ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES

DESIGN CHARTS FOR REINFORCED CONCRETE BRIDGES

BY
YISIHAK GEBRE TAREKEGN

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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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ACKNOWLEDGEMENTS

Thanks to the Almighty God and St. Mary for each and every success in my life and for their endless blessings. They have endowed me courage and strength as well as precious health throughout my life.

My deepest gratitude goes to my research advisor Dr. Asnake Adamu for his professional, genuine guidance and valuable advice to accomplish this research work. It is a privilege to work with him. I am grateful to thank my brother Dr. Abrham Gebre for his continuous support.

I would like to extend my special appreciation to my beloved family for their encouragement and being with me in all ups and downs. They have been in my side in every aspect. Had it not been your genuine co-operation, it would have not been possible to conduct this research.

I would like to express my profound heartfelt thanks to my relatives, friends and to those people who have collaborated with me.

ABSTRACT

Design of bridge structure is a complex engineering problem, which includes design of bridge systems, selection of design manuals and standards. During design process of bridges, an internationally accepted manuals and standards has to be exercised. In line with this, deck design of reinforced concrete slab bridges and longitudinal girders of T- and Box- girder bridges may be computed by either the traditional or empirical design method set in Bridge Design Manuals. To simplify the design problem of slab and girder bridges, a spreadsheet is used in the country as a design tool. A further work on this problem is important to minimize the effort and time required for the design of reinforced concrete bridges.

In this study, design charts for reinforced concrete bridges have been developed following standard specifications, technical requirements and ERA Bridge Design Manual. These charts enable bridge engineers to reduce the time effort during design and to optimize concrete bridges. By using these charts, one can design different alternatives for a particular bridge problem. Moreover, such kind of attempt could be helpful to examine the correlation between sectional parameters for cost analysis.

Finally, the use of design charts for practical application has been verified by different examples and the result showed that smaller variation in the design output was obtained as compared with an empirical design approach.

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NOMENCLATURE

Abbreviation

AACRA	Addis Ababa City Roads Authority
AASHTO	American Association of State Highway and Transportation Officials
ASD	Allowable Stress Design
ERA	Ethiopian Roads Authority
HS-20	Highway semi trailer 20Tons
IL	Influence Line
LFD	Load Factor Design
LRFD	Load and Resistance Factor Design
RC	Reinforced Concrete

Symbols

Latin upper case letters

A_s : area of steel reinforcement bars

A_g : gross concrete area

A_{st} : area of steel reinforcement for shrinkage and temperature

C_d : curb depth

C_s : clear span of bridge

C_w : curb width

C_{wf} : curb width factor

D : depth of slab/slab thickness

D_w : structural depth for simple span T- and Box beams

E : interior strip width

E_e : edge strip width

E_i : equivalent transverse strip width

E_w : equivalent width

F.S : Factor of Safety

IM : dynamic load allowance

L : bridge length

L_1 : modified span length

L_{eff} : effective span length

M_D : moment from dead loads

M_{DL} : dead load moment

M_{DW} : dead load moment from wearing surfaces

M_{LL+IM} : moment from live load and impact

$M_{\ln}$: moment from lane load

$M_{max,p}$: maximum positive live load moment

M_{sd} : design moment

$M_{\tan}$: moment from Tandem load

M_{tr} : moment from Truck load

M_u : ultimate design moment/Resistance Moment

ΣM : sum of applied moments

N : number of longitudinal girders

N_c : number of cells in a concrete Box girder

N_L : number of lanes

R_A, R_B, R_C : reactions at the supports at the location of girders

R_n : nominal resistance

R_r : factored resistance

R_{wt} : road way width

S : elastic section modules

Q_i : nominal force effect , force effects from loads

W : edge-to-edge width of bridge

W_A : width of abutment

W_1 : modified edge-to-edge width of bridge

W_{cb} :weight of curbs

W_f : width factor

W_{oh} : weight of overhanging slab

W_s : weight of slab

W_w : weight of wearing surface

Latin lower case letters

b : width
b_e : effective width of the exterior girder
b_{eff} : effective flange width
b_i : effective width of the interior girder
b_{min} : minimum web width
b_w : web width, web thickness
d : effective depth
f'_c : compressive strength of concrete
f_y : yield strength of steel
m : multiple presence factor
$m_1,m_2,\ldots,m_6$: Influence line ordinates for maximum moment
p_e : percentage of distribution reinforcement
p_h : post height
s : girder spacing
$s_1,s_2,s_3,\ldots,s_6$: Influence line ordinates for maximum shear
t_s : slab thickness (top flange thickness)
t_{sb} : bottom flange thickness

Greek Symbols

γ_i : load factors
η_D : factor relating to ductility
η_i : load modifier
η_I : factor relating to operational importance
η_R : factor relating to redundancy
ρ : reinforcement ratio
ρ_{min} : minimum reinforcement ratio
φ : resistance factor
ϕ : strength reduction factor
φR_n : factored resistance

1. INTRODUCTION

1.1 Background

Bridges provide a critical link for transportation systems and economic growth. Significant increases in illegal loads as well as growth in the volume of traffic and reductions in adequate resources for bridge maintenance could contribute to the deterioration of many bridges. To whatever degree there exist problems, we have to have adequate information about the condition of the bridges the extent of damage and how much it cost us to allocate adequate fund to mitigate the problem.

Bridges are vital component in the transportation infrastructure of nation. They represent a large capital expense in a road or rail network and are important not only because of their location, but also by virtue of the cost implications if their capacity is impaired or if they fail outright. Users expect a bridge to be ‘safe’ and by that it has to look safe and the user should feel safe.
Bridges play an important role on the social and economic life and are, by all means, strategic structures. Able to span long distances, they are expected to be able to promise serviceability in different conditions, among the others, after extreme loading events.

Bridges can be classified based on construction materials. Among them, 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. 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.

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 approximate calculation is made based on costs of construction and maintenance.

Once the type of bridge is selected and classified according to the special characteristics required, optimal configuration of supports, arrangements and optimal sizing of shapes and reinforcements are also selected to optimize the overall cost of the bridge. Thus, cost optimization of reinforced concrete bridges depends not only on the configuration of the bridge but also on their sizes.

The layout and size of the bridge has to be optimized to make the bridge function at its best effective or intended advantage. Because of this, layout and sizing optimization of reinforced concrete bridges is important in the design process.

In this study, design charts for reinforced concrete bridges have been developed using standard specifications, technical requirements and bridge design manuals. Bridge designers can simply use these charts for checking and design review works.

1.2 Objectives of the Study

The objective of this thesis is to develop design charts for the design of reinforced concrete bridges (Slab, T- and Box Girder Bridges) using standard specifications, technical requirements and bridge design manuals.

The design charts are used for the computation of area of reinforcement bars for both interior and edge strips of a reinforced concrete slab bridges with different span lengths, roadway width, concrete cover and curb width with different material properties. Moreover, charts for the design of top flange and longitudinal girders of T- and box girder bridges by considering the variation of bridge dimensions and material properties are developed. For box girder bridges, the bottom flange should be provided with minimum reinforcement as specified in ERA bridge design manual.

1.3 Statement of the problem

Structural design of bridges using rational or computational method is not a simple task for the structural engineer.

As per ERA bridge data, almost 70% of the country's bridge is reinforced concrete Slab and T-Girder bridges, mostly with simple supports but either single span or multiple spans are the most commonly used bridges. Single span slab bridges are perhaps the most common forms of bridges in the country.

Currently, the dominant types of bridges in the country are slab and girder bridges. For the design of such structures, most designers are widely using spreadsheets. For the design of reinforced concrete slab and girder bridges, no design charts are developed so far. Therefore, based on this fact, developing a design chart using a rational method for the design of bridges in terms of both time and cost using standard specifications, technical requirements and bridge design manuals is important.

1.4 Applications and limitations

1.4.1 Applications

The design charts are applicable for the design of reinforced concrete slab bridges, T- and Box Girder Bridges. Structural bridge designers and bridge contractors involving in the checking and design review works can simply use these charts to look solution with the most advantageous, minimum time and cost.

1.4.2 Limitations

In this thesis, charts for the design of flexural reinforcements for RC bridges have been developed. The developed charts do not considered control of cracking, deflection and fatigue limit state. Moreover shear stirrups for girder bridges are not considered.

1.5 Structure of the Thesis

This thesis consists of six chapters. The first chapter deals with the general background of bridge, scope, limitation and the objectives of the thesis.

The second chapter is devoted to discuss the literature survey carried on general design considerations, basic trends in design of bridges, requirements of bridges under design including planning, location selection, technical consideration, functional, economic, safety and efficiency. In addition to this, it included the description of LRFD-of AASHTO, commencing loading, the techniques of analysis such as influence line.

The third chapter addresses the analysis and design of slab, T-Girder and Box 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 specifications and ERA Bridge Design Manuals. The flow charts and an Algorithm for analysis and design of bridges are also presented in this section.

The fourth chapter focused on the development of design charts and design procedures for the design of RC Slab, T- and Box bridges are presented.

Chapter five is devoted for demonstrating the application of the developed design chart and illustrates using examples to verify design of Slab, T- and Box Girder bridges using design charts with empirical method. In addition, summary of design results are presented.

The last chapter of this thesis is made to contain the conclusions drawn from the outputs based on the developed design charts and the recommendations based on the findings is the subject of discussion in this chapter.

2 LITRATURE SURVEY

Bridge design is a complex engineering problem. The design process includes consideration of other important factors, such as choice of bridge system, materials, dimensions, foundations, aesthetics, and local landscape and environment.

Planning is essential stage for bridge design & construction and it incorporated analyze environmental features, such as topography, drainage patterns, soils, climate, and existing land use. Natural drainage systems can be taken advantage of, clearing and grading can be minimized, natural vegetation areas can be preserved, and sensitive land and water areas that provide water quality benefits and areas susceptible to erosion and sedimentation can be avoided. Poor planning can contribute to pollution problems [1].

The scope of such a problem encompasses the determination of general dimensions of the structure, the span system (i.e., number and length of spans), the choice of a rational type of substructure. Also, within this scope, there is a demand to find the most advantageous solution to the problem in order to determine the maximum safety with minimum cost that is compatible with structural engineering principles. Fulfilling these demands will provide the proper solution to the technical and economic parameters, such as structure behavior, cost, safety, convenience, and external view.

The design of the bridge usually starts with the development of a series of possible alternatives. Comparing different alternatives, considering technical and economic parameters are used to find the most practical solution for the local site conditions. At the present time, the development and comparison of alternatives is the only way to find the most practical solution [1].

2.1 General Design Consideration of Bridges

Basically, the design process of bridges consists of two major parts:

- preliminary design phase and
- Final design phase.

2.1.1 Preliminary Design Phase

The preliminary design stage consists of a comprehensive search of current practical and analytical applications of old and new methods in structural bridge engineering. The final design stage consists of a complete treatment of a new project in all its aspects. This includes any material, steel, or concrete problems. The important argument is that with this approach a significant savings in design effort can be easily achieved, particularly in the final stage [2].

In the preliminary design stage it is also required to find a rational scientific analysis scheme for the conceived design. Thus, an essential part of preliminary design is to select and refine various schemes in order to select the most appropriate one [2].

2.1.2 Final Design Phase

The final stage requires a detailed study and analysis of structural behavior and stability. Economy and safety are also important aspects in bridge design, but considerable attention must be given to detailed study for the analysis, which involves the final choices of the structural system, dimensions, material, system of spans, location of foundations, wind factor, and many others [2].

2.2 Basic Trends in Design of Bridges

In many aspects, the design of bridges is based on exact analysis and for this reason it is analogous to the solution of mathematical problems, where the results are obtained by examining the problem data and utilizing mathematical methods to arrive at a solution. This approach works well for technical and economic analyses which present very important aspects of bridge design.

Technical analysis is valid for providing information for construction, but not significant for the solution of basic problems: choice of bridge system, choice of material, general dimensions, foundation problems, etc. These problems are solved on the basis of general considerations and the designer’s judgment. The basic trends in design of bridges are classified as follows.

2.2.1 Creative Trends

The construction of highway bridges and the application of reinforced concrete presented designers with a basic problem regarding the choice of the bridge system. This created strong demand for preliminary design. This new concept required developing new methods and has put pressure on designers to look at the bridge not as a condensation of essential parts but rather as a monolithic compound unit with interrelated parts.

Because of the growing demand for reinforced-concrete and suspension bridges, the designer had large choice of materials and means to develop new bridge systems and the idea of cable-stayed bridges followed. The new century created strong demand for an analytical approach and necessitated a growing need for preliminary design with more schemes.

The acceptance that for each case there is no one solution but, rather, that there are several from which it is possible to choose the one most consistent with prevailing, accepted standards and most effective for the actual project leads to the basic characteristic of the second significant trend in bridge design, which will be called “creative.”

Therefore, the design of each bridge is a process of finding a solution to a new problem. If there is no solution available, it must be sought. Considering the role of personal creation, this second trend may provide original new projects. Supporters of such a trend believe that creation of a bridge depends upon personal predisposition, capability, and vision. Design is considered to be a creative process that consists of a combination of structural expressions based on required knowledge and professional intuition [2].

2.2.2 Practical Trends

Practicability is the main consideration in this trend. The word practical goes hand in hand with scientific investigation using modern technology. Designers use both scientific principles and creativity for their designs only in order to solve the actual problem. In this trend, the bridge is considered as part of the highway or railway and its basic purpose is to satisfy the requirements of transportation [2]

2.3 Requirements of Bridges under Design

Choosing the right location is crucial for designing and planning a bridge. But above all, safety considerations that govern the technical, functional, economic, efficiencies, expeditiousness, and aesthetic requirements are very important. It is necessary for the bridge and each of its components to be safe, durable, reliable, and stable. This is usually checked by analysis using current specifications.

But not all questions of durability, reliability, and stability may be answered by analysis. Therefore, in some cases it is necessary to provide special measures such as testing the performance of the structure and examining its behavior under maximum loading on the construction site [2].

Planning

As plans are developed for new bridges, or for reconstructing existing facilities, best management practices to help reduce the volume and concentration of erosion and sedimentation produced by the project should be incorporated into project design [1].

Route Location

As per ERA Bridge Design Manual [3], the choice of location of bridges shall be supported by analyses of alternatives with consideration given to economic, engineering, social, and environmental concerns as well as costs of maintenance and inspection associated with the structures and with the relative importance of the above-noted concerns.

Attention, commensurate with the risk involved, shall be directed toward providing for favorable bridge locations with the following requirement [3]:

- Fit the conditions created by the obstacle being crossed;
- Facilitate practical cost effective design, construction, operation, inspection and maintenance;
- Provide for the desired level of traffic service and safety; and
- Minimize adverse highway impacts.

Bridge Site Arrangement

According to ERA Bridge Design Manual, article 2.3.2, the location and the alignment of the bridge should be selected to satisfy both on-bridge and under-bridge traffic requirements. Consideration should be given to possible future variations in alignment or width of the waterway, highway, or railway spanned by the bridge. Where appropriate, consideration should be given to future addition of mass-transit facilities or bridge widening [3, 6].

Economy

Structural types, span lengths, and materials shall be selected with due consideration of projected cost. The cost of future expenditures during the projected service life of the bridge should be considered. Regional factors, such as availability of material, fabrication, location, shipping, and erection constraints, shall be considered [3, 4].

Regarding the maintenance of the roadway and the bridge, it is possible to consider this as a general expense and therefore relate it to economic considerations.

Efficiently

Also, additional consideration must be given to issues other than elementary demands in order to make traffic flow efficiently. Note that the height of the bridge and the elevation of the roadway must be determined at an early stage, because they have influence on the traffic flow. Also, greater or smaller grades of the approaches should be designed earlier in the project. Maximum grades are defined by specifications, but for practical purposes minimum grades are the most convenient. Further, it is important to define the number of joints in the roadway that correlate to the division of the structure in separate sections [3, 4].

Environment

The impact of a bridge and its approaches on local communities, historic sites, wetlands, and other aesthetically, environmentally, and ecologically sensitive areas shall be considered. Compliance with state water laws; federal and state regulations concerning encroachment on floodplains, fish, and wildlife habitats; and the provisions of the National Flood Insurance Program shall be assured. Stream geomorphology, consequences of riverbed scour, removal of embankment stabilizing vegetation, and, where appropriate, impacts to estuarine tidal dynamics shall be considered [3, 4].

Construction Requirements

For conventional bridges to be built from a certain material, construction is carried out by established methods. Therefore, during comparison of alternatives, construction criteria are not so important. In special cases of complicated erection of bridges having large spans, or for urgent work, construction requirements are very important and may influence the choice of the bridge system and material. In these cases, it may be necessary to use a great quantity of materials, thus increasing the cost of construction and ignoring other requirements.

For example, during the initial period of application, assembled reinforced-concrete constructions were more expensive than monolithic ones. However, with increased use of these constructions, the application of assembled structures is more rational and economical [4].

Safety

Specifications and technical requirements should be satisfied because they guarantee the carrying capacity of the structure. From the safety point of view, all bridges designed according to the technical requirements are equal. But practically speaking, different aspects of technical requirements may be satisfied with different margins of safety. Regarding the various bridge components, it is necessary to know that for engineering structures, the best solution should provide the appropriate material and carrying capacity.

Bridge Aesthetics

Bridges should complement their surroundings, be graceful in form, and present an appearance of adequate strength. Engineers should seek more pleasant appearance by improving the shapes and relationships of the structural component themselves. The application of extraordinary and nonstructural embellishment should be avoided [3].

2.4 Design Standard and Philosophy

A review of the philosophy used in a variety of specifications resulted in three possibilities, allowable stress design (ASD), load factor design (LFD), and reliability-based design, a particular application of which is referred to as load and resistance factor design (LRFD). These philosophies are discussed below [5].

2.4.1 Allowable Stress Design

Allowable Stress Design (ASD) - is based on the premise that one or more factors of safety can be established based primarily on experience and judgment which will assure the safety of a bridge component over its design life; for example, this design philosophy for a member resisting moments is characterized by design criteria such as

$$\Sigma M / S \leq F_y / F.S \tag{2.1}$$

where:

ΣM : sum of applied moments
F_y : specified yield stress
S : elastic section modules
F.S : factor of safety=1.82

The "allowable stress" is assumed to be an indicator of the resistance and is compared with the results of stress analysis of loads. Allowable stresses are determined by dividing the elastic stress at the onset of some assumed undesirable response, e.g., yielding of steel or aluminum, crushing of concrete, loss of stability, by a safety factor. In some circumstances, the allowable stresses were increased on the basis that more representative measures of resistance, usually based on inelastic methods, indicated that some behaviors are stronger than others.

2.4.2 Load Factor Design

In Load Factor Design (LFD) a preliminary effort was made to recognize that the live load, in particular, was more highly variable than the dead load. This thought is embodied in the concept of using a different multiplier on dead and live load; e.g., design criteria can be expressed as [5]:

$$1.3M_D + 2.17M_{L+I} \leq \phi M_u \tag{2.2}$$

where:

M_D : moment from dead loads
M_{L+I} : moment from live load and impact
M_u : resistance
ϕ : strength reduction factor

Resistance is usually based on attainment of either loss of stability of a component or the attainment of inelastic cross-sectional strength.

In the Standard Specifications, the same loads are used for ASD and LFD. In the case of LFD, the loads are multiplied by factors greater than unity and added to other factored loads to produce load combinations for design purposes.

The drawback to load factor design as seen from the viewpoint of probabilistic design is that the load factors and resistance factors were not calibrated on a basis that takes into account the statistical variability of design parameters in nature.

2.4.3 Probability- and Reliability-Based Design

Probability-based design seeks to take into account directly the statistical mean resistance, the statistical mean loads, the nominal or notional value of resistance, the nominal or notional value of the loads, and the dispersion of resistance and loads as measured by either the standard deviation or the coefficient of variation, i.e., the standard deviation divided by the mean. This process can be used directly to compute probability of failure for a given set of loads, statistical data, and the designer's estimate of the nominal resistance of the component being designed. Thus, it is possible to vary the designer's estimated resistance to achieve a criterion which might be expressed in terms, such as the component (or system) must have a probability of failure of less than 0.0001, or whatever variable is acceptable to society. Design based on probability of failure is used in numerous engineering disciplines, but its application to bridge engineering has been relatively small.

Alternatively, the probabilistic methods can be used to develop a quantity known as the "reliability index" which is somewhat, but not directly, relatable to the probability of failure. Using reliability based code in the purest sense, the designer is asked to calculate the value of the reliability index provided by his or her design and then compare that to a code-specified minimum value. Through a process of calibrating load and resistance factors to reliability indexes in simulated trial designs, it is possible to develop a set of load and resistance factors, so that the design process looks very much like the existing LFD methodology.

In the case of the LRFD Specifications, some loads and resistances have been modernized as compared with the Standard Specifications. In many cases, the resistances are very similar. Most of the load and resistance factors have been calculated using a statistically based probability method which considers the joint probability of extreme loads and extreme resistance.

In the parlance of the LRFD Specifications, "extreme" encompasses both maximum and minimum events [5].

2.4.4 The Probabilistic Basis of the LRFD Specifications

A consideration of probability-based reliability theory can be simplified considerably by initially considering that natural phenomena can be represented mathematically as normal random variables, as indicated by the well-known bell-shaped curve. This assumption leads to closed-form solutions for areas under parts of this curve.

In the particular case of the LRFD formulation of a probability-based specification, load factors and resistance factors are developed together in a way that forces the relationship between the resistance and load to be such that the area of overlap in Figure 2.1 is less than or equal to the value that a code-writing body accepts. Note in Figure 2.1 that it is the nominal load and the nominal resistance, not the mean values, which are factored.

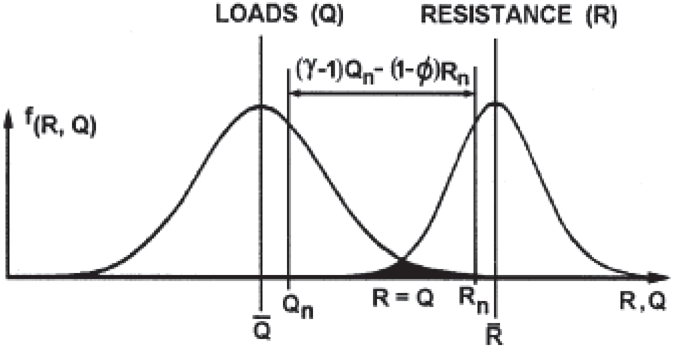


Figure 2.1 Separation of loads and resistance [5]

It is more technically correct to consider the reliability index to be a comparative indicator. One group of bridges having a reliability index that is greater than a second group of bridges also has more safety. Thus, this can be a way of comparing a new group of bridges designed by some new process to a database of existing bridges designed by either ASD or LFD. This is, perhaps, the most correct and most effective use of the reliability index. It is this use which formed the basis for determining the target, or code specified, reliability index, and the load and resistance factors in the LRFD Specifications.

The probability-based LRFD for bridge design may be seen as a logical extension of the current LFD procedure. ASD does not recognize that various loads are more variable than others. The introduction of the load factor design methodology brought with it the major philosophical change of recognizing that some loads are more accurately represented than others. The conversion to probability-based LRFD methodology could be thought of as a mechanism to select the load and resistance factors more systematically and rationally than was done with the information available when load factor design was introduced [5].

In design specifications, the issue of safety is usually codified by an application of the general statement the design resistances must be greater than, or equal to, the design load effects.

In LRDF, design philosophy for a member resisting moments is characterized by design criteria and can be generalized as:

$$\sum \eta_i \gamma_i Q_i \leq \phi R_n = R_r \tag{2.3}$$

In which, $\eta_i = \eta_D \, \eta_R \eta_I$:

$\eta i = \eta_D \eta_R \eta_I \geq 0.95$ for loads for which a maximum value of γ_i is appropriate and

$\eta i = 1/\left(\eta_I \eta_D \eta_R\right) \leq 1.0$ for loads for which a minimum value of γ_i is appropriate.

where:

γ_i : load factor: a statistically based multiplier on force effects

φ : resistance factor: a statistically based multiplier applied to nominal resistance

η_i : load modifier

η_D : factor relating to ductility

η_R : factor relating to redundancy

η_I : factor relating to operational importance

Q_i : nominal force effect: a deformation, stress, or stress resultant

R_n : nominal resistance: based on the dimensions as shown on the plans and on permissible stresses, deformations, or specified strength of materials

R_r : factored resistance: φR_n

2.4.4.1. Special Requirements of the LRFD Specifications

Comparison of the equation of sufficiency as it was written in equations (2.1), (2.2) and (2.3) for ASD, LFD, and LRFD respectively show that, as the design philosophy evolved through these three stages, more aspects of the component under design and its relation to its environment and its function to society must be expressly considered. This is not to say that a designer using ASD necessarily considers less than a designer using LFD or LRFD. The specification provisions are the minimum requirements, and prudent designers often consider additional aspects.

Ductility, redundancy, and operational importance are significant aspects affecting the margin of safety of bridges. While the first two directly relate to the physical behavior, the last concerns the consequences of the bridge being out of service. The grouping of these aspects is, therefore, arbitrary; however, it constitutes a first effort of modification. In the absence of more precise information, each effect, except that for fatigue and fracture, is estimated as ±5%, accumulated geometrically, a clearly subjective approach. With time, improved quantification of ductility, redundancy, and operational importance, and their interaction, may be attained [5].

2.5 Influence Lines and Surfaces

In the design and analysis of bridge structures, it is necessary to study the effects intrigued by loads placed in various positions. This can be done conveniently by means of diagrams showing the effect of moving a unit load across the structures. Such diagrams are commonly called influence lines (for framed structures) or influence surfaces (for plates). Observe that whereas a moment or shear diagram shows the variation in moment or shear along the structure due to some particular position of load, an influence line or surface for moment or shear shows the variation of moment or shear at a particular section due to a unit load placed anywhere along the structure [6].

Exact influence lines for statically determinate structures can be obtained analytically by statics alone. The total primary internal forces vector can be expressed by which given a unit load at one node, the excited internal forces of all members will be obtained, and thus gives the analytical expression of influence lines of all member internal forces for discretized structures subjected to moving nodal loads.

For statically indeterminate structures, influence values can be determined directly from a consideration of the geometry of the deflected load line resulting from imposing a unit deformation corresponding to the function under study, based on the principle of virtual work.

3 ANALYSIS AND DESIGN OF RC BRIDGES

3.1 General

Bridges shall be designed for specified limit states to achieve the objectives of constructability, safety, and serviceability, with due regard to issues of inspectability, economy, and aesthetics. Ductility, redundancy, and operational classification are considered in the load modifier η. Whereas the first two directly relate to physical strength, the last concerns the consequences of the bridge being out of service [4].

Limit States

In LRFD Bridge Design, different limit states should be considered. These are strength limit state, service limit state and extreme event limit state.

Each component and connection shall satisfy Eq. (3.1) for each limit state, unless otherwise specified. For service and extreme event limit states, resistance factors shall be taken as 1.0, except for special provisions. All limit states shall be considered of equal importance.

$$\sum \eta_i \gamma_i Q_i \leq \phi R_n = R_r \tag{3.1}$$

In which:

For loads for which a maximum value of γ_i is appropriate:

$$\eta_i = \eta_D \eta_R \eta_I \geq 0.95 \tag{3.2}$$

For loads for which a minimum value of γ_i is appropriate:

$$\eta_i = \frac{1}{(\eta_I \eta_D \eta_R)} \leq 1.0 \tag{3.3}$$

where:

η_i : load modifier

η_D : factor relating to ductility

η_R : factor relating to redundancy

η_I : factor relating to operational importance

The service limit state shall be taken as restrictions on stress, deformation, and crack width under regular service conditions.

Strength limit state shall be taken to ensure that strength and stability, both local and global, are provided to resist the specified statistically significant load combinations that a bridge is expected to experience in its design life.

The extreme event limit state shall be taken to ensure the structural survival of a bridge during a major earthquake or flood, or when collided by a vessel, vehicle, or ice flow, possibly under scoured conditions.

Ductility

The structural system of a bridge shall be proportioned and detailed to ensure the development of significant and visible inelastic deformations at the strength and extreme event limit states before failure [4].

For the strength limit state:

$\eta_D \geq 1.05$ for non-ductile components and connections

$= 1.00$ for conventional designs and details complying with AASHTO

≥ 0.95 for components and connections for which additional ductility-enhancing measures have been specified beyond those required by AASHTO

For all other limit states:

$\eta_D = 1.00$.

Redundancy

Multiple-load-path and continuous structures should be used unless there are compelling reasons not to use them [4].

For the strength limit state:

$\eta_R \geq 1.05$ for non redundant members

$= 1.00$ for conventional levels of redundancy, foundation elements where ϕ already accounts for redundancy as specified in ASSHTO Article 10.5

≥ 0.95 for exceptional levels of redundancy beyond girder continuity and a torsionally-closed cross-section.

For all other limit states:

$\eta_R = 1.00$

Operational Importance

This Article shall apply to the strength and extreme event limit states only. The Owner may declare a bridge or any structural component and connection thereof to be of operational priority [4].

For the strength limit state:

$\eta_I \geq 1.05$ for critical or essential bridges

$= 1.00$ for typical bridges

≥ 0.95 for relatively less important bridges.

For all other limit states:

$\eta_I = 1.00$

The total factored force effect shall be taken as:

$$Q = \sum \eta_i \gamma_i Q_i \qquad (3.4)$$

where: η_i : load modifier specified in AASHTO Article 1.3.2

Q_i : force effects from loads

γ_i : load factors specified in AASHTO Tables 3.4.1-1 and 3.4.1-2

Design Vehicular Live Load

Vehicular live loading on the roadways of bridges or incidental structures, designated HL-93, and shall consist of a combination of the:

- Design truck or design tandem, and
- Design lane load

Except as modified in Article 3.6.1.3.1 of ERA Bridge Design Manual, each design lane under consideration shall be occupied by either the design truck or tandem, coincident with the lane load, where applicable. The loads shall be assumed to occupy 3000mm transversely within a design lane [3, 4].

Design Truck: The weights and spacing of axles and wheels for the design truck shall be as specified in Figure 3.1(HS-20 Loading). A dynamic load allowance shall be considered. Except as specified in Articles 3.6.1.3.1 and 3.6.1.4.1, of ERA Bridge Design Manual, the spacing between the two 145000-N axles shall be varied between 4300 and 9000mm to produce extreme force effects [3, 4].

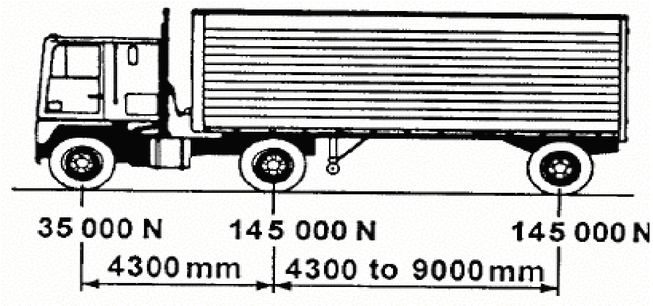


Figure 3.1 Characteristics of the Design Truck [4]

Design Tandem: The design tandem shall consist of a pair of 110kN axles spaced 1200mm apart. The transverse spacing of wheels shall be taken as 1800mm. A dynamic load allowance shall be considered as specified in AASHTO, Article 3.6.2 [3, 4].

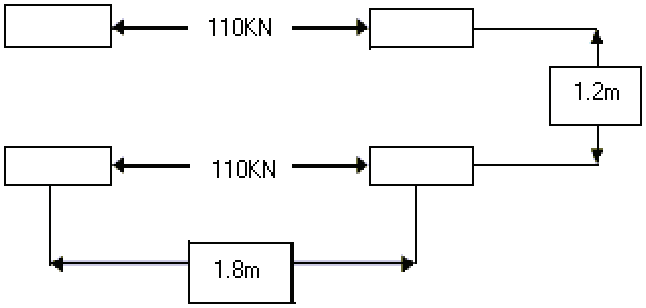


Figure 3.2 Design Tandem Load [4]

Design Lane Load: The design lane load shall consist of a load of 9.3kN/m uniformly distributed in the longitudinal direction. Transversely, the design lane load shall be assumed to be uniformly distributed over a 3.0m width. The force effects from the design lane load shall not be subject to a dynamic load allowance [3, 4].

Dead Load

Dead load shall include the weight of all components of the structure, appurtenances and utilities, earth cover, wearing surface, future overlays, and planned widening. In the absence of more precise information, the unit weights, specified in AASHTO, Table 3.5.1-1, may be used for the computation of dead loads [3, 4].

Shear and Moment Calculations

Live Load Force Effects: For the calculation of Live Load Force Effects, the concept of influence line is used and the maximum effect will be selected for the design.

Dead Load Force Effects: The maximum effects of forces due to weight of each component are computed for both interior and edge strips.

Design Moment

The design moment is computed using Eqn. (3.4) by combining the effects of dead loads and live loads and applying the corresponding load combinations and load factors specified in AASHTO, Table 3.4.1.1.

$$M_{sd} = \eta(1.25M_{DL} + 1.5M_{DW} + 1.75M_{LL+IM}) \tag{3.5}$$

For strength limit state η=1.05- for critical or essential bridges.

where:

M_{sd} : design moment

M_{DL} : dead load moment

M_{DW} : dead load moment from wearing surfaces

M_{LL+IM} : moment from live load and impact and given by

$= 1.33 max\left(M_{tr},\, M_{\tan}\right) + M_{\ln}$

M_{tr} : moment from Truck load

$M_{\tan}$: moment from Tandem load

$M_{\ln}$: moment from lane load

Material Properties

The nominal yield strength shall be the minimum as specified for the grade of steel selected, except that yield strengths in excess of 520MPa shall not be used for design purposes. Bars with yield strengths less than 270MPa shall be used only with the approval of the client [3].

3.2 Design for 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 6m to 15m. However, above 15m they should preferably be ribbed [3]. 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 [7]. Slab brides are most commonly used to short spans ranging from 10-12m [4]. A span of 14m is found as a demarcation span between Slab and T-Girder Bridges [8]. The above facts show that there is no clear demarcation span for selecting Slab Bridge. Thus, in selecting bridge spans regional factors, such as availability of construction material, fabrication, location, transportation, erection constraints, inspection, maintenance, repair, and/or replacement shall be considered.

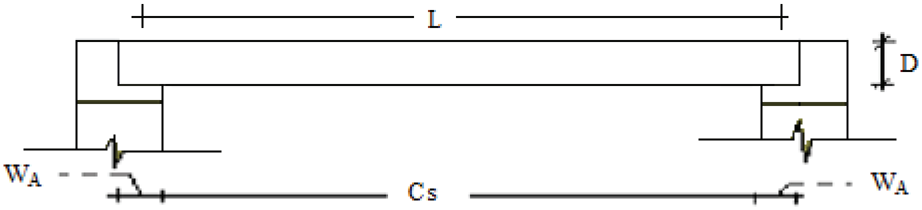


Figure 3.3 Longitudinal Section

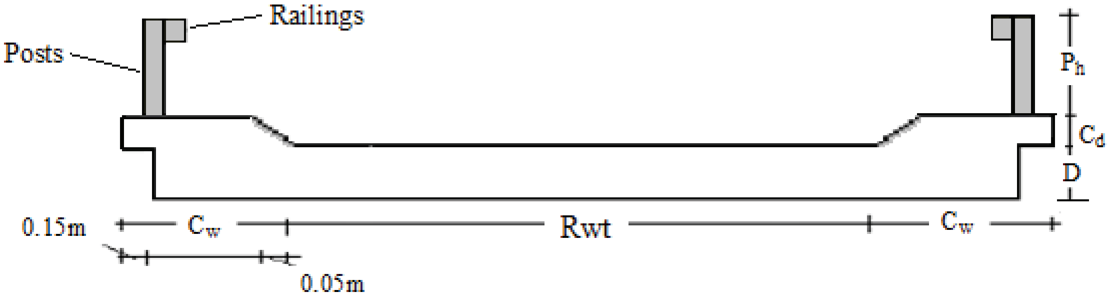


Figure 3.4 Cross section of Slab Bridge

For the design of slab bridges, the following are the major steps to be followed.

3.2.1 Depth Determination:

According to AASHTO, Table 2.5.2.6.3.1, minimum recommended depth for slab with main reinforcement parallel to the traffic is [4]:

$$D = \frac{1.2(S+3000)}{30} \qquad (mm) \qquad (3.6)$$

where:

D : slab thickness
S : c/c spacing of the bridge (mm)

According to ERA Bridge Design Manual, article 5.4.1.1, the depth of a concrete deck, excluding any provision for grinding, grooving, and sacrificial surface, should not be less than 185 mm and minimum cover should not be less than 35mm [3].

3.2.2 Live Load Equivalent Strip Widths

The equivalent width (*E*) of longitudinal strips per lane for both shear and moment with one lane or more than one lane loaded may be determined as: [4].

Interior Strip width

$$E = min\begin{cases} 250 + 0.42\sqrt{(L_1 * W_1)} & (\textit{for one lanes loaded}) \\ 2100 + 0.12\sqrt{(L_1 * W_1)} \leq \frac{W}{N_L} & (\textit{for multiple lanes loaded}) \end{cases} \tag{3.7}$$

where:

E : Equivalent width (mm)

L_1 : modified span length taken equal to the lesser of actual span length or 18000mm

W : edge-to-edge width of bridge

W_1 : modified edge-to-edge width of bridge taken to be equal to the lesser of the actual width or 18000mm for multilane loading, or 9000mm for single-lane loading.

N_L : Number of lanes loaded = R_{Wt}/3600

R_{Wt} : Road way width

Edge Strip width

Edge strip is limited to half lane width; use multiple presence factors 1.2 and half design lane load (for a two-lane bridge, because the possibility of occurrence of two trucks at a time is less). Thus, live loads due to truck and tandem are divided by 2 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. Thus the effect of the live load is reduced by half [4].

Longitudinal edge strip width for a line of wheels is the distance between the edge of the deck and the inside face of the barrier plus 300mm and half of the interior strip width less than full strip or 1800mm and which is given by:

$$E_e = \min \begin{cases} \left(C_w + 300 + \frac{E}{2} \right) \\ 1800(mm) \end{cases} \tag{3.8}$$

where:

E_e : Edge strip width

C_w : Curb width

E : interior strip width

Equivalent Concentrated and Distributed Loads

The equivalent concentrated and distributed loads per meter width of both interior and edge strips are obtained by dividing the design loads to the corresponding strip width and applying a dynamic impact factor. For the calculation of live load force effects, influence line is used and the maximum effect will be selected for the design.

Truck Load

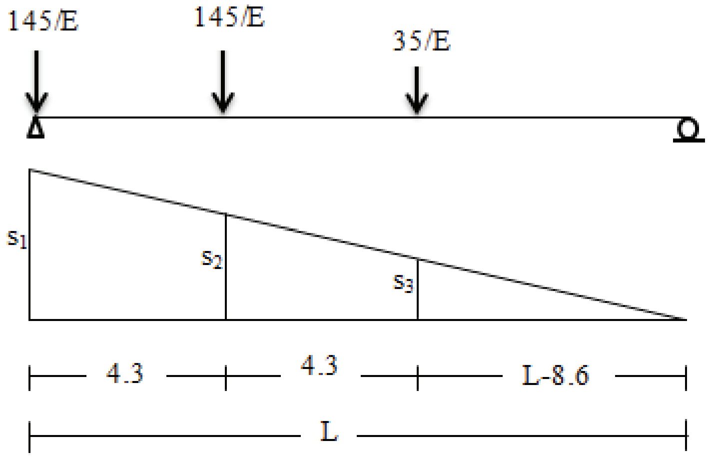
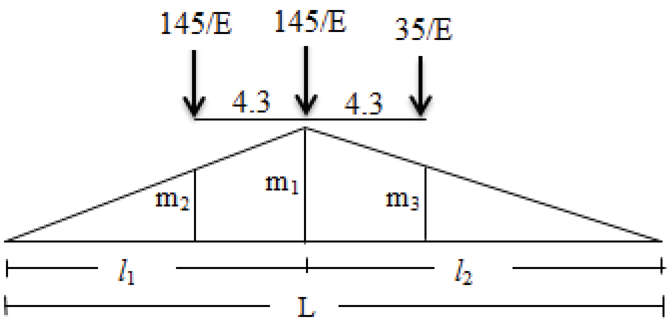


Figure 3.5a IL for maximum shear force due to truck loads



$$l_1 = \frac{L + 1.455}{2} \quad and \quad l_2 = L - l_1$$

Figure 3.5b IL for maximum bending moment due to truck loads

For the vehicular truck load arrangement shown in Figures 3.5a and 3.5b, the influence coefficients for both shear and bending moment can be obtained from Table 3.1.

Table 3.1 Influence line ordinates for truck loads

shear force	bending moment
$S_1 = 1$	$m_1 = \frac{l_1 l_2}{L}$
$S_2 = \frac{L-4.3}{L}$	$m_2 = \frac{l_2 \langle l_1 - 4.3 \rangle}{L}$
$S_3 = \frac{L-8.6}{L}$	$m_3 = \frac{l_1 \langle l_2 - 4.3 \rangle}{L}$

Tandem load

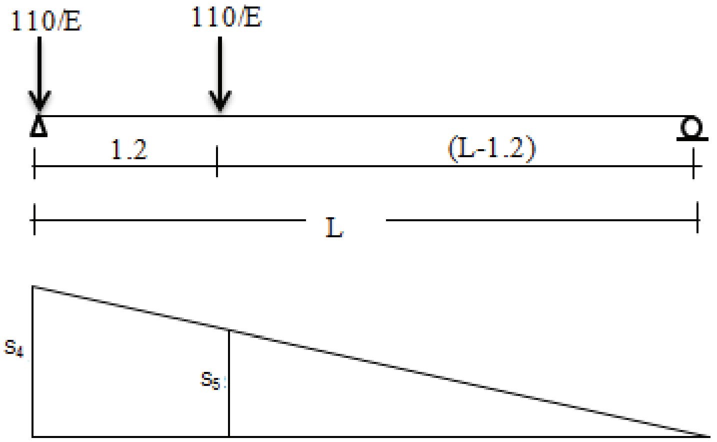


Figure 3.6a IL for maximum shear force due to tandem loads

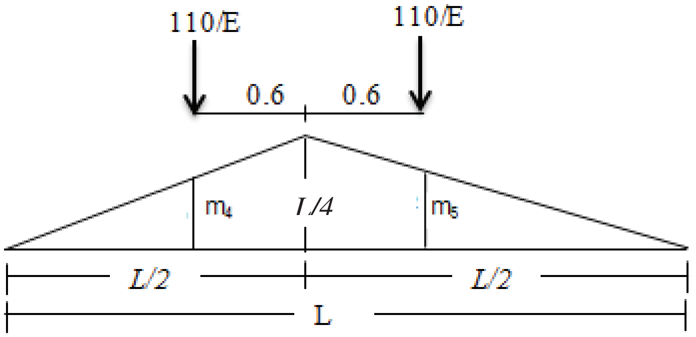


Figure 3.6b IL for maximum bending moment due to tandem loads

For the tandem load arrangement shown in Figures 3.6a and b, the influence coefficients for both shear and bending moment can be obtained from Table 3.2.

Table 3.2 Influence line ordinates, tandem loads

shear force	bending moment
$S_4 = 1$	$m_4 = m_5 = \frac{(L-1.2)}{4}$
$S_5 = \frac{L-1.2}{L}$	

Lane Load:

The design lane load shall consist of a load of 9.3kN/m uniformly distributed in the longitudinal direction.

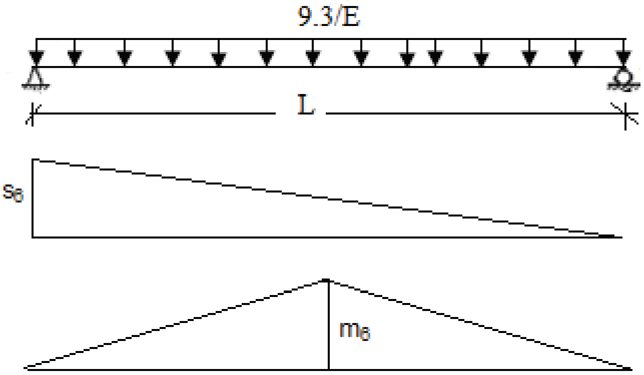


Figure 3.7 IL for maximum force effects due to lane load

For the lane load arrangement shown in Figure 3.7, the influence coefficients for both shear and bending moment can be obtained from Table 3.3.

Table 3.3 Influence line ordinates, lane loads

shear force	bending moment
$s_6 = 1$	$m_6 = \frac{L}{4}$

Maximum Live Load Moments for interior and edge strips

The maximum Live Load Moments for both interior and edge strips can be computed using influence line concepts and the influence line coefficients (maximum ordinates) for moments can be obtained from Tables 3.1 -3.3.

Maximum Live Load Moments for interior strips

$$M_{tr} = \frac{145}{E}\left(m_1 + m_2\right) + \frac{35}{E} m_3 \tag{3.9a}$$

$$M_{\tan} = \frac{110}{E}\left(m_4 + m_5\right) \tag{3.9b}$$

$$M_{ln} = \frac{9.3}{E}\frac{\left(L^2\right)}{8} \tag{3.9c}$$

$$(M_{LL+IM})_{\text{int}} = 1.33 max\ \left(M_{tr},\ M_{\tan}\right) + M_{\ln} \tag{3.10}$$

where:

$(M_{LL+IM})_{\text{int}}$	: moment from live load and impact for interior strip
M_{tr}	: moment from Truck load
$M_{\tan}$	: moment from Tandem load
$M_{\ln}$	: moment from lane load
m_1, m_2, …, m_5	: maximum influence line ordinates

Maximum Live Load Moments for edge strips

$$(M_{LL+IM})_{edge} = \frac{m.E(M_{LL+IM})_{\text{int}}}{2E_e} \tag{3.11}$$

where:

E_e	: edge strip width
E	: interior strip width
$(M_{LL+IM})_{edge}$	: moment from live load and impact for edge strip
m	: multiple presence factor (=1.2)

Thus, the design moment is taking by considering the maximum effects due to live and dead load moments and computing by using Eqn. (3.5).

Reinforcement Design

i) Main Reinforcement

The required amount of reinforcement for both interior and edge strips are computed using the general equation.

$$\rho = \left(1 - \sqrt{1 - \frac{2M_u}{0.9bd^2 \varphi f'_c}}\right)\frac{\varphi f'_c}{f_y} \tag{3.12}$$

where:

A_s : area of reinforcement bars

b : width

d : effective depth

f'_c : compressive strength of concrete

f_y : yield strength of steel

M_u : ultimate design moment/Resistance Moment

φ : resistance factor

ρ : reinforcement ratio

The factor φ accounts the reduction in concrete compressive strength due to slow loading or the weakening of the concrete, $\varphi = 0.85$

Thus, ρ becomes

$$\rho = \left(1 - \sqrt{1 - \frac{2.352M_u}{0.9bd^2 f'_c}}\right)\frac{f'_c}{1.176 f_y} \tag{3.13}$$

$$\rho_{min} = \frac{0.03 f_c'}{f_y} \tag{3.14}$$

$$A_s = \rho bd \tag{3.15}$$

where:

$\rho_{\min}$: minimum reinforcement ratio

ii) Distribution Reinforcement

According to AASHTO, article 5.14.4.1, the amount of bottom transverse reinforcement may be taken as a percentage of the main reinforcement required for positive moment. [4].

$$p_e = min\ [50, \frac{1750}{\sqrt{L_1}}] \tag{3.16}$$

where:

p_e : percentage of distribution reinforcement

L_1 : modified span length

iii) Shrinkage & Temperature Reinforcement

As indicated in AASHTO, section 5.10.8, reinforcement for shrinkage and temperature reinforcement shall be provided near surfaces of concrete exposed to daily temperature changes. The specified amount of the steel should be distributed equally on both sides [4].

$$A_{st} \geq \frac{0.75 A_g}{f_y} \tag{3.17}$$

where:

A_g : gross concrete area

A_{st} : steel reinforcement for shrinkage and temperature

iv) Shear reinforcement

Slab bridges designed for moment may be considered satisfactory for shear [4].

A step- by- step procedure for the design of RC slab bridges

Design Input Data

The input data consists of steel strength, cylindrical compressive strength of concrete, concrete density, and bituminous density.

Moreover, input data includes initial dimensions of the bridge to be designed such as: clear spans, roadway width, curb width, curb depth and support width.

Analysis:

Having material properties and bridge dimensions as an input data, the thickness of the slab is computed from Eqn. (3.6). In addition, the live load equivalent strips widths for both interior and edge strips are calculated using Eqns. (3.7) and (3.8) respectively.

Influence lines will be used to determine load positions for maximum effect and magnitude of these effects.

Appropriate load factors and load combinations are applied for the selected limit state design from Tables 3.4.1-1 and 3.4.1-2 given in AASHTO LRFD Bridge Design Specifications and ERA Bridge Design Manual [3, 4].

Then the critical force effects due to dead and live loads are obtained.

Designing:

The interior and edge strip of the deck are designed for the critical moments obtained from the analysis. The positive reinforcement for the slab is calculated on the basis of Eqn. (3.15) for both strips. Reinforcements are computed based on Strength and Service Limit States. Flow chart for the design of RC slab bridges is shown in **Fig.3.8** [8].

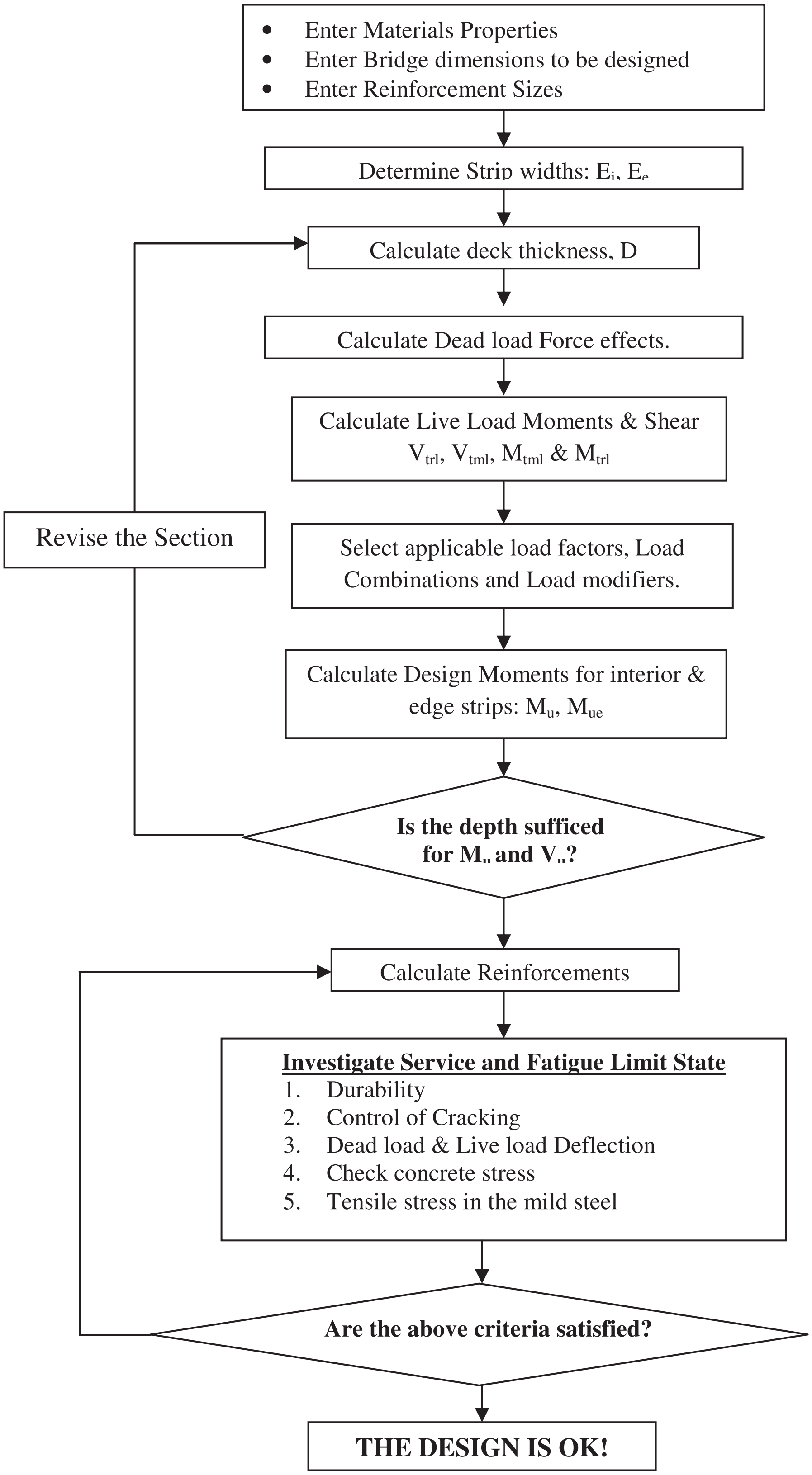


Figure 3.8 Flow chart for the design of RC slab bridges [8]

3.3 T- and Box Girder Bridges

T-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 to 25 m [3]. And as of AASHTO bridge design specifications, T- Girders are used for bridges spanning from about 10-25m [4].

The T-girder construction consists of a transversely reinforced slab deck which spans across to the longitudinal support girders. These require a more-complicated formwork, particularly for skewed bridges, compared to the other superstructure forms. T-girder bridges are generally more economical for spans of 12 to 18m. The girder stem thickness usually varies from 35 to 55cm and is controlled by the required horizontal spacing of the positive moment reinforcement. Optimum lateral spacing of longitudinal girders is typically between 1.8 and 3.0m for a minimum cost of formwork and structural materials. However, where vertical supports for the formwork are difficult and expensive, girder spacing can be increased accordingly. [9].

Box-girder bridges contain top deck, vertical web, and bottom slab and are often used for spans of 15 to 36m with girders spaced at 1.5 times the structure depth. They are similar to T-beams in configuration except the webs of T-beams are all interconnected by a common bottom flange resulting in a cellular superstructure [9].

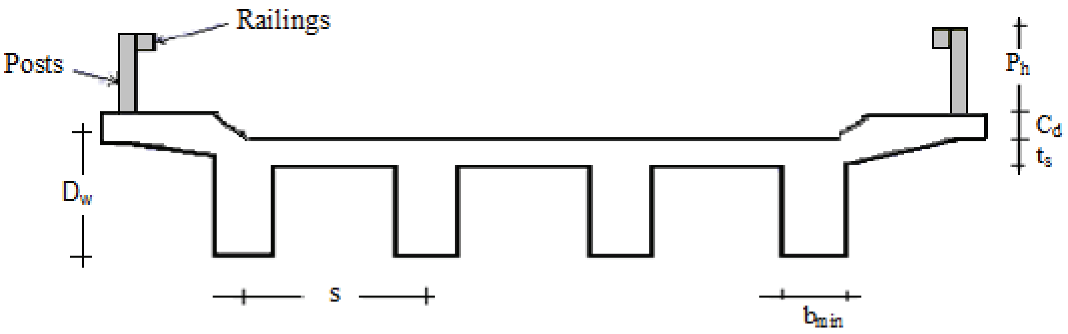


Figure 3.9 Cross section of T-Girder Bridge

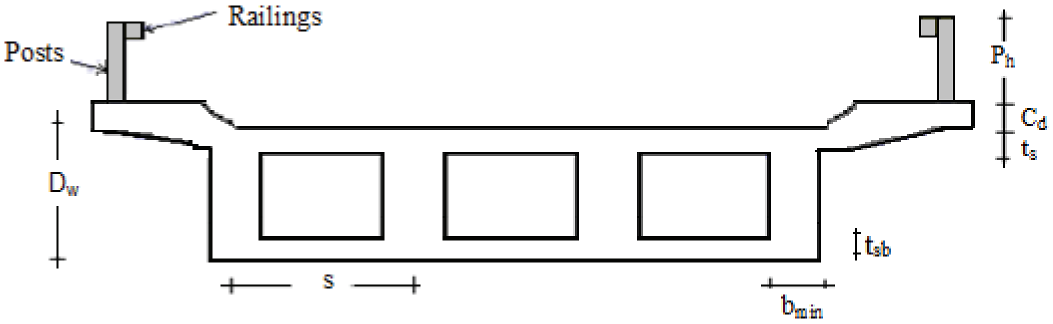


Figure 3.10 Cross section of Box -Girder Bridge

3.3.1 Design for T- and Box Girder Bridges

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 or tandem load and lane load)

Load Distribution

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.

Design of Deck Slab

Depth Determination:

i. Slab thickness

According to AASHTO, Table 2.5.2.6.3.1, minimum recommended depth for continuous deck slab is [4]:

$$t_s = \frac{(s+3000)}{30} \tag{3.18}$$

where:

t_s : slab thickness (mm)
s : girder spacing (mm)

Top Flange thickness

According to AASHTO, article 5.14.1.5.1a, the thickness of top flanges serving as deck slabs shall be not less than the clear span between fillets, haunches, or webs divided by 20, unless transverse ribs at a spacing equal to the clear span are used or transverse pre-stressing is provided [4].

Bottom Flange thickness

For Box-girder bridge, as specified in AASHTO, article 5.14.1.5.1b, the bottom flange thickness shall be not less than:

- 140mm;
- the distance between fillets or webs of non prestressed girders and beams divided by 16; or
- the clear span between fillets, haunches, or webs for prestressed girders divided by 30, unless transverse ribs at a spacing equal to the clear span are used.

In the determination of girder spacing, the overhang is assumed to be 0.4 times the girder spacing. Hence, the spacing between longitudinal girders is determined by the following equation.

$$s = \begin{cases} \dfrac{W}{(N-0.2)} & for\ T-girder \\ \dfrac{W}{(N_c+0.8)} & for\ Box\ girder \end{cases} \tag{3.19}$$

where:

s : girder spacing (mm)
W : total width of the bridge (mm)
N : number of longitudinal girders
N_c : number of cells in a concrete Box girder

ii. Web thickness

The minimum web thickness shall be determined by requirements for shear, torsion, concrete cover and adequate field placement and consolidation of concrete. As per AASHTO, article C5.14.1.5.1C, the minimum web thickness, b_w is given by [4]:-

$$b_w = \begin{cases} 200 \text{ mm for webs without prestressing ducts} \\ 300 \text{ mm for webs with only longitudinal or vertical ducts} \\ 380 \text{ mm for webs with both longitudinal and vertical ducts} \end{cases} \tag{3.20}$$

where:

b_w : web thickness (mm)

Dead load moments

An approximate analysis of strips perpendicular to girders is considered [4]. 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 and Wearing surface

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

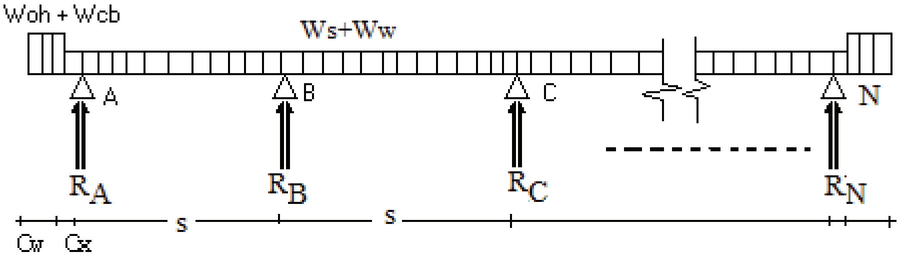


Figure 3.11 Slab dead load of a girder bridge

Moments due to dead load of the slab (w_s), end barriers and wearing surface (w_w), will be computed using influence segment coefficient or using cross method of moment distribution and then reactions at supports will be computed.

Vehicular live load

Maximum positive live load moment

For repeating equal spans, the maximum positive bending moment ($M_{max,p}$) occurs near the 0.4 points of the first interior span.

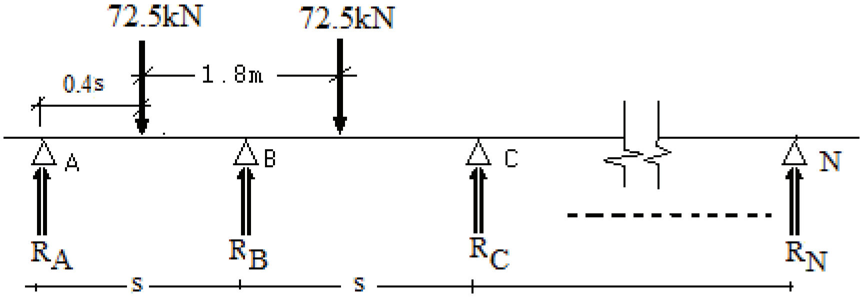


Figure 3.12 Truck Load position for max. Positive moment

According to ASSHTO Table 4.6.2.1.3-1, the equivalent width of the strip for positive moment over which the live load is applied (Direction of Primary Strip Relative to Traffic is Either Parallel or Perpendicular) is given by [4]:

$$E_w = 660 + 0.55s \tag{3.21}$$

where:

E_w : the equivalent width (mm)

s : girder spacing (mm)

The maximum positive live load moment by considering one lane loading, $M_{max,p}$ will be:

$$M_{max,p} = \frac{m(0.4sR_A)}{E_w} \tag{3.22}$$

where:

R_A : the reaction at the exterior support

E_w : the equivalent width (mm)

s : girder spacing (mm)

$M_{max,p}$: maximum positive live load moment

m : multiple presence factor (=1.2)

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).

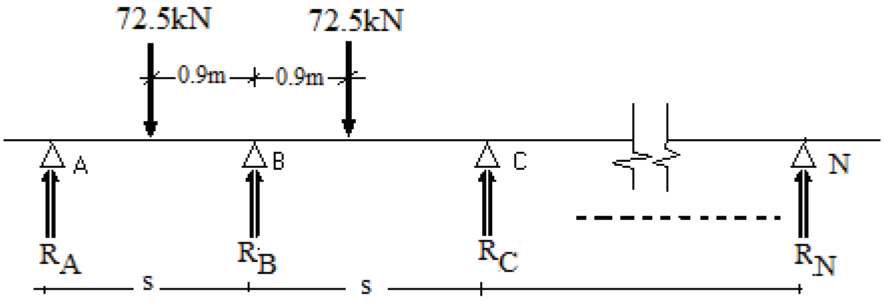


Figure 3.13 Truck Load position for max. Negative moment

According to ASSHTO Table 4.6.2.1.3-1, the width of equivalent transverse strip for negative moment (Direction of Primary Strip Relative to Traffic is Either Parallel or Perpendicular) is given by [4]:

$$E_i = 1220 + 0.25s \tag{3.23}$$

where:

E_i : the equivalent transverse strip width (mm)

s : girder spacing (mm)

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.

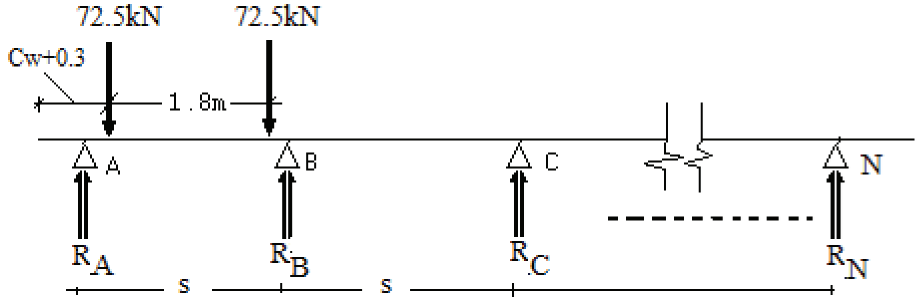


Figure 3.14 Truck Load position for max. Reaction

Remark: For reinforcement computation, negative moment may be taken at face of support.

Reinforcement Design

Based on the design moments, the amount of reinforcement required for positive and negative moments will be computed using Eqn. (3.15).

Design of Longitudinal Girders

Depth of Girder

According to AASHTO, Table 2.5.2.6.3.1, minimum structural depth (including deck) for simple span T- and Box beams is given as follows [4]:

$$D_w = a * L \tag{3.24}$$

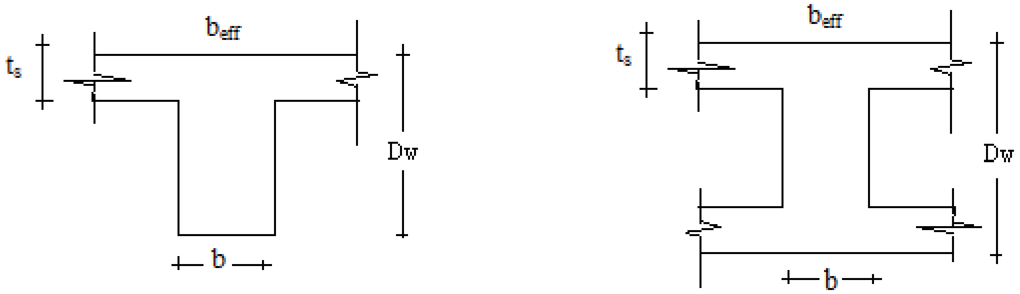
where:

D_w : structural depth for simple span T- and Box beams

L : c/c spacing of the bridge

a : 0.07 for T-girder and 0.06 for Box-girder bridges

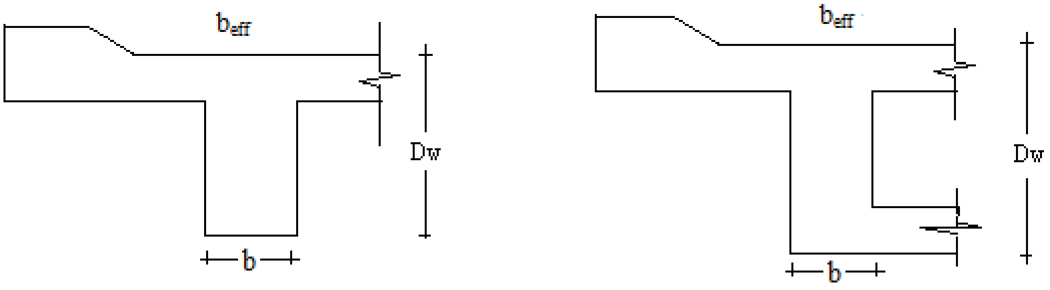
The cross sections to be used for the design of both longitudinal girders of T- and Box girders are shown in **Figures 3.15** and **3.16.**



T-girder Bridge

Box girder Bridge

Figure 3.15 Cross sections of an interior girder



T-girder Bridge

Box girder Bridge

Figure 3.16 Cross sections of an exterior girder

Effective flange width:

As the longitudinal compressive stress varies across the flange width of same level, it is convenient in design to make use of an effective flange width, (may be smaller than the actual flange width) which is considered to be uniformly stressed [9].

(a) **<u>For T-girders</u>**

$$b_i = \min \begin{cases} \dfrac{L_{eff}}{4} \\ \\ 12t_s + b_w \\ s \end{cases} \qquad (3.25)$$

$$b_e - \frac{b_i}{2} = \min \begin{cases} \dfrac{L_{eff}}{8} \\ 6t_s + \dfrac{b_w}{2} \\ \\ width\, of\ overhang \end{cases} \qquad (3.26)$$

(b) **For Box-girders**

$$b_i = \min \begin{cases} \dfrac{L_{eff}}{4} \\ 12t_s + b_w \\ \\ web\, spacing \end{cases} \qquad (3.27)$$

$$b_e - \frac{b_i}{2} = \min \begin{cases} \dfrac{L_{eff}}{8} \\ 6t_s + \dfrac{b_w}{2} \\ \\ width\, of\ overhang \end{cases} \qquad (3.28)$$

where:

L_{eff} : effective span

t_s : slab thickness

b_w : web width

s : girder spacing

b_i : effective width of the interior girder

b_e : effective width of the exterior girder

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 in AASHTO Table 4.6.2.2-1[4].

Live Load Force Effects

Determination of distributed live load shear and moment

The influence lines for shear force and moment for truck and lane loads of T- and Box- girder bridges are similar to that of slab bridges as shown in **Figures 3.5** and **3.6**. Moreover, the influence line coefficients, the equations for shear force and moments are the same.

Dead Load Force Effects

The dead load force effects computed for both interior and exterior girders. In the calculation of shear force and moment due to dead loads, reactions due to dead load slab are transferred to the girders in addition to its own weight.

Designing

Design Moment

The design moment for both interior and exterior girders are computed using Eqn. (3.4) by considering appropriate load factors specified in AASHTO Tables 3.4.1-1 and 3.4.1-2.

Reinforcing bars determination

The neutral axis of a T-beam may be either in the flange or in the web, depending upon the proportions of the cross-section, the amount of tensile steel, and the strength of the materials. The area of reinforcements required for both interior and exterior girders are computed accordingly. Reinforcements are computed based on Strength and Service Limit States.

According to ERA Bridge design manual, article 5.5.2.4, a uniformly distributed reinforcement of 0.4 percent of the flange area shall be placed in the bottom slab parallel to the girder span, either in single or double layers. The spacing of such reinforcement shall not exceed 450mm.

A uniformly distributed reinforcement of 0.5 percent of the cross-sectional area of the slab, based on the least slab thickness, shall be placed in the bottom slab transverse to the girder span. Such reinforcement shall be distributed over both surfaces with a maximum spacing of 450mm. All transverse reinforcement in the bottom slab shall be extended to the exterior face of the outside web in each group and shall be anchored by a standard 90-degree hook [4].

A step- by- step procedure for the design of T and Box-Girder Bridges

Design Input Data

The input data consists of: steel strength, cylindrical compressive strength of concrete, concrete density, and bituminous density. Moreover, input data includes initial dimensions of the bridge to be designed such as: clear spans, roadway width, curb width, curb depth, support width, bitumen thickness and girder spacing.

Analysis:

Given the above input data of material properties and dimension of the bridge, the followings will be computed accordingly:

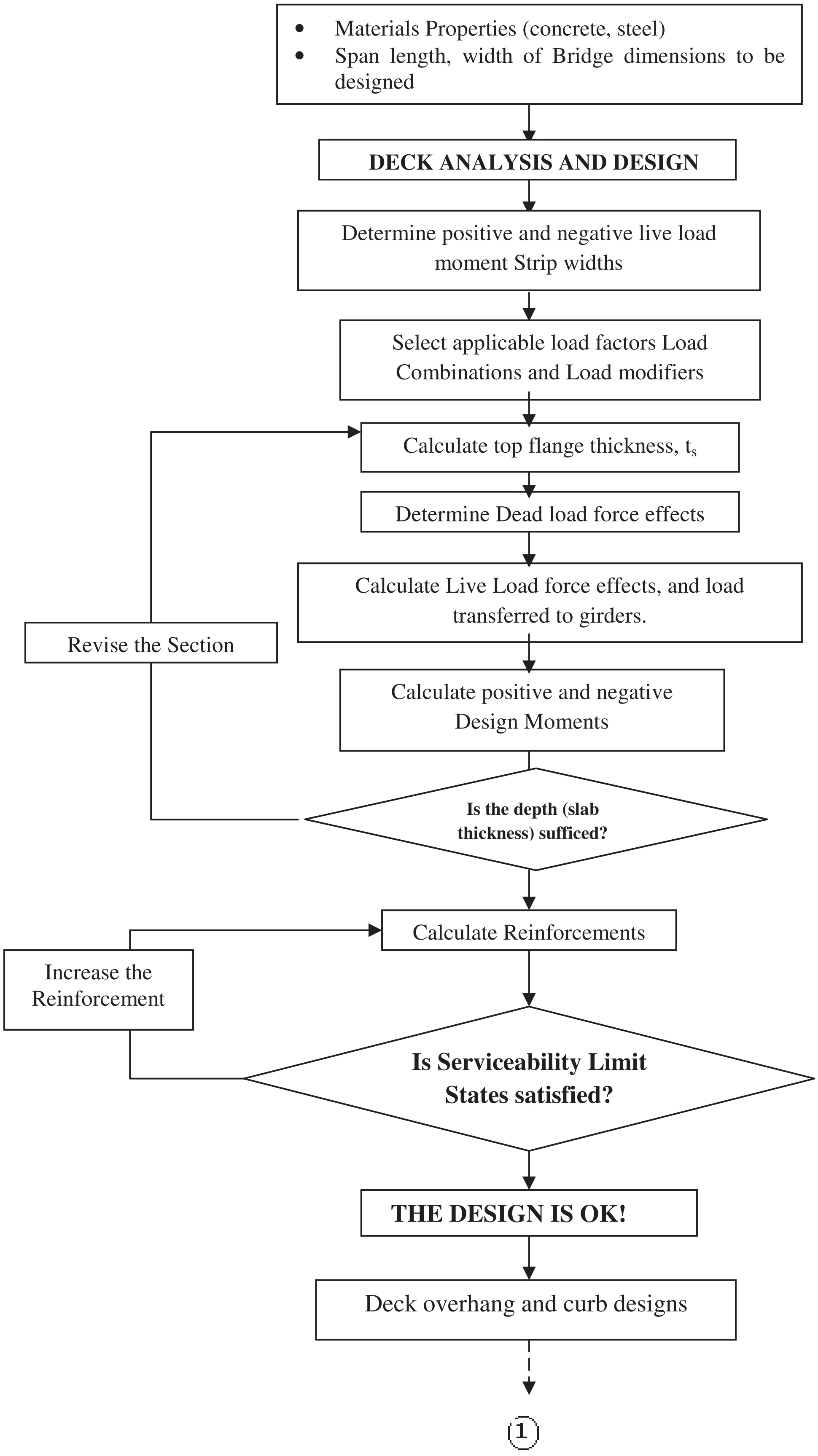
- The thickness of the deck slab is determined from Eqn. (3.18).
- Structural analysis of the deck slab involves taking a continuous strip perpendicular to the girders. The dead load force effects, due to slab and wearing surface loads, are obtained by analyzing the continuous beam loaded in **Figure 3.11**. The critical live load effects are obtained by varying the position of the wheel loads.
- The negative and positive live load moments are obtained by analysis the beam loaded in **Figures 3.12** and **3.13** respectively.
- To get the load per unit width, divide the total load on one design traffic lane by the calculated equivalent strip widths.

Appropriate load factors and load combinations are applied for the selected limit state design.

Designing:

The deck slab is designed for both the critical positive and negative moments.

For Exterior and Interior longitudinal girders of T- and Box girder bridges, influence lines will be used to determine load positions for maximum force effects and magnitude of these effects. The live load force effects due to vehicular loads and lane load is obtained and distributed to the longitudinal girders with the appropriate distributed factors for shear and moments. Based on these forces, the girders are designed. The above procedures can be summarized in a flow chart as shown in **Figure 3.17** [8].


Materials Properties (concrete, steel)
Span length, width of Bridge dimensions to be designed
DECK ANALYSIS AND DESIGN
Determine positive and negative live load moment Strip widths
Select applicable load factors Load Combinations and Load modifiers
Calculate top flange thickness, t_s
Determine Dead load force effects
Calculate Live Load force effects, and load transferred to girders.
Revise the Section
Calculate positive and negative Design Moments
Is the depth (slab thickness) sufficed?
Calculate Reinforcements
Increase the Reinforcement
Is Serviceability Limit States satisfied?
THE DESIGN IS OK!
Deck overhang and curb designs
1

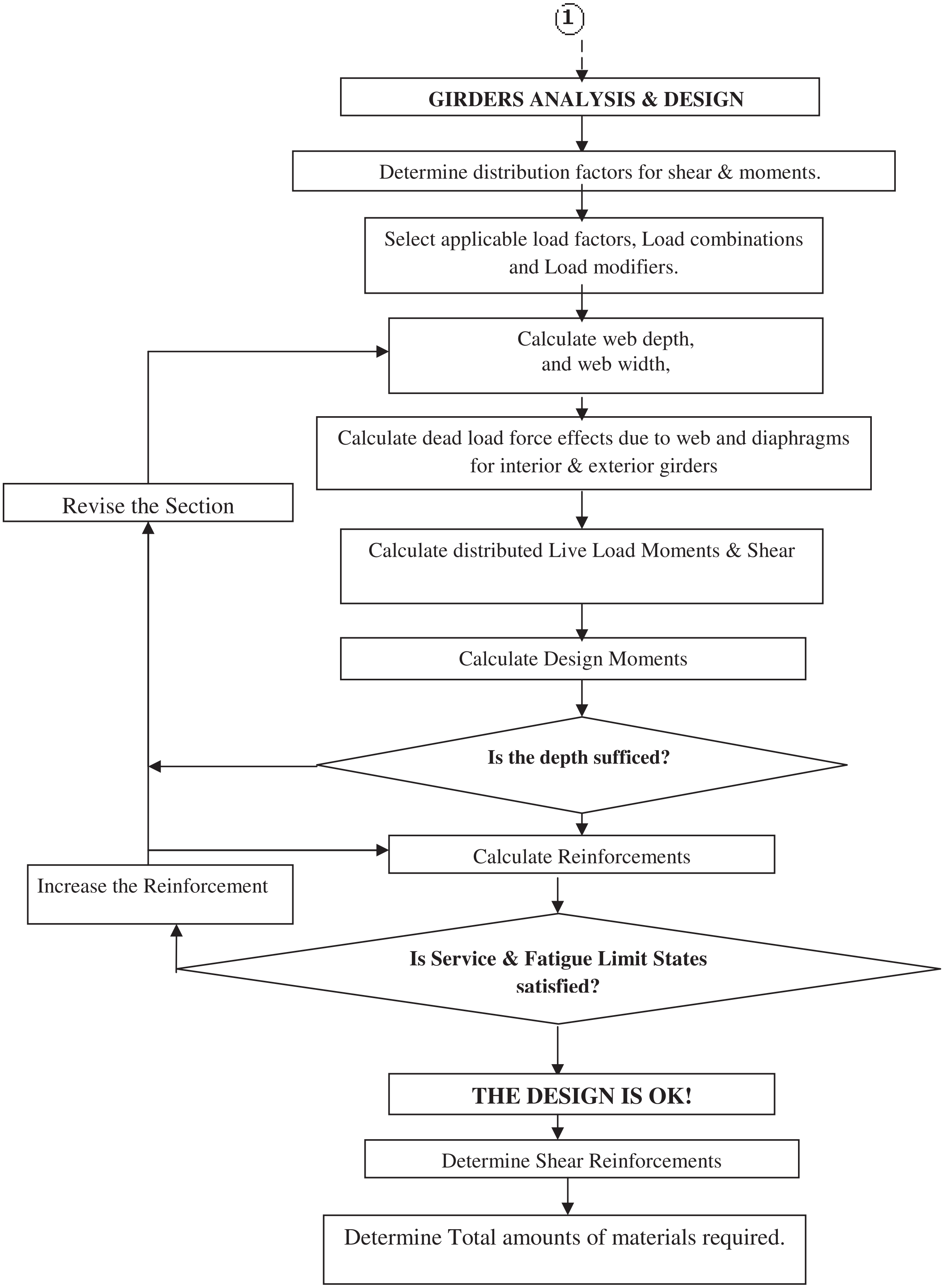


Figure 3.17 Flow chart for the design of RC T-girder bridges [8]

4 DESIGN CHARTS FOR RC BRIDGES

In developing the design charts for slab and girder bridges, the following assumptions are taken into account.

- The design chart is developed only for single span bridges
- The width of abutment is 0.5m
- For slab bridges, the maximum curb width is limited to 1.25m
- For T-girder bridges, the numbers of girders are limited to four
- The number of cells in a concrete Box girder bridges are limited to three
- Width of overhang is 0.4 of girder spacing
- The thickness of the bitumen layer is considered as 100mm
- The widths of webs for T-and Box-girder bridges are considered as 400mm.

4.1 Design Charts for RC Slab Bridges

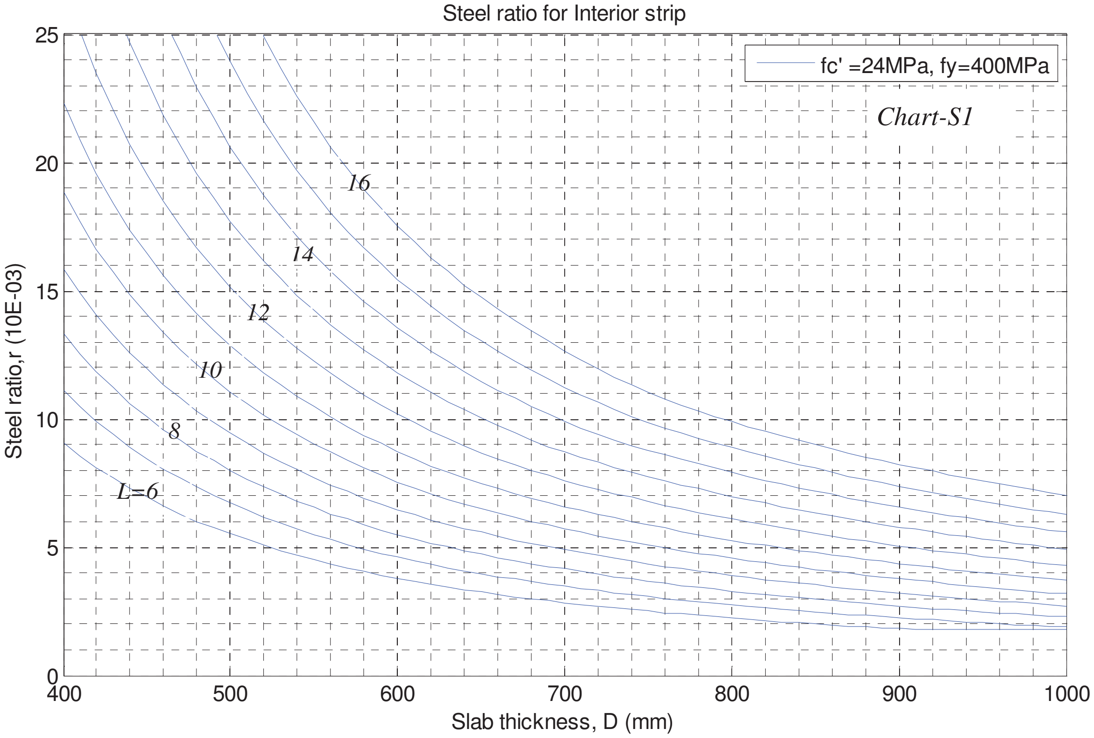
For the determination of area of reinforcement bars for both interior and edge strips of a reinforced concrete slab bridges, design charts are prepared. For this purpose, different span lengths, roadway width, depth of slab and curb width with different material properties are considered. The design charts for interior and edge strips are prepared by using a roadway width of 7.32m and a curb width of 0.8m on both sides.

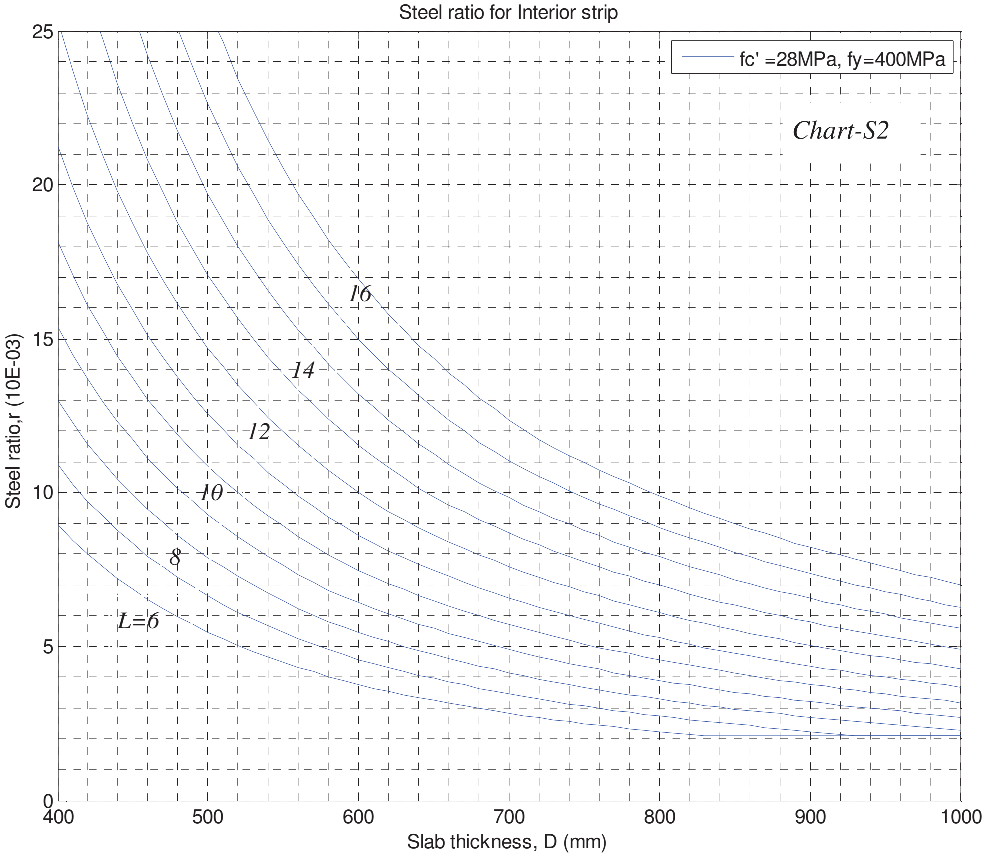
If the roadway width of the bridge is different from 7.32m, for the computation of area of reinforcement bars, modification factor for roadway width (W_f) for interior strip has been developed. Moreover, if the curb width of the bridge is different from 0.8m, modification factor for edge strip, CW_f, has been developed.

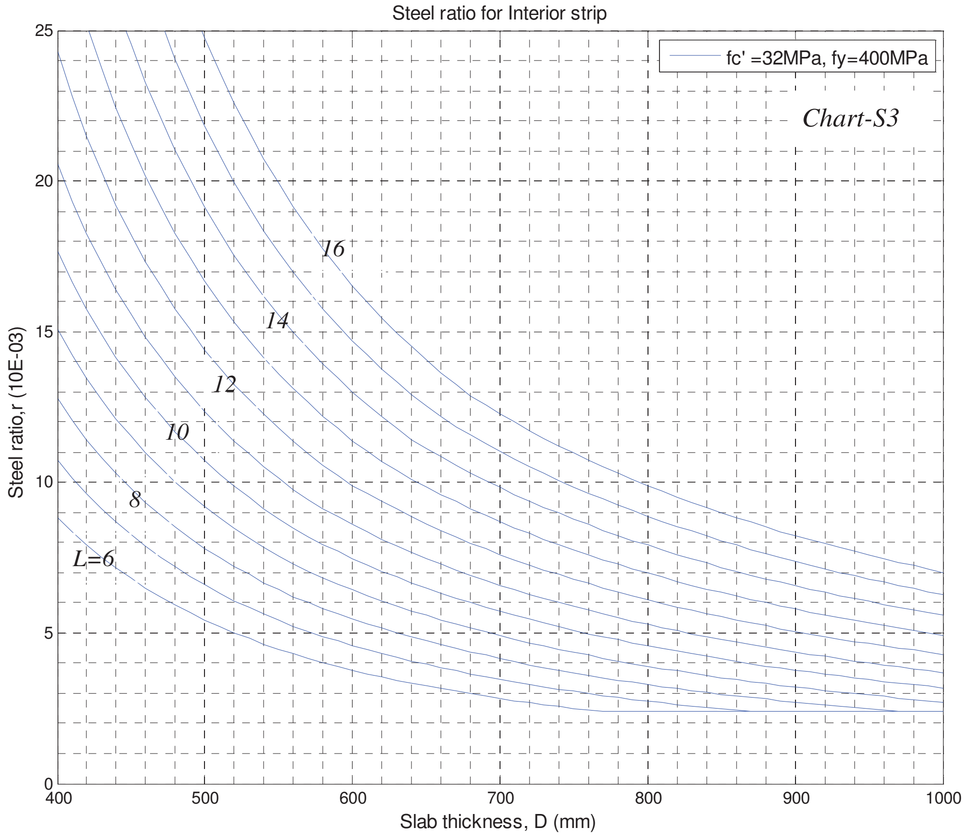
Derivation of modification factors W_f and CW_f

In the case of roadway width of the bridge is different from 7.32m, for the computation of area of reinforcement bars for interior strip, reinforcement ratios for any arbitrary bridge width (ρ) and for a reference width of 7.32m (ρ_r) is computed and the ratio (ρ/ρ_r) is considered as the modification factor for roadway width (W_f). Similarly, if the curb width of the bridge is differing from 0.8m, for the computation of area of reinforcement bars for edge strip, modification factor (curb width factor, CW_f) is developed.

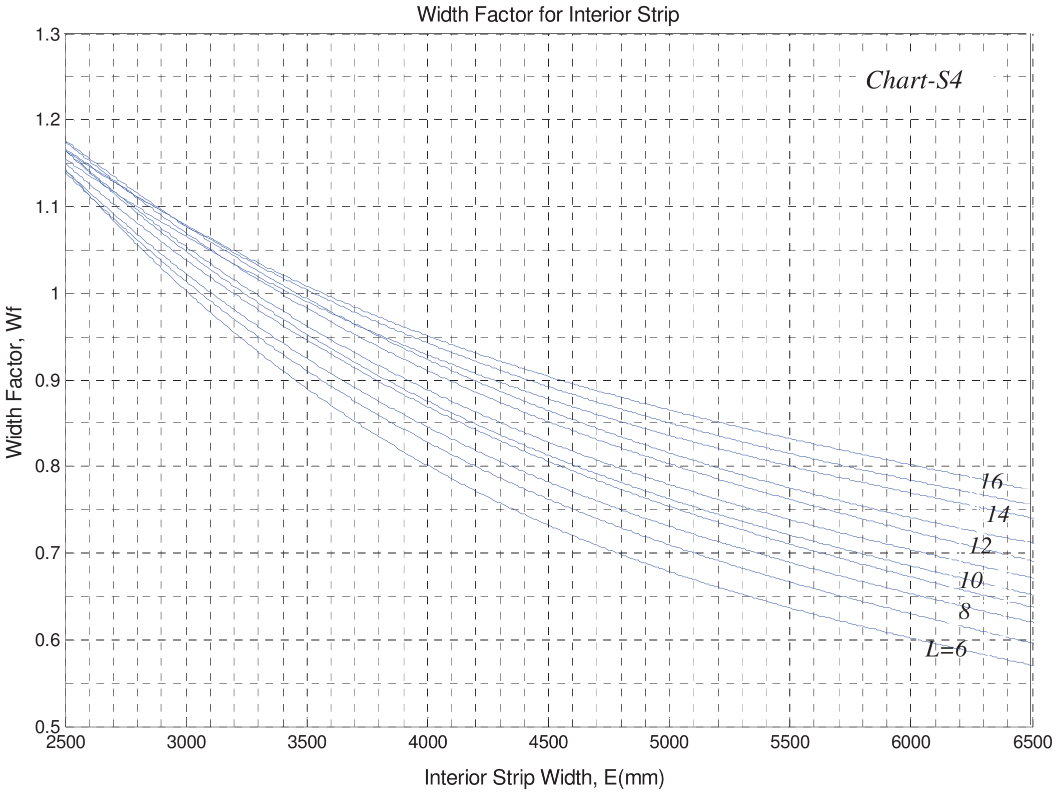
i) Design Charts for Interior Strip



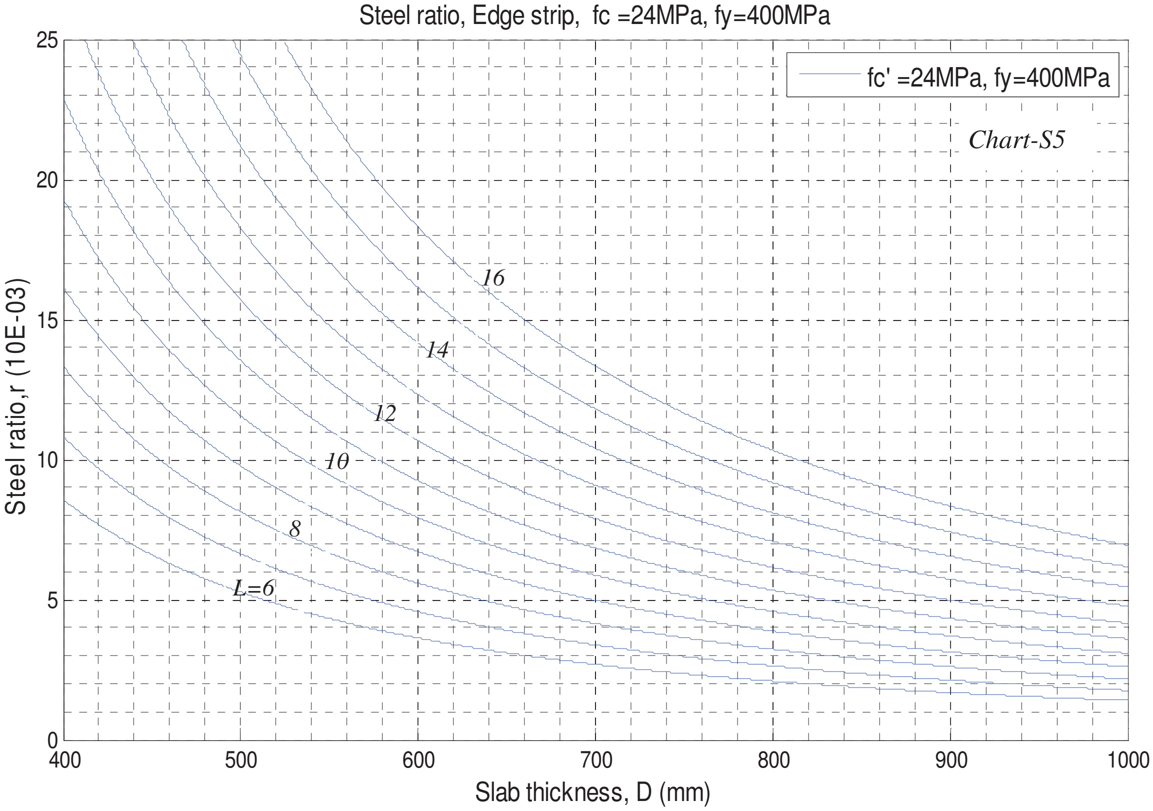


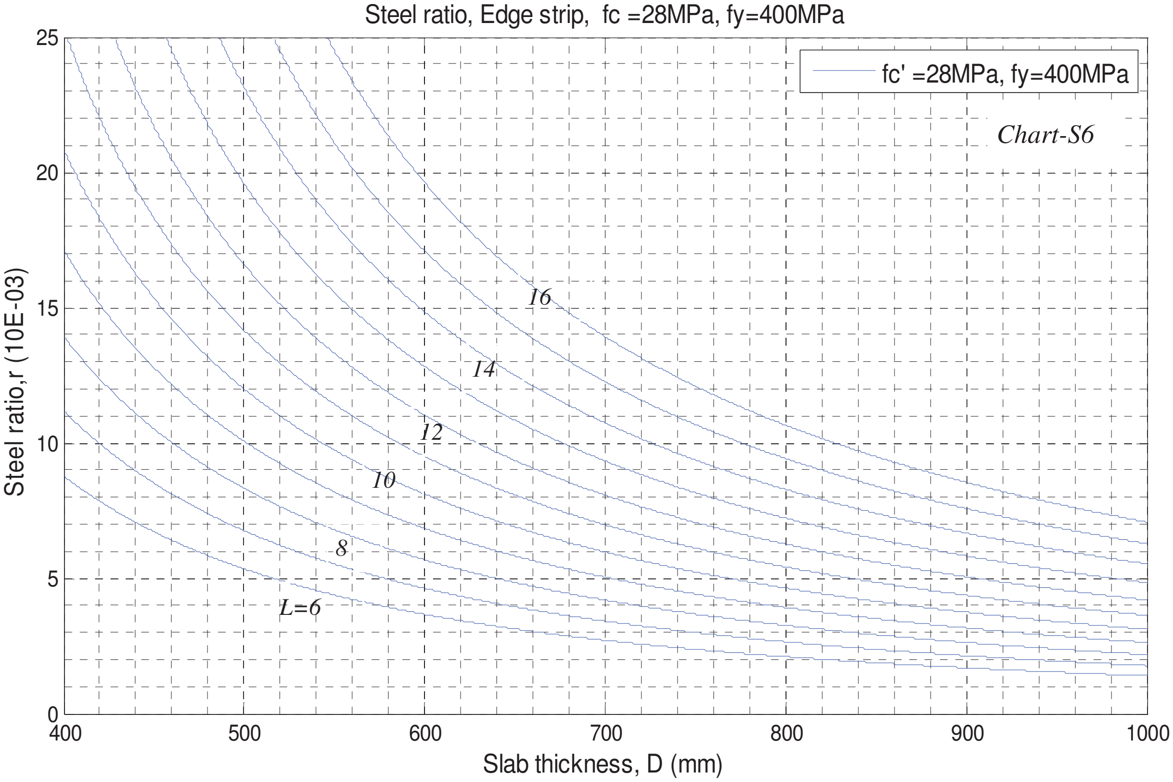


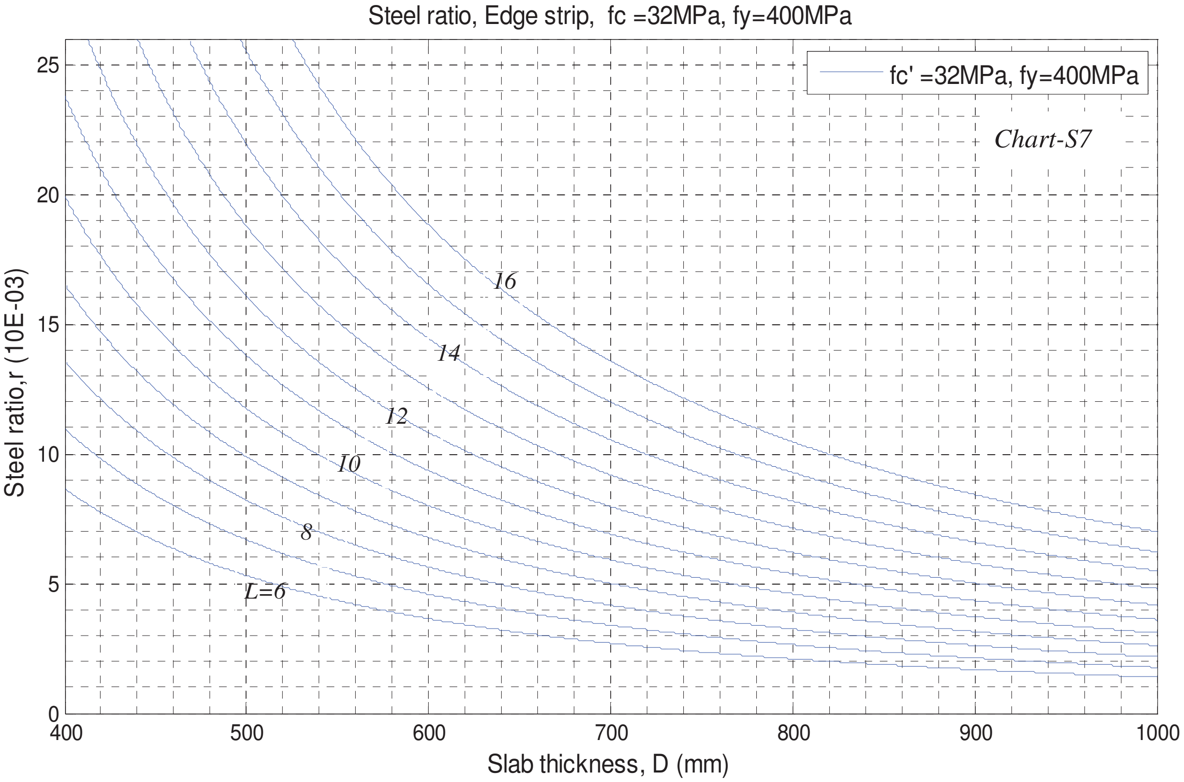
ii) Width factor (W_f)



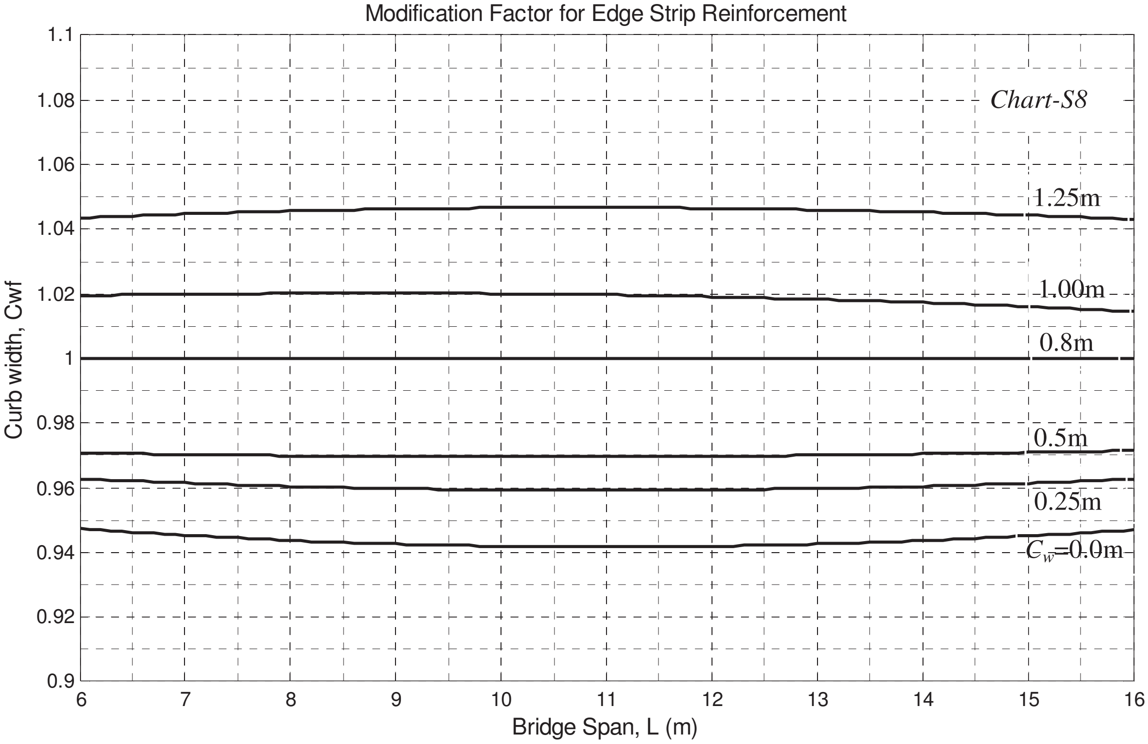
iii) Design Charts for Edge Strip







iv) Curb width factor for edge strip (C_{wf})



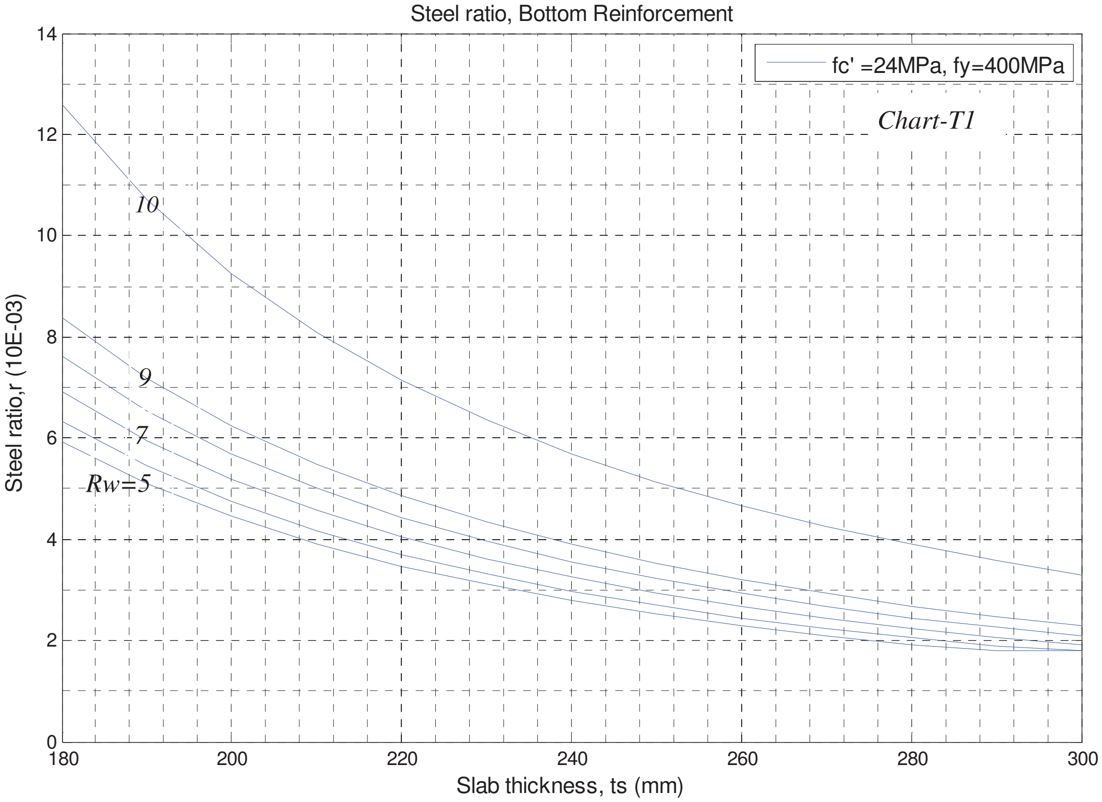
4.2 Design Charts for T- and Box-Girder Bridges

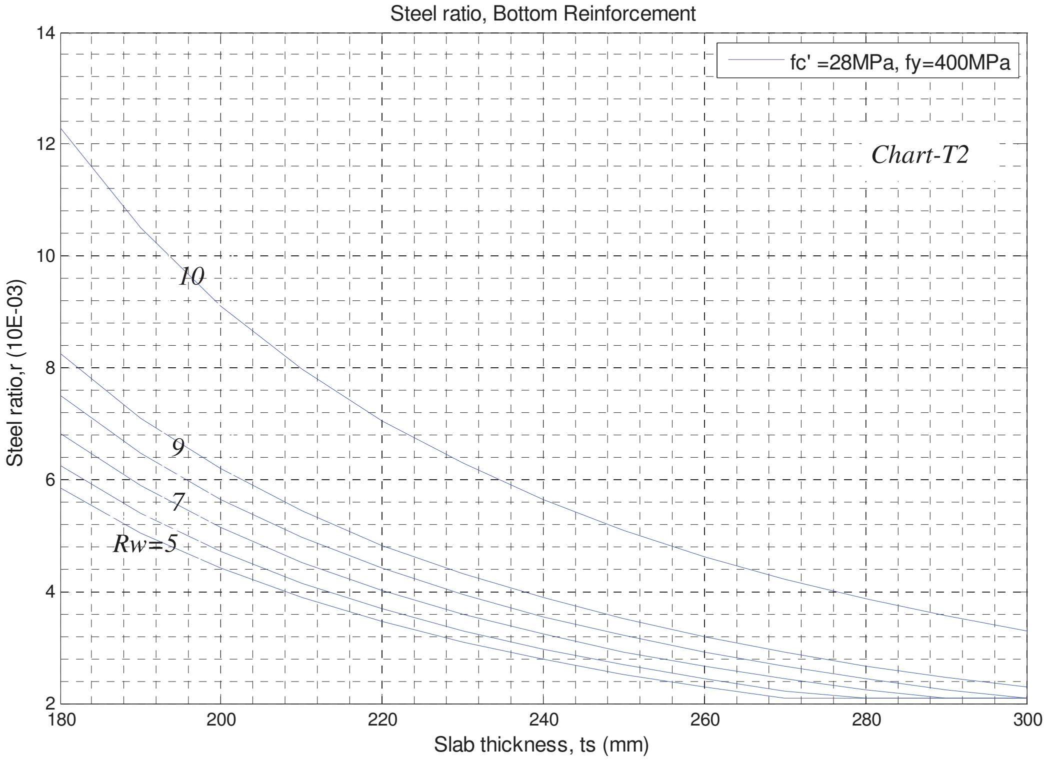
For the determination of area of reinforcement bars, for deck slab and longitudinal girders of a reinforced concrete T- and Box girder bridges, the variation of roadway width and slab thickness with different material properties are considered. Based on this, design charts for the determination of area of steel for both top and bottom surfaces are developed. Moreover, charts for the computation of reinforcing bars for the longitudinal girders are carried out by considering variations in girder depth and span length. In this case, the widths of webs for T-and Box-girder bridges are considered as 400mm and 200mm, respectively.

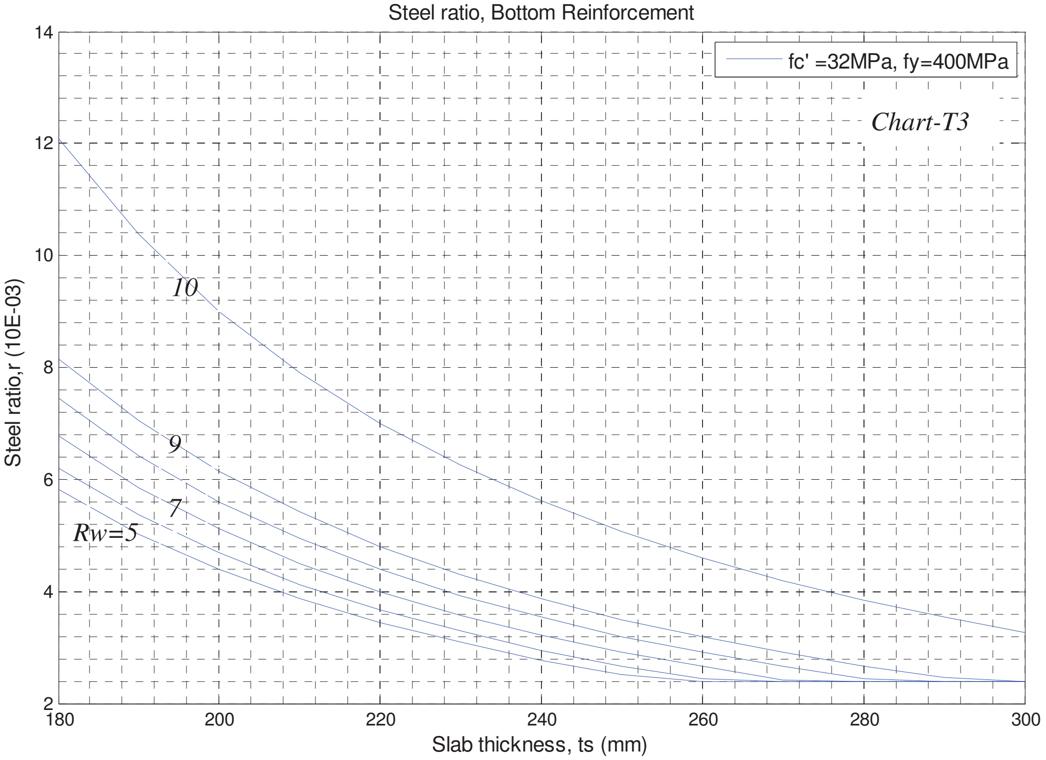
Charts for deck slab (Top flange) design

i) Positive Reinforcement

N=4 (Number of Girders)

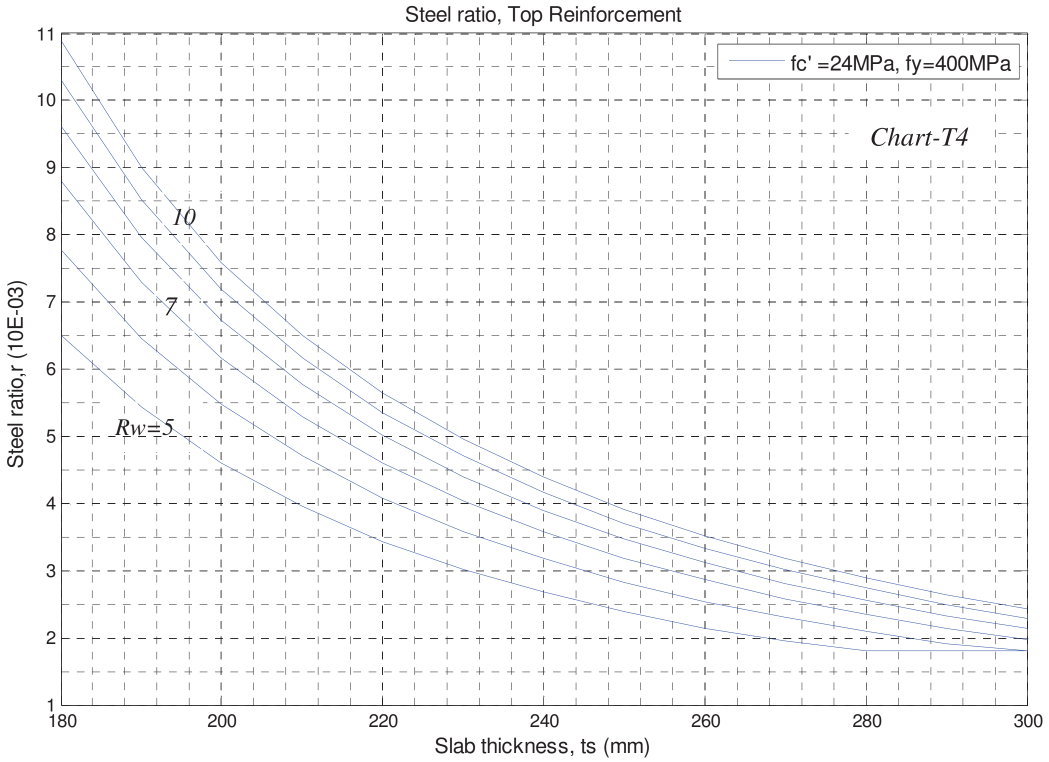


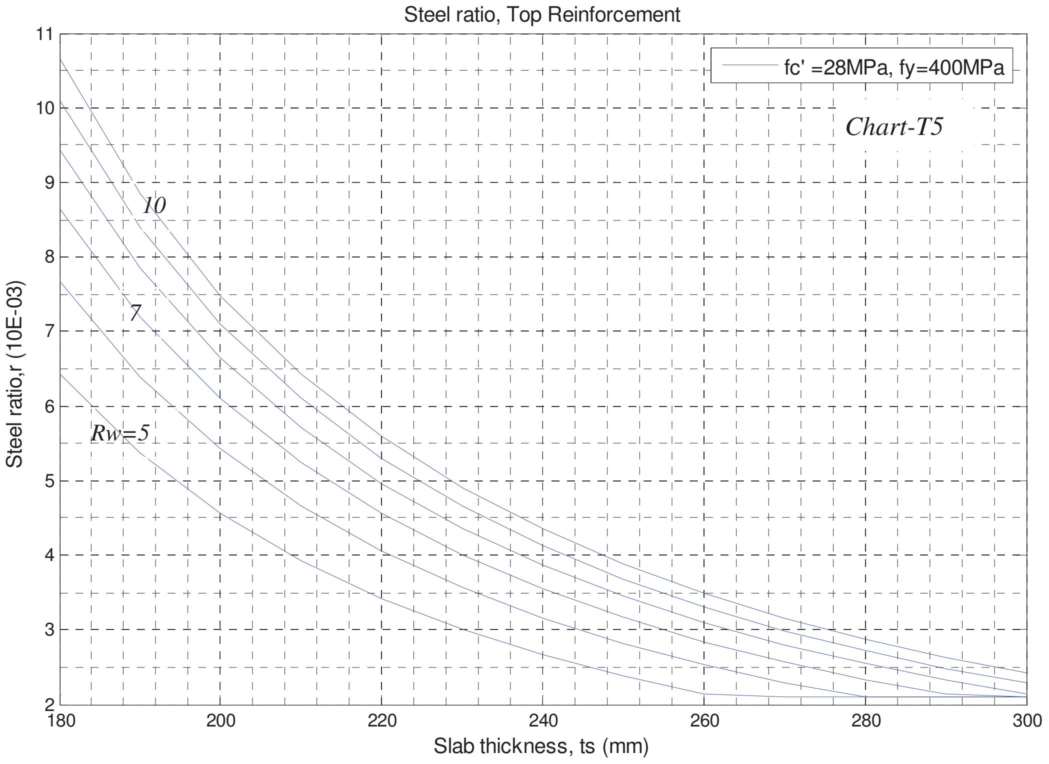

Steel ratio, Bottom Reinforcement
fc' =28MPa, fy=400MPa
Chart-T2
Steel ratio,r (10E-03)
14
12
10
8
6
4
2
10
9
7
Rw=5
180
200
220
240
260
280
300
Slab thickness, ts (mm)

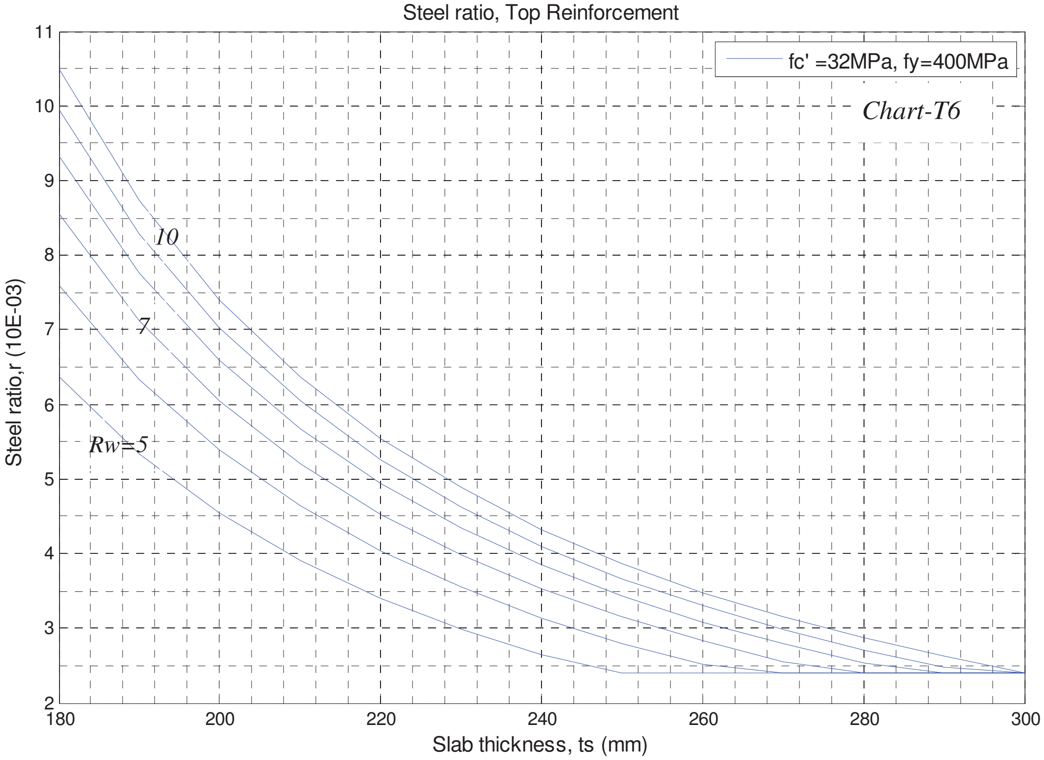

Steel ratio, Bottom Reinforcement
fc' =32MPa, fy=400MPa
Chart-T3
Steel ratio,r (10E-03)
14
12
10
8
6
4
2
10
9
7
Rw=5
180
200
220
240
260
280
300
Slab thickness, ts (mm)

ii) Negative Reinforcement

N=4 (Number of Girders)

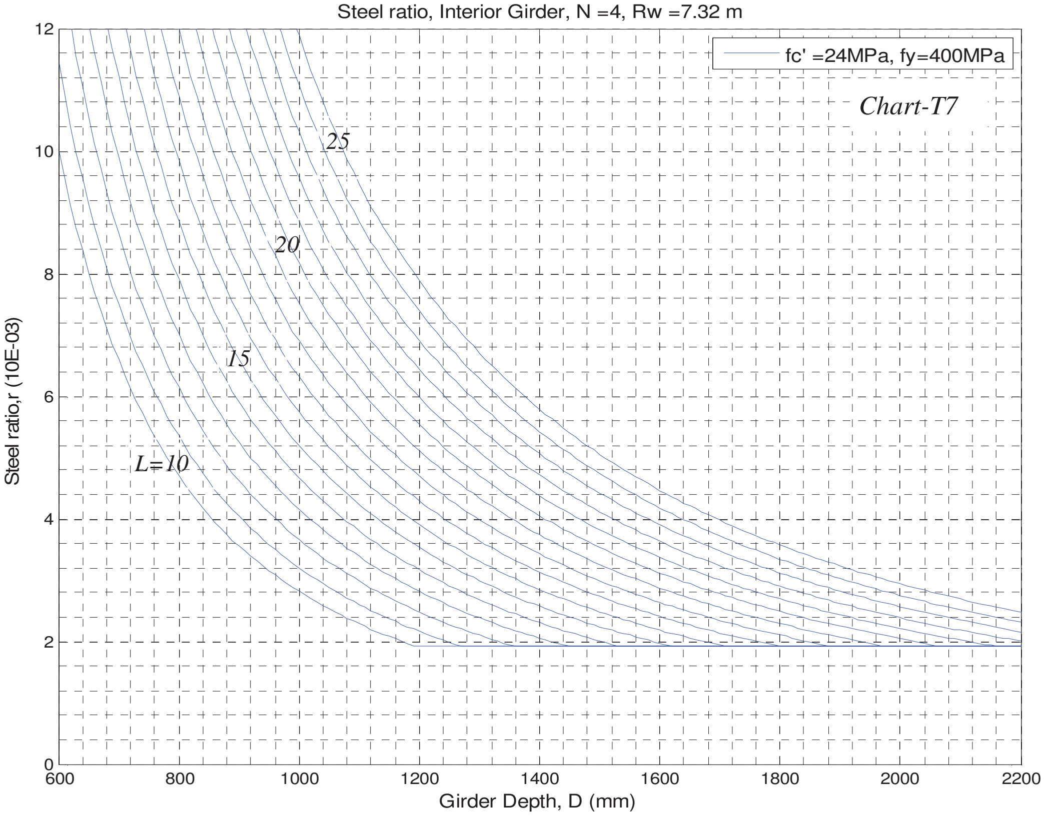


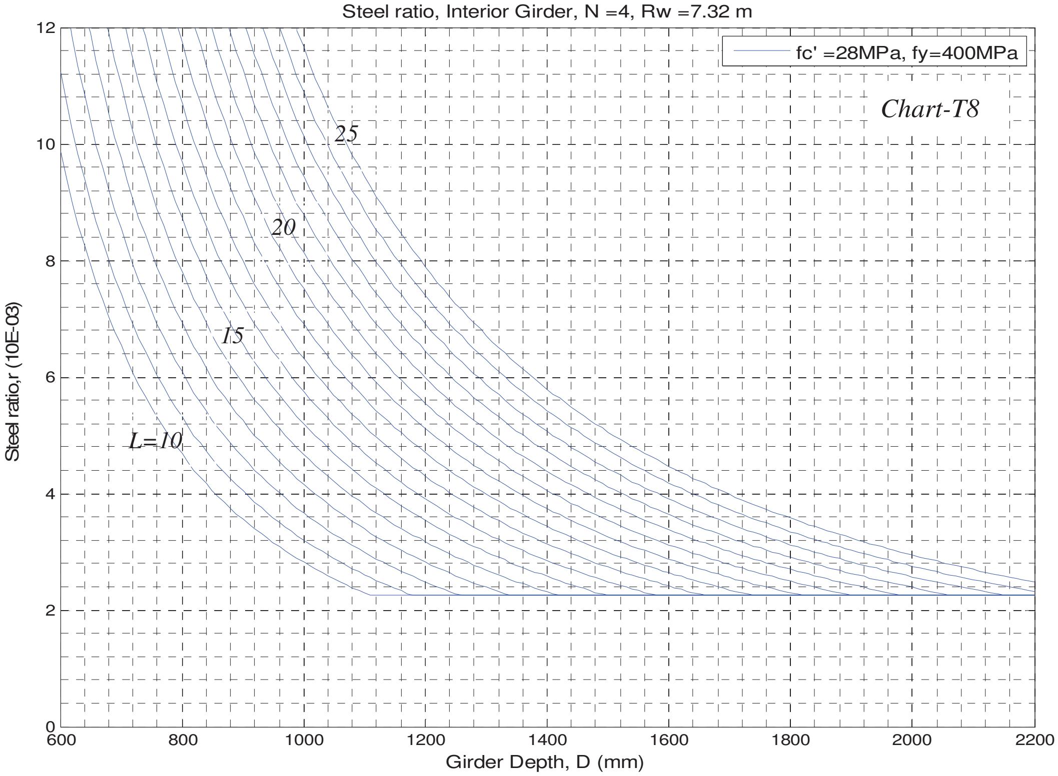


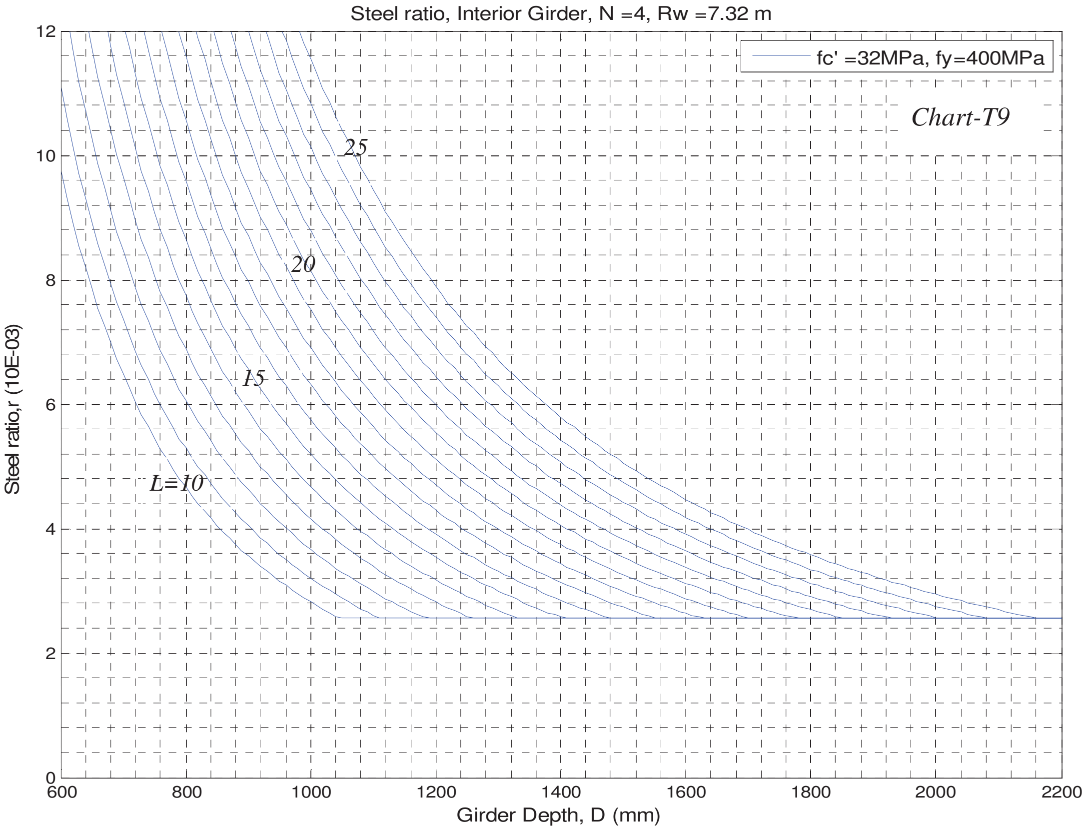

Steel ratio, Top Reinforcement
fc' =32MPa, fy=400MPa
Chart-T6
10
7
Rw=5
Steel ratio,r (10E-03)
2
3
4
5
6
7
8
9
10
11
180
200
220
240
260
280
300
Slab thickness, ts (mm)

Design chart for longitudinal Girders (T-Girder Bridges)

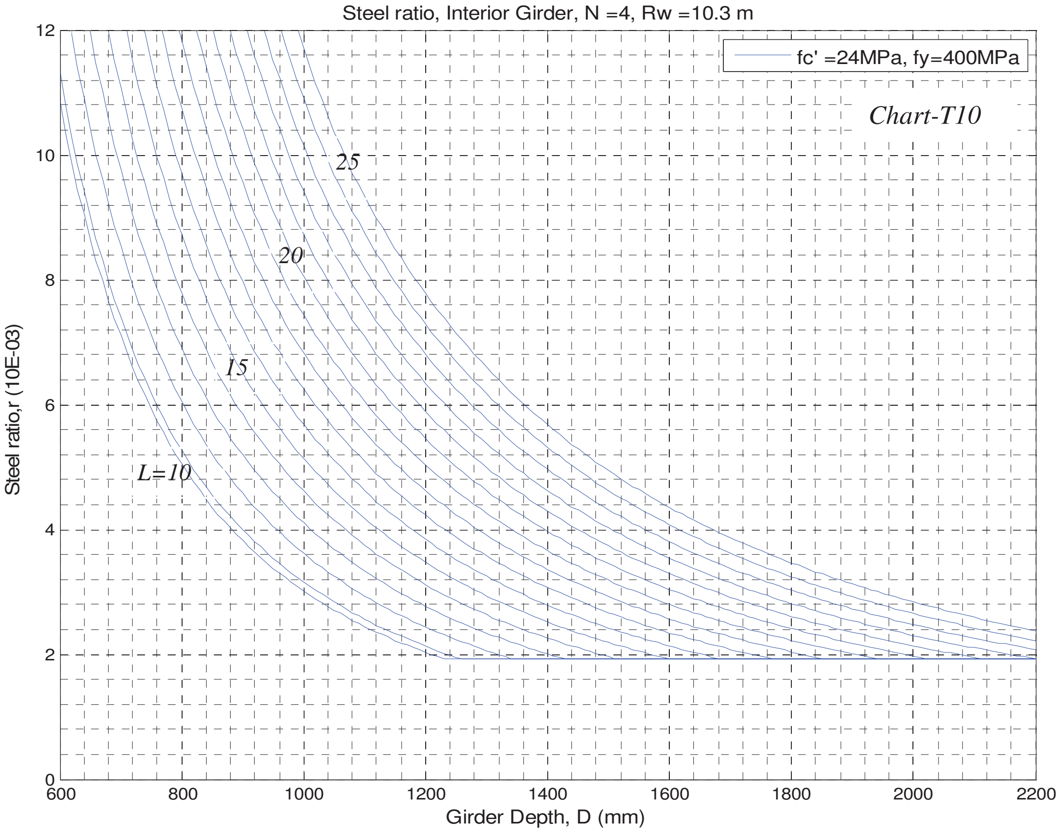
Interior Girder, N=4, Roadway width=7.32m

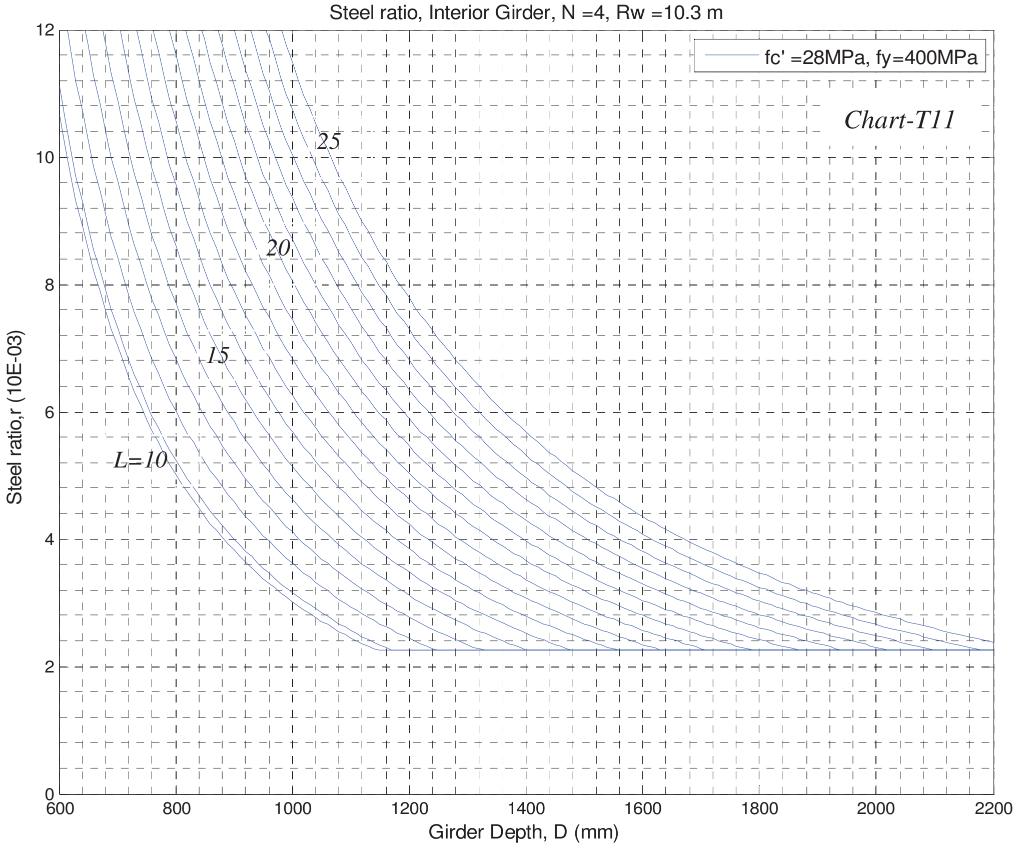


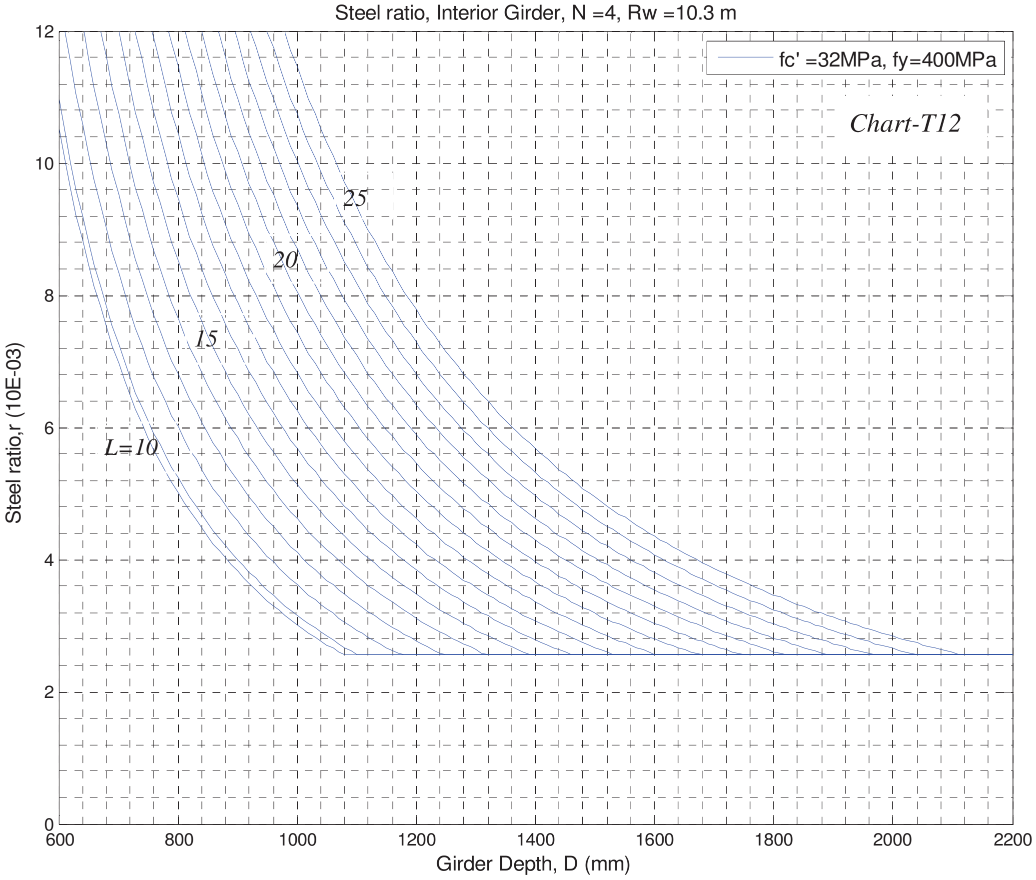




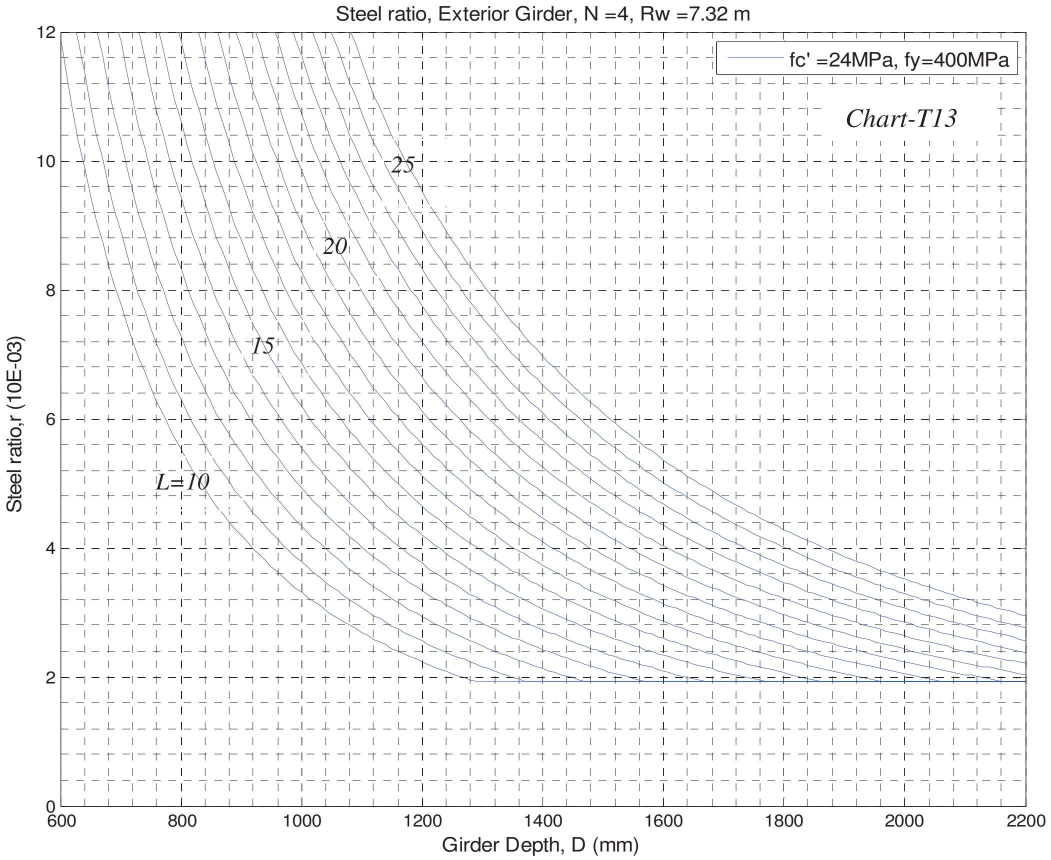
Interior Girder, N=4, Roadway width=10.30m

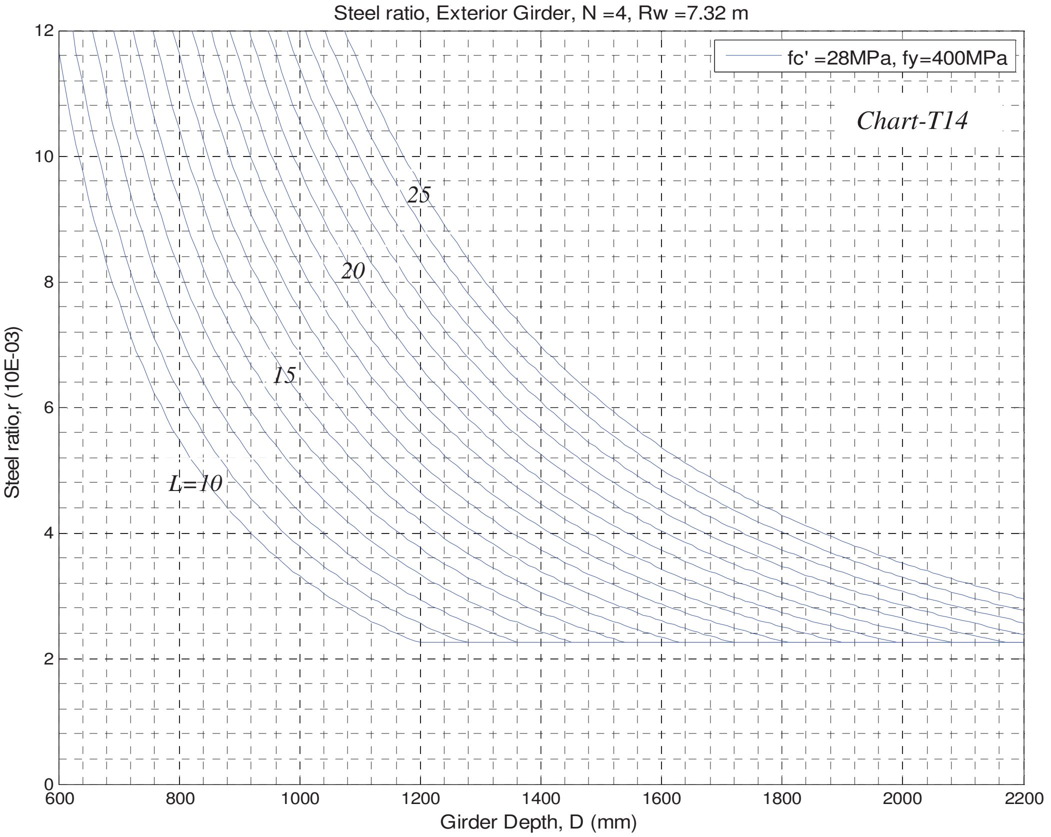


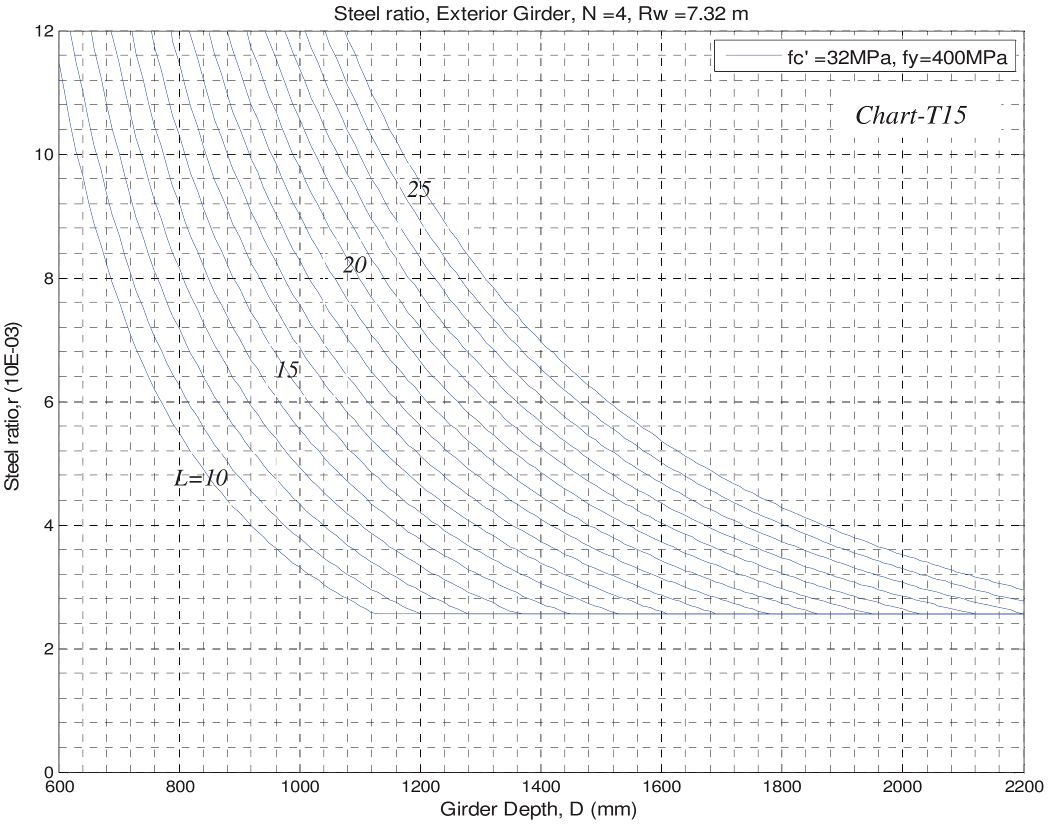

Steel ratio, Interior Girder, N =4, Rw =10.3 m
fc' =28MPa, fy=400MPa
Chart-T11
25
20
15
L=10
Steel ratio,r (10E-03)
0
2
4
6
8
10
12
600
800
1000
1200
1400
1600
1800
2000
2200
Girder Depth, D (mm)


Steel ratio, Interior Girder, N =4, Rw =10.3 m
fc' =32MPa, fy=400MPa
Chart-T12
25
20
15
L=10
Steel ratio,r (10E-03)
0
2
4
6
8
10
12
600
800
1000
1200
1400
1600
1800
2000
2200
Girder Depth, D (mm)

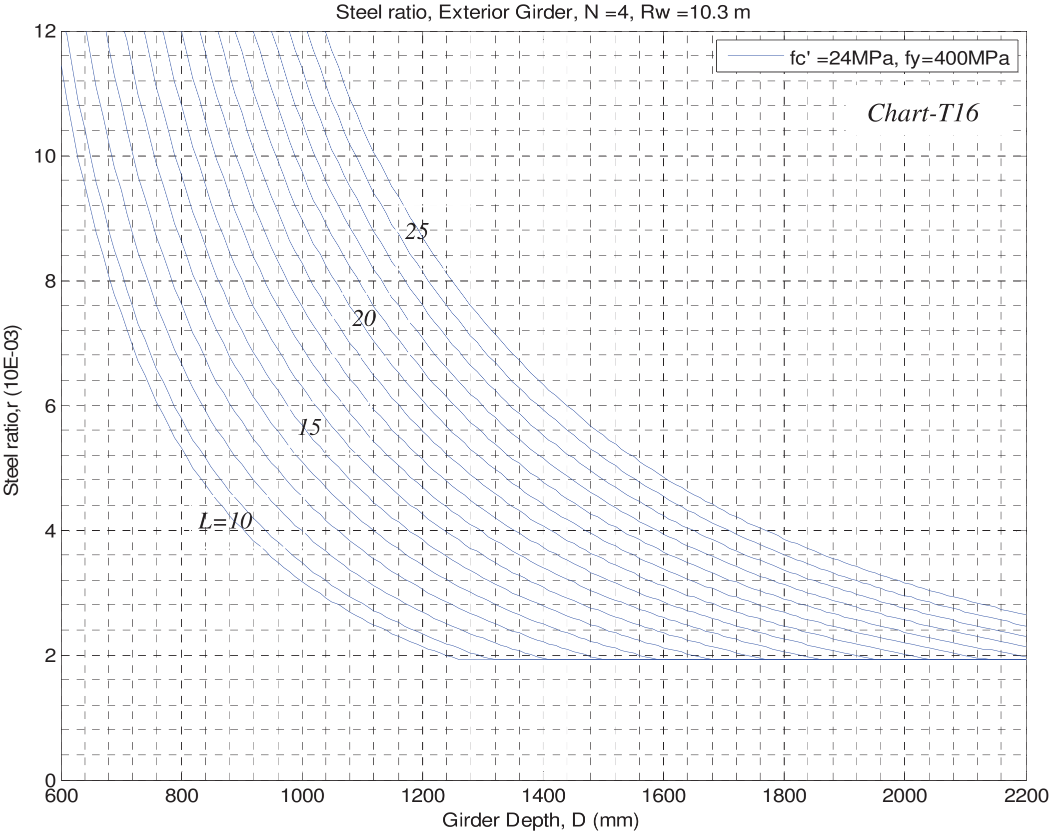
Exterior Girder, N=4, Roadway width=7.32m

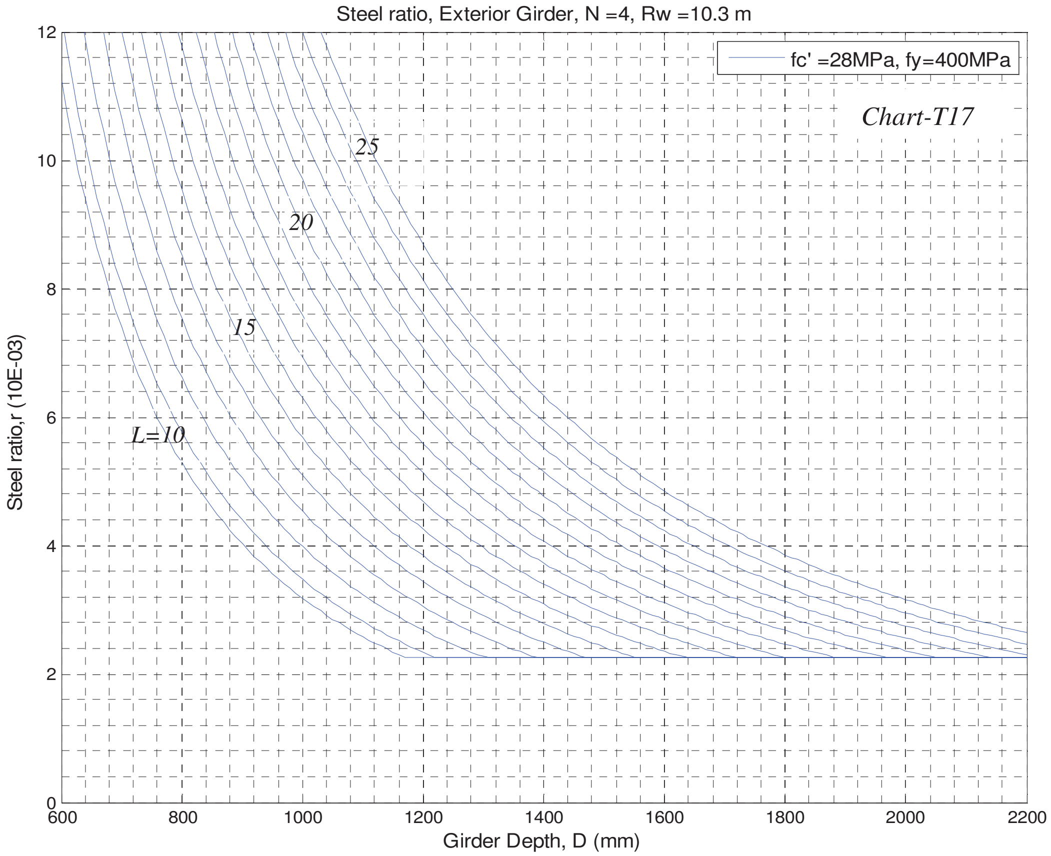


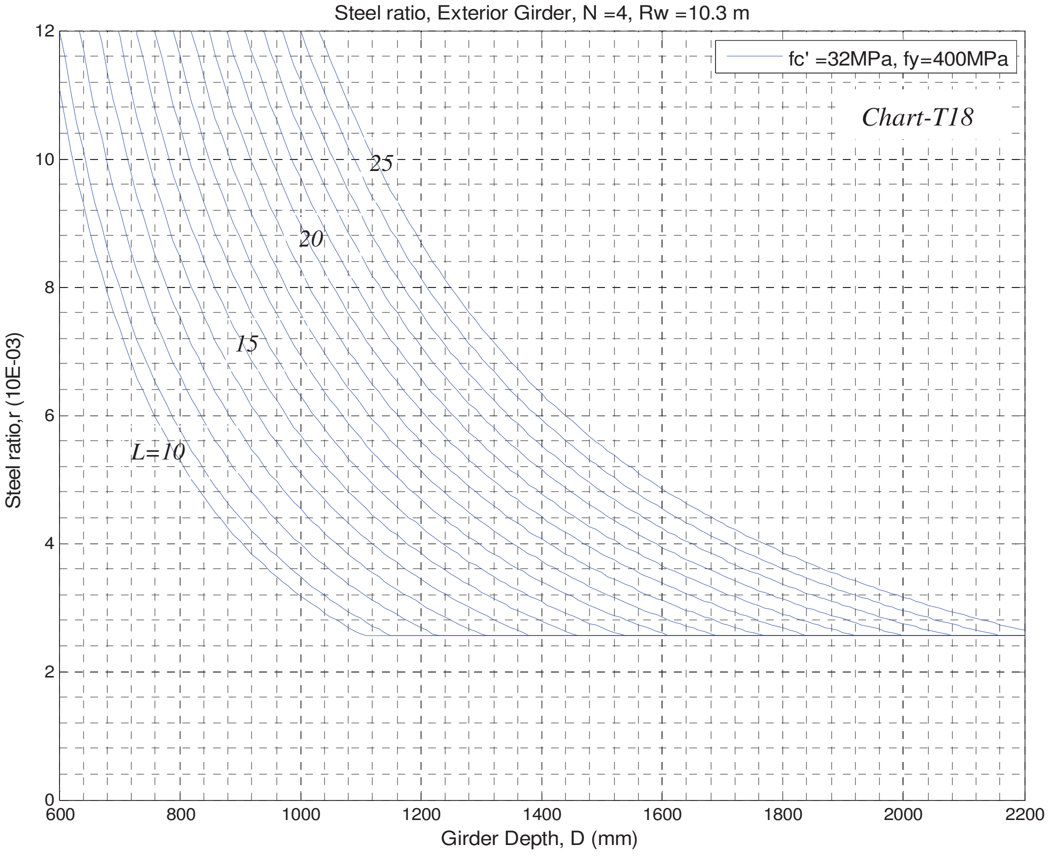




Exterior Girder, N=4, Roadway width=10.30m



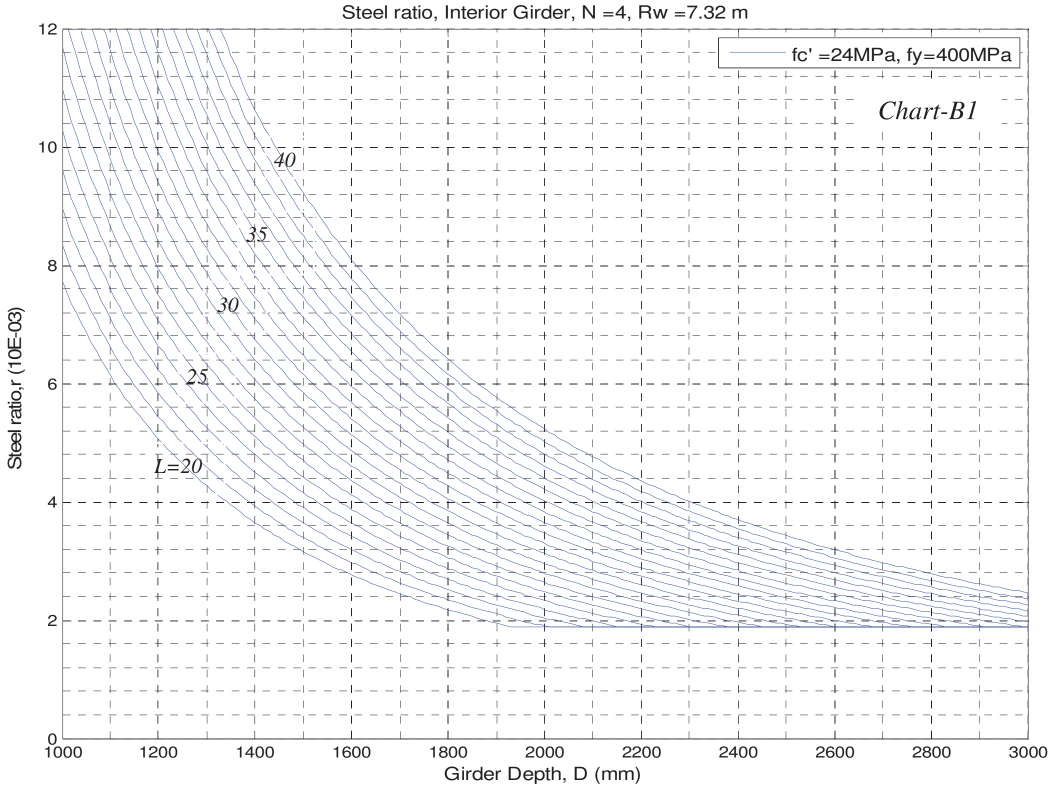

Steel ratio, Exterior Girder, N =4, Rw =10.3 m
fc' =28MPa, fy=400MPa
Chart-T17
25
20
15
L=10
Steel ratio,r (10E-03)
0
2
4
6
8
10
12
600
800
1000
1200
1400
1600
1800
2000
2200
Girder Depth, D (mm)

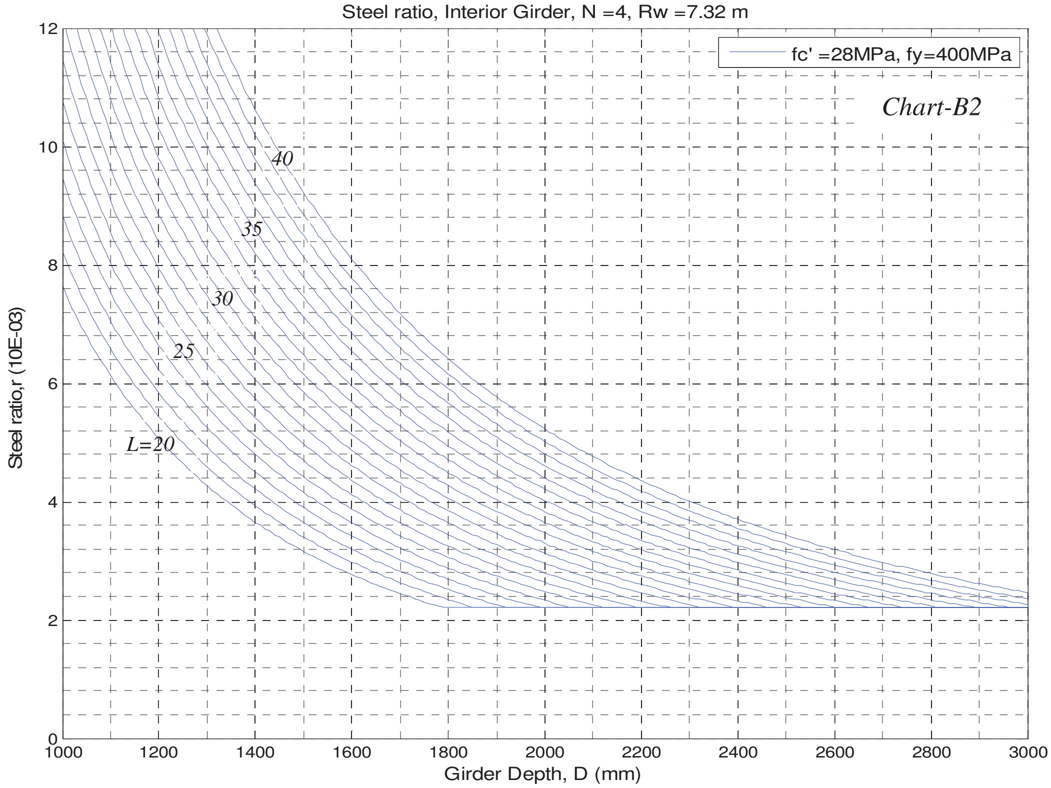

Steel ratio, Exterior Girder, N =4, Rw =10.3 m
fc' =32MPa, fy=400MPa
Chart-T18
25
20
15
L=10
Steel ratio,r (10E-03)
0
2
4
6
8
10
12
600
800
1000
1200
1400
1600
1800
2000
2200
Girder Depth, D (mm)

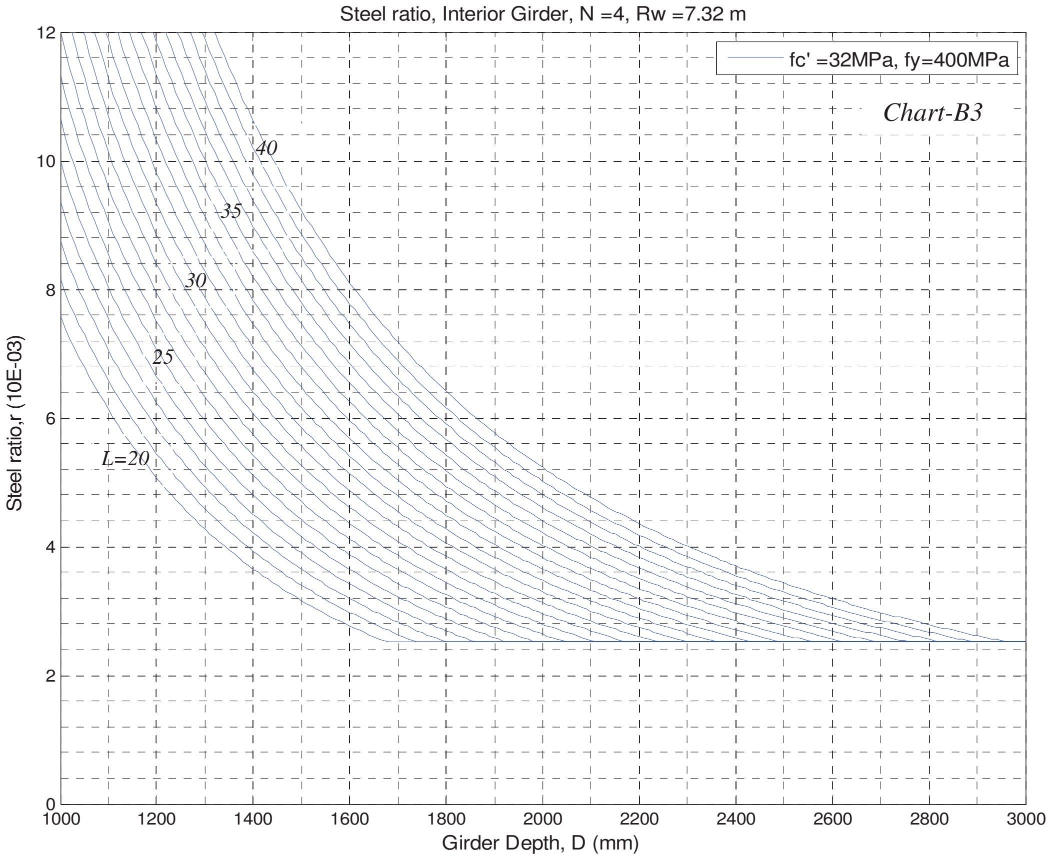
Design chart for longitudinal Girders (Box-Girder Bridges)

Number of Girders N=4 (i.e., number of cells in Box- girder, N_c= 3)

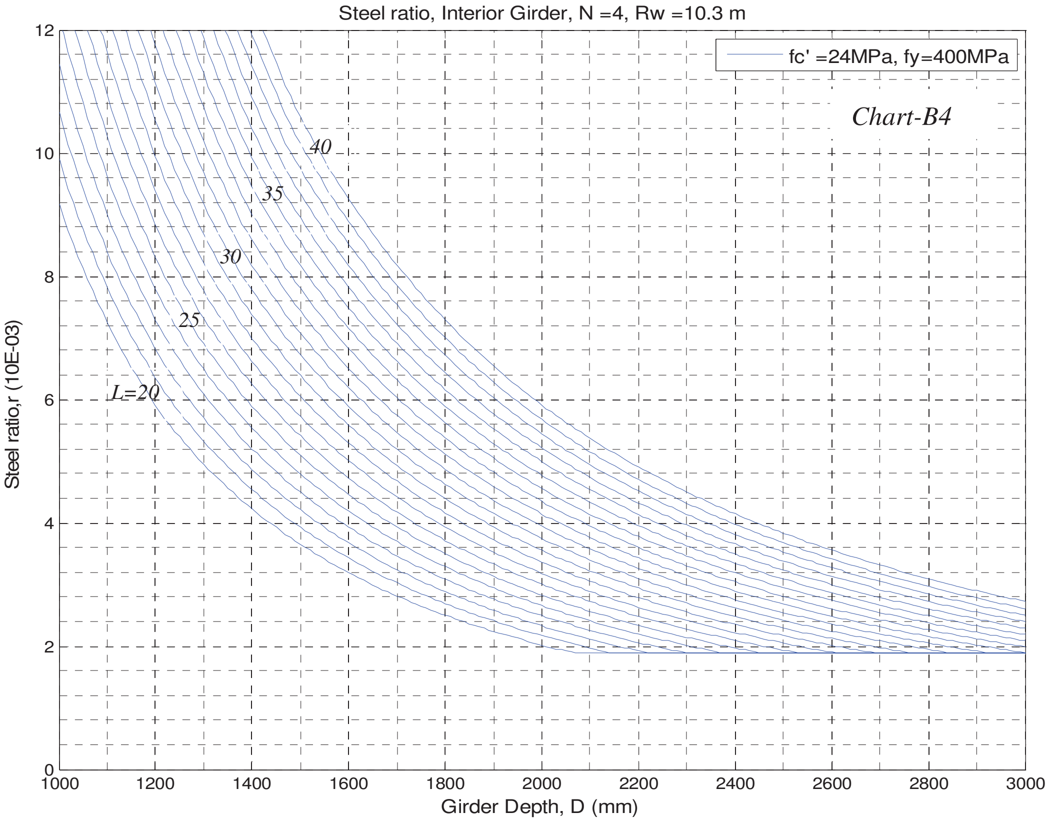
Interior Girder, N=4, Roadway width=7.32m

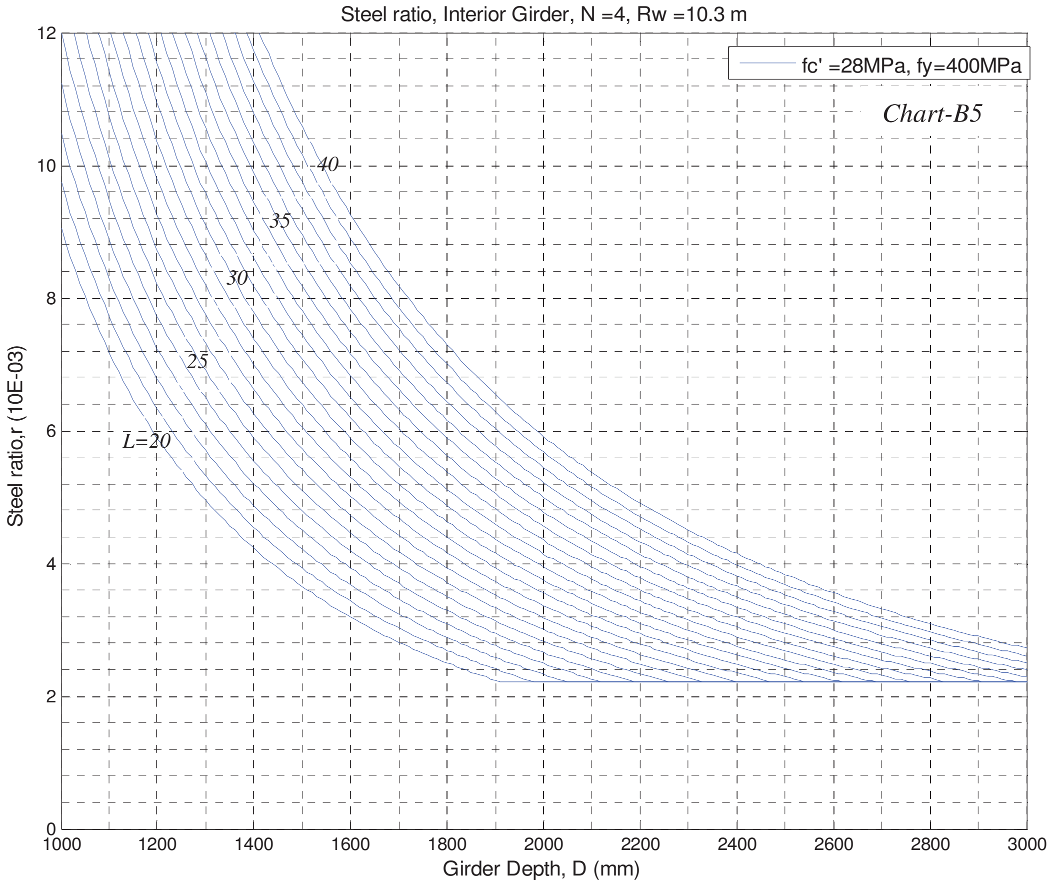


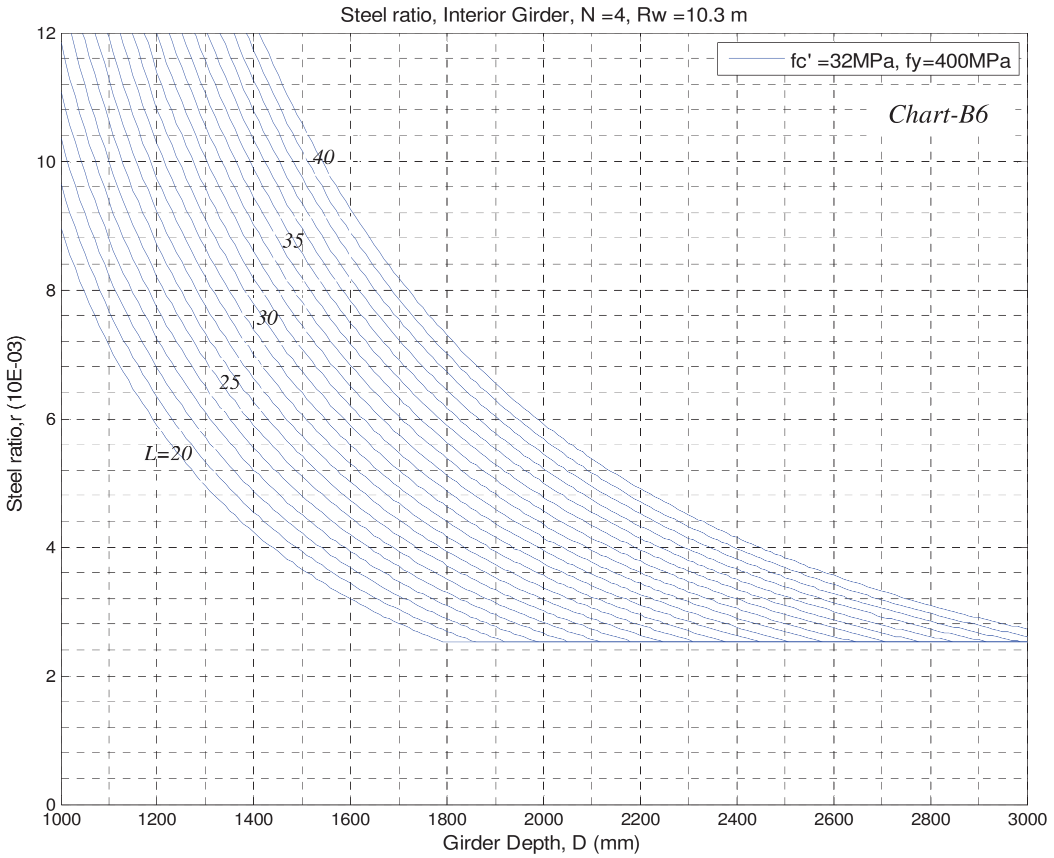




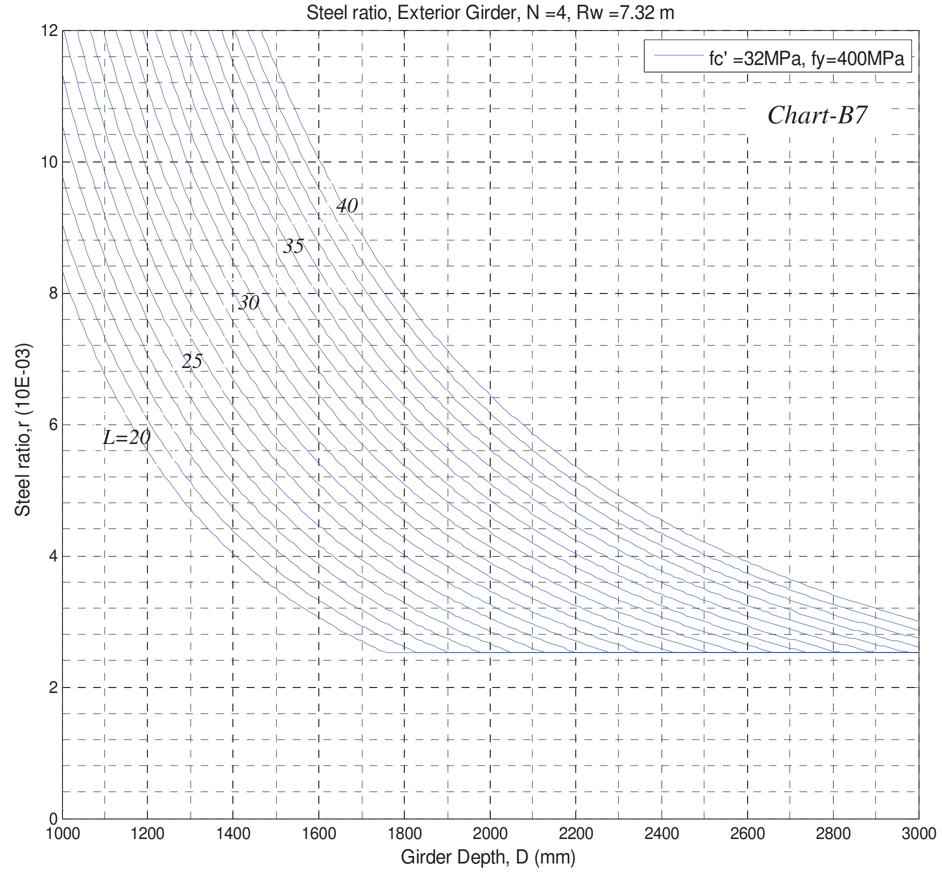
Interior Girder, N=4, Roadway width=10.30m

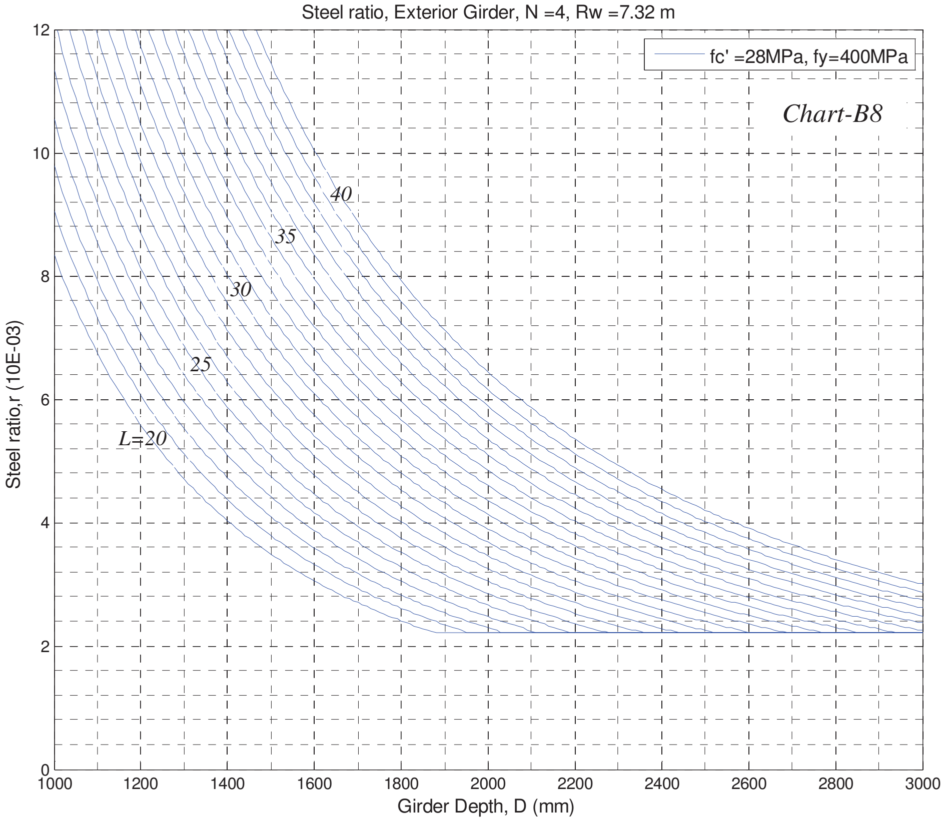


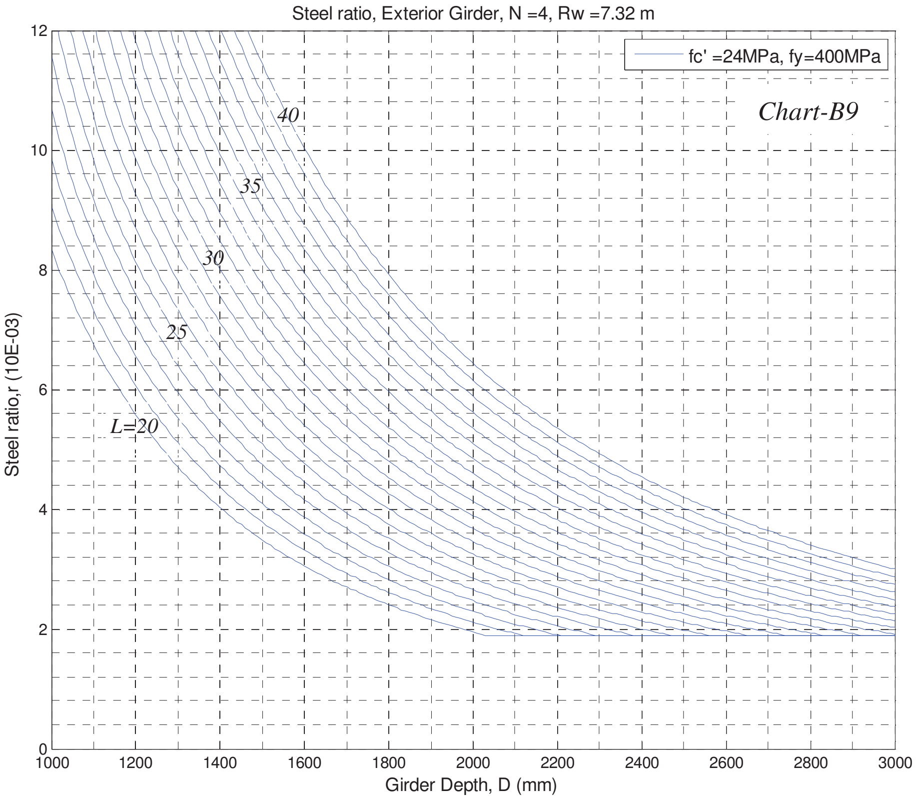

Steel ratio, Interior Girder, N =4, Rw =10.3 m
fc' =28MPa, fy=400MPa
Chart-B5
40
35
30
25
L=20
Steel ratio,r (10E-03)
0
2
4
6
8
10
12
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
Girder Depth, D (mm)


Steel ratio, Interior Girder, N =4, Rw =10.3 m
fc' =32MPa, fy=400MPa
Chart-B6
40
35
30
25
L=20
Steel ratio,r (10E-03)
0
2
4
6
8
10
12
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
Girder Depth, D (mm)

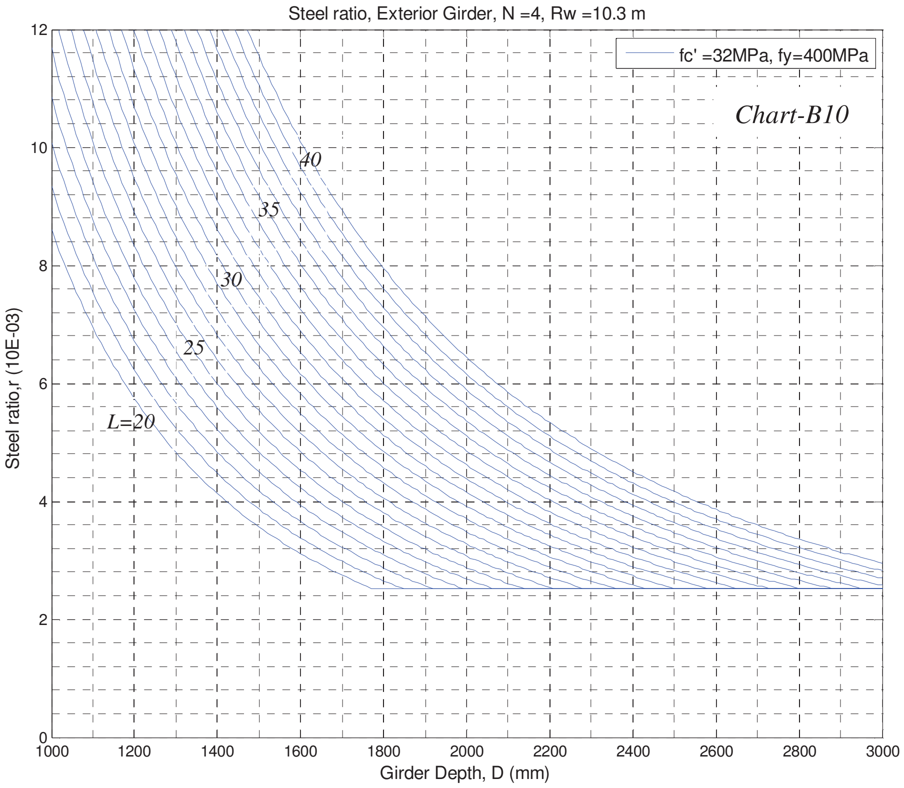
Exterior Girder, N=4, Roadway width=7.32m

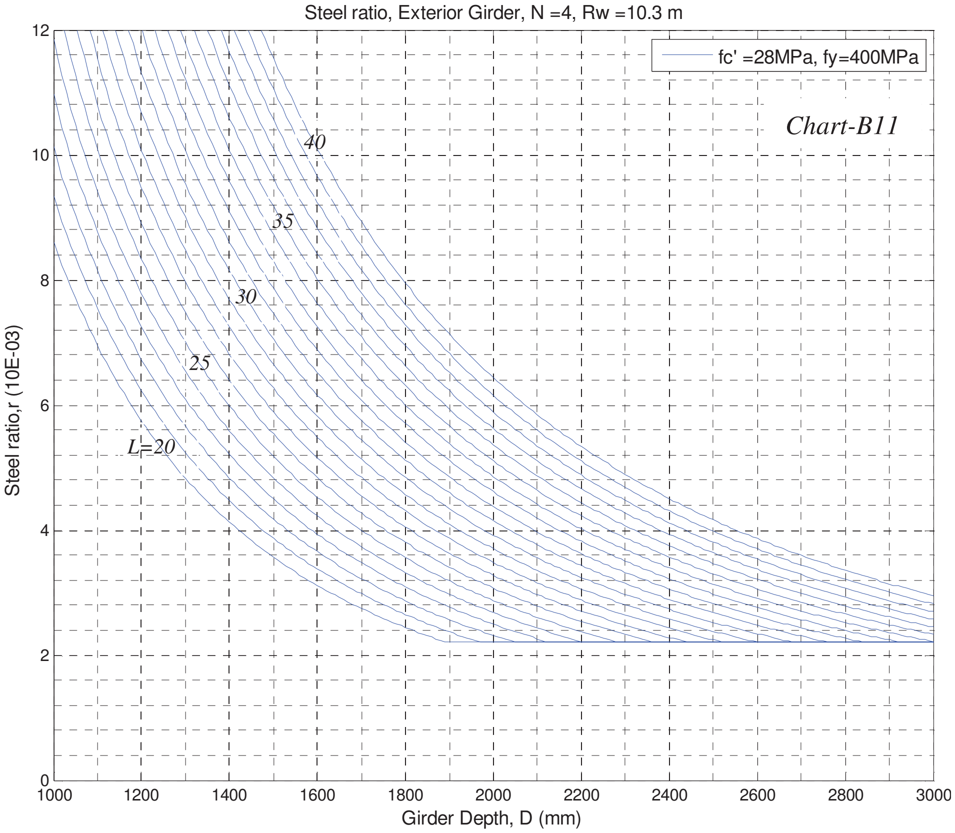


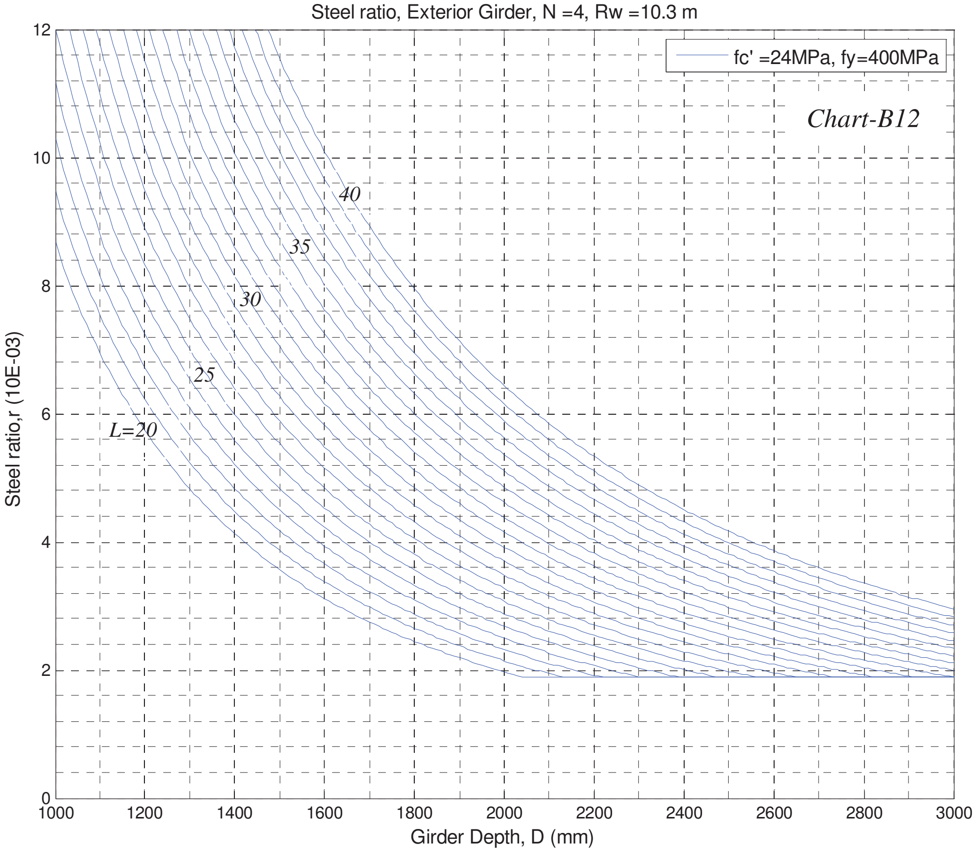




Exterior Girder, N=4, Roadway width=10.30m




Steel ratio, Exterior Girder, N =4, Rw =10.3 m
fc' =28MPa, fy=400MPa
Chart-B11
40
35
30
25
L=20
Steel ratio,r (10E-03)
12
10
8
6
4
2
0
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
Girder Depth, D (mm)


Steel ratio, Exterior Girder, N =4, Rw =10.3 m
fc' =24MPa, fy=400MPa
Chart-B12
40
35
30
25
L=20
Steel ratio,r (10E-03)
12
10
8
6
4
2
0
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
Girder Depth, D (mm)

4.3 Design Procedures

4.3.1 Design procedures for the design of RC Slab bridges using design charts

In order to design RC slab bridges using design charts, the following procedures may be considered.

Procedures

1. Determine the minimum thickness of slab D using Eqn. (3.6)
2. with slab thickness (D), bridge length (L), and material properties (f_y and f_c'), determine the steel ratio ρ_i for interior strip (from *Charts S1-S3*)
3. Calculate the equivalent interior strip width, *E*, using Eqn. (3.7), with equivalent interior strip width (*E*) and bridge length (*L*), obtain the width factor for interior strip, W_f (from *Chart S4*)
4. with slab thickness (D), bridge length (L), and material properties (f_y and f_c'), determine the steel ratio ρ_e for edge strip (from *Charts S5-S7*)
5. If the curb width of the bridge is different from 0.8m, modification factor for edge strip, CW_f, has to used. With bridge length (*L*) and curb width (C_W), obtain the modification factor for edge strip (from *Chart S8)*
6. Compute reinforcement bars for both interior and edge strips, $A_{si}=W_f * \rho_i bd$ and $A_{se}= CW_f * \rho_e$ bd

4.3.2 Design procedures for the design of T- and Box girder bridges using design charts

In order to design RC T- and Box girder bridges using design charts, the following procedures may be considered.

1. Compute reinforcement bars for deck slab (Top flange)
    i) Determine girder spacing, s, using Eqn. (3.19)
    ii) Using Eqn. (3.18), compute the minimum thickness of the top flange
    iii) Using appropriate charts (*Charts T1-T6*), obtain the corresponding values of the steel ratio ρ for both positive and negative moments and compute the reinforcements accordingly (A_s= ρbd, b=1000mm)

2. Compute reinforcement bars for both interior and exterior longitudinal girders
    - i) First determine the minimum depth of girder from Eqn. (3.24)
    - ii) Compute effective flange widths for both interior and exterior girders using Eqns. (3.25) and (3.26) respectively.
    - iii) From appropriate charts (*Charts T7-T18*), obtain values of ρ corresponding to f_y, f_c', *D* and *L*. Compute $A_{si}= \rho b_i d$ and $A_{se}= \rho b_e d$ for interior and exterior girders respectively.

For the design of Box- girder bridges, similar procedures with that of T-girder bridges can be followed. However, for the computation of effective flange widths for both interior and exterior girders use Eqns. (3.27) and (3.28) respectively. Thus, for the design of both interior and exterior longitudinal girders, *Charts B1-B12* can be used.

According to ERA Bridge design manual, article 5.5.2.4, a uniformly distributed reinforcement of 0.5 percent of the cross-sectional area of the slab, based on the least slab thickness, shall be placed in the bottom slab transverse to the girder span. Such reinforcement shall be distributed over both surfaces with a maximum spacing of 450mm [4].

Remark

If one selects a depth less than the minimum criteria for deflection, serviceability limit will not be satisfied.

5 DESIGN EXAMPLES

For illustration of using the design charts and for verification purpose, three different design examples are considered.

5.1 Design of Slab Bridge

Design a 10m clear span concrete slab bridge having a roadway width of 7.32m with 0.8m curbs on both sides. The width of the abutment on both sides is 0.5m. Consider a concrete cover of 35mm. Assume f_y=400MPa, and f_c'= 32MPa

Solution

1) determine the minimum thickness of slab using Eqn.(3.6)

$$D = \frac{1.2(S+3000)}{30} \qquad (mm)$$

S=10,000+500=10,500mm (c/c spacing of bridge)

D= 540mm Take D=550mm

2) determine design values from charts
   a) From *Chart S3* (f_y=400MPa, and f_c'= 32MPa) for D=550mm and L= 10m, obtain the corresponding value of ρ_i for interior strip, $\rho_i = 8.9*10^{-3}$.
   b) From *Chart S7* (f_y=400MPa, and f_c'= 32MPa) for D=550mm and L= 10m, obtain the corresponding value of ρ_e for edge strip, $\rho_e = 9.5*10^{-3}$.

   Obtain curb width factor *(modification factor)* for edge strip from *Chart S8*

   - For bridge span of 10m and curb width of 0.8, $CW_f = 1.0$

3) Compute interior strip width

   R_{wt}= 7320+2*(0.8*1000) =8,920*mm*, N_L=int (8.92/3.6)=2

   W_1=min [R_{wt}, 9000], thus W_1=8,920*mm*

$$L_1 = 10,000 + \frac{500}{2} + \frac{500}{2} = 10,500mm$$

$$E = min\begin{cases} 250 + 0.42\sqrt{(L_1 * W_1)} = 4314.68mm & (for\ one\ lanes\ loaded) \\ 2100 + 0.12\sqrt{(L_1 * W_1)} = 3261.34mm \le \dfrac{W}{N_L} & (for\ multiple\ lanes\ loaded) \end{cases}$$

$$\frac{W}{N_L} = \frac{8920}{2} = 4,460mm$$, thus use E=3261.34mm

The width factor, W_f, for interior strip can be obtained from *Chart S4*.

- For strip width of E= 3261.34mm and L=10m, $W_f = 0.99$.

4) Compute reinforcement bars for interior and edge strips

Using ϕ 32 rebars & 35mm concrete cover, d=D-35- ϕ /2 =499mm

i. Interior strip

$A_{si} = W_f *(\rho_i bd)$

$=0.99*(8.9*10^{-3}*1000*499) = 4396.69mm^2/m$

Use ϕ 32 c/c 180mm

ii. Edge strip

$A_{se} = CW_f * (\rho_e bd)$

$=1.0*9.6*10^{-3}*1000*499=4790.4mm^2/m$

Use ϕ 32 c/c 160mm

5.2 Design of T-girder Bridge

Design a 15m RC T-girder Bridge with a roadway width of 7.32m and 0.8m curbs on both sides. The width of the abutment on both sides is 0.5m and the number of girders is four. Assume f_y=400MPa, and f_c'= 28MPa

Solution

1) Determine girder spacing, s

$$s = \frac{W}{(N-0.2)} = \frac{7.32+2*0.8}{4-0.2} = 2.35m$$

2) Determine minimum thickness of the top flange

$$t_s = \frac{(s+3000)}{30} = 178.3\text{mm}$$

use t_s=200mm

3) Compute top and bottom reinforcement bars

i) Positive reinforcement bars

From *Chart T2* (f_y=400MPa, and f_c'= 28MPa, N=4, and R_{wt}=7.32m) obtain the value of ρ.

- For t_s=200mm, the corresponding value of ρ becomes $5.3*10^{-3}$.

  d= (t_s-35-16/2), using ϕ 16 rebars & 35mm concrete cover at the bottom

  d=157mm, b=1000mm

  A_s= ρbd=$5.25*10^{-3}$*1000*157=824.25mm^2/m

  Using ϕ 16 bars, S= 244mm, thus use ϕ 16 c/c 240mm

ii) Negative reinforcement bars

From *Chart T5* (f_y=400MPa, and f_c'= 28MPa), obtain the value of ρ.

- For t_s=200mm and R_{wt}=7.32m, the corresponding value of ρ becomes $6.2*10^{-3}$.

  d= (t_s-60-16/2), using ϕ 16 rebars & 60mm concrete cover at the top

  d=132mm, b=1000mm

  A_s= ρbd= $6.2*10^{-3}$*1000*132=818.4mm^2/m

  Using ϕ 16 bars, S= 245mm, thus use ϕ 16 c/c 240mm

4) Compute reinforcement bars for longitudinal girders

Determine minimum girder depth

D_w =0.07*L, L=15000+500= 15,500mm (mm)

D_w = 1085mm use D_w=1200mm and b=400mm

Interior Girders

i) using Eqn. (3.25), compute effective flange width

b_i =2350mm

ii) From *Chart T8* (f_y=400MPa, and f_c'= 28MPa), obtain the corresponding value of ρ for D_w=1200mm, N=4 and L=15

Thus, ρ=$3.6*10^{-3}$

d=(D_w-50-1.5*32-12)=1090, using ϕ 32 rebars, ϕ12 stirrups & 50mm concrete cover at the bottom with two rows of bars, d=1090mm

A_s= ρb_id=$3.6*10^{-3}$*2350*1090=9221.4mm^2, Use 12 ϕ 32 bars

Exterior Girders

a) using Eqn. (3.26) compute effective flange width

b_e =2115mm

iii) From *Chart T14* (f_y=400MPa, and f_c'= 28MPa) obtain the corresponding value of ρ for D_w=1200mm, N=4 and L=15.

Thus, $\rho=4.25*10^{-3}$

$A_s= \rho b_e d =4.25*10^{-3}*2115*1090=9797.74mm^2$, Use 13 ϕ 32 bars

5.3 Design of Box-Girder Bridge

Design a 30 m RC Box-Girder Bridge with a roadway width of 7.32m with 0.8m curbs on both sides. The width of the abutment on both sides is 0.5m and the number of girders is four. (i.e., number of cells is three). Consider a concrete cover of 35mm. Assume f_y=400MPa, and fc'= 28MPa.

Solution

1) Determine girder spacing, s

$$s=\frac{W}{(N-0.2)}=\frac{7.32+2*0.8}{4-0.2}=2.35m$$

2) Determine minimum thickness of the top flange

$$t_s=\frac{(s+3000)}{30}=178.3mm$$

use t_s=200mm

3) Compute top and bottom reinforcement bars

i) Positive reinforcement bars

From Chart T2 (f_y=400MPa, and f_c'= 28MPa, N=4, and R_{wt}=7.32m) obtain the value of ρ.

- For t_s=200mm, the corresponding value of ρ becomes $5.2*10^{-3}$.

  $d=(t_s-35-16/2)$, using ϕ 16 rebars & 35mm concrete cover at the bottom

  d=157mm, b=1000mm

  $A_s= \rho bd=5.25*10^{-3}*1000*157=824.25mm^2/m$

  Using ϕ 16 bars, S= 244mm, thus use ϕ 16 c/c 240mm

ii) Negative reinforcement bars

From *Chart T5* (f_y=400MPa, and f_c'= 28MPa), obtain the value of ρ.

- For t_s=200mm and R_{wt}=7.32m, the corresponding value of ρ becomes $6.2*10^{-3}$.

  d=(ts-60-16/2), using ϕ 16 rebars & 60mm concrete cover at the top

  d=132mm, b=1000mm

  A_s= ρbd=$6.2*10^{-3}$*1000*132=818.4mm^2/m

  Using ϕ 16 bars, S= 245mm, thus use ϕ 16 c/c 240mm

4) Provide minimum reinforcement bars for the bottom flange as specified in article 5.5.2.4 of ERA bridge design manual.

5) Compute reinforcement bars for longitudinal girders

Determine minimum girder depth

D_w =0.06*L,

L=30,000+500= 30,500mm

D_w = 0.06*L =1830mm

use D_w=1850mm and b=400mm

Interior Girders

i) using Eqn. (3.27), compute effective flange width

b_i =2350mm

ii) From *Chart B2* (f_y=400MPa, and f_c'= 28MPa), obtain the corresponding value of ρ for D_w=1850mm, N=4 and L=30

Thus, ρ=$3.8*10^{-3}$

d=(D_w-50-1.5*32/2), using ϕ 32 rebars & 50mm concrete cover at the bottom with two rows of bars, d=1740mm

A_s= ρb_id=$3.8*10^{-3}$*2350*1740=15,538.2mm^2

Exterior Girders

i) using Eqn. (3.28) compute effective flange width

b_e =2115mm

ii) From *Chart B8* (f_y=400MPa, and f_c'= 28MPa) obtain the corresponding value of ρ for D_w=1850mm, N=4 and L=30

Thus, $\rho=4.6*10^{-3}$

$A_s = \rho b_e d = 4.6*10^{-3}*2115*1740=16928.46mm^2$

5.4 Summary of Results

For comparison of design results, the above examples are summarized in the following Tables.

Table 5.1 **Comparison of Design Results of a Slab Bridge**

Clear Span Length (m)	Road width (m)	Curb width (m)	Slab Thickness (mm)	Area of Reinforcement (mm^2/m)				Ratio	
				Using Design Charts		Using Empirical Method			
				Interior Strip (1)	Edge Strip (2)	Interior Strip (3)	Edge Strip (4)	(1)/(3)	(2)/(4)
10	7.32	0.8	550	4396.69	4790.4	4230.21	4689.8	1.04	1.02

Table 5.2 **Comparison of Design Results of a T-and Box Girder Bridges (top slab)**

Bridge Type	**Bridge Dimensions**						Area of Reinforcement (mm^2/m)				Ratio	
	Clear Span Length (m)	Road width (m)	Curb width (m)	Slab Thickness (mm)	Number of Girders	Girder Spacing (m)	Using Design Charts		Using Empirical Method		(1)/(3)	(2)/(4)
							Top Rebars (1)	Bottom Rebars (2)	Top Rebars (3)	Bottom Rebars (4)		
T-Girder	15	7.32	0.8	200	4	2.35	818.4	824.25	848.54	752.93	0.96	1.09
Box-Girder	30	7.32	0.8	200	4	2.35	818.4	824.25	848.54	752.93	0.96	1.09

Table 5.3 **Comparison of Design Results of a T-and Box Girder Bridges (Longitudinal girders)**

Bridge Type	Clear Span Length (m)	Girder depth (mm)	Area of Reinforcement (mm^2)				Ratio	
			Using Design Charts		Using Empirical Method			
			Interior Girder (1)	Exterior Girder (2)	Interior Girder (3)	Exterior Girder (4)	(1)/(3)	(2)/(4)
T-Girder	15	1200	9221.4	9797.74	9248.8	9650.9	0.99	1.02
Box-Girder	30	1850	15,538.2	16,928.46	15,280.7	16,084.95	1.02	1.05

As shown in the above tables, there is a variation of 2% to 9% have been observed. The reason for this variation is summarized in Table 5.4.

Table 5.4 **Reason for Variation**

No.	Description	Design Charts	Empirical Method
1	Load modifier, η (Strength Limit State)	1.05	1.00
2	Thickness of wearing surface (mm)	100	50
3	Abutment width (m)	0.5	0.4
4	Influence line coefficient, m_1, for maximum moment; $m_1 = \frac{l_1 l_2}{L}$	$l_1 \neq l_2$	$l_1 = l_2$
5	Weight of end barriers/ posts	Concrete barriers are used (3.6kN/m)	Concrete posts and railings are used (2.7kN/m)
6	For girder bridges, overhang width	0.4*S	0.5*S

6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This study has attempted to address analysis and design of RC bridges using computer program. Moreover, charts for the design of reinforced concrete slab bridges, T- and Box Girder Bridges are developed. From this research, the following conclusions are made.

- The charts are user friendly and short cut for selecting appropriate types of bridges during feasibility stage. This facilitates the selection technique and simplifies the design work in obtaining an optimal solution.
- Structural Bridge Designers can simply use these charts in the checking and design review works with the most advantageous and minimum time.
- If the bridges are designed using design charts, as shown in Tables 5.1-5.3, more or less accurate results with a variation range of 2% to 9% have been obtained.

6.2 Recommendation

Based on the finding on this thesis, the following recommendations are drawn.

- As the developed design charts are easy to apply, consulting firms can make use of charts for the design of RC slab, T and Box-girder bridges.
- One can develop similar charts for continuous span bridges with different number of girders.
- One can extend this research by considering service limit state requirement for control of cracking, deflection and fatigue limit state. Moreover, charts for the design of shear stirrups for longitudinal girders bridges should be considered.

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Declaration

I, the undersigned, declare that this thesis is my original work, and has not been presented in any University for a degree, and that all sources of materials used for this thesis have been duly acknowledged.

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