Introduction

To

Bridge Engineering
1. **Introduction:**

Bridges are important to everyone. But they are not seen or understood in the same way by everyone, which is what makes their study so fascinating. A single bridge over a small river will be viewed differently by different people.

- Civic leaders see the bridge as link between the neighborhoods and a way to provide fire and police protection and access to hospitals.
- In business community, the bridge is seen as opening up new markets and expanding commerce.

Everyone is looking at the same bridge, but it produces different emotions and visual images in each one of them.

Bridges affect people. People use them, and engineers design them and later build and maintain them. Bridges do not just happen. They must be planned and engineered before they can be constructed.

2. **A bridge is the key element in a transportation system**

- It controls the capacity of the system.
- It is the highest cost per mile of the system.
- If the bridge fails, the system fails.

Because the bridge is the key element in the transportation system, balance must be achieved between handling future traffic volume and loads and the cost of a heavier and wider bridge structure. Strength must always be foremost, but so should measures to prevent deterioration. The designer of new bridge has control over these parameters and must take wise decisions so that capacity and cost are in the balance, and safety is not compromised.

3. **Role of bridge engineer:**

Oftentimes engineers deceive themselves into believing that if they gather enough information about a bridge site and the traffic loads, the selection of a bridge type for that situation will be automatic. Furthermore the use of analysis/design software will complete the job.

Unfortunately, or perhaps fortunately it is not the case.
A bridge engineer must have three points in mind while working on a bridge project.

- Creative and aesthetic,
- Analytical,
- Technical and practical,

So as to give a realistic evaluation of the possibilities of the construction technique envisaged and the costs involved. If these three mentalities do not coexist in a single mind, they must always be present on terms of absolute equality in the group or team responsible for the design.

4. **Aesthetics in bridge design:**

There are no equations, no compute programs or design specifications that can make our bridges beautiful.

It is an awareness of beauty on our part.

Aesthetics must be a part of the bridge design program from the beginning. It cannot be added on at the end to make the bridge look nice. At that time, it is too late. From the beginning, the engineer must consider aesthetics in selection of spans, depth of girders, piers, abutments, and the relationship of one to another. It is a responsibility that cannot be delegated. We must demand it of ourselves, because the public demands it of us.

5. **Types of bridges:**

There are a number of ways in which to classify bridges. Bridges can be classified according to:

- Materials (concrete, steel or wood etc),
- Usage (pedestrian, highway, or railroad),
- Span (short, medium, or long),
- Structural form (slabs, girder, truss, arch, suspension, or cable-stayed).

They all seem to contain parts of one another within each other.

It is however suitable to classify bridges according to the location of the main structural elements relative to the surface on which the user travels, that is, whether the main structure is below, above, or coincides with the deck line.
a. Main structure below the deck line:
Arched and truss-arched bridges are included in this classification.
Examples are the masonry arch, the concrete arch, the steel-truss arch, the steel deck
truss, figs 1 to 5, the rigid frame, and the inclined leg frame bridges,
With the main structure below the deck line in the shape of an arch, gravity loads are
transmitted to the supports primarily by axial compressive forces. At the supports,
both vertical and horizontal reactions must be resisted. The arch rib can be solid or it
can be a truss of various forms.
Salient features of arch type bridges are:
• The arch form is intended to reduce bending moments (and hence tensile stresses)
in the superstructure and should be economical in material compared with an
equivalent straight, simply supported girder or truss.
• The efficiency is achieved by providing horizontal reactions to the arch rib. If
these are external reactions, they can be supplied at reasonable cost only if the site
is suitable. The most suitable site for this form of structure is a valley, with the
arch foundation located on dry rock slopes.
• The conventional curved arch rib may have high fabrication and erection costs,
although these may be controlled by skilled labor. The arch is predominantly a
compression structure. For example, the open spandrel arch with the rib below the
deck consists of deck, spandrel columns, and arch rib. The last two are
compression members. The design must include accurate estimates of buckling
behavior and should be detailed so as to avoid excessive reductions in allowable
stress. The classic arch form tends to favor concrete as a construction material.
• The arch rib is usually shaped to take dead load without bending moments. This
load is then called the form load. If the form load is large, the live load becomes
essentially a small disturbance applied to a compressed member.
• The conventional arch has two moments resisting components-the deck and the
arch rib. Undesirable and unanticipated distributions of moment may occur,
particularly in regions where the spandrel columns are short, normally near the
crown of the arch, which may be avoided by careful detailing; for example by
using pin ended columns.
Figure 1: Masonry arch bridge.

Figure 2: Masonry arch bridge.
Figure 3: Concrete arch bridge.

Figure 4: Steel truss arch bridge.
b. **Main structure above the deck line:**

Suspension, cable stayed, and through-truss bridges are included in this category. Both suspension and cable-stayed bridges are tension structures whose cables are supported by towers, fig. 6 and 8.

Suspension bridges are constructed with two main cables from which the deck, usually a stiffened truss is hung by secondary cables. Cable-stayed bridges, fig 7, have multiple cables that support the deck directly from the tower. Analysis of the cable forces in a suspension bridge must consider non linear geometry due to large deflections, while linear elastic analysis is usually sufficient for cable stayed bridges.

*Salient features of suspension bridges:*

- The major element of a stiffened suspension bridge is a flexible cable, shaped and supported in such a way that it can transfer the major loads to the towers and anchorages by direct tension.
- This cable is commonly constructed from high strength wires.
• The deck is hung from the cable by hangers constructed of high strength wire ropes in tension.

• This use of high strength steel in tension, primarily in the cables and secondarily in the hangers, leads to an economical structure, particularly if the self-weight of the structure becomes significant, as in the case of long spans.

• The main cable is stiffened either by a pair of stiffening trusses or by a system of girders at deck level:

• This stiffening system serves to (a) control aerodynamic movements and (b) limit local angle changes in the deck. It may be unnecessary in the cases where the load is great.

• It is the only alternative of spans over 600 m, and it is greatly regarded as competitive for spans down to 300 m.

Salient features of cable-stayed bridges:

• As compared with suspension bridges, the cables are straight rather than curved. As a result, the stiffness is greater.

• The cables are anchored to the deck and cause compressive forces in the deck.

• Compared with the stiffened suspension bridge, the cable-braced bridge tends to be less efficient in supporting dead load, but more efficient in supporting live load. As a result is not likely to be economical in the longest spans.

• The cables may be arranged in a single plane, at the longitudinal centerline of the deck.

• Aerodynamics instability has not found to be a problem in such structures.

Salient features of through bridges, fig 9 & 10:

• A bridge truss has two main structural advantages: (1) the primary member forces are axial loads; (2) the open web system permits the use of a greater overall depth than for an equivalent solid web girder. Both these factors lead to economy in material and a reduced dead weight. The increased depth also leads to reduced deflection, that is, a more rigid structure,

• Economical for medium spans,

• Aesthetically pleasing.
Figure 6: Suspension bridge.

Figure 7: Suspension bridge.
Figure 8: Cable stayed bridge.

Figure 9: Through Bridge.
c. **Main structure coinciding with the deck line:** Girder bridges of all types are included in this category.

Examples are:
- Slab (solid and voided),
- T-beam,
- I-beam,
- Wide-flange beam,
- Concrete box girder,
- Steel box,
- Steel plate girder.
Figure 11: Box Girder Bridge.

Figure 12: Girder Bridge under construction.
6. **Important concepts in Bridge Engineering:**

**Bridge:** A structure having an opening not less than 6000 mm that forms part of a highway or over, or under which the highway passes.

**Collapse:** A major change in geometry of the bridge rendering it unfit for use.

**Design:** Proportioning and detailing the components and connections of a bridge.

**Design life:** Period of time up on which the statistical derivation of a transient load is based: 75 years for AASHTO specifications.

**Service life:** The period of time that the bridge is expected to be in operation.

**Force effect:** A deformation stress or stress resultant i.e. axial force, shear force, torsional or flexure moment, caused by applied loads, imposed deformations or volumetric changes.

**Load factors:** A factor accounting for variability of loads, the lack of accuracy in analysis, and the probability of simultaneous occurrence of different loads.

**Load modifier:** A factor accounting for ductility, redundancy and the operational importance of the bridge.
Resistance factor: A factor accounting for the variability of material properties, structural dimensions, and the workmanship, and the uncertainty in the prediction of resistance.

The resistance of components and connections is determined, in many cases, on the basis of inelastic behavior, although the force effects are determined by using elastic analysis in LRFD design specifications.

Ductile behavior is characterized by the significant inelastic deformations before any loss of load carrying capacity occurs.

The owner (of bridge) may specify a minimum ductility factor an assurance that ductile failure modes will be obtained.

Ductility factor $\mu = \Delta_u/\Delta_y$

$\Delta_u$ = deformation at ultimate.

$\Delta_y$ = deformation at the elastic limit.

Traditional minimum depth (span to depth ratio) for constant depth super structure is given as follows:

i. R.C.C Slabs:
   
   Simple span = $1.2(S + 3000)/30$

   = $1.2(S + 10)/30$ (in fps system)

   Continuous spans = $(S + 3000)/30$

ii. R.C.C T-Beams:

   Simple span = 0.070L

   Continuous = 0.065L

iii. Prestressed I Beams:

   Simple span = 0.045L
Continuous spans = 0.040L

iv. **Steel I Beams:**
   - Simple span (over all depth) = 0.040L
   - Continuous = 0.032L

v. **Trusses** = 0.100L

Super structure: structural parts of the bridge which provides the horizontal span.
Sub structure: Structural parts of the bridge which supports the horizontal span.

Maximum ADT: Research has shown that average daily traffic ADT, including all vehicles, i.e., cars and trucks, is physically limited to about 20,000 vehicles per lane per day under normal conditions.

Abutments: A structure that supports the end of a bridge span, and provides lateral support for fill material on which the roadway rests immediately adjacent to the bridge.

Counterfort: A counterfort wall consists of a thin concrete face slab, usually vertically supported at intervals on inner side by vertical slabs or counterforts that meet the face slab at right angles.

Pile: A relatively slender deep foundation unit, wholly or partly embedded in the ground, installed by driving, drilling, jetting or otherwise, and which derives its capacity from surrounding soil and/or from the soil or rock strata below its tip.

Use of piles: piling should be considered when footings cannot be founded on rock, stiff cohesive or granular foundation material at reasonable cost. Pile may be used as a protection against scour.

7. **Important points for bridge design:**

Roadway widths: When the traffic is crossing the bridge, there should not be a sense of restriction. To avoid a sense of restriction requires that the roadway width on the bridge be the same as that of the approaching highway.

Loads: to be considered in bridge design can be divided into two broad categories:

  - Permanent loads, and,
  - Transient loads.

Permanent loads: Self weight of girders and deck, wearing surface, curbs and parapets and railings, utilities and luminaries and pressures from earth retainments.
Two important dead loads are:

DC: Dead load of structural components and non structural attachments.

DW: Dead load of wearing surface.

\[
\gamma_{\text{bitumen}} = 2250 \text{ kg/m}^3 = 22.1 \text{ kN/m}^3
\]

\[
\gamma_{\text{concrete}} = 2400 \text{ kg/m}^3 = 23.6 \text{ kN/m}^3
\]

The maximum load factor for DC = 1.25

The maximum load factor for DW = 1.5

**Transient loads:** Gravity loads due to vehicular, railway and pedestrian traffic. Lateral loads due to water and wind i.e., floes (sheet of floating ice), ship collisions and earthquake, temperature fluctuations, creep and shrinkage etc.

Some loads such as ship collision etc are important loads for substructure design.

The effects of these loads will be different for super structure and sub structure.

The automobile is one of the most common vehicular live load on most bridges; it is the truck that causes the critical load effects.

AASHTO design loads attempt to model the truck traffic that is highly variable, dynamic and may occur independent of, or in unison with other truck loads.

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

Different design limit states may require slightly different truck models.

**Design Lanes:** The number of lanes a bridge may accommodate must be established and is important design criterion. Two such terms are used in the lane design of the bridge:

- Traffic lane,
- Design lane.

**Traffic lane:** is the number of lanes of traffic that the traffic engineer plans to route across the bridge. Lane width is associated with a traffic lane and is typically 3600 mm = 3.6 m = 12 ft.

**Design lane:** is the lane designation used by the bridge engineer for live load placement. The design lane width and location may or may not be the same as that of the traffic lane.
AASHTO uses a 3000 mm = 3.0 m = 10.0 ft design lane and Vehicles is to be positioned within the lane for extreme effects.

No of Design lanes \[ A361.1.1 \] = Clear roadway width (mm) / 3600 mm = rounded to larger integer.

Clear roadway width is the distance between the curbs or barriers.

When traffic lane width < 3600 mm

No. of design lanes = No. of traffic lanes, and

Width of design lane = Width of traffic lane

**Vehicular design loads:** A study by the Transportation Research Board (TRB) was used as a basis for AASHTO loads (TRB, 1990).

It was felt by the engineers developing the load model that the exclusion truck (over loaded or more than allowed legally) best represented the extremes involved in the present truck traffic (Kulicki 1992).

The AASHTO design loads model consists of three distinctly different loads:

- Design truck,
- Design Tandem,
- Design lane.

**Design truck:** The configuration of design truck as given in figure 14 is the same that has been presented by AASHTO (1996) standard specifications since 1944 and commonly referred to as HS. The H denotes highway and S denotes Semi tractor and 20 is the weight of tractor in tons (USC units).

The new vehicle combination as described in AASHTO (1994) LRFD Bridge specifications are designated as HL-93 for Highway Loading accepted in 1993.
The variable range, in figure 14 means that the spacing used should cause critical load effect. The long spacing typically only controls where the front and rear positions of the truck may be positioned in adjacent structurally continuous spans, such as continuous short span bridges.

**Design Tandem:** The other configuration is the design tandem as shown in figure 15.

**Design lane load:** 9.3 kN/m and is assumed to occupy a region of 3.0 m (10 ft). It is applied as 3.1 kN/m² or 0.064 k/ft² (64 lb/ft²) of pressure to a width of 3.0 m or 10 ft over the entire length of bridge for FEM.
In summary three design loads should be considered: the design truck, design tandem, and the design lane.

These loads are superimposed two ways to yield the live load effects, which are combined with the other load effects (D loads) are:

- Truck + lane,
- Tandem + lane,
Design Pb: Design the simply supported slab bridge of fig. 17, with a span length of 35 ft centre to centre of bearings for a HL-93 live load. The roadway width is 44 ft curb to curb. Allow for a future wearing surface of 3 inch thick bituminous overlay. Use $f_c' = 4000$ psi and $f_y = 60$ ksi.

![Elevation Diagram](image1)

(a) Elevation

![Plan Diagram](image2)

(b) Plan

![Section Diagram](image3)

(c) Section

Figure 17: Solid Slab Bridge design example

Solution:

Step No 1: Sizes.

Span length of bridge $(S) = 35$ ft c/c

Clear roadway width $(W) = 44$ ft (curb to curb)

For a curb width of 15 inches, total width of the bridge $(W_1) = 44 + 2 \times 15/12 = 46.5$ ft

According to AASHTO (1994) LRFD Bridge specifications (table A.2.5.2.6.3-1), minimum thickness of bridge slab is given by formula:
h_{\text{min}} = 1.2(S + 10)/30
= 1.2 (35 + 10)/30 = 1.8 \text{ ft} = 21.6 \text{ inches}

Use h = 22 \text{ inches}.

**Step No 2: Loads.**

Slab load (w_{DC}) = (22/12) \times 0.15 = 0.275 \text{ ksf}
Wearing surface load (w_{DW}) = (3/12) \times 0.14 = 0.035 \text{ ksf}

**Step No 3: Analysis.**

(1) Dead load moments:

Slab moments (M_{DC}) = 0.275 \times (35^2)/8 = 42 \text{ ft-kip/ft}
Wearing surface moment (M_{DW}) = 0.035 \times 35^2/8 = 5.3 \text{ ft-kip/ft}

(2) Live load moments:

(a) Truck Load moments:

![Shear force and bending moment diagrams for truck load.](image)

Therefore, M_{\text{Truck}} = 350 \text{ ft-kip}
(b) Lane moment:
\[ M_{\text{lane}} = 640 \times 35^2/8 = 98 \text{ ft-kip} \]

\[ 640 \text{ lb/ft} \]

\[ 35' \]

Figure 19: Lane load.

(c) Tandem moment:
\[ M_{\text{tandem}} = 372 \text{ ft-kip} \]

\[ 24 \text{ kip} \]

\[ 4' \]

\[ 35' \]

Figure 20: Tandem load.

\[ M_{\text{tandem}} > M_{\text{truck}} \]

Therefore we will use \( M_{\text{tandem}} \)

\[ M_{\text{LL+IM (Including impact)}} = 1.33M_{\text{tandem}} + M_{\text{lane}} \]

\[ [M_{\text{LL+IM}} = 1.33 \times 372 + 98 = 593 \text{ ft-kip}] \]

Now converting \( M_{\text{LL+IM}} \) to moment/ft, Divide \( M_{\text{LL+IM}} \) by “E” design lane width.

**Note:** While calculating truck/tandem (live load) moments, it has been assumed that axle load is acting as a point load. However in reality the vehicle will occupy some definite width, hence this live load moment must be divided by this width. AASHTO LRFD gives following procedure for converting this moment to per foot width. Similarly AASHTO LRFD also emphasizes that live load will produce different effects on interior and edge strips of slabs as shown below.

**Design Lane width “E” for interior strip:**

(a) For single lane loaded:
\[ E = 10.0 + 5.0 \sqrt{L_1W_1} \]

\[ L_1 = \text{Modified span length} = \text{Minimum of (S = 35 ft) and 60 ft} \]

\[ L_1 = 35 \text{ ft} \]

\[ W_1 = \text{Modified edge to edge width} = \text{Minimum of (W_1 = 46.5 ft) or 30 ft} \]


\[ W_1 = 30 \text{ ft} \]

Therefore, \[ E = 10.00 + 5.0 \sqrt{(35 \times 30.00)} = 172 \text{ in} = 14.3 \text{ ft} \]

(b) For multilane loaded:

\[ E = 84 + 1.44 \sqrt{(L_1 W_1)} \leq \frac{W_1}{N_L} \]

\[ L_1 = 35 \text{ ft} \]

\[ W_1 = \text{Minimum of (}W_1 = 46.5 \text{ ft}) \text{ or } 60 \text{ ft} \]

\[ W_1 = 46.5 \text{ ft} \]

\[ N_L = \text{No. of design lanes.} \]

\[ N_L = \text{INT (}W/12) = \text{INT (}44/12) = 3 \]

Therefore, \[ E = 84 + 1.44 \sqrt{(35 \times 46.5)} \leq \frac{46.5}{3} \]

\[ = 142 \text{ inch or } 11.84 \text{ ft} \leq 15.5 \]

Therefore, \[ E = 11.84 \text{ ft (Least of all)} \]

Hence interior strip moment per foot width is equal to:

\[ M_{LL+IM} (\text{Interior strip}) = \frac{593}{11.84} = 50 \text{ ft-kip/ft} \]

Now,

\[ M_u = 1.05 (1.25M_{DC} + 1.5M_{DW} + 1.75M_{LL+IM}) \]

\[ M_u = 1.05 (1.25 \times 42 + 1.5 \times 5.33 + 1.75 \times 50) \]

\[ M_u (\text{interior strip}) = 155.3 \text{ ft-kip/ft} = 1863.6 \text{ in-kip/ft} \]

**Design lane width for edge strip:** According to AASHTO LRFD code A4.6.2.1.4,

\[ E = \text{Barrier width at base} + 1 \text{ ft} + (1/2) \text{ strip width} \leq \text{Full strip width or 6 ft (whichever is less)} \]

Therefore \[ E = 1.25 \text{ ft} + 1 \text{ ft} + (1/2) \times 11.84 \leq 11.84 \text{ ft or 6 ft} \]

\[ E = 8.17 \text{ ft} > 6 \text{ ft} \]

Therefore \[ E = 6 \text{ ft} \]

Because the strip width is limited to 6', one-lane loaded (wheel line = ½ lane load) with a multiple presence factor, \( m \) (chapter 4, Barker and Puckett) of 1.2 will be critical. Hence edge strip moment per foot width is equal to:

\[ M_{LL+IM} (\text{Edge strip}) = \frac{1}{2} \times (593) \times 1.2/6 = 59.3 \text{ ft-kip/ft} \]

\[ M_u = 1.05 (1.25M_{DC} + 1.5M_{DW} + 1.75M_{LL+IM}) \]

\[ M_u = 1.05 (1.25 \times 42 + 1.5 \times 5.33 + 1.75 \times 59.3) \]

\[ M_u (\text{edge strip}) = 172.48 \text{ ft-kip/ft} = 2069.79 \text{ in-kip/ft} \]
Step No 4: Design.

(a) Design for Interior strip:

Interior strip moment ($M_u$) = 155.3 ft-kip/ft = 1863.6 in-kip/ft
Effective depth of bridge slab ($d$) = $h - \text{cover} - \frac{1}{2} \times \text{Dia of bar used}$
Using #8 bar, effective depth is:
Bottom cover for slab is taken equal to 1 inch.

\[ d = 22 - 1 - \frac{1}{2} \times 1 = 20.5 \text{ inch} \]

\[ A_{\text{min}} = 0.0018 \times 12 \times 22 = 0.47 \text{ in}^2 \]
\[ A_s = \frac{M_u}{\Phi f_y (d - a/2)} \]
Let $a = 0.2d = 0.2 \times 20.5 = 4.1$ inches
Therefore,
\[ A_s = \frac{1863.6}{\{0.9 \times 60 \times (20.5 - 4.1/2)\}} = 1.87 \text{ in}^2 > A_{\text{min}} \]

Trial 1:
\[ a = \frac{A_s f_y}{(0.85f'_c b)} = \frac{1.87 \times 60}{(0.85 \times 4 \times 12)} = 2.75 \text{ inch} \]
\[ A_s = \frac{1863.6}{\{0.9 \times 60 \times (20.5 - 2.75/2)\}} = 1.804 \text{ in}^2 \]

Trial 2:
\[ a = 1.804 \times 60/ (0.85 \times 4 \times 12) = 2.65 \text{ inch} \]
\[ A_s = \frac{1863.6}{\{0.9 \times 60 \times (20.5 - 2.65/2)\}} = 1.80 \text{ in}^2, \text{ O.K.} \]

Use #8 bar with bar area = 0.79 in$^2$
Spacing = (0.79/1.80) $\times$ 12 = 5.33 inches $\approx$ 5 inches c/c
Use #8 @ 5 inches c/c.
(b) Distribution reinforcement for interior strip (bottom transverse reinforcement)

\{A5.14.4.1\}:

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

\[
100/\sqrt{L} \leq 50 \%
\]

\[
100/\sqrt{35} = 16.9 \% < 50 \%
\]

Therefore, bottom transverse reinforcement = \(0.169 \times 1.80 = 0.304 \text{ in}^2\)

Using #5 bar, with bar area = 0.31 in\(^2\)

Spacing = \((0.31/0.304) \times 12 = 12 \text{ inches c/c}\)

Maximum spacing for temperature steel reinforcement in one way slab according to ACI 7.12.2.2 is minimum of:

(i) \(3h_f = 3 \times 22 = 66''\)

(ii) \(18''\)

Finally use #5 @ 12 inches c/c.

(c) Design for Edge strip:

Edge strip moment (\(M_u\)) = 172.48 ft-kip/ft = 2069.79 in-kip/ft

Effective depth of bridge slab (\(d\)) = \(h – \text{cover} - \frac{1}{2} \times \text{Dia of bar used}\)

Using #8 bar, effective depth is:

\(d = 22 – 1 - \frac{1}{2} \times 1 = 20.5 \text{ inch}\)

\(A_{s_{\text{min}}} = 0.0018 \times 12 \times 22 = 0.47 \text{ in}^2\)

\(A_s = M_u/\{\Phi f_y (d - a/2)\}\)

Let \(a = 0.2d = 0.2 \times 20.5 = 4.1 \text{ inches}\)

Therefore,

\(A_s = 2069.79/\{0.9 \times 60 \times (20.5 - 4.1/2)\} = 2.00 \text{ in}^2 > A_{s_{\text{min}}}\)

Trial 1:

\(a = A_s f_y/(0.85f_y 'b) = 2.00 \times 60/ (0.85 \times 4 \times 12) = 2.94 \text{ inch}\)

\(A_s = 2069.79/\{0.9 \times 60 \times (20.5 - 2.94/2)\} = 2.014 \text{ in}^2\)

Trial 2:

\(a = 2.014 \times 60/ (0.85 \times 4 \times 12) = 2.96 \text{ inch}\)
\[ A_s = \frac{2069.79}{\{0.9 \times 60 \times (20.5 - 2.96/2)\}} = 2.014 \text{ in}^2, \text{ O.K.}\]

Use #8 bar, with bar area = 0.79 in\(^2\)
Spacing = (0.79/2.014) \times 12 = 4.7 \text{ inches} \approx 4.5 \text{ inches c/c}
Finally use #8 @ 4 inches c/c.

(d) Distribution reinforcement for edge strip:
Bottom transverse reinforcement = 0.169 \times 2.014 = 0.34 \text{ in}^2
Spacing = (0.31/0.34) \times 12 = 11 \text{ inches c/c}

Maximum spacing for temperature steel reinforcement in one way slab according to ACI 7.12.2.2 is minimum of:
(i) 5h\(_f\) = 3 \times 22 = 66''
(ii) 18''
Finally use #5 @ 8 inches c/c.

(e) Shrinkage and temperature reinforcement in top of slab (long and transverse both):
For grade 60 steel,
\[ A_{st} = 0.0018A_g = 0.0018 \times 12 \times 22 = 0.47 \text{ in}^2\]
Use #5 bars, with bar area = 0.31 in\(^2\)
Spacing = (0.31/0.47) \times 12 = 8 \text{ inches c/c}
Finally use #5 @ 8 inches c/c.

**Final Recommendation:**

Main steel (bottom) = #8 @ 4'' c/c for interior as well as exterior.
Transverse bottom reinforcement = #5 @ 8'' c/c throughout.
Top steel (long and transverse) = #5 @ 8'' c/c.
Step No 5: Drafting.

Transverse Section.

Figure 22: Reinforcement details in half transverse section.
References

- *Design of Concrete Structures by Nilson, Darwin and Dolan (13th ed.),*

- *Design of Highway Bridges by Richard M. Barker.*