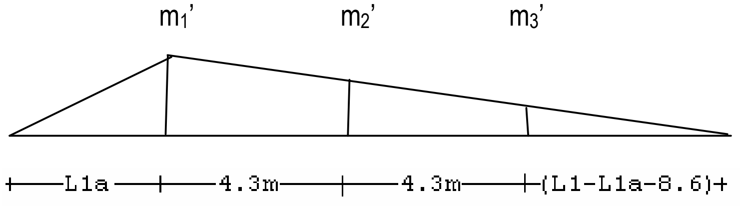


Figure 4.3.2 IL for Bending Moment

Influence line coefficients for bending moment

$m_1' = L_{1a}(L_1-L_{1a})/L_1$

$m_2' = L_{1a}(L_1-L_{1a}-4.3)/L_1$

$m_3' = L_{1a}(L_1-L_{1a}-8.6)/L_1$

$M_{trl}= (P_1*m_1'+P_1*m_2'+K*P_1*m_3')+0.5*(L_1-L_{1a})*m_1'$

$= P_1*(L_{1a}/L_1)*((L_1-L_{1a})+(L_1-L_{1a}-4.3)+K*(L_1-L_{1a}-8.6))+0.5*L_{1a} (L_1-L_{1a})^2/L_1$

Where:

M_{trl} is Moment at a distance L_{1a} due to truck and lane loads.

If the value in bracket is negative, then it is taken as zero. It implies that the wheel is out of the span.

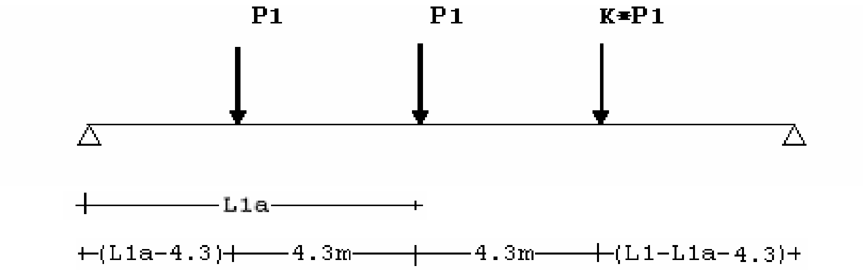


Figure 4.4 Truck moving to the Left

Influence Lines for Shear Force and Bending Moment

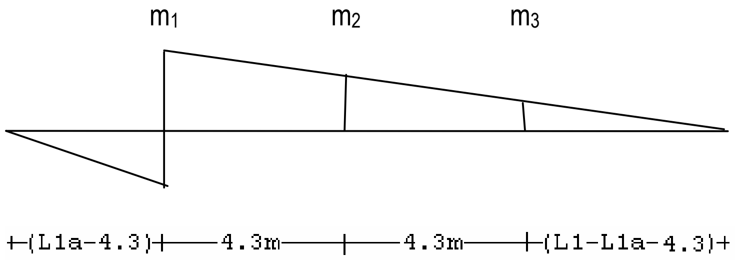


Figure 4.4.1 IL for Shear Force

Influence line coefficients for Shear Force

$m_1= (L_1-L_{1a})/L_1$

$m_2= L_{1a}(L_1-L_{1a}-4.3)/L_1$

$m_3= (L_{1a}-4.3)(L_1-L_{1a})/L_1$

$K=P_2/P_1$

$V_{trl}=(P_1*m_1+P_1*m_2+K*P_1*m_3)+0.5*L_1*m_1$

Where:

V_{trl} = shear force at a distance L_{1a} due to truck and lane loads.

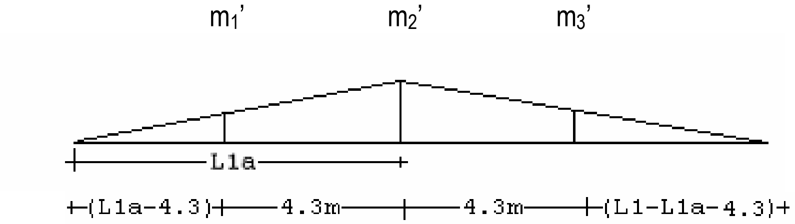


Figure 4.4.2 IL for Bending Moment

Influence line coefficients for Bending moment

$m_1'= (L_{1a}-4.3L_{1a})(L_1-L_{1a}+4.3)/L_1$

$m_2'= L_{1a}(L_1-L_{1a})/L_1$

$m_3'= L_{1a}(L_1-L_{1a-}4.3)/L_1$

$M_{trl}=(P_1*m_1'+P_1*m_2'+K*P_1*m_3')+0.5*L_1*m_1'$

Where:

M_{trl} is Moment at a distance L_{1a} due to truck and lane loads.

If the value in bracket is negative, then it is taken as zero. It implies that the wheel is out of the span.

ii) Shear force and Bending Moment for Tandem and lane loads

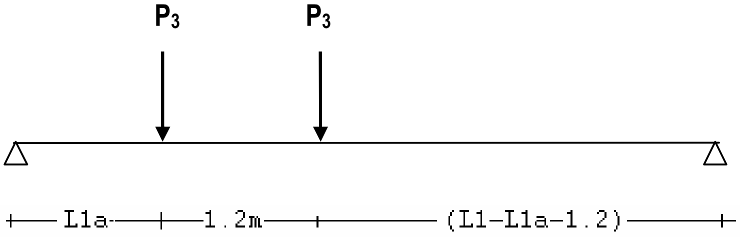


Figure 4.5 Tandem load

Influence Lines for Shear Force and Bending Moment

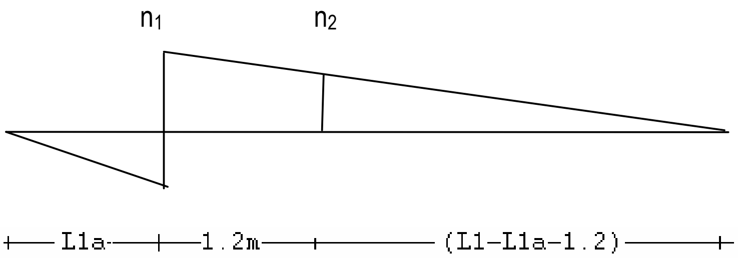


Figure 4.5.1 IL for Shear Force

Influence line coefficients for Shear Force

$n_1 = L_{1a}(L_1-L_{1a})/L_1$

$n_2 = L_{1a}(L_1-L_{1a}-1.2)/L_1$

$V_{tml} = (P_3*n_1+P_3*n_2+0.5*(L_1-L_{1a})*n_1$

$= P_3*(L_{1a}/L_1)*((L_1-L_{1a})+(L_1-L_{1a}-1.2))+0.5*L_{1a}(L_1-L_{1a})^2/L_1$

Where:

- V_{tml} is shear force at a distance L1a due to tandem and lane loads.

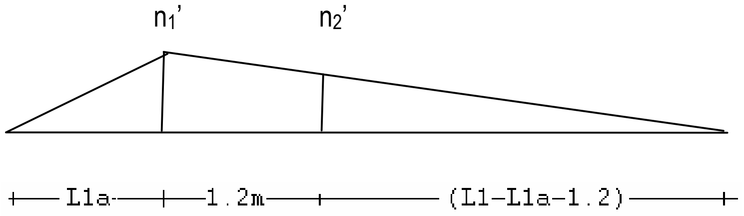


Fig 4.5.2 IL for Bending Moment

Influence line coefficients for Bending moment

$$n_1' = L_{1a}(L_1 - L_{1a})/L_1$$

$$n_2' = L_{1a}(L_1 - L_{1a} - 1.2)/L_1$$

$$M_{tml} = (P_3 * n_1' + P_3 * n_2') + 0.5 * (L_1 * n_1')$$

$$= P_3 * (L_{1a}/L_1) * ((L_1 - L_{1a}) + (L_1 - L_{1a} - 1.2)) + 0.5 * L_{1a}(L_1 - L_{1a})^2/L_1$$

Where:

- M_{tml} is Moment at a distance L_{1a} due to tandem and lane loads.

If the value in bracket is negative, then it is taken as zero. It implies that the wheel is out of the span. In the above derivation of distributed and concentrated live loads due to tandem, truck and lane loads, L_{1a} is the location of the rear wheel from the support and it is given by the equation:

$$L_{1a} = a_{11} * L_1$$

Where:

a_{11}= 0.1, 0.2, 0.3, 0.4, 0.5 and 0.6

L_1= C/C length of the bridge into consideration.

The effects of forces due to distributed and concentrated live loads are calculated at all distances, L_{1a}. The computation stops at L_{1a} is 0.6 of L_1, because the absolute maximum moment occurs at somewhere in the mid span.

Among the above-calculated results of live load effects the maximum effects are the one which govern the design.

Dead Load Force Effects

The dead loads are the followings:

1. Interior Strip

$W_{dc} = 24 * D/1000$ D is in mm

$W_{dw} = Y_b * 9.81 * b_t/1000000$

$W_{di} = W_{dc} + W_{dw}$

Where:

W_{dc} = dead load of the deck slab (KN)

b_t= bituminous thickness (mm)

W_{di}= total dead load, interior strip (KN)

W_{dw} = dead load due to wearing surfaces

Y_b= bituminous density (Kg/m^3)

2. Edge Strip

$W_c = (C_w\text{-}0.025)C_d{**}24$

$W_{ra} = 2*(R_{ww}*R_d)*24*L_1$

$W_p = P_w*P_h*P_d*P_n*24/(L_1*E_e)$

$W_{de}=W_c + W_{ra} + W_p$

Where:

W_c = dead load due to curbs (KN)

W_{ra}= dead load due to railings(KN)

W_p= dead load due to posts(KN)

R_{ww} = railing width (m)

R_d= railing depth (m)

W_{de} = total dead load edge strip(KN)

P_w=post width (m)

P_d =post depth (m)

P_h= post height (m)

P_n= total number of posts

Similarly, the shear force and moment due to dead loads at a distance L_{1a} from the support is given by the following formula for both interior and edge strips;

Interior strip:

$V_{dl}= W_{di}(L_1/2\text{-}L_{1a})$

$M_{dl}= W_{di}*L_{1a}/2(L_1\text{-}L_{1a})$ ....(4.4)

Edge strip:

$V_{dle}= W_{de}(L_1/2\text{-}L_{1a})$

$M_{dle}= W_{de}*L_{1a}/2(L_1\text{-}L_{1a})$ ……………………………………………(4.5)

Where:

V_{dl}, V_{dle} = Shear force due to dead loads for interior & edge strips, respectively

M_{dl}, M_{dle} = Moment due to dead loads for interior & edge strips, respectively

Designing

Design Moment

The design moment for interior strip is taken as by applying load factors, 1.25 for dead loads and 1.75 for live loads, and by combining the effects of dead loads and live loads. At a distance L_{1a} from the support, MD and MDU (unfactored design moment, at service load) is respectively given by the equation:

$MD(L_{1a})= 1.25*M_{dl}+1.75*[\max(M_{trl},M_{tml})]$ ………………..…..(4.6)

$MDU(L_{1a})= M_{dl}+[\max(M_{trl},M_{tml})]$

Mu, the maximum design moment is the one which is maximum of $MD(L_{1a})$.

Checking the adequacy of the section

The section is checked for the maximum design moment whether the initial depth under consideration is sufficed or not.

$d_{ic}= 71.37*\sqrt{(Mu/f_c)}$

If $d_{ic} < d_1$, then the assumed depth suffice. Otherwise, the section has to be revised until the depth requirement is satisfied.

Check for shear:

$VD= 1.25*V_{dl}+1.75[\max (V_{trl},V_{tml})]$

Vu is the maximum values of VD's

$V_{cc}=(0.14*\sqrt{F_c'} +17.2*R_o(Vu*d_1/Mu)*10^{-3}) \leq 0.29*\sqrt{F_c}$

$R_o= (1-\sqrt{(1-(2.352MD/0.9*b*d_1^2 f_c'))}$

Where:

V_{cc}=Allowable shear stress of concrete (MPa)

R_o= steel ratio

MD is in N-mm, b and d_1 are in mm

Required depth for shear, $d_{reqd} = Vu/(V_c*b)$

If $d_{reqd} > d_1$, then revise the section. Otherwise, OK!

Reinforcing bars Determination.

i) Main Reinforcement

$R_{min}= 0.03f_c'/f_y$

$A_{sti}=max(R_o,R_{min})*b*d_1$ ……..................………...….......(4.7)

$S_i =min[3.14*(db)^2*1000/A_{sti},200]$

Where:

F_y= steel strength (MPa)

R_{min}= minimum steel ratio

A_{sti} is the area of reinforcing bars provided in interior strip. (mm^2/m)

S_i= Spacing of main bars

ii) Distribution Reinforcement

The amount of bottom transverse reinforcement may be taken as a percentage of the main reinforcement required for positive moment.

$P_e= min[50,1750/\sqrt{(L_1)}]$

$A_{ti}=P_e*A_{sti}$

$S_{di} =min[\pi *(dd)^2*1000/A_{ti},250]$

Where:

P_e = percentage of distribution reinforcement

A_{ti} = the area of transverse reinforcing bars provided (distribution reinforcement)

dd = diameter of the distribution bars used

S_{di} = Spacing of distribution bars

iii) Shrinkage and Temperature Reinforcement

Reinforcement for shrinkage and temperature reinforcement shall be provided near surfaces of concrete exposed to daily temperature changes. The steel should be distributed equally on both sides.

$A_{st}\geq 0.75*A_g/F_y$

$S_{ti} =min[3.14*(dt)^2*1000/A_{ti},250]$

Where:

A_g is the gross concrete area, A_g=D*b

dt = diameter of the temperature bars used

S_{ti}= Spacing of temperature bars

Edge Strip

For calculation of dead load force effects, W_{de} replaces W_{di} of the interior strip and the corresponding moment due to this dead load is M_{dle}.

For live load force effect computations, E_{m1} of the interior strip width is substituted by E_e (edge strip width) and multiple presence factors are included.

Edge strip is limited to half lane width; use multiple presence factors 1.2 and half design lane load. Thus, live loads due to truck and tandem are divided by two as the width of the edge strip is less than 2.1m (wheel are placed 300mm from curb edge and wheel spacing of 1800mm) plus curb width. [9]

Truck Load: P_1= 1.2*(1.33* 145/E_e)/2; P_2= 1.2*(1.33* 35/E_e)/2

(For a truck load of 145 and 35 KN, respectively)

Tandem Load: P_3= 1.2*(1.33*110/E_e)/2 (a tandem load of 110KN)

Lane Load: 1.2*(9.3/ E_e) (a lane load of 9.3KN/m)

- in the above derivations E_e is in meter.

Thus, the same procedure has been carried out as did for interior strips. A multiple presence factor of 1.2 is taken for a two-lane bridge, because the possibility of occurrence of two trucks at a time is less.

Investigation of Service Limit State

i) Durability

For durability, adequate cover shall be used (for bottom of cast in place slab the cover is 25mm). A 25mm concrete cover is provided here, thus there is no problem of durability.

a) Interior Strip

The load factors used above in all dead and live loads are taken as unity.

MDU(L_{1a})= M_{dl}+[max.(M_{trl},M_{tml})] . . . . (KN-m/m)

VDU(L_{1a})= V_{dl}+[max.(V_{trl},V_{tml})] . . . . (KN/m)

Where:

- MDu and VDu are unfactored moment and shear forces at all intervals of L_{1a}, respectively.

$A_{si}=MD_U/(f_s*j*d_1)$

$j= 0.875$ and $f_s=0.6f_y$

Therefore, area of steel provided, A_{pi}, is the maximum of A_{sti} and A_{si}.

i.e. $A_{pi}= \max[A_{sti}$ and $A_{si}]$

ii) Control of Cracking.

Cracking may occur in the tension zone for RC members due to the low tensile strength of concrete. The cracks may be controlled by distributing steel reinforcements over the maximum tension zone in order limit the maximum allowable crack widths at the surface of the concrete for given types of environment [9].

Components shall be so proportioned that the tensile stress in the mild steel reinforcement at the service limit state, f_{sa} doesn't exceed.

$F_s \leq F_{sa}$

$F_{sa}=Z/(d_c*A)^{1/3} \leq 0.6f_y$

$Z=23000N/mm$

d_c= concrete cover + (diam. of bars/2)

- clear cover to compute $d_c \leq 50mm$

$A_c= 2d_c*S$

$F_r=0.63*\sqrt{(f_c')}$

$F_{cten} = 6*Mus/(b*D^2)$; D is in mm.

Where:

Z= Crack width parameter

A= area of concrete having the same centroid as the principal tensile reinforcement are bounded by the surfaces of the cross section and a line parallel the neutral axis divided by the number of bars (mm2), clear cover here also≤50mm.

S = spacing of bars.

= S_i for interior strip and S_e for exterior strip.

F_r = modulus of rupture

F_{cten}= tensile strength of the concrete

If $F_{cten}> 0.8f_r$, the section has cracked.

Now, steel stress for elastic cracked section for which moment of inertia of the composite transformed section, I_{cr}, should be used.

$E_c= 0.043Y_c^{1.5}*F_c'$

$N=Int(E_s/E_c)$

Where:

N= the modular steel ratio

E_s= the modulus elasticity of steel (Gpa)

E_c= modulus of elasticity of concrete (Gpa)

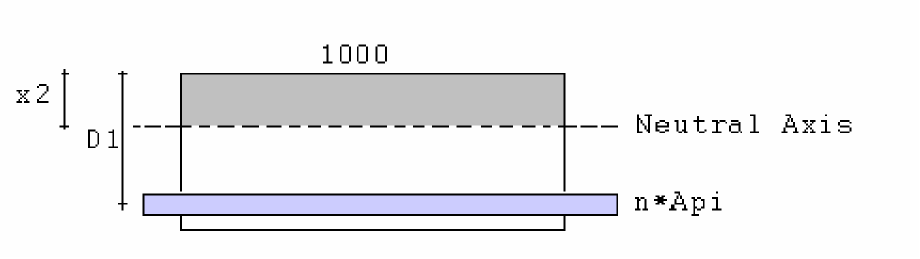


Figure 4.6 Cross Section across interior strip

The equivalent concrete area is $n*A_{pi}$.

$x_2=((-n*A_{pi})+ \sqrt{((n*A_{pi})^2+2000*n*d_1*A_{pi})})/1000$

$I_{cr}=(b*x_2^3)/3+(n*A_{pi}*(d_1-x_2)^2)$

$f_s=(MDu*(d_1-x_2)*n)/I_{cr}$

$f_{sa}=23000/(2*((D-d_1)^2)*S_i)^{1/3}$

where:

X_2 is the neutral axis depth from top fiber, interior strip

Mue= unfactored max moment, interior strip.

I_{cr} = moment of inertia of the composite transformed section for an interior strip.

If $f_s > f_{sa}$, then the area of reinforcing bars has to be increased by reducing the spacing of bars or the section depth has to be increased.

a) <u>Exterior Strip</u>

Similarly calculate A_{pe}, f_{se}, f_{sae} and I_{cre} for edge strip and check against the minimum requirements.

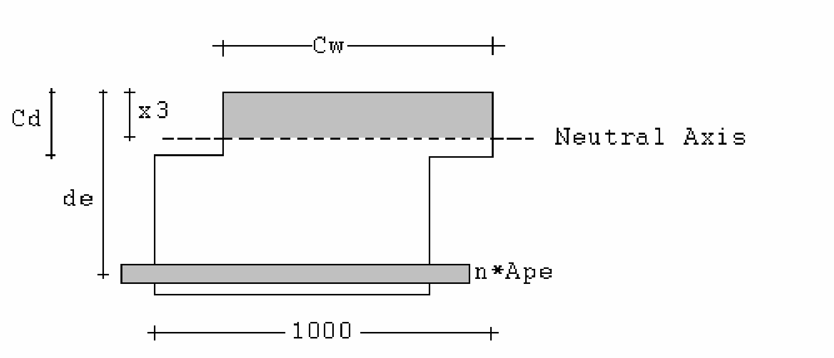


Figure 4.7 Cross Section across exterior strip

The equivalent concrete area is n*Ape

$x_3=((-n*A_{pe})+\sqrt{((n*A_{pe})^2+1500*n*d_e*A_{pe})})/((C_w-0.05)*1000)$

IF($x_3<C_d$) then

$I_{cre}=((((C_w-0.05)*1000)/3)*x_3^3)+(n*A_{pe}*(d_e-x_3)*(d_e-x_3))$

Else

$I_{cre}=(((C_w-0.05)*1000)/3*(1000*C_d)^3)+(n*A_{s2}*(d_e-x_3)^2)+((((C_w-0.05)*1000)*(1000*C_d))*(x_3-1000*C_d/2)^2)$
$+(850/3)*(x_3-(1000*C_d))^3$

$f_{se}=(Muse*(d_e-x_3)*n)/I_{cre}$

$f_{sae}=23000/(2*((D-d_1)\ ^2)*S_e)^{1/3}$

where:

Muse = unfactored max moment for edge strip (N-mm)

X_3 = the neutral axis depth from top fiber, for edge strip.

I_{cre} = moment of inertia of the composite transformed section for an edge strip.

iii) Deformations

Deflection and camber calculations shall consider dead load, live load, erection loads, concrete creep and shrinkage [5]. Immediate (Instantaneous) deflections may be computed taking the moment of inertia as either the effective moment of inertia I_e, or the gross moment of inertia I_g.

The long-term deflection due to creep and shrinkage may be taken as the immediate deflection multiplied by the following factor [2].

(3 to 1.2) $A_s'/A_s \geq 1.6$ if d_{dl} is calculated using I_e.

(4)$A_s'/A_s \geq 1.6$ if d_{dl} is calculated using I_g.

Where:

d_{dl} is the total dead load deflection.

Dead load camber

Total dead load of the bridge and the whole bridge cross section is considered.

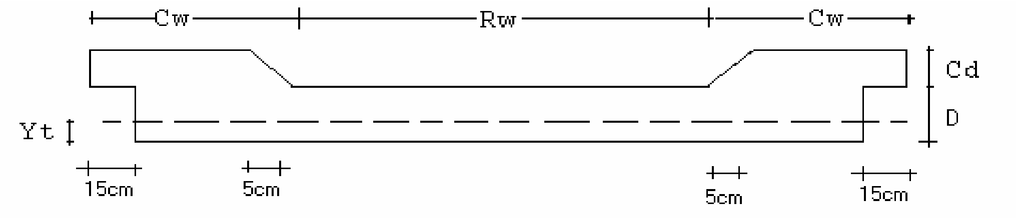


Figure 4.8 Slab Bridge cross section

$Y_t=(R_w+2*C_w-0.3)*D^2/2+C_w*C_d*(C_d/2+D)*2)/((R_w+2*C_w)*D+C_w*C_d*2))$

$I_{crt}=I_{cr}*(R_w+2*C_w-2)+I_{cre}*2$

$I_g=((R_w+2*C_w)*D^3)/12)+R_w+2*C_w)*D*((0.5*D-Y_t)^2))+((C_w*C_d^3))/12)+ 2*(C_w*C_d*((D+C_d/2-Y_t)^2)$

- all the above dimensions are in mm.

$W_{ddc}=W_{dc}*(R_w+2*C_w-0.3)+((2*C_w-0.1)*C_d*24)+W_{ra}+W_p$

$W_{ddw}=W_{dw}*R_w$

$W_{dd}=W_{ddc}+W_{ddw}$

Where:

W_{ddc}=total dead load of the whole bridge excluding load due to wearing surface

W_{ddw}=total dead load of the bridge of the whole bridge due to wearing surface

W_{dd}=total dead load of the whole bridge.

I_{crt}= critical moment of inertia for the whole section of a slab bridge.

Y_t= location of Neutral Axis from bottom for the whole of a slab bridge.

The total, maximum and critical moments due to dead and live load of the whole slab bridge, respectively are given by the equations:

$M_{lld}=M_{md}+MAX(M_{trl},M_{tml})*E_{m1}*NL$; E_{m1} is in m.

$M_{md}= W_{dd}*L_1^2/8$

$M_{cr}=f_r*I_g/Y_t$

$I_e=(((M_{cr}/M_{lld})^3)*I_g)+(1-((M_{cr}/M_{lld})^3))*I_{crt}$

Where:

M_{lld}= total moment due to dead and live load of the whole slab bridge

M_{md}= total dead load moment of the whole slab bridge

M_{cr}= critical moment of the whole slab bridge

If $M_{cr} \geq M_{dl}$, then use I_g else Ie is used for computation of dead load deflection. Thus, the dead load deflection of the slab bridge is given by:

$d_{dl}=5W_{dl}*L_1^4/384E_cI_g$

$d_{max}=L_1/800$ (L_1 is in mm); the permissible limit

Where:

d_{max} is the permissible limit (max. deflection)

Live Load Deflection

In the computation of live load deflection, design truckload alone or design lane load plus 25% of truckload is considered.

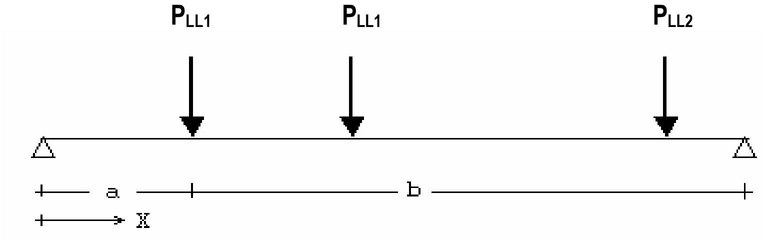
i) Deflection due truckload

$P_{LL1}=1.33*145*NL$

$P_{LL2}=1.33*35*NL$

Where:

P_{LL1} and P_{LL2} are truck loads.



The maximum deflection of the bridge due to truck load occurs at a wheel load position where moment is a maximum. Thus, the deflection at the point of maximum moment due to each truck load at a distance a from the left support is given by:

$d_{ki}=P_{LLi}*b*x(L_1^2-b^2-x^2)/6E_cI_c$

where:

d_{ki}= deflection due to each truck load.

Using the method of superposition, the total live load deflection due truckload is the sum of each deflections, d_{ki}'s. Thus, compare the value obtained with the permissible limit.

ii) Deflection due to tandem load

The maximum deflection due to tandem load occurred when a single concentrated tandem load is acting at the mid span.

$$d_{tl}=P_{stl}*L_1^3/48E_cI_c$$

where:

d_{tl} = deflection due to tandem load.

P_{stl} = single concentrated factored tandem load= 1.33*110*2*NL

iii) Deflection due lane load

$WL_1=9.3*NL$

$d_{La}=WL_1*L_1^4/(384EI_e)$

$d_{kt}=0.25*d_k+d_{la}$

Where:

d_{la} = deflection due to lane load.

WL_1= lane load = 9.3*NL

d_{Kt} = total live load deflection

Compare the value obtained with the permissible limit.

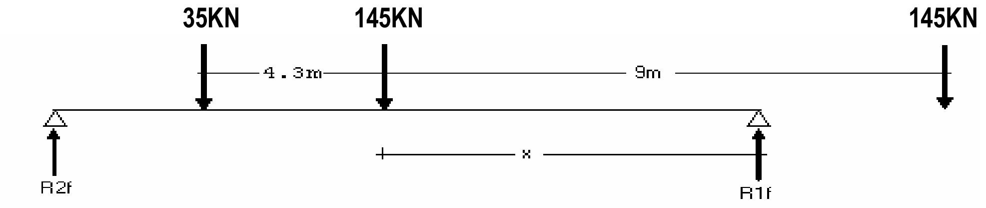
Investigation of Fatigue Limit State

U=0.75*(LL+IM) ;IM is taken as 15%

Where:

U= Fatigue load shall be one design truck with 9m spacing. [2]

Maximum moment results when the two front axles are on the span and the rear axle is out of the span.



M_{mf}= 0.75*1.15(R_{1f}*x)

Where:

R_{1f} and R_{2f} are the reactions at right & left supports due to truck load, respectively.

M_{mf}= the maximum moment for fatigue.

a) Tensile live load stresses

One lane loaded, Strip width is E_{m1} (for interior strip)

M_{llf}= M_{mf}/E_{m1} (E_{m1} is in meter)

$f_{smax}=n^*(M_{llf}^*(D-x_2)/I_{cr}$

where:

M_{llf} is the maximum moment per meter width for fatigue.

If $f_{smax} < 0.6f_y$ OK! Otherwise revise the section or increase area of reinforcing bars.

b) Reinforcing Bars

The stresses range in straight reinforcement bars resulting from fatigue load combination shall not exceed.

$f_f=145-0.33f_{min}+55(r/h)$

where:

f_f is the stress range.

f_{min} is the minimum live load stress where there is stress reversal. For simply supported slab bridge, r/h is 0.30 and f_{min} is zero.

If $f_{smax} < f_f$, then there is no problem of fatigue. Otherwise increase area of reinforcing bars.

If all the above criteria for service limit state are satisfied, then the **DESIGN IS COMPLETED**!

The source program for Analysis and Design of Slab Bridge is attached herewith as Annex III.

4.3.2. T-Girder Bridges

4.3.2.1. Design Load

Loads that constitutes in the design of T- Girder bridges are :

- Self-weight of the slab part of the Bridge including loads due to railings and posts.
- Loads due to beams (girders)
- Self weight of the wearing surface if exists and
- Vehicular loads (truck load, land load and tandem loads)

4.3.2.2. Load Distribution

If the spacing of supporting components in the secondary direction is less than 1.5 times the spacing in the primary direction, the deck shall be modeled as a system of intersecting strips.

The live load on each beam shall be the reaction of the loaded lanes based on the lever rule.

The reinforcement in the deck slab of cast-in-place T-beams shall be determined by either the traditional or by empirical design methods.

4.3.2.3. Design Procedures

For T-Beams bridge type, 175mm is the minimum flange thickness for deflection requirement [5].

Deck Analysis

Depth Determination:

t_s= max[(1000*G_s+3000)/30,175] ; ………………………………………..….(4.8)

$L_1 = (W_{rs} + C_s)$

where:

t_s =depth of deck slab (mm)

W_{rs}= Support width (m)

Weight of components

$W_s = 24*t_s/1000$

$W_{oh} = 24*(ts+5)/1000$

$W_{dw} = Y_b*9.81*b_t/1000000$

$W_{cb} = C_d*24$

$W_{ra} = R_{ww}*R_d*24$

$W_p=P_w*p_h*P_d*p_n*24/(L_1*1000)$

where:

W_s is weight of the deck slab (KN/m^2)

W_{oh} is weight of the overhang slab (KN/m^2)

Dead load moments

An approximate analysis of strips perpendicular to girders will be considered.

For case in applying load factors, the bending moments will be determined for slab dead load, wearing surface and vehicle loads separately.

i) Slab dead load

A one-meter strip width is taken for the analysis.

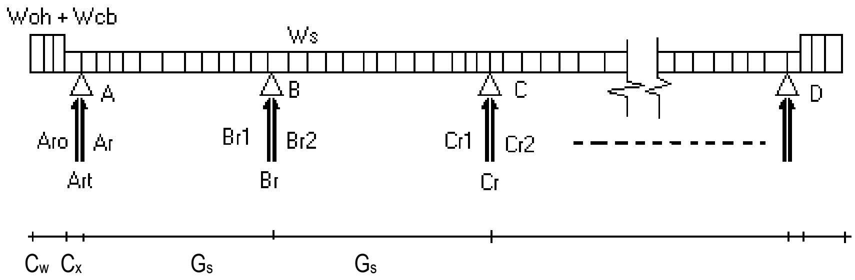


Figure 4.9 Slab dead load of a T- girder bridge

Moments and reactions due to dead load of the slab are given as follows:

$C_x=0.5*(R_w-(N_g-1)*G_s)$

$M_e= W_s(C_x+C_w)^2/2+(W_{cb}+W_{ho}-W_s)C_w*(0.5*C_w+C_x)$

$M_b=M_c=W_s*C_f*(G_s^2)+2*M_e*C_{f1}$

$B_{r1}=((W_s*G_s^2/2)-M_e-M_B)/G_s$

$A_r=W_s*G_s-B_{r1}$

$B_{r2}=W_s*G_s/2$

$C_{r1}=B_{r2}$

$B_r=B_{r1}+B_{r2}$

$A_{ro}=(W_{cb}+W_{oh})*C_w+W_s*C_x$

$A_{rt}=A_r+A_{ro}$

$N_{mom}=(B_{r2}*G_s/2)+M_b$

Where:

- N_g = INT(R_w/G_s)+1 is the total number of girders
- M_e = End moment at support A (exterior girder)
- M_b and M_c are support moments at supports B and C respectively
- B_{r1}, B_{r2}, A_{ro} and A_r are shear forces at the left and right of supports B and A respectively.
- B_r and A_{rt} are reactions at supports B and A respectively.
- N_{mom} = Negative moment at support A.
- C_f and C_{f1} are influence segment coefficient for moment obtained from tables.

ii) Wearing surface

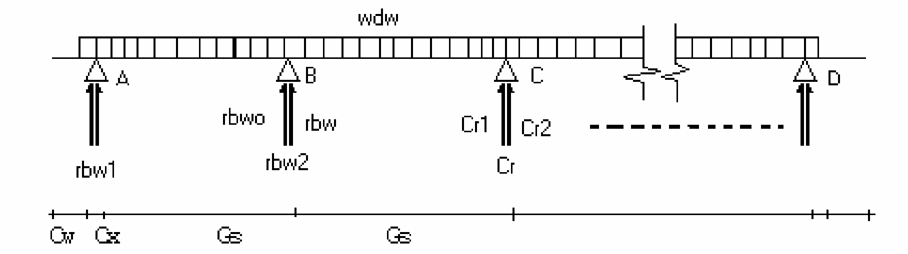


Figure 4.10 Wearing surface load of a T- girder bridge

Moments and reactions due to wearing surface at the ends and are given follows by:

$$M_{ew}= W_{dw}(C_x)^2/2$$

$$M_{bw}=M_{cw}=W_{dw}*C_f*(G_s^2)+2*M_{ew}*C_{f1}$$

$$r_{bw1}=W_{dw}*C_x+(W_{dw}*Gs^2/2+M_{bw})/G_s$$

$$r_{bw}=W_{dw}*G_s-r_{bw1}$$

$$r_{bwo}=W_{dw}*G_s-(W_{dw}*G_s^2/2+M_{bw})/G_s$$

$$r_{bw2}=r_{bw}+r_{bwo}$$

Where:

- M_{ew} = end moment at support A due to wearing surface (exterior girder)
- M_{bw} and M_{cw} are support moments at supports B and C due to wearing surface respectively
- r_{bw}, r_{bwo} are shear forces at the left and right of supports B respectively.
- r_{bw1} and r_{bw2} are reactions at supports A and B respectively.

Moment due to railings, posts and overhang

$$M_{rp}=(W_{ra}+W_p)*(C_x+C_w)$$

$$M_{bp}=M_{rp}*(C_f)=M_{cp}$$

$$M_{oh}=A_r*(0.4*G_s)$$

Where:

- M_{rp} is an end moment at support A due to railings and posts.
- M_{bp} and M_{cp} are support moments due to railings and posts at supports B and C respectively.
- M_{oh} = overhang moment at support A.

Vehicular live load

Maximum positive live load moment

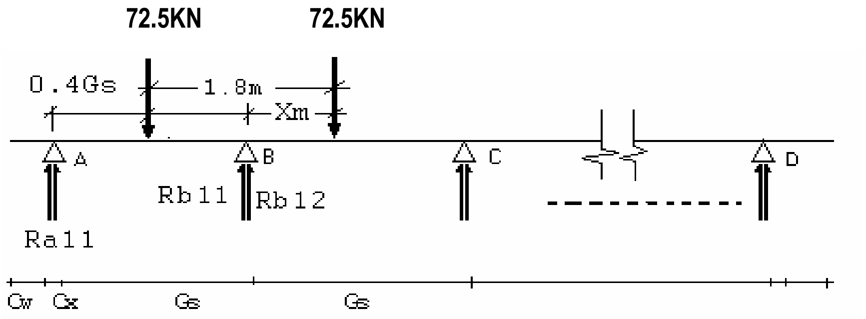


Figure 4.11 Truck Load position for max. positive moment

For repeating equal spans, the maximum positive bending moment occurs near the 0.4 points of the first interior span.

The equivalent width of the strip over which the live load is applied is:

$$E_w=660+0.55*(1000*G_s)$$

Where:

- E_w is the equivalent width (mm)

Thus, the maximum support reactions and positive moment is:

$$R_{m1}=R_{b11}+R_{b12}$$

$$M_{11}=(R_{a11}*0.4*G_s)$$

$$M_{p1}=1.2*M_{11}/E_w$$

$$R_{rm1}=1.2*R_{m1}/E_w$$

Where:

- R_{b11} and R_{b12} are shear forces at the left and right of support B respectively.
- R_{m1} is the maximum reaction at support B.
- M_{11} is the positive moment at support A.
- M_{p1} is the maximum positive moment at support A per unit meter (KN-m/m).
- R_{rm1} is the reaction transferred to girders per unit meter (KN/m).

Maximum Interior Negative Live Load Moment

The critical placement of live load for maximum negative moment is at the first interior support with one lane loaded (m=1.2). The width of equivalent transverse strip is

E_i=1220+0.25*G_s*1000

Where:

- E_i is the equivalent transverse strip width (mm)

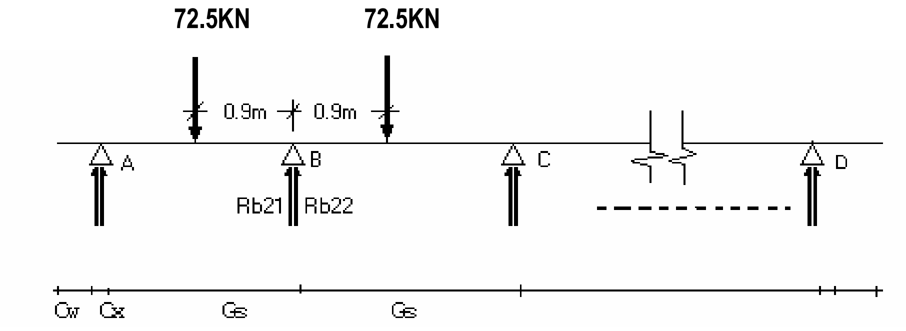


Figure 4.12 Truck Load position for max. negative moment

The maximum interior negative live load moment per unit meter becomes,

M_n= -1.2*b_{t3}/E_i (In this case E_i is in meter).

Where:

- B_{t3} is the negative moment at joint B. (Obtained using cross method of moment distribution)
- M_n is maximum interior negative live load moment.

Maximum Live Load Reaction on Exterior Girder

The maximum live load reaction on the exterior girder is obtained when the exterior wheel is placed 300mm from the curb.

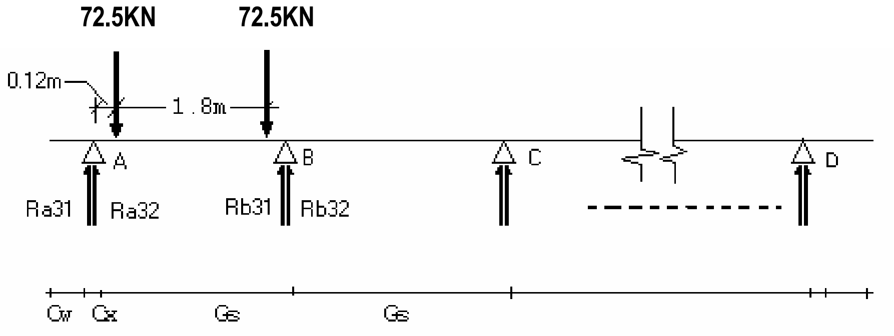


Figure 4.13 Truck Load position for max. Reaction

Where:

- R_{b31} and R_{b32} are shear forces at the left and right of supports B respectively.

- R_{m3} is the reaction at support B.
- R_{a31} is the reaction at support A.
- R_{rm3} is the maximum live load reaction on the exterior girder.

Maximum values of Shear and Moment

Applying strength limit state,

$R_A=0.95*(1.25*A_{rt}+1.5*r_{bw1}+1.75*1.33*R_{rm3})$

$M_{BM}=0.95*(1.25*M_B+1.5*M_{bw}+1.75*1.33*M_n)$

$M_{maxp}=0.95*[1.25*(A_r*aa-W_s*aa^2/2)+1.5*(r_{bw1}*aa-W_{dw}*aa^2/2)+1.75*1.33M_{p1}]$

……………………………………(4.9)

Where:

- R_A is the total reaction at support A. (KN/m)
- M_{maxp} is the maximum positive moment. (KN-m/m)
- M_{BM} is the maximum negative moment at support B. (KN-m/m)
- $aa= 0.4*G_s$ (m)

For reinforcement computation, negative moment may be taken at face of support. The T-beams are b_{min} wide. Thus, we calculate moments at support B. A minimum web width of the girders is 200mm [2].

$b_{11}=8*db+100$ for $L_1 \leq 15m$

$b_{11}=11*db+100$ for $L_1>15m$

$b_{min}=(Max(b_{11},200))$ (mm) ……………………………………………………(4.10)

$M_{DC}=M_B-W_s*(b_{min}/2000)^2/2+B_{r2}*C_x$

$M_{DW}=M_{bw}-W_{dw}*Cx^2/2+r_{bw}*C_x$

$M_{LL}=-1.2*(b_{t3}-R_{b22}*c_x)*1000/E_i$

$M=0.95*(1.25*M_{DC}+1.5*M_{DW}+1.75*1.33*M_{LL})$ ………………………………(4.11)

Where:

- M_{DC} = total moment due to deck slab (KN-m/m)
- M_{DW} = total moment due to wearing surface (KN-m/m)
- M = design maximum negative moment at B. (KN-m/m)
- b_{min} = the minimum web width. (mm)
- db = diameter of main bars used for girders.

Checking the adequacy of the section

The section is checked for the maximum design moment whether the initial thickness of the deck slab under consideration is sufficed or not.

$t_{ic}= 71.37*\sqrt{}(M_{maxp}/f_c)$

If $t_{ic} < t_s$, then the assumed depth suffice. Otherwise, the section has to be revised until the depth requirement is satisfied.

Deck Design

Reinforcement computation

i) Positive Moment Reinforcement

Using dd bars, the effective depth becomes,:

$d_p= t_s-25-dd/2$

$R= (1-\sqrt{}(1-(2.352M_{maxp}/0.9*b*d_p^2*f_c'))$ ………………(4.12)

$R_{min}= 0.03f_c'/f_y$

$A_{s1}=max(R,R_{min})*b*d_p$

$S_i =min[\pi *(dd)^2*1000/A_{s1},200]$

$A_{pp}=3.14(dd)^2/(4*S_i)$

Where:

- A_{s1} = area of positive moment reinforcing bars. (mm^2/m)
- A_{pp} = area of positive moment reinforcing bars provided (mm^2/m).
- d_p = effective depth for positive reinforcement(mm)
- S_i= Spacing of main bars.
- dd = diameter of bars for the deck slab

ii) Negative Moment Reinforcement

Using dd bars, the effective depth becomes,:

$d_n= t_s-60-dd/2$

$R_1= (1-\sqrt{}(1-(2.352M/0.9*b*d_n^2*f_c'))$..............................(4.13)

$R_{min}= 0.03f_c'/f_y$

$A_{s2}=max(R,R_{min})*b*d_n$

$S_e =min[\pi *(dd)^2*1000/A_{s2},200]$

$A_{pn}=3.14(dd)^2/(4*s_e)$

Where:

- A_{s2} = area of negative moment reinforcing bars. (mm^2/m)

- A_{pn} = area of negative moment reinforcing bars provided (mm^2/m).
- d_n = effective depth for negative reinforcement (mm)
- S_e= Spacing of main bars

iii) Distribution Reinforcement

The amount of bottom transverse reinforcement may be taken as a percentage of the main reinforcement required for positive moment.

$S_x=G_s*1000-b_{min}$

P_e= min [67, $3840/\sqrt{S_x}$]

$A_{di}=P_e*A_{pp}$

S_{di} =min[$3.14*(dd1)^2*1000/A_{pp}$,250]

Where:

P_e = percentage of distribution reinforcement

S_x = Clear spacing between girders (mm)

A_{di} = the area of transverse reinforcing bars provided (distribution reinforcement)

dd1 = diameter of the distribution bars used

S_{di}= Spacing of distribution bars.

iv) Shrinkage and Temperature Reinforcement

Reinforcement for shrinkage and temperature reinforcement shall be provided near surfaces of concrete exposed to daily temperature changes. The steel should be distributed equally on both sides.

$A_{st} \geq 0.75*A_g/F_y$

$A_g=0.75*1000*t_s/F_y$

S_{st} =min[$3.14*(d1t)^2*1000/A_{st}$,450,$3*t_s$]

Where:

A_g is the gross concrete area.

d1t = diameter of the temperature bars used

S_{st}= Spacing of temperature bars

<u>Investigation of Service Limit State</u>

i) Durability

For durability, adequate cover shall be used (for bottom of cast in place slab the cover is 25mm and it is provided here).

ii) Control of Cracking.

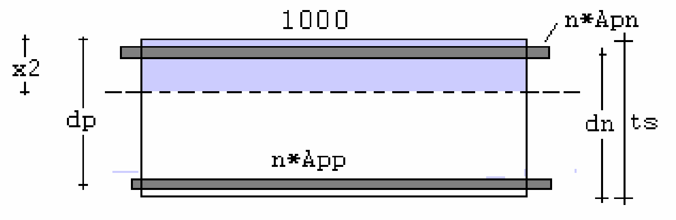
Components shall be so proportioned that the tensile stress in the mild steel reinforcement at the service limit state, f_{sa} doesn't exceed.

If $F_{cten} > 0.8fr$, the section has cracked.

Now, steel stress for elastic cracked section for which moment of inertia of the composite transformed section should be used.

The equivalent concrete area for positive and negative reinforcements are $n*A_{pp}$ and $n*A_{pn}$, respectively.

Check positive moment Reinforcement



$M_{pp}=A_r*0.4*G_s-W_s*(0.4*G_s)^2/2+r_{bw}*0.4*G_s-W_{dw}*(0.4*G_s)^2/2+1.33*M_{p1}$

$x_2=-n(A_{pp}+A_{pn})+ \sqrt{}((n*(A_{pp}+A_{pn}))^2+2000*n*(A_{pp}*(t_s-d_n)+A_{pn}*dp)))/1000$

$Icr=(333.33*x_2^3)+(n*A_{pp}*(t_s-d_n-x_2)^2)+(n*A_{pn}*(d_p-x_2)^2)$

$f_s=(M_{pp}*(d_p-x_2)*n)/I_{cr}$

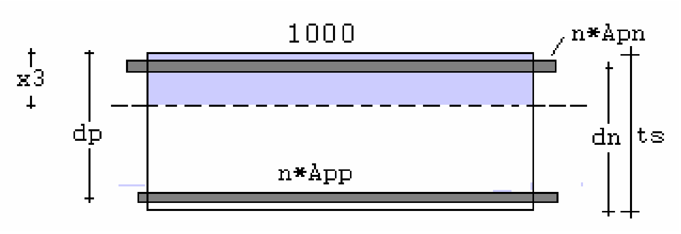
$f_{sa}=23000/(2*((t_s-d_p)^2)*S_i)^{1/3}$

where:

- M_{pp} is the positive max. moment for service limit investigation, load factors are taken as unity.
- X_2 is the neutral axis depth.
- I_{cr} is the critical moment of inertia for positive reinforcement.

If $f_s > f_{sa}$, then the area of reinforcing bars has to be increased by reducing the spacing of bars or the section depth has to be increased.

Check negative moment Reinforcement



$M_{pn}=M_{dc}+M_{dw}+1.33*M_{ll}$

$x_3=((-1*(n-1)*(A_{pp}+A_{pn}))+\sqrt{((n*(A_{pp}+A_{pn}))^2+2000*n*(A_{pp}*(t_s-d_n)+A_{pn}*d_p))})/1000$

$I_{cre}=(333.33*x_3^3)+(n*A_{pp}*(ts-d_n-x_3)^2)+(n*A_{pn}*(d_n-x_3)^2)$

$f_{se}=(1E+6*M_{pn}*(d_n-x_3)*n)/I_{cre}$

$f_{sae}=23000/(2*((t_s-d_n)^2)*S_e)^{1/3}$

if ($f_{se}>f_{sae}$) then increase the area of steel provided.

where:

- M_{pn} is the negative max. moment for service limit investigation; load factors are taken as unity.
- X_3 is the neutral axis depth.
- I_{cre} is the critical moment of inertia for negative reinforcement.

Investigation of Fatigue Limit State

Fatigue need not be investigated for concrete decks in multi-girder applications. [2]

Design of Longitudinal Girders

Structural depth of the web for simple span T- beams is given as follows:

$D_w=0.07*L_1$ ……………………………………………………………(4.14)

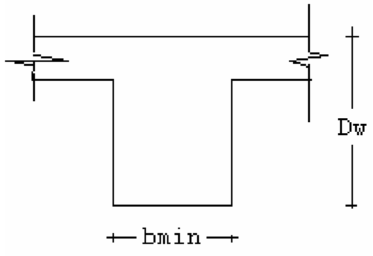


Figure 4.14 Cross section of an interior girder

Dead load effects:

$W_W=b_{min}*(D_w-t_s)*24*1E-6$

$D_{Le}=D_t*(D_w-t_s)*(G_s/2-t_s/1000)*24/1000$

$D_{Li}=2*D_{Le}$

Where:

- D_W= Web depth
- W_W= own weight of the web
- D_{le} is diaphragm load on exterior girder.
- D_{li} is diaphragm load on interior girder.

The following reactions are summaries of slab dead load and live slab reactions transferred to girders.

$R_{ae1}=A_{rt}+W_W$

$R_{ae2}=r_{bwo}+W_W$

$R_{bi1}=B_{r1}+B_{r2}+W_W$

$R_{bi2}=r_{bw}+((W_{dw}*G_s^2/2+M_{bw})/G_s)+W_W$

Where:

- R_{ae1} and R_{ae2} are reactions transferred to exterior girders due to DL of the deck slab and wearing surfaces respectively.
- R_{bi1} and R_{bi2} are reactions transferred to interior girders due to DL of the deck slab and wearing surfaces respectively.

Distribution factors for moment and shear

The distribution factors for moments and shears for both external and internal girders are obtained from the empirical formula given Table Art 4.6.2.2-1 of AASHTO 1998.

iii) Distribution factors for moments

a) Interior beams with concrete decks:

Girder distribution factor with multiple presence factor included is,

$mg_1=0.06+(G_s/4.3)^{0.4}*(G_s/L_1)^{0.3}$

$mg_2=0.075+(G_s/2.9)^{0.6}*(G_s/L_1)^{0.2}$

Where:

- mg_1 and mg_2 are distribution factors for moment of interior beams for one lane loaded and two lanes loaded respectively.

b) exterior beams with concrete decks:

$mge=1.22*(0.5*(2/G_s))$

$ex=MAX((0.77+C_x/2.8),1)$

$mgee=ex*\ mg_2$

Where:

- mgee is distribution factor for moment of exterior beams.

iv) Distribution factors for shear

$mgv_1=0.36+(G_s/7.6)$

$mgv_2=0.2+(G_s/3.6)-(G_s/10.7)^2$

$ev=(0.6+C_x/3)$

$mgev=ev*\ mgv_2$

Where:

- mgv_1 and mgv_2 are distribution factors for shear of interior beams for one lane loaded and two lanes loaded respectively.
- mgev is distribution factor for shear of exterior beams.

Live Load Force Effects

Determination of Distributed Live Load Moments and Shear

The influence lines for Shear force and Moment for truck and lane loads of a T- Girder bridge is similar to that of Slab bridges. Moreover, the influence line coefficients, the equations for shear force and moments are the same.

$P_1=1.33*35$; $P_2=1.33*145$	Truck loads	(KN)
$P_3=1.33*110$	Tandem load	(KN)
$W=9.3$	Lane load	(KN/m)
$K=35/145$		

The effects of forces due to distributed and concentrated live loads are calculated at all distances, L_{1a}. The computation stops at L_{1a} is 0.6 of L_1, because the absolute maximum moment occurs at somewhere in the mid span.

Among the above-calculated results of live load effects the maximum effects are the one which govern the design.

Dead Load Force Effects

The shear force and moment due to dead loads at every distance L_{1a} from the support is computed for both interior and exterior girders.

$L_{1a}=a_{11}*L_1$

$ii=L_1-L_{1a}$

1. Interior Girder

$M_{dl}(L_{1a})=((0.5*(R_{bi1}*L_1+D_{li})*L1a)-(R_{bi1}*L_{1a}^2/2))+((0.5*(R_{bi2}*L_1*L_{1a})-R_{bi2}*L_{1a}^2/2))$

$V_{dl}(L_{1a})=((0.5*(R_{bi1}*L_1+D_{li}))-(R_{bi1}*L_{1a}))+((0.5*(R_{bi2}*L1)-R_{bi2}*L_{1a}))$

Where:

- $M_{dl}(L_{1a})$= moment due to dead load at L_{1a} distance from the support for interior girder.
- $V_{dl}(L_{1a})$=shear due to dead load at L_{1a} distance from the support for interior girder.

2. Exterior Girder

$M_{dle}(L_{1a})=((0.5*(R_{ae1}*L_1+D_{le})*L_{1a})-(R_{ae1}*L_{1a2}/2))+((0.5*(R_{ae2}*L_1*L_{1a})-R_{ae2}*L_{1a2}/2))$

$V_{dle}(L_{1a})=((0.5*(R_{ae1}*L_1+D_{le}))-(R_{ae1}*L_{1a}))+((0.5*(R_{ae2}*L_1)-R_{ae2}*L_{1a}))$

Where:

- $M_{dle}(L_{1a})$=moment due to dead load at L_{1a} distance from the support for exterior girder.
- $V_{dle}(L_{1a})$= shear force due to dead load at L_{1a} distance from the support for exterior girder.

Designing

Design Moment

The design moment for both interior and exterior girders are taken by applying load factors, 1.25 for dead loads and 1.75 for live loads, and by combining the effects of dead loads and live loads.

a) Interior girder

At a distance L_{1a} from the support, MD and MDU (unfactored design moment, at service load) is respectively given by the equation:

$MD(L_{1a})= 1.25*M_{dl}+1.75*[max.(M_{trl},M_{tml})]$ . . . .(4.15)

$MDU(L_{1a})= M_{dl}+[max.(M_{trl},M_{tml})]$

Mu, the maximum design moment is the one which is maximum of $MD(L_{1a})$.

Similarly, at a distance L_{1a} from the support, VD and VDU (unfactored design Shear, at service load) is respectively given by the equation:

$VD(L_{1a})=1.75*[\max(V_{trl}(L_{1a}), V_{tml}(L_{1a}))]+ 1.25*V_{dl}(L_{1a})$

$VDU(L_{1a})=1.75*[\max(V_{trl}(L_{1a}), V_{tml}(L_{1a}))]+ 1.25*V_{dl}(L_{1a})$

Vu, the maximum design shear is the one which is maximum of $VD(L_{1a})$.

b) Exterior girder

A similar procedure is carried for exterior girder to obtain the design shear and moment.

Checking the adequacy of the section

The section is checked its adequacy for compression in concrete (maximum design moment) for both interior and exterior girders whether the initial depth under consideration is suffices or not.

$M_{om11}=MAX (Mu,Mue)$

$d_{tic}= 71.37*\sqrt{}(M_{om11}/f_C)$

Where:

d_{tic}= a depth required for carrying the maximum moment for singly reinforced section.

M_{om11}= maximum of the interior and exterior design moments.

If $d_{tic} < d_w$, then the assumed depth suffice. Otherwise, the section has to be revised until the depth requirement is satisfied.

Check for shear:

The section is also check for shear.

$VD= 1.25V_{dl}+1.75[\max(V_{trl},V_{tml})]$

Vu is the maximum values of VD's

Allowable shear stress of concrete is given by:

$V_{cc}=(0.14*\sqrt{}F_c' +17.2*R_o(Vu*d_1/Mu)*10^{-3}) \leq 0.29*\sqrt{}F_c$

Required depth for shear, $d_{reqd} = Vu/(V_{cc}*b)$

If $d_{reqd} > d_w$, then revise the section. Otherwise, OK!

Reinforcing bars Determination.

a) Interior Girder

Effective width computations

$b_{ii}=\min(L_1/4,G_s)$ (m)

$d_{pp}=D_w-50-3.5*db$ (mm)

$d_{ig}=\sqrt{}(MD/(0.245*b_{ii}*0.8*F_c)$

$C_{ci}=0.42*d_{ig}$

If $C_{Ci} \leq t_s$, then the beam is acted as a rectangular beam otherwise it is a T-beam.

$R_7=(1-\sqrt{}(1-(2.352*MU)/(0.9*b_{ii}*d_{pp}^2*(0.9)*F_c')))*F_c'/(1.176*F_y))$

$R_{min}= 0.03*0.8*F_c/F_y)$

$A_{s7}= max(R_7,R_{min})*d_{pp}*b_{ii}$……………………………………(4.16)

For a T- beam, $C_{ci}>t_s$, then some of the moments are carried by the flanges and some by the webs. The moments are as follows:

$M_{dfi}=((b_{ii}-b_{min})*t_s*f_c'(d_{pp}-t_s/2))$ (KN-m)

$M_{dwi}=MU-M_{dfi}$ (KN-m)

$A_{sfi}=M_{dfi}/(F_y*(d_{pp}-t_s/2))$ (mm^2)

$R_7=((1-\sqrt{}(1-2.352*M_{dwi})/(0.9*(b_{min})*d_{pp}^2*(0.9)F_c')))*F_c'/(1.176*F_y))$

$A_{swi}=max(R_7,R_{min})*d_{pp}*b_{min}*1000$

$A_{s7}=A_{swi}+A_{sfi}$

All dimensions are in units of mm.

The area of reinforcements required for the girders are computed at every L_{1a} distances to curtail bars at these distances.

Where:

b_{ii}= effective width of the interior girder.

d_{pp}= effective depth of the interior girder.

d_{ig}= depth of the interior girder which is capable of carrying the maximum design moment.

C_{ci} = depth of the Neutral axis.

M_{dfi} and M_{dwi} are moments carried by the flanges and webs respectively.

b) <u>Exterior Girder</u>

Effective width computations:

$b_{eii}= G_s$

$d_{bi}= b_{eii}-b_{ii}$

$b_{ex}= G_s+C_x+C_w$

$C=MAX (L_1/8,d_{bi}, b_{ex})$

d_{pn}= D_w-50-2.5*db

Where:

b_e= effective width of the exterior girder.

d_{pn}= effective depth of the exterior girder.

Similarly as did for interior girders the same procedure is carried out for the exterior girder.

Investigation of Service Limit State

i) Durability

For durability, adequate concrete cover shall be provided (for beams the cover is 50mm and provided here).

ii) Crack control

The area of reinforcements for both interior and exterior girders shall be determined using unfactored maximum moments.

a) Interior Girder

The load factors used above in all dead and live loads are taken as unity.

$MDU(L_{1a})= M_{dl}+[max.(M_{trl},M_{tml})]$ . . . . (KN-m/m)

$VDU(L_{1a})= V_{dl}+[max.(V_{trl},V_{tml})]$ . . . . . . (KN/m)

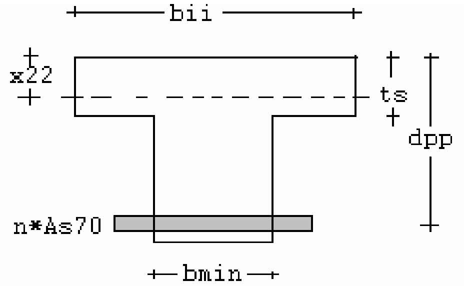
MDu ,VDu are unfactored moment and shear forces at all intervals of L_{1a}, respectively.

$A_{s70}=MDU/(f_s*j*d_{pp})$

j= 0.875 and f_s=0.6fy

Components shall be so proportioned that the tensile stress in the mild steel reinforcement at the service limit state, f_{sa} doesn't exceed. If $F_{cten}> 0.8f_r$, the section has cracked.

Now, steel stress for elastic cracked section for which moment of inertia of the composite transformed section should be used.



The equivalent concrete area is $n*A_{s70}$.

$X_{22}=((-n*A_{s70})+\surd((n*A_{s70})^2+2000*n*d_{pp}*A_{s70}))/1000$

$I_{cr1}=(b_{ii}*x_{22}^3)/3+(n*A_{s70}*(d_{pp}-x_{22})^2)$

If $X_{22}>t_s$, then X_{22} and I_{cr1} has to be recalculated.

where:

X_{22} is the neutral axis depth from top fiber

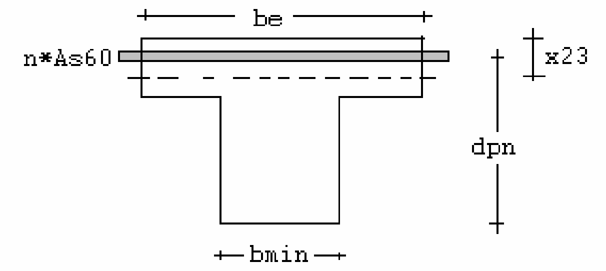
M_{ue}= unfactored max moment.

d_{pp}= the effective depth for positive bending moment reinforcement(mm)

If $f_{s1} > f_{sa1}$, then the area of reinforcing bars has to be increased by reducing the spacing of bars or the section depth has to be increased.

a) Exterior Girder

Similarly, calculate A_{s60}, f_{s2}, f_{sa2} and I_{cr2} for edge strip and check against the minimum requirements.



The equivalent concrete area is $n*A_{s60}$.

$X_{23}=((-n* A_{s60})+\surd((n* A_{s60})^2+2000*n*d_{pn}* A_{s60}))/1000$

$I_{cr2}=(be*x_{23}^3)/3+(n* A_{s60}*(d_{pn}-x_{23})^2)$

If $X_{23}>t_s$, then X_{23} and I_{cr2} has to be recalculated.

where:

X_{23} is the neutral axis depth from top fiber

M_{use}= unfactored max moment.

If $f_{s2} > f_{sa2}$, then the area of reinforcing bars has to be increased by reducing the spacing of bars or the section depth has to be increased.

ii) Deformations

Deflection and camber calculations shall consider dead load, live load, erection loads, concrete creep and shrinkage. (Art 5.7.3.6.2)

Immediate (Instantaneous) deflections may be computed taking the moment of inertia as either the effective moment of inertia, or the gross moment of inertia. The long-term deflection due to creep and shrinkage may be taken as the immediate deflection multiplied by the following factor:

$(3 \text{ to } 1.2)\ A_s'/A_s \geq 1.6$ if d_{dl} is calculated using I_e.

$(4) A_s'/A_s \geq 1.6$ if d_{dl} is calculated using I_g.

Dead load camber, exterior girder

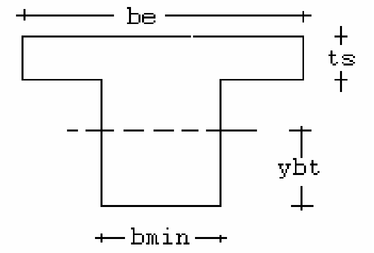


Figure 4.15 Exterior girder cross section

$Y_{bt}=b_e*t_s*(d_w-t_s+t_s/2)+b_{min}*(0.5*(d_w-t_s)_2))/A_{gc}$ (b_e is in meter)

$A_{gc}= b_e*1000*ts+b_{min}*(dw-ts)$

$I_{gex}=((1000*b_e*t_s^3)/12)+(1000*b_e*ts*(d_w-0.5*ts-Y_{bt})^2)+((b_{min}*(d_w-t_s)^3)/12)+$
$(b_{min}*(d_w-t_s)*(Y_{bt}-(0.5*(d_w-t_s)))^2)$

$M_{crex}= f_r*I_{gex}/Y_{bt}$

$M_{ad}= m_{gd}*\ MAX(M_{trem},M_{tmem})+M_{dlem}$

$I_{eff}=(((M_{crex}/M_{ad})^3)*I_{gex})+(1-((M_{crex}/M_{ad})^3))*I_{cr2}$

If $M_{crex} \geq M_{ad}$, then use I_{gex} else use I_{eff}.

The deflection for the exterior girder is assumed to have maximum value where moment is the maximum. Thus, the maximum dead load moment for exterior girder is M_{dlem}.

$D_{dl}= 5*M_{dlem}*L_1^2/48E_cI_{gex}$

Where:

Y_{bt}=Neutral axis depth from the bottom.

A_{gc}= is the gross area of uncracked section

I_{gex} = the gross moment of inertia

I_{eff}= effective moment of inertia for exterior girder

M_{crex}= critical moment for exterior girder

M_{ad}= maximun dead load moment

M_{gd}= distribution factor for deflection (=NL/N_g)

Live load deflection exterior girder

Deflection due to truck, tandem and lane loads are computed and compare it with the permissible limit.

Live load deflection interior girder

Because interior girder is subjected to smaller load than exterior girder, live load deflection requirement is satisfied once it is satisfied for exterior girder. There is no need to check it.

Investigation of Fatigue Limit State

A Similar procedure as did for slab bridges is investigated here.

Shear Reinforcement

Interior girder

V_{cc}=0.083*b_{min}*√(0.8*f_c)*2*d_v/1000

d_v=MAX((d_{pp}-A_{s7}*$f_{y)}$/(0.64*f_c*1000*b_{ii}),0.9*d_{pp},0.72*$d_{w)}$

V_{si}=VD/0.9-V_{cc}

The spacing of the shear reinforcement, S_{ri}, is the minimum of:

=as*f_y*d_v/V_{si}, and

=0.8*1000*d_v*a_s*f_y/0.083*b_{min}*√(0.8*f_c)

Where:

V_{cc}= shear strength of concrete

d_v= effective shear depth

V_{si}= critical shear at a distance dv from face of support

VD= design maximum factored shear force

A_{s7}= area of reinforcement provided

a_s= area of shear reinforcement

Exterior girder

Such a similar approach is carried out to exterior girder.

The source program for Analysis and Design of T-Girder Bridge is attached as Annex III.

4.3.3. Selection Criteria and Comparison

4.3.3.1. Cost Comparison

It is being shown that minimum material content alone does not necessarily give the best value or most economic solution in overall terms. Issues such as buildability, repeatability, simplicity, esthetics, thermal mass and notability, speed of construction must all be taken into account.

Nevertheless, for selecting bridge type of same material, cost comparison will be a useful parameter to select a better optimum. In this regard the materials used for the construction of the bridges such as total volume of concrete, total amount of reinforcing bars, volume of bitumen, area of formwork & steel pipes for posts and railings or their associated costs are the only costs taken into consideration. The cost analysis of the bridges is carried in order to select the most economical span length.

5. Computer Program for Design of Slab and T-Girder Bridges

5.1. Algorithm / Flow Chart

5.1.1. Algorithm/ Flow Chart for Slab Bridges

Input Data

The input data consists of: Steel strength, cylindrical compressive strength of concrete, concrete density, the modulus of elasticity of steel, and bituminous density.

Moreover, input data includes initial dimensions of the bridge to be designed such as: clear Span, roadway width, curbs width, curb depth, support width, bitumen thickness, railing dimensions, post depth and width, post height and spacing.

Further more reinforcement sizes for main, distribution and temperature bars are the input data. Material costs are also taken as an input data for cost analysis.

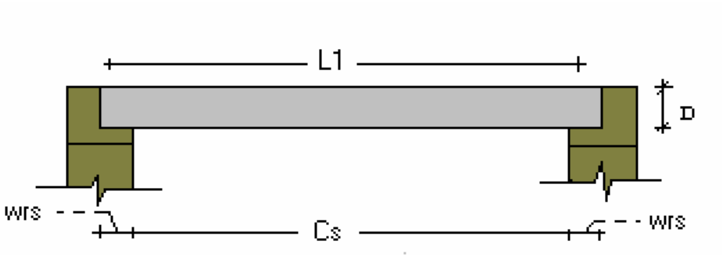


Figure 5.1 Longitudinal section of a slab bridge

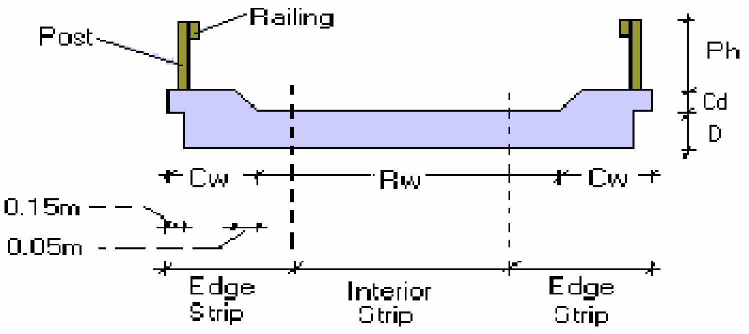


Figure 5.2 Cross Section of a slab bridge

Analysis:

Having material properties and bridge dimensions as an input data, the thickness of the slab is computed using equation (4.1). In addition to this, the followings are computed:

- the live load equivalent strip widths from equations (4.2) and (4.3) for both interior and edge strips, respectively.
- dead load force effects on the basis of equations (4.4) and (4.5) .

Influence lines will be used to determine load positions for maximum effect and magnitude of these effects as shown in figure 4.3 to figure 4.5.2

Appropriate load factors and load combinations are applied for the selected limit state design from Tables given in ERA Bridge Design Manual [5].

Then the critical force effects due to dead and live loads are obtained from (4.6)

Designing:

The interior and edge strip of the deck is designed for the critical moments obtained from the analysis.

The positive reinforcement for the slab is calculated on the basis of equation (4.7) for interior strip. Distribution and temperature reinforcements may be taken as a percentage of the main reinforcements required for positive moment.

The designed section is investigated for different limit states and if the section is safe against durability, cracking, deflection and fatigue, then the section is sufficed and the design is completed.

Total amount of materials used

After examining and investigating the adequacy of the section for different limit states, the total amount of materials used are obtained by determining all the reinforcing bars, volume of concrete, area of asphalt coat, area of formworks and weight of steel pipes.

After calculating all the required materials, the total cost of the superstructure is obtained by applying current material prices for the purpose of cost analysis.

The above algorithm can be summarized in a flow chart shown in figure 5.3.

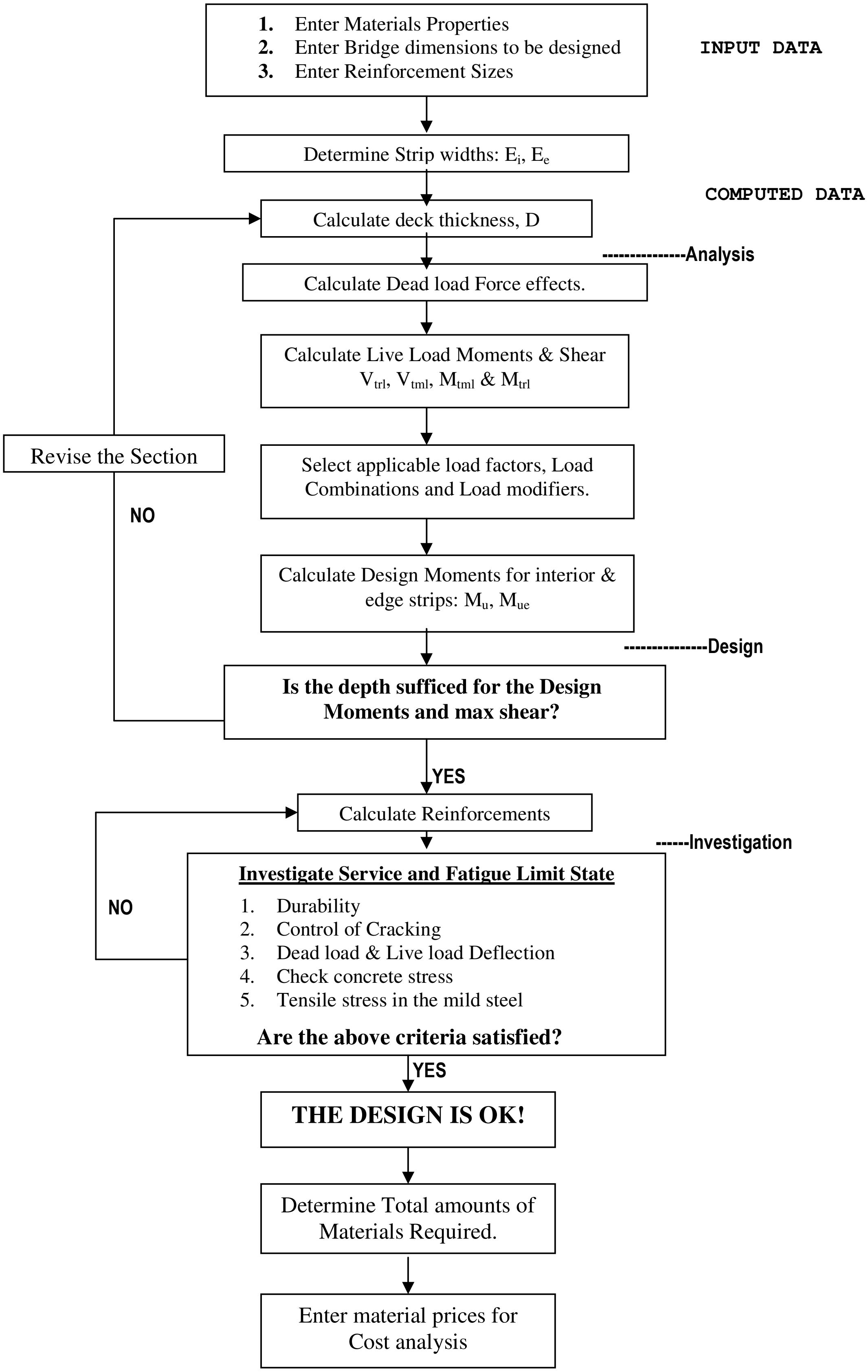


Figure 5.3 Flow chart for Slab Bridges

5.1.2. Algorithm/ Flow Chart for T-Girder Bridges

Design Input Data

The input data consists of: Steel strength, cylindrical compressive strength of concrete, concrete density, the modulus of elasticity of steel, and bituminous density.

Moreover, input data includes initial dimensions of the bridge to be designed such as: clear Span, roadway width, curb width, curb depth, support width, bitumen thickness, railing and post dimensions, post height, post and girder spacings.

Further more reinforcement sizes for main, distribution, temperature bars and shear reinforcement bars are the input data. Material costs are also taken as input data for cost analysis.

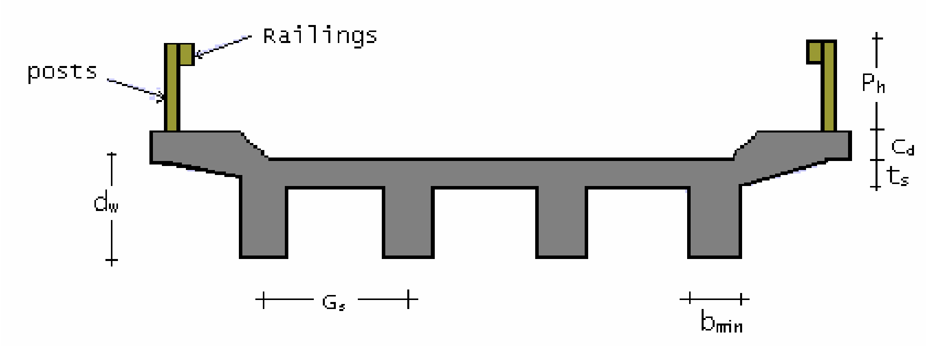


Figure 5.4 T-Girder Bridge cross section

Analysis:

Given the above input data of material properties and dimension of the bridge going to be designed, the following will be computed:

- the thickness of the deck slab is determined from equation (4.8).
- structural analysis of the deck slab involves taking a continuous strip perpendicular to the girders. The dead load force effects are obtained by analyzing the continuous beam loaded in figure 4.9 and 4.10 for dead load force effects due to slab and wearing surface loads. The critical live load effects are obtained by varying the position of the wheel loads as shown in figures 4.11, 4.12, and 4.13.
- equations (4.9) and (4.11) are used to determine critical effects due to dead and live loads. To get the load per unit width of the equivalent strip, divide the total load on one design traffic lane by the calculated strip widths

Appropriate load factors and load combinations are applied for the selected limit state design from Tables provided in ERA's Bridge Design Manual.

Designing:

The deck slab is designed for both the critical positive and negative moments obtained from equations (4.1) and (4.2), respectively.

The positive reinforcements for the deck slab are calculated on the basis of equation (4.12) and negative reinforcement computations; equation (4.13) is used.

Distribution and temperature reinforcements may be taken as a percentage of the main reinforcements required for positive moment.

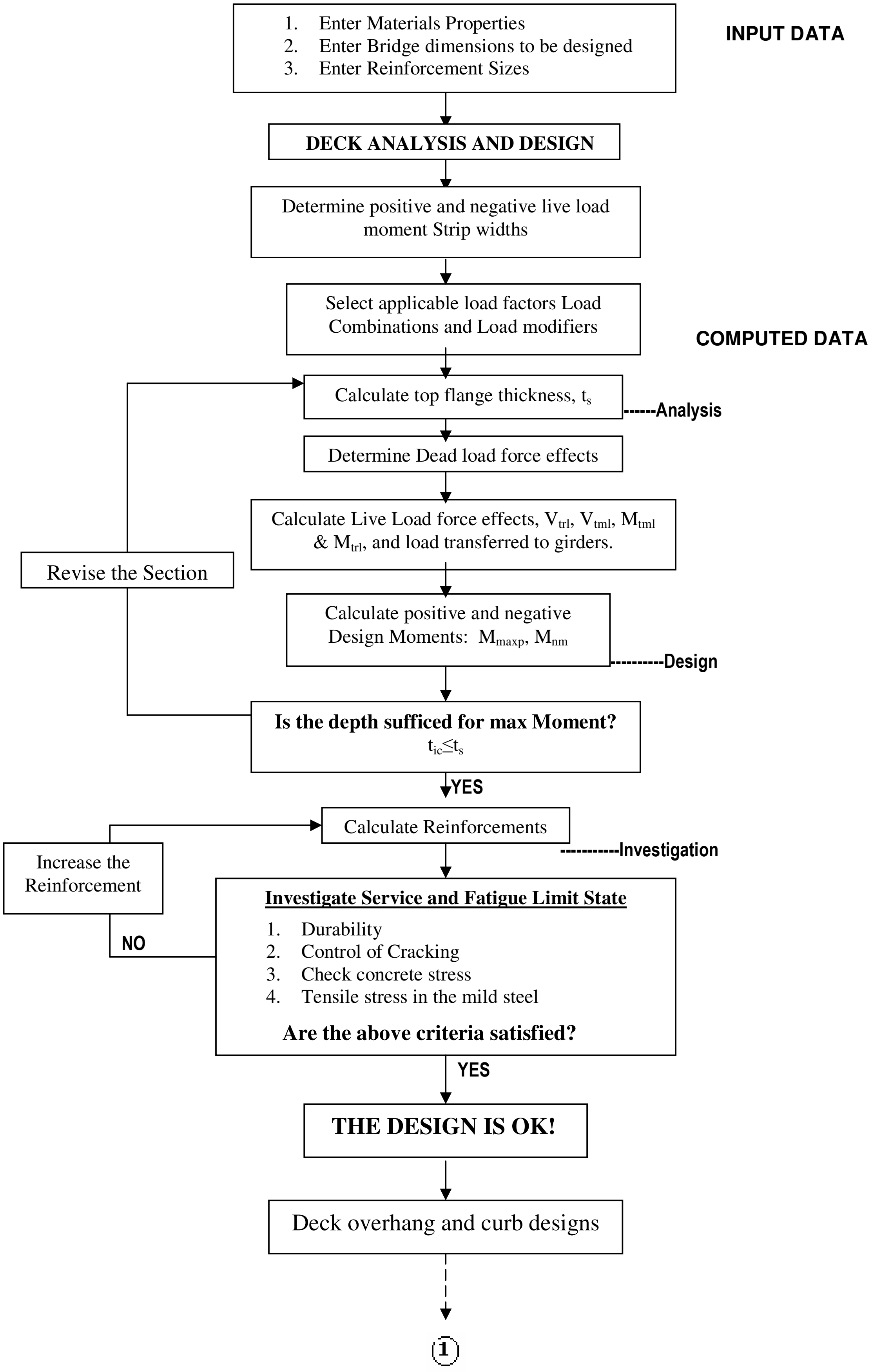
The designed section is investigated for service and fatigue limit states. If the section is safe against durability, cracking, deflection and fatigue, then section is sufficed and the design is completed.

Next to this, both exterior and interior longitudinal girders are designed. The minimum web thickness and depth are determined from equation (4.8) and (4.10), repressively. The live load force effects due to vehicular loads and lane load is obtained and distributed for the girders with the appropriate distributed factors for shear and moments.

Influence lines will be used to determine load positions for maximum force effects and magnitude of these effects as shown in figure 4.3 to figure 4.5.2. Here again load factors and load combinations are applied.

The critical shear and moments obtained from the analysis is used to design the girders. Service limit state is investigated for the sufficiency of the section. If the section is adequate, then the construction materials are calculated using in a similar way did for slab bridges and total cost for the bridge is determined.

The above algorithm can be summarized in a flow chart as shown in figure 5.5.


1. Enter Materials Properties
2. Enter Bridge dimensions to be designed
3. Enter Reinforcement Sizes
INPUT DATA
DECK ANALYSIS AND DESIGN
Determine positive and negative live load moment Strip widths
Select applicable load factors Load Combinations and Load modifiers
COMPUTED DATA
Calculate top flange thickness, t_s
------Analysis
Determine Dead load force effects
Calculate Live Load force effects, V_{trl}, V_{tml}, M_{tml} & M_{trl}, and load transferred to girders.
Revise the Section
Calculate positive and negative Design Moments: M_{maxp}, M_{nm}
----------Design
Is the depth sufficed for max Moment?
$t_{ic} \leq t_s$
YES
Calculate Reinforcements
-----------Investigation
Increase the Reinforcement
NO
Investigate Service and Fatigue Limit State
1. Durability
2. Control of Cracking
3. Check concrete stress
4. Tensile stress in the mild steel
Are the above criteria satisfied?
YES
THE DESIGN IS OK!
Deck overhang and curb designs
①

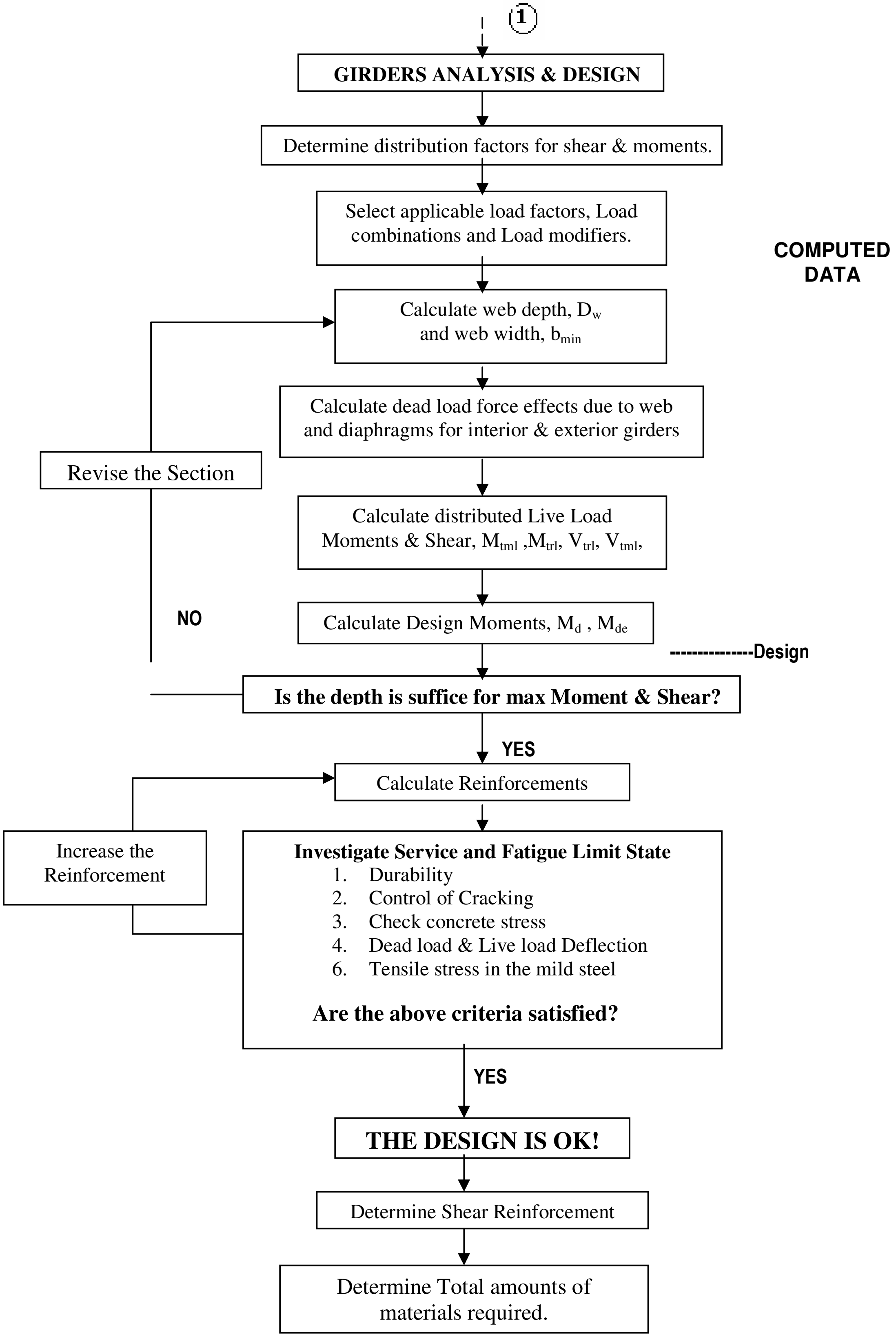


Figure 5.5 Flow chart for T-Girder Bridges

6. Design Example

6.1. Design Outputs

The summary of necessary outputs obtained from the design program for a 10m, 12m and 14m span slab and T-girder bridges are provided in Table 6.1 and Table 6.2, respectively. To show the whole process of computation involved in the program, the detailed Input-Output of a 10m slab and T-girder bridges are attached in Annex II.

6.2. Summary on Outputs

6.2.1. Cost Analysis

The materials volume obtained from the output of the program and current material prices are used for the cost analysis in order to identify the economical span of the two types of bridges (Slab and T-Girder bridges).

The cost of the main girders and cross-girders will be directly proportional to the span. The cost of sub-structure will be the cost of abutments, which will not vary, and cost of piers.

For cost analysis, recent values of construction costs including overhead cost are used here. Table 6.3 below shows the cost for different items.

Table 6.1 Summary of outputs for 10, 12 and 14m of slab bridges.

Span (m)	Total width (m)	Depth (mm)	Volume of Concrete (m^3)	Area of Formwork (m^2)	Reinforcement				
					Main Bars		Dist'n bars bottom(trans.) 12mm rebars	Temp. bars longitudinal 12mm rebars	Temp. bars transversal 12mm rebars
					Interior Strip 32mm rebars	Exterior Strip 32mm rebars			
10	8.92	540	65.58	179.37	c/c 180mm L=13100mm	c/c 140mm L=13100mm	c/c 130mm L=8520mm	c/c 160mm L=10600mm	c/c 160mm L=8820mm
12	8.92	620	85.28	213.15	c/c 150mm L=15400mm	c/c 120mm L=15400mm	c/c 130mm L=8520mm	c/c 140mm L=13200mm	c/c 140mm L=8820mm
14	8.92	700	107.48	247.57	c/c 130mm L=17700mm	c/c 100mm L=17700mm	c/c 130mm L=8520mm	c/c 120mm L=15300mm	c/c 120mm L=8820mm

Table 6.2 Summary of outputs for 10, 12 and 14m of T-Girder bridges.

Span (m)	Deck thickness (mm)	Girder Spacing (m)	Girder Dimension		Diaphragm Dimension		Reinforcement								Volume of Concrete (m^3)	Area of Formwork (m^2)
							Main Bars		Dist'n bars bottom (longt.) 12mm rebars	Temp. bars longitudinal 12mm rebars	Interior Girder		Exterior Girder			
			Web width (mm)	Depth (mm)	Thickness (mm)	Depth (mm)	+ve Reinf. 16mm rebars	-ve Reinf. 16mm rebars			Main 32 mm rebars	shear reinf 12mm rebars	Main 32 mm rebars	shear reinf 12mm rebars		
10	180	2.32	360	750	250	500	c/c 195mm L=8820mm	c/c 195mm L=8820mm	c/c 160mm L=10300mm	c/c 450mm L=10300mm	10	c/c 190mm	12	c/c 280mm	43.70	246.73
12	180	2.32	360	850	250	500	c/c 195mm L=8820mm	c/c 195mm L=8820mm	c/c 160mm L=12900mm	c/c 450mm L=12900mm	11	c/c 180mm	13	c/c 260mm	53.3	299.71
14	180	2.32	360	1050	250	500	c/c 195mm L=8820mm	c/c 195mm L=8820mm	c/c 160mm L=15000mm	c/c 450mm L=15000mm	11	c/c 190mm	13	c/c 280mm	66.03	370.99

Table 6.3 Unit price for materials

No.	Material	Unit	Unit Price (Br)
1	Reinforcing bars	kg	12.00
2	Concrete	m^3	2000.00
3	Formwork	m^2	120.00
4	Asphalt (bitumen)	m^3	1300.00
5	Steel Pipe	kg	30.00
6	Steel bearings	pcs	500.00

An output of the results of the two types of bridges of span ranges from 10 to 15 m and their total associated costs are summarized and tabulated in Table 6.4 below.

Table 6.4. Total costs for different span lengths.

No.	Span Length (m)	Total Cost (Birr) (Concrete price 2000br)	
		Slab Bridge	Girder Bridge
1	10.00	239,697.81	254,140.00
2	10.50	256,792.34	272,229.94
3	11.00	274,722.41	294,927.00
4	11.50	294,697.69	311,988.94
5	12.00	318,630.06	335,215.09
6	12.50	340,699.03	356,798.62
7	13.00	361,619.16	373,886.19
8	13.50	386,550.00	395,842.00
9	14.00	405,850.56	381,979.03
10	14.50	436,406.78	390,922.69
11	15.00	455,263.00	417,632.38

Figure 6.1 shows a relationship between span length and total cost of a superstructure for span length of a bridge ranging from 10 to 15m.

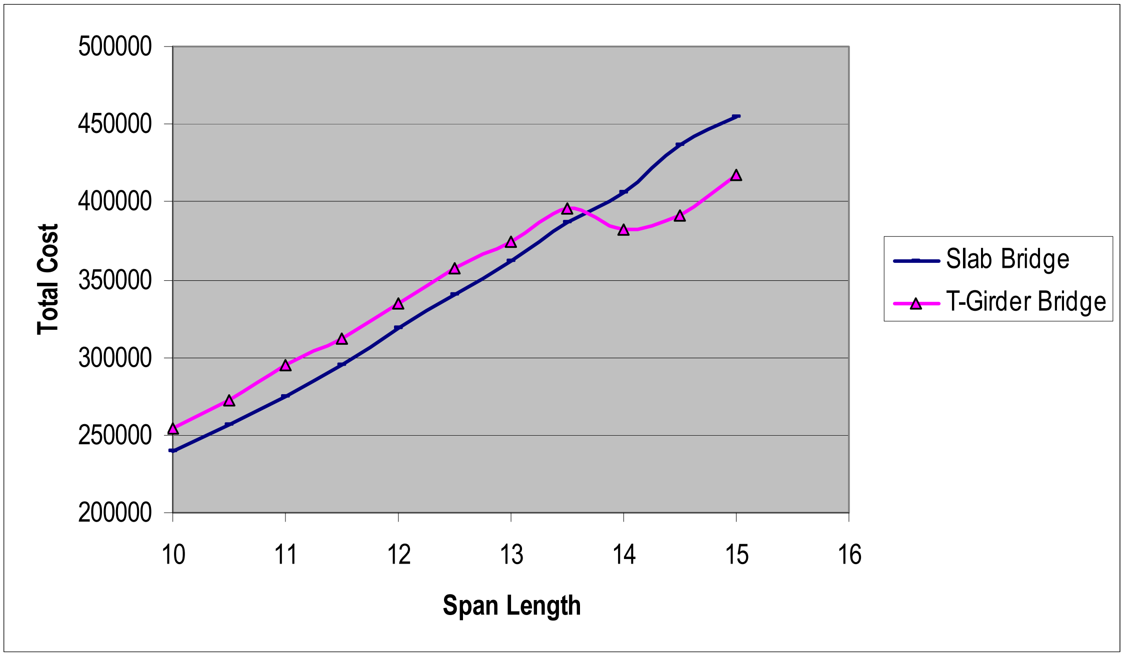


Figure 6.1 Span Length Vs Cost graph

6.2.2. Comparison

The total cost of the superstructure of a bridge is considered as a criterion for the comparative study of the bridges.

7. Conclusions and Recommendations

7.1. Conclusions

This study has attempted to address the selection problem of type of bridge for a defined as Slab or T-Girder bridge. Per the condition survey made, it is observed that some designers even have not adopted the standard as in the case of the 9m span T-Girder. Though, no particular fatal failure problem observed, in consistence in the selection of type of bridge have been noted as in the case of 9, 10m T-Girder bridges and 10 and 11m Slab bridges. Thus, to define the particular span on the basis of some engineering parameter happen to be found reasonable. In this regard cost of the superstructure is used for delimiting the demarcation span.

Per the observation of the result of Figure 6.1 of cost comparison for superstructures of the two types of bridges using the prevailing costs, it is found that a span of 14m is the demarcation span for selecting Slab or T-Girder bridge. Accordingly, up to 14m span, slab bridges are economical. Moreover, slab bridges are observed to be easier and simple to construct and consumes less time compared with T-Girder type bridges.

Moreover, trends show that the cost of concrete is increasing at alarming rate and may result in the cost of Slab Bridge to be more expensive than that of T- Girders in which the demarcation span may be lower.

Since bars are not curtailed for the deck slab of a T-girder bridge, it is observed that the amount of reinforcement used for a girder bridge is higher and this also governs the total cost. The thickness of Slab bridges is quite considerable and the amount of concrete required is generally more than that required for the girder bridges. Construction problems in simple concrete girder spans were primarily due to the complication of forms and falsework.

In selection of bridge types, not only the cost of construction is taken into account but also the cost of future expenditures during the projected service life of the bridge should be considered.

Regional factors, such as availability of construction material, fabrication, location, transportation, erection constraints, inspection, maintenance, repair, and/or replacement shall be considered. Lower first cost does not necessarily lead to lowest total cost.

Constructed bridges have to be inspected and maintained as soon as possible prior to damages, and this need be also accounted in future works.

7.2. Recommendations

From the study that has been carried out, the followings are the recommendations drawn from the result:

1. Slab Bridge is economical up to 14m span and per the standard 6 to 10m are also under this category.
2. T-Girders are economical beyond 14m up to the standard 24m in which the later need be standard with that of box Girder.
3. As the developed program is easy to apply, consulting firms can make use of the program for analysis and design of slab and girder bridges, with appropriate consultation with the department and the producer.
4. The department can update this program for multi-span Slab and T- Girder bridges and even upgrade it to that of Box-Girders with some modifications.

References

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4. Delelegn Teshome, Master's Thesis. (1982), Bridge Practice in Ethiopia, Addis Ababa, AAU
5. Ethiopian Roads Authority. (2002),Bridge Design Manual, Addis Ababa: ERA
6. Fundamental of Bridge Design. (2002), Lecture notes, Civil Engineering Department, Faculty of Technology, AAU
7. M.G Aswani . (1995), Design of Concrete Bridges, 2nd edition, Nai Sarak, KHANNA Publishers
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9. Wai-Fah (2002) Bridge Engineering Handbook, CRC Press, USA
10. W.F. Chen (1999), Structural Engineering Handbook, CRC Press, USA

ANNEXES

Slab Bridge Design Output

```
 SLAB BRIDGE DESIGN PROGRAM
  1. ENTER MATERIAL PROPERTIES
    Steel strength, fy, in Mpa = 400
     Concrete Grade fc, in Mpa = 35
    Concrete density, yc, in Kg/m3 = 2400
    Bituminous density, yb, in Kg/m3 = 2250
    The modulus of elasticity of steel, Es, in Gpa = 200

   2. ENTER BRIDGE DIMENSION
    Clear span of the bridge,Cs, in m = 10
    Road way width Rw, in m = 7.32
    Curb width Cw, in m = 0.8
    Curb depth Cd, in m = 0.25
    Support Width, WRs, in m = 0.4
    Bituminous thickness, bt, in mm = 75
    Railing depth of concrete, Rd, in m = 0.3
    Railing width of concrete, Rww, in m = 0.3
    Steel Railing pipe diameter, Rds, in mm = 0
    Post depth of concrete, Pd, in m = 0.3
    Post width of concrete, Pw, in m = 0.3
    Steel Post pipe diameter, pds, in mm = 0
    Post height, Ph, in m = 0.55
    Post spacing, Ps, in m = 2.32

 3. ENTER  REINFORCEMENT SIZES
      What is the main dia. of the bar,db,used?  32
      What is the dia. of the distn. bar,dd,used?  12
      What is the dia. of the temp. bar,dt,used?  12

        DESIGN OF SLAB BRIDGE HAVING A CLEAR SPAN
   OF 10.0000000 m AND A ROADWAY WIDTH OF 7.32000017 m.

    Total no. of posts =10.0
    NL, Number of lanes loaded =2.0
    S =10.400m,              Ec = 26.752Gpa
Interior Strip
```

E = 4295.2778 mm for one lane loaded
Em = 3255.7937 mm for two lanes loaded

Equivalent concentrated and distributed loads
Truck: p1 = 14.298 KN/m, Truck: p2 = 59.233 KN/m
Tandem: p3 = 44.935 KN/m, Lane Load :W = 2.856 KN/m2
Edge Strip, Ee = 1800.000 mm

wdi= 14.9465256 KN-m/m wde= 16.6477699 KN-m/m

Live Load Force Effects

INTERIOR STRIP

Truck Load + Lane Load

Mtr(0.10399995)= 11.4220238 ; Vtr(0.103999995)= 96.6362000
Mtr(1.14400005)= 108.754898 ; Vtr(1.14400005)= 95.3055420
Mtr(2.18400002)= 176.536438 ; Vtr(2.18400002)= 89.3432770
Mtr(3.22399998)= 217.619263 ; Vtr(3.22399998)= 80.0502014
Mtr(4.26399994)= 230.971695 ; Vtr(4.26399994)= 67.4513245
Mtr(5.30399990)= 216.593735 ; Vtr(5.30399990)= 52.4735107
Mtr(6.34399986)= 183.301575 ; Vtr(6.34399986)= 37.4333115

Tandem Load + Lane Load

Mtm(0.10399995)= 10.2431679 ; Vtm(0.103999995)= 85.3010406
Mtm(1.14400005)= 100.694412 ; Vtm(1.14400005)= 88.2596588
Mtm(2.18400002)= 169.363052 ; Vtm(2.18400002)= 86.0587616
Mtm(3.22399998)= 216.249069 ; Vtm(3.22399998)= 79.6252060
Mtm(4.26399994)= 241.352493 ; Vtm(4.26399994)= 69.8858490
Mtm(5.30399990)= 244.673294 ; Vtm(5.30399990)= 57.7675476
Mtm(6.34399986)= 226.211502 ; Vtm(6.34399986)= 44.1971703

Dead Load Moment (interior strip)

Mdl(0.10399995)= 8.00224972 ; Vdl(0.103999995)= 76.1674957
Mdl(1.14400005)= 79.1333618 ; Vdl(1.14400005)= 60.6231079
Mdl(2.18400002)= 134.098312 ; Vdl(2.18400002)= 45.0787201
Mdl(3.22399998)= 172.897110 ; Vdl(3.22399998)= 29.5343342
Mdl(4.26399994)= 195.529739 ; Vdl(4.26399994)= 13.9899473
Mdl(5.30399990)= 201.996201 ; Vdl(5.30399990)= -1.55443978
Mdl(6.34399986)= 192.296494 ; Vdl(6.34399986)= -17.0988274

Design Moment, Interior strip

```
MD( 0.10399995 )= 29.9913540   ,  VD( 0.103999995 )= 264.322723
MD( 1.14400005 )= 289.237762   ,  VD( 1.14400005 )= 242.563583
MD( 2.18400002 )= 476.561646   ,  VD( 2.18400002 )= 212.699127
MD( 3.22399998 )= 596.955078   ,  VD( 3.22399998 )= 177.005768
MD( 4.26399994 )= 666.779053   ,  VD( 4.26399994 )= 139.787674
MD( 5.30399990 )= 680.673523   ,  VD( 5.30399990 )= 99.1501617
MD( 6.34399986 )= 636.240723   ,  VD( 6.34399986 )= 55.9715118
```

```
 Maximum Design Moment & Shear, factored
    Mu= 680.673523 KN-m/m        Vu= 264.322723 KN/m
    Mus=  446.67KN-m/m    Vus=  172.80KN/m
```

EXTERIOR STRIP

Truck Load + Lane Load

```
Mtre( 0.10399995 )= 12.3959188  ;  Vtre( 0.103999995 )= 104.875847
Mtre( 1.14400005 )= 118.027847   ;   Vtre( 1.14400005 )= 103.431732
Mtre( 2.18400002 )= 191.588745   ;   Vtre( 2.18400002 )= 96.9610977
Mtre( 3.22399998 )= 236.174500   ;   Vtre( 3.22399998 )= 86.8756485
Mtre( 4.26399994 )= 250.665421   ;   Vtre( 4.26399994 )= 73.2025375
Mtre( 5.30399990 )= 235.061508   ;   Vtre( 5.30399990 )= 56.9476471
Mtre( 6.34399986 )= 198.930725   ;   Vtre( 6.34399986 )= 40.6250496
```

Tandem Load + Lane Load

```
Mtme( 0.10399995 )= 11.1165476  ;   Vtme( 0.103999995 )= 92.5741959
Mtme( 1.14400005 )= 109.280083   ;    Vtme( 1.14400005 )= 95.7850876
Mtme( 2.18400002 )= 183.803726   ;    Vtme( 2.18400002 )= 93.3965302
Mtme( 3.22399998 )= 234.687469   ;    Vtme( 3.22399998 )= 86.4144135
Mtme( 4.26399994 )= 261.931335   ;    Vtme( 4.26399994 )= 75.8446350
Mtme( 5.30399990 )= 265.535278   ;    Vtme( 5.30399990 )= 62.6930771
Mtme( 6.34399986 )= 245.499344   ;    Vtme( 6.34399986 )= 47.9656258
```

Dead Load Moment (exterior strip)

```
Mdle( 0.10399995 )= 8.91308308    ;Vdle( 0.103999995 )= 84.8370361
Mdle( 1.14400005 )= 88.1404877    ;Vdle( 1.14400005 )= 67.5233536
Mdle( 2.18400002 )= 149.361664    ;Vdle( 2.18400002 )= 50.2096748
```

Mdle(3.22399998)= 192.576614 ;Vdle(3.22399998)= 32.8959923
Mdle(4.26399994)= 217.785339 ;Vdle(4.26399994)= 15.5823126
Mdle(5.30399990)= 224.987823 ;Vdle(5.30399990)= -1.73136938
Mdle(6.34399986)= 214.184082 ;Vdle(6.34399986)= -19.0450516

Mdlem= 224.99KN-m/m Vdlem= 84.84KN/m

Design Moment, Edge strip
MDe(0.10399995)= 32.8342133 , VDe(0.103999995)= 289.579041
MDe(1.14400005)= 316.724335 , VDe(1.14400005)= 265.409729
MDe(2.18400002)= 521.982361 , VDe(2.18400002)= 232.444016
MDe(3.22399998)= 654.026123 , VDe(3.22399998)= 193.152374
MDe(4.26399994)= 730.611511 , VDe(4.26399994)= 152.206009
MDe(5.30399990)= 745.921509 , VDe(5.30399990)= 107.548676
MDe(6.34399986)= 697.353943 , VDe(6.34399986)= 60.1335297

Maximum Design Moment & Shear, factored
Mue= 745.92KN-m/m Vue= 289.58KN/m

Design Moment, edge strip (Unfactored)
MDue(0.103999995)= 21.3090019
MDue(1.14400005)= 206.168335
MDue(2.18400002)= 340.950409
MDue(3.22399998)= 428.751099
MDue(4.26399994)= 479.716675
MDue(5.30399990)= 490.523102
MDue(6.34399986)= 459.683411

Maximum Design Moment , factored
Muse= 490.52KN-m/m
D= 540.000mm d1= 499.000mm de= 749.000mm

Reinforcement, Interior Strip
Api= 4565.78mm2 Use 30.0 f 32.0 mm Rebars
C/C 180.0mm, Length = 13100.0mm

Reinforcement, Edge Strip

Ape= 4980.46mm2 Use 12.0 f 32.0 mm Rebars total on both edges

C/C 140.0mm, Length = 13100.0mm both sides

Distribution bar bottom transversal reinf.

Ate= 854.65mm2 Use 83.0 f12.0mm Rebars

C/C 130.0mm, Length = 8520.0mm

Edge strip top Reinf.,longitudinal

Use 3 f 12.0mm Rebars at the top of curbs

use f 12.0 C/C 130.0mm, length =10600.0mm transversal

Temp Reinforcement, top transversal

Ast= 1350.000 Use 67.0 f12.0mm Rebars

C/C 160.0mm, length = 8820.0mm

Temp Reinforcement, top longitudinal

Ast= 1350.00mm2 Use 56.0 f12.0mm Rebars

C/C 160.0mm, Length =10600.0mm

Mdl, Max DL moment for the whole Bridge= 1797 KN/m

Mcr= 1910.68628 KN/m

Provide a camber of = 21.923mm

dtl= 6.423mm < dmax= 13.000mm ?
dkt= 2.631mm < dmax= 13.000mm ?

Satisfies deflection requirement!

CURBS DESIGN

Ap3= 565.20mm2 Use 67.0 f12.0mm Rebars

C/C 200.0mm, Length = 2470.0mm both sides

SLAB BRIDGE OF 10.0000000 m & 7.32000017 m. wide

Total amount of materials used are:

1) Reinforcement bars = 6560.172kg
2) Volume of concrete = 65.586m3
3) Area of Asphalt = 84.91m2
4) Area of Formwork = 179.79m2

```
    5) Total wt. of steel pipe   =   0.00kg

4. ENTER CURRENT CONSTRUCTION COSTS IN BIRR
     Unit price for Rein. bars/Kg = 12
     Unit price for concrete /m3 = 2000
     Unit price for formwork/m2 =  120
     Unit price for bitumen/m3 =   1300
     Unit price for steel pipes/Kg =  30

      Total Cost for comparison   =  239697.81Birr

          *** ============THE END============ ***
   Program Completed
   Press Enter to Continue.
```

T-Girder Bridge Design Output

```
T-GIRDER BRIDGE DESIGN
 1. ENTER MATERIAL PROPERTIES
   Steel strength, fy, in Mpa = 400
   Concrete Grade fc, in Mpa = 35
   Concrete density, yc, in Kg/m3 = 2400
   Bituminous density, yb, in Kg/m3 = 2250
   The modulus of elasticity of steel, Es, in Gpa = 200

  2. Enter Bridge span and support dimension
   Clear span of the bridge,Cs, in m = 10
   Road way width Rw, in m = 7.32
   Curb width Cw, in m = 0.8
   Curb depth Cd, in m = 0.25
   Support Width , WRs, in m = 0.4
   Bituminous thickness, bt, in mm = 75
   Railing depth of concrete, Rd, in m = 0.3
   Railing width of concrete, Rww, in m = 0.3
   Steel Railing pipe diameter, Rds, in mm = 0
   Post depth of concrete, Pd, in m = 0.3
   Post width of concrete, Pw, in m = 0.3
   Steel Post pipe diameter, pds, in mm = 0
   Post height, Ph, in m = 0.55
   Post spacing ,Ps, in m = 2.32
   Girder spacing,Gs, in m = 2.32

3. Enter REINFORCEMENT SIZES
  What is the bar diam. in the girders,db,used?   32
  What is the dia. of the bar for the deck ,dd,used?  16
  What is the dia. of the distn. bar,dd1,used?  12
  What is the dia. of the temp. bar,d1t,used?  12
  What is the dia. of the shear rein,dst,used?  12
```

DESIGN OF T-GIRDER BRIDGE HAVING A CLEAR SPAN

OF 10.0000000 m AND A ROADWAY WIDTH OF 7.32000017 m.

Total no. of posts =10.0

L1 =10.400m

Ec = 26.752Gpa

Ng = 4

Cx = 0.180m

ts= 180.00mm bmin= 360.00mm

Ew= 1936.00000 mm, dx= 0.119999945 mm

Rm1= 110.734085 KN/m Mp1= 18.8283577 KN-m/m Rrm1= 68.6368332 KN/m

Mmaxp = 46.020KN-m/m Mnegp= 36.918KN-m/m

Reinforcements

Positive Reinforcement

App= 1030.56mm2 Use 53.0 f16.0 mm Rebars

C/C 195.0mm, Length = 11300.0mm

Negaitive Reinforcement

Apn= 1030.56mm2 Use 53.0 f16.0 mm Rebars

C/C 195.0mm, Length = 10300.0mm

Distribution bar transversal (bottom)

Adi= 690.48mm2 Use 56.0 f12.0 mm Rebars

C/C 160.0mm, Length = 10300.0mm

Temp. bar transversal (top)

Adi= 225.00mm2 Use 23.0 f12.0 mm Rebars

C/C 450.0mm, Length = 8820.0mm

DECK OVERHANG DESIGN

Transversal reinforcement

Ap3= 1339.73mm2 Use 72.0 f16.0mm Rebars

C/C 150.0mm, Length = 2470.0mm both sides

Ast3= 237.50mm2 Use 3.0 f12.0mm Rebars

C/C 450.0mm, Length =10300.0mm both sides

DESIGN OF LONGITUDINAL GIRDERS

Total depth of girder including flange, Dw= 750.00mm

INTERIOR GIRDER

Truck Load + Lane Load

Mtr(0.10399995)= 26.8850765 ; Vtr(0.10399995)= 250.894211
Mtr(1.14400005)= 255.986496 ; Vtr(1.14400005)= 247.439468
Mtr(2.18400002)= 415.530182 ; Vtr(2.18400002)= 231.959778
Mtr(3.22399998)= 512.230652 ; Vtr(3.22399998)= 207.832397
Mtr(4.26399994)= 543.659485 ; Vtr(4.26399994)= 175.122238
Mtr(5.30399990)= 509.816742 ; Vtr(5.30399990)= 136.235703
Mtr(6.34399986)= 431.453918 ; Vtr(6.34399986)= 97.1872025

Tandem Load + Lane Load

Mtm(0.10399995)= 24.1102924 ; Vtm(0.1039995)= 221.465012
Mtm(1.14400005)= 237.013779 ; Vtm(1.14400005)= 229.146408
Mtm(2.18400002)= 398.645508 ; Vtm(2.18400002)= 223.432266
Mtm(3.22399998)= 509.005493 ; Vtm(3.22399998)= 206.728989
Mtm(4.26399994)= 568.093750 ; Vtm(4.26399994)= 181.442932
Mtm(5.30399990)= 575.910217 ; Vtm(5.30399990)= 149.980484
Mtm(6.34399986)= 532.454956 ; Vtm(6.34399986)= 114.748047

Dead Load Moment

Mdl(0.10399995)= 12.6807747 ; Vdl(0.10399995)= 120.707367
Mdl(1.14400005)= 125.495598 ; Vdl(1.14400005)= 96.2442093
Mdl(2.18400002)= 212.868744 ; Vdl(2.18400002)= 71.7810516
Mdl(3.22399998)= 274.800201 ; Vdl(3.22399998)= 47.3178978
Mdl(4.26399994)= 311.289978 ; Vdl(4.26399994)= 22.8547401
Mdl(5.30399990)= 322.338043 ; Vdl(5.30399990)= -1.60841751
Mdl(6.34399986)= 307.944458 ; Vdl(6.34399986)= -26.0715752

Design Moment, interior girder (Factored)

MD(0.103999995)= 62.8998489 , VD(0.103999995)= 589.949097
MD(1.14400005)= 604.845825 , VD(1.14400005)= 553.324341
MD(2.18400002)= 993.263672 , VD(2.18400002)= 495.655945

MD(3.22399998)= 1239.90393 , VD(3.22399998)= 422.854065
MD(4.26399994)= 1383.27637 , VD(4.26399994)= 346.093567
MD(5.30399990)= 1410.76538 , VD(5.30399990)= 260.455322
MD(6.34399986)= 1316.72681 , VD(6.34399986)= 168.219620

Maximum Design Moment & Shear, factored
Mu= 1410.76538 KN-m/m Vu= 589.949097KN/m
Maximum Design Moment, unfactored
Mus= 898.248291KN-m/m

EXTERIOR GIRDER

Truck Load + Lane Load

Mtre(0.103999995)= 26.8850765 ; Vtre(0.103999995)= 165.590179
Mtre(1.14400005)= 255.986496 ; Vtre(1.14400005)= 163.310043
Mtre(2.18400002)= 415.530182 ; Vtre(2.18400002)= 153.093460
Mtre(3.22399998)= 512.230652 ; Vtre(3.22399998)= 137.169388
Mtre(4.26399994)= 543.659485 ; Vtre(4.26399994)= 115.580681
Mtre(5.30399990)= 509.816742 ; Vtre(5.30399990)= 89.9155655
Mtre(6.34399986)= 431.453918 ; Vtre(6.34399986)= 64.1435547

Tandem Load + Lane Load

Mtme(0.10399995)= 24.1102924 ; Vtme(0.103999995)= 146.166916
Mtme(1.14400005)= 237.013779 ; Vtme(1.14400005)= 151.236633
Mtme(2.18400002)= 398.645508 ; Vtme(2.18400002)= 147.465302
Mtme(3.22399998)= 509.005493 ; Vtme(3.22399998)= 136.441132
Mtme(4.26399994)= 568.093750 ; Vtme(4.26399994)= 119.752327
Mtme(5.30399990)= 575.910217 ; Vtme(5.30399990)= 98.9871216
Mtme(6.34399986)= 532.454956 ; Vtme(6.34399986)= 75.7337112

Dead Load Moment (exterior Girder)

Mdle(0.10399995)= 13.9112597 ;Vdle(0.10399995)= 132.419449
Mdle(1.14400005)= 137.663727 ;Vdle(1.14400005)= 105.566071
Mdle(2.18400002)= 233.488678 ;Vdle(2.18400002)= 78.7126923
Mdle(3.22399998)= 301.386139 ;Vdle(3.22399998)= 51.8593140
Mdle(4.26399994)= 341.356049 ;Vdle(4.26399994)= 25.0059376
Mdle(5.30399990)= 353.398468 ;Vdle(5.30399990)= -1.84743953
Mdle(6.34399986)= 337.513397 ;Vdle(6.34399986)= -28.7008171
Vdlem= 132.419449 Mdlem= 353.398468

Design Moment, exterior girder (Factored)

```
MDe( 0.10399995 )= 64.4379578    , VDe( 0.10399995 )= 455.307190
MDe( 1.14400005 )= 620.056030    , VDe( 1.14400005 )= 417.750214
MDe( 2.18400002 )= 1019.03864    , VDe( 2.18400002 )= 366.304443
MDe( 3.22399998 )= 1273.13635    , VDe( 3.22399998 )= 304.870605
MDe( 4.26399994 )= 1420.85901    , VDe( 4.26399994 )= 240.824036
MDe( 5.30399990 )= 1449.59094    , VDe( 5.30399990 )= 170.918198
MDe( 6.34399986 )= 1353.68787    , VDe( 6.34399986 )= 96.6579895
```

```
Maximum Design Moment & Shear, factored
Mue= 1499.59094 KN-m/m     Vue= 455.307190KN/m
```

Design Moment, exterior girder (Unfactored)

```
 MDue( 0.10399995 )= 40.7963333
MDue( 1.14400005 )= 393.650208
MDue( 2.18400002 )= 649.018799
MDue( 3.22399998 )= 813.616821
MDue( 4.26399994 )= 909.449707
MDue( 5.30399990 )= 929.308716
MDue( 6.34399986 )= 869.968384
```

REINFORCEMENT INTERIOR GIRDER

```
As7= 4041.90137    n7= 3.00000000    nbp= 3.00000000   Lo= 11150.0000
As7= 8484.62402    n7= 9.0000000    nbp=  6.00000000   Lo= 7400.00000
As7= 9722.54004    n7= 11.0000000    nbp= 1.00000000   Lo= 3240.00000
```

REINFORCEMENT EXTERIOR GIRDER

```
As6= 5728.80029    n6= 8.00000000    nbpe= 8.00000000   Loe= 11150.0000
As6= 8133.63525    n6= 10.0000000    nbpe= 2.00000000   Loe= 7400.00000
As6= 9305.26562    n6= 12.0000000    nbpe= 2.00000000   Loe= 3240.00000
```

```
dtl=  10.386mm  < dmax= 13.000mm ?
dkt= 5.827mm  < dmax= 13.000mm ?
      Satisfies deflection requirement!
      Provide a camber of =  30.711mm
```

DESIGN FOR SHEAR

Interior Girder

Use 10.0000000 phi 12.0000000 mm shear reinf. C/C 1900.000000 mm
For 2.07999992 m from both ends, Length= 1860.00000 mm

Use 27.0000000 phi 12.0000000 mm shear reinf. C/C 190.000000 mm
For the rest of 6.24000025 m , Length=1860.00000 mm

Exterior Girder

Use 7.00000000 phi 12.0000000 mm shear reinf. C/C 280.000000 mm
For 2.07999992 m from both ends, Length= 1860.00000 mm

Use 1571.00000 phi 12.0000000 mm shear reinf. C/C 280.000000 mm
For the rest of 6.24000025 m , Length=1860.00000 mm

Diaphragm Reinforcement

Use 3 f 24mm bars at the bottom and f 12mm stirups

Beam seat Reinforcement

Provide 36.00 length 2500.0mm f12.0mm Rebars stirups

Transverse Reinforcement of the cap

Provide 12.00 length 8820.0mm f12.0mm bars

T-GIRDER BRIDGE OF 10.0000000 m & 7.32000017 m. wide

Total amount of materials used are:

1) Reinforcement bars = 11087.47kg
2) Volume of concrete = 43.699m3
3) Area of Asphalt = 76.13m2 (75mm thick used)
4) Area of Formwork = 246.73m2
5) Total wt. of steel pipe = 0.00kg
6) Total No. of steel bearings = 8.00

4. ENTER CURRENT CONSTRUCTION COSTS IN BIRR

Unit price for Rein. bars/Kg = 12
Unit price for concrete /m3 = 2000
Unit price for formwork/m2 = 120

```
        Unit price for bitumen/m3 =   1300
        Unit price for steel pipes/Kg =  30
        Unit price for steel bearings/pcs =  500

 Total Cost for comparison   = 254140.02Birr
              *** ============THE END============ ***
Program Completed
Press Enter to Continue.
```