1. Sketch a typical cross section of a post tensioned box girder bridge deck. (APR/MAY 2008, MAY/JUNE 2012)

Post-tensioned bridge decks are generally composed of in-situ concrete in which ducts have been cast in the required positions.

- **T-Beam**
  - $20m < \text{Span} < 35m$

- **Voiced Slab**
  - $20m < \text{Span} < 35m$

- **Box**
  - $\text{Span} > 30m$
  - **Post-tensioned Bridge Decks**

When the concrete has acquired sufficient strength, the tendons are threaded through the ducts and tensioned by hydraulic jacks acting against the ends of the member. The ends of the tendons are then anchored. Tendons are then bonded to the concrete by injecting grout into the ducts after the stressing has been completed.

It is possible to use pre-cast concrete units which are post-tensioned together on site to form the bridge deck.

Generally it is more economical to use post-tensioned construction for continuous structures rather than in-situ reinforced concrete at spans greater than 20 metres.

For simply supported spans it may be economic to use a post-tensioned deck at spans greater than 20 metres.
2. Explain the uses of Pigeaud's curves. (APR/MAY 2008)

M. Pigeaud developed these curves which help to analysis and design RCC bridge deck. But these curves are cumbersome to use since they involve lot of minute graphical works and interpolations. To use these curves in computer we need the equations, which could make the engineer's life a lot easier.

3. Why PSC bridges are used?
Prestressed concrete is ideally suited for the construction of medium and long span bridges. Solid slabs are used for the span range of 10 m to 20 m. While T beam slab decks are suitable for spans in the range of 20 m to 40m. Single or multicell box girders are preferred for large spans of the order of 30 m to 70 m. Prestressed concrete is ideally suited for long span of the order continuous bridges in which precast box girders of variable depth are used for spans exceeding 50 m.

1. High-strength concrete and high-tensile steel, besides being economical make for slender sections, which are aesthetically superior.
2. Prestressed concrete bridges can be designed as Class 1 type structures without any tensile stresses under service loads, thus resulting in a crack free structure.
3. In comparison with steel bridges, prestressed concrete bridges require very little maintenance.
4. PSC is ideally suited for composite bridge construction in which precast prestressed girders support the cast in-situ slab deck.

Types of beams in common use are inverted T-beams, M-beams and Y beams. Inverted T-beams are generally used for spans between 7 and 16 metres and the voids between the beams are filled with in-situ concrete thus forming a solid deck.

M-Beams are used for spans between 14 and 30 metres and have a thin slab cast in-situ spanning between the top flanges. The Y-beam was introduced in 1990 to replace the M-beam. This lead to the production of an SY-beam which is used for spans between 32 and 40 metres.


7. What are the methods for design of deck slab?
   - This first depends on the method of dispersion of wheel load on the slab and effective width of slab to be considered for working out moments and shear. The methods used for this are based on piggard’s method or westerguard’s method.
   - Determination of effective width of slab for a single concentrated load over a slab simply supported at two ends.
   - Determination of effective width of slab for a single concentrated load placed on a cantilever slab.
   - Determination of effective width of slab area over which the concentrated load is dispersed and coefficients to be used direction when slab is supported on four sides.
8. Mention the components of design of composite girders?
   1. Steel beam which may be a rolled joist or a built up section
   2. Cast-in-situ reinforced concrete slab
   3. Shear connections
      ✓ Intermediate beams:
         1. One-fourth of the span of the beam
         2. Web thickness plus twelve time the least thickness of the slab.
         3. Centre of centre distance between beams.
      ✓ For edge beams:
         1. One-twelfth of the span
         2. Half web thickness plus six times the least thickness of slab.
         3. Half the distance to the adjoining beam.

9. What are the types of bridges usually used in PSC construction?
   ✓ Arch bridge
   ✓ Slab bridges
   ✓ Beam and plate girder bridges
   ✓ Open web girder bridges
   ✓ Suspension bridges
   ✓ Cable stayed bridges

10. What are the concrete bridges?
    Reinforced concrete and prestressed concrete have been found most suited for the construction of high way bridges the former for small and medium spans and latter for long spans. Reinforcement concrete has been used on the railways up to 10 m span and prestress concrete up to 24m. In India but upto 35 m in many outer countries.

11. Mention the design procedure for bridges.
    - Deck type bridges
    - Semi-through and through type bridges
    - Main girders
    - Concrete girders

12. What is the girder and slab type?
    In this the deck slab is supported on and cost monolithically with the longitudinally girders and no cross beam is provided. This has the disadvantages of providing no tensional rigidity and there will be always the danger of the girder tending to separate at the bottom level.

14. What are the codes referred to for design to the concrete bridges elements?
   1. IRC codes for concrete and prestressed composite bridges on Railways.
   4. IS 432 - 1966 Indian Standard specification for mild steel and medium tensile bars and hard drawn wire for concrete mix for cement.
   5. IRC 18-2000, Design criteria for prestressed concrete road bridges.

15. Sketch a neat diagram of general arrangement of RCC as well as PSC girders.

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[diagrams of box girders and flat slabs]
1. **List the advantages of prestressed concrete bridges.** (APR/MAY 2008)

Prestressed concrete is a method for overcoming concrete's natural weakness in tension. It can be used to produce beams, floors or bridges with a longer span than is practical with ordinary reinforced concrete.

Prestressing tendons (generally of high tensile steel cable or rods) are used to provide a clamping load which produces a compressive stress that balances the tensile stress that the concrete compression member would otherwise experience due to a bending load.

Traditional reinforced concrete is based on the use of steel reinforcement bars, rebars, inside poured concrete.

- High-strength concrete and high-tensile steel, besides being economical make for slender sections, which are aesthetically superior.
- Prestressed concrete bridges can be designed as Class 1 type structures without any tensile stresses under service loads, thus resulting in a crack free structure.
- In comparison with steel bridges, prestressed concrete bridges require very little maintenance.
- PSC is ideally suited for composite bridge construction in which precast prestressed girders support the cast in-situ slab deck.

2. **Explain the basic principle components of a bridge structure in PSC construction.**

Bridges have been built by man in order to overcome obstacles to travel caused by, for example, straits, rivers, valleys or existing roads. The purpose of a bridge is to carry a service such as a roadway or a railway.

The choice between a steel bridge and a concrete bridge (reinforced concrete or prestressed concrete) is a basic decision to be taken at a preliminary design stage. Several factors influence this decision, for example:

- spans required
- execution processes
- local conditions
- Foundation constraints.
The decision should be based on comparisons of:

- structural behavior
- economic aspects
- aesthetics.

In comparing costs, both initial costs and costs associated with maintenance during the life of the structure should be considered. The time required for execution, which in steel bridges is generally shorter than in prestressed concrete bridges, may also influence the decision.

In the past, concrete bridges could not compete with steel bridges for medium and long spans due to the lower efficiency (strength/dead load) of concrete solutions. With the development of prestressed concrete it is not a straightforward decision to decide between a concrete and a steel solution for medium span (about 40 to 100m) bridges. Even for long spans between 200 and 400m, where cable stayed solutions are generally proposed, the choice between a concrete, steel or composite bridge superstructure is not an easy task.

The choice between steel and a concrete solution is sometimes reconsidered following the contractors' bids to undertake the bridge works.

Generally speaking, steel solutions may have the following advantages when compared to concrete solutions:

- reduced dead loads
- more economic foundations
- simpler erection procedures
- shorter execution time.

A disadvantage of steel when compared to concrete is the maintenance cost for the prevention of corrosion. However it is now recognized that concrete bridges also have problems relating to maintenance, i.e. relating to the effects of the corrosion of steel reinforcement on the durability of the structure.
Although maintenance costs and aesthetics play a significant role in the design decision, the initial cost of the structure is generally the most decisive parameter for selecting steel or a concrete bridge solution. Solutions of both types are generally considered, at least at a preliminary design stage.

In Figure 1 the principal components of a bridge structure are shown

The two basic parts are:

- The substructure
- The superstructure.

The former includes the piers, the abutments and the foundations.

The latter consists of the deck structure itself, which supports the direct loads due to traffic and all the other permanent and variable loads to which the structure is subjected.

The connection between the substructure and the superstructure is usually made through bearings. However, rigid connections between the piers (and
sometimes the abutments) may be adopted, particularly in frame bridges with tall (flexible) piers.

INTRODUCTION TO THE SUPERSTRUCTURE

It is common in bridge terminology to distinguish between:

- The longitudinal structural system
- The transverse structural system.

It should be understood that bridge structures are basically three-dimensional systems which are only split into these two basic systems for the sake of understanding their behavior and simplifying structural analysis.

The longitudinal structural system of a bridge may be one of the following types

- beam bridges
- frame bridges
- arch bridges
- cable stayed bridges
- Suspension bridges.

- The types of girder incorporated in all these types of bridges may either be continuous i.e. rolled sections, plate girders or box girders, or discontinuous i.e. trusses.
- Beam bridges are the most common and the simplest type of bridge whether they use statically determinate beams (simply supported or Gerber beams) or continuous beams.
- Simply supported beams are usually adopted only for very small spans (up to 25m). Continuous beams are one of the most common types of bridge. Spans may vary from small (10 - 20m) to medium (20 - 50m) or large spans (> 100m). In medium and large spans continuous beams with variable depth section are very often adopted for reasons of structural behavior, economy and aesthetics.
- Frame bridges are one of the possible alternatives to continuous beams avoiding bearings and providing a good structural system to support horizontal longitudinal actions, e.g. earthquakes, frames have been adopted in modern bridge technology in prestressed concrete bridges or in steel and composite bridges.
- Frames may be adopted with vertical piers (the most common type) or with inclined struts.
Arches have played an important role in the history of bridges. Several outstanding examples have been built ranging from masonry arches built by the Romans to modern prestressed concrete or steel arches with spans reaching the order of 300m.

The arch may work from below the deck, from above the deck or be intermediate to the deck level. The most convenient solution is basically dependent on the topography of the bridge site.

In rocky gorges and good geotechnical conditions for the springing, an arch bridge of the type represented is usually an appropriate solution both from the structural and aesthetic point of view.

Arches work basically as a structure under compressive stress. The shape is chosen in order to minimize bending moments under permanent loads. The resultant force of the normal stresses at each cross-section must remain within the central core of the cross-section in order to avoid tensile stresses in the arch. Arches are ideal structures to build in materials which are strong in compression but weak in tension, e.g. concrete.

The ideal "inverted arch" in its simplest form is a cable. Cables are adopted as principal structural elements in suspension bridges where the main cable supports permanent and imposed loads on the deck.

Good support conditions are required to resist the anchorage forces of the cable. In the last few years, a simpler form of cable bridges has been used - the cable stayed bridge.

Cable stayed bridges have been used for a range of spans, generally between 100m and 500m, where the suspension bridge is not an economical solution. The range of spans for cable stayed bridges is quite different from the usual range of spans for suspension bridges - from 500m to 1500m.

Cable stayed bridges may be used with a deck made in concrete or in steel. Generally, cable stayed bridges are designed with very slender decks which are "continuously" supported by the stays which are made of a number of strands of high strength steel.

Three main types of transverse structural system may be considered slab-beam-slab (slab with cross-girders)

Box girders for longitudinal structural system which contribute to the transverse structural system.

Slab cross-sections are only adopted for small spans, generally below 25m, or where multiple girders are used for the longitudinal structural system, at spacing’s of 3 - 4,5m. Beam-slab cross-sections are generally adopted for medium spans below 80m where only two longitudinal girders are provided.

For large spans (> 100m), and also for some medium spans (40 - 80m), box girder sections are very convenient solutions leading to good structural behavior and aesthetically pleasing bridge structures. Box girders are used in prestressed concrete or in steel or composite bridges.
3. Explain the details about steel bridges in PSC bridge construction.

STEEL BRIDGES

General Aspects

During the Industrial revolution of 19th century steel products became more competitive and structural steel began to be adopted for bridge construction. From then on, large truss bridges and suspension bridges where developed. Truss girders or arches built by truss systems have been widely adopted.

The behavior of stiffened plates is now sufficiently known for safe large box girder bridges to be designed in steel. Special consideration during erection and execution phases is given to all aspects of structural stability.

Three basic types of structural elements are adopted for steel bridge superstructures:

- Beam and Plate Girders
- Truss Girders
- Box Girders.

Plate girder bridges with only two girders, even for very wide decks are very often preferred for the sake of simplicity [2]. However, in bridge construction, a classical solution consists in adopting several I beams (hot rolled sections for small spans - up to 25m) with 3,0 to 4,5m spacing.
Diaphragms may be provided between the beams (transverse beams) to contribute to transverse load distribution and also to lateral bracing. The top flanges of the beams have continuous lateral support against buckling provided by the deck.

![Figure 8 Plate girder bridge with two girders with maximum span of 71m](image)

**Deck Systems**

There are two basic solutions for the deck - a reinforced concrete or partially prestressed concrete slab and an orthotropic steel plate. In the former the slab may act independently of the girders (a very uneconomic solution for medium and large spans) or it may work together with the girders (composite bridge deck). The composite action requires the shear flow between the slab and the girders to be taken by shear connectors.

Concrete decks are usually more economic than orthotropic steel plates. The latter are only adopted when deck weight is an important component of loading, i.e. for long span and moveable bridges.

The orthotropic plate deck, acting as the top flange of the main girders, gives a very efficient section in bending. The deck is basically a steel plate overlain with a wearing surface which may be concrete or mastic asphalt.

The steel plate is longitudinally stiffened by ribs which may be of open or closed section. Transversally, the ribs are connected through the transverse beams yielding a complex grillage system where the main girders, the steel plate, the ribs and the floor beams act together.

Top flanges of box girders, e.g. in Niteroi bridge with a 300m span (the largest in the world for a box girder bridge) or in the deck of cable stayed bridges or
suspension bridges like the Humber bridge with a lightweight wearing surface give a deck of very low dead load which makes this type of solution very suitable for long spans.

The biggest disadvantage of orthotropic steel plate decks is their initial cost and the maintenance required when compared to a simple concrete slab. However, for box girders the maintenance cost may be lower than for an open orthotropic deck.

4. Explain the prestressed concrete in PSC construction with basic components.

Prestressed Concrete

- Since concrete is weak in tension in normal reinforced concrete construction cracks develop in the tension zone at working loads and therefore all concrete in tension is ignored in design.
- Prestressing involves inducing compressive stresses in the zone which will tend to become tensile under external loads. This compressive stress neutralizes the tensile stress so that no resultant tension exists, (or only very small values, within the tensile strength of the concrete).
- Cracking is therefore eliminated under working load and all of the concrete may be assumed effective in carrying load. Therefore lighter sections may be used to carry a given bending moment, and prestressed concrete may be used over much longer spans than reinforced concrete.
- The prestressing force also reduces the magnitude of the principal tensile stress in the web so that thin-webbed I - sections may be used without the risk of diagonal tension failures and with further savings in self weight. The prestressing force has to be produced by high tensile steel, and it is necessary to use high quality concrete to resist the higher compressive stresses that are developed.
- There are two methods of prestressing concrete:
  - Pre-cast Pre-tensioned
  - Pre-cast Post-tensioned.
- Both methods involve tensioning cables inside a concrete beam and then anchoring the stressed cables to the concrete.
1) Pretensioned Beams

**Stage 1**
Tendons and reinforcement are positioned in the beam mould.

**Stage 2**
Tendons are stressed to about 70% of their ultimate strength.

**Stage 3**
Concrete is cast into the beam mould and allowed to cure to the required initial strength.

**Stage 4**
When the concrete has cured the stressing force is released and the tendons anchor themselves in the concrete.

2) Post-tensioned Beams

**Stage 1**
Cable ducts and reinforcement are positioned in the beam mould. The ducts are usually raised towards the neutral axis at the ends to reduce the eccentricity of the stressing force.

**Stage 2**
Concrete is cast into the beam mould and allowed to cure to the required initial strength.

**Stage 3**
Tendons are threaded through the cable ducts and tensioned to about 70% of their ultimate strength.

**Stage 4**
Wedges are inserted into the end anchorages and the tensioning force on the tendons is released. Grout is then pumped into the ducts to protect the tendons.

**Loss of Prestress**
When the tensioning force is released and the tendons are anchored to the concrete a series of effects result in a loss of stress in the tendons. The effects are:
a. relaxation of the steel tendons  
b. elastic deformation of the concrete  
c. shrinkage and creep of the concrete  
d. slip or movement of the tendons at the anchorages during anchoring  
e. Other causes in special circumstances, such as when steam curing is used with pre-tensioning.  
f. Total losses in prestress can amount to about 30% of the initial tensioning stress.  

**Choice of Abutment**

Current practice is to make decks integral with the abutments. The objective is to avoid the use of joints over abutments and piers. Expansion joints are prone to leak and allow the ingress of de-icing salts into the bridge deck and substructure. In general all bridges are made continuous over intermediate supports and decks less than 60 metres long with skews not exceeding 30° are made integral with their abutments.

![Open Side Span with Bank Seats](image)

**Solid Side Span with Full Height Abutments**

Usually the narrow bridge is cheaper in the open abutment form and the wide bridge is cheaper in the solid abutment form. The exact transition point between the two types depends very much on the geometry and the site of the particular bridge. In most cases the open abutment solution has a better appearance and is less intrusive on the general flow of the ground contours and for these reasons is to be preferred. It is the cost of the wing walls when related to the deck cost which swings the balance of cost in favor of the solid abutment solution for wider bridges. However the wider bridges with solid abutments produce a tunneling effect and costs have to be considered in conjunction with the proper functioning of the structure where fast traffic is passing beneath. Solid abutments for narrow bridges should only be adopted where the open abutment solution is not possible. In the case of wide bridges the open
abutment solution is to be preferred, but there are many cases where economy must be the overriding consideration.

**Design Considerations**

Loads transmitted by the bridge deck onto the abutment are:

i. Vertical loads from self weight of deck
ii. Vertical loads from live loading conditions
iii. Horizontal loads from temperature, creep movements etc and wind
iv. Horizontal loads from braking and skidding effects of vehicles.

These loads are carried by the bearings which are seated on the abutment bearing platform. The horizontal loads may be reduced by depending on the coefficient of friction of the bearings at the movement joint in the structure. However, the full braking effect is to be taken, in either direction, on top of the abutment at carriageway level. In addition to the structure loads, a horizontal pressure exerted by the fill material against the abutment walls is to be considered. Also a vertical loading from the weight of the fill acts on the footing.

Vehicle loads at the rear of the abutments are considered by applying a surcharge load on the rear of the wall.

For certain short single span structures it is possible to use the bridge deck to prop the two abutments apart. This entails the abutment wall being designed as a propped cantilever.

**Design Considerations**

The functions of each bearing type are:

a. **Elastomeric**
   
   the elastomeric bearing allows the deck to translate and rotate, but also resists loads in the longitudinal, transverse and vertical directions. Loads are developed, and movement is accommodated by distorting the elastomeric pad.

b. **Plane Sliding**

c. Sliding bearings usually consist of a low friction polymer, polytetrafluoroethylene (PTFE), sliding against a metal plate. This bearing does not accommodate rotational movement in the longitudinal or transverse directions and only resists loads in the vertical direction. Longitudinal or transverse loads can be accommodated by providing mechanical keys. The keys resist movement, and loads in a direction perpendicular to the keyway.

d. **Roller**

   Large longitudinal movements can be accommodated by these bearings, but vertical loads only can generally be resisted.
The designer has to assess the maximum and minimum loads that the deck will exert on the bearing together with the anticipated movements (translation and rotation). Bearing manufacturers will supply a suitable bearing to meet the designers' requirements. Bearings are arranged to allow the deck to expand and contract, but retain the deck in its correct position on the substructure. A 'Fixed' Bearing does not allow translational movement. 'Sliding Guided' Bearings are provided to restrain the deck in all translational directions except in a radial direction from the fixed bearing. This allows the deck to expand and contract freely. 'Sliding' Bearings are provided for vertical support to the deck only.

**Choice of Deck**

Making the correct choice of deck will depend on many factors. Use the links below to find out about each type.

- Preliminary Design
- Making the correct choice of bridge deck type.
- Reinforced Concrete
- Prestressed Concrete
- Composite
- Steel Box Girder
- Steel Truss
- Cable Stayed
- Suspension

**Preliminary Design**

In selecting the correct bridge type it is necessary to find a structure that will perform its required function and present an acceptable appearance at the least cost.

Decisions taken at preliminary design stage will influence the extent to which the actual structure approximates to the ideal, but so will decisions taken at detailed design stage. Consideration of each of the ideal characteristics in turn will give some indication of the importance of preliminary bridge design.

a. **Safety.**

The ideal structure must not collapse in use. It must be capable of carrying the loading required of it with the appropriate factor of safety. This is more
significant at detailed design stage as generally any sort of preliminary design can be made safe.

b. **Serviceability.**
The ideal structure must not suffer from local deterioration/failure, from excessive deflection or vibration, and it must not interfere with sight lines on roads above or below it. Detailed design cannot correct faults induced by bad preliminary design.

c. **Economy.**
The structure must make minimal demands on labour and capital; it must cost as little as possible to build and maintain. At preliminary design stage it means choosing the right types of material for the major elements of the structure, and arranging these in the right form.

d. **Appearance.**
The structure must be pleasing to look at. Decisions about form and materials are made at preliminary design stage; the sizes of individual members are finalized at detailed design stage. The preliminary design usually settles the appearance of the bridge.

**Preliminary Design Considerations**

1. **A span to depth ratio of 20 will give a starting point for estimating construction depths.**
2. **Continuity over supports**
   i. Reduces number of expansion joints.
   ii. Reduces maximum bending moments and hence construction depth or the material used.
   iii. Increases sensitivity to differential settlement.
3. **Factory made units**
   i. Reduces the need for soffit shuttering or scaffolding; useful when headroom is restricted or access is difficult.
   ii. Reduces site work which is weather dependent.
   iii. Dependent on delivery dates by specialist manufactures.
   iv. Specials tend to be expensive.
   v. Special permission needed to transport units of more than 29m long on the highway.
4. **Length of structure**
   i. The shortest structure is not always the cheapest. By increasing the length of the structure the embankment, retaining wall and abutment costs may be reduced, but the deck costs will increase.
5. **Substructure**
i. The structure should be considered as a whole, including appraisal of piers, abutments and foundations. Alternative designs for piled foundations should be investigated; piling can increase the cost of a structure by up to 20%.

**Costing and Final Selection**

The preliminary design process will produce several apparently viable schemes. The procedure from this point is to:

i. Estimate the major quantities.
ii. Apply unit price rates - they need not be up to date but should reflect any differential variations.
iii. Obtain prices for the schemes.

The final selection will be based on cost and aesthetics. This method of costing assumes that the scheme with the minimum volume will be the cheapest, and will be true if the structure is not particularly unusual.

**Reinforced Concrete Decks**

The three most common types of reinforced concrete bridge decks are:

- **Solid Slab**
- **Voided Slab**
- **Beam and Slab**

Solid slab bridge decks are most useful for small, single or multi-span bridges and are easily adaptable for high skew. Voided slab and beam and slab bridges are used for larger, single or multi-span bridges. In circular voided decks the ratio of [depth of void] / [depth of slab] should be less than 0.79; and the maximum area of void should be less than 49% of the deck sectional area.
Analysis of Deck
For decks with skew less than 25° a simple unit strip method of analysis is generally satisfactory. For skews greater than 25° then a grillage or finite element method of analysis will be required.
Skew decks develop twisting moments in the slab which become more significant with higher skew angles. Computer analysis will produce values for Mx, My and Mxy where Mxy represents the twisting moment in the slab. Due to the influence of this twisting moment, the most economical way of reinforcing the slab would be to place the reinforcing steel in the direction of the principal moments.
However these directions vary over the slab and two directions have to be chosen in which the reinforcing bars should lie. Wood and Armbr have developed equations for the moment of resistance to be provided in two predetermined directions in order to resist the applied moments Mx, My and Mxy.

Prestressed Concrete Decks

There are two types of deck using prestressed concrete:

1. Pre-tensioned beams with insitu concrete.
2. Post-tensioned concrete.

The term pre-tensioning is used to describe a method of prestressing in which the tendons are tensioned before the concrete is placed, and the prestress is transferred to the concrete when suitable cube strength is reached. Post-tensioning is a method of prestressing in which the tendon is tensioned after the concrete has reached a suitable strength.
The tendons are anchored against the hardened concrete immediately after prestressing.
There are three concepts involved in the design of prestressed concrete:

i. Prestressing transforms concrete into an elastic material. By applying this concept concrete may be regarded as an elastic material, and may be treated as such for design at normal working loads. From this concept the criterion of no tensile stresses in the concrete was evolved. In an economically designed simply supported beam, at the critical section, the bottom fibre stress under dead load and prestress should ideally be the maximum allowable stress; and under dead load, live load and prestress the stress should be the minimum allowable stress.

ii. Therefore under dead load and prestress, as the dead load moment reduces towards the support, and then the prestress moment will have to reduce accordingly to avoid exceeding the permissible stresses. In post-tensioned
structures this may be achieved by curving the tendons, or in pre-tensioned structures some of the prestressing strands may be deflected or de-bonded near the support.

Prestressed concrete is to be considered as a combination of steel and concrete with the steel taking tension and concrete compression so that the two materials form a resisting couple against the external moment. (Analogous to reinforced concrete concepts). This concept is utilized to determine the ultimate strength of prestressed beams. Prestressing is used to achieve load balancing. It is possible to arrange the tendons to produce an upward load which balances the downward load due to say, dead load, in which case the concrete would be in uniform compression.

6. Write technical notes on
   - Pre-stressed PSC bridge decks
   - Post-stressed PSC bridge decks
   - Forces to be considered in PSC bridges.

Pre-stressed PSC bridge decks

Precast prestressed concrete deck panels are widely used in the construction of bridges in the United States. A 1982 survey of the State Highway Departments by the PCI Bridge Committee showed that 21 states use the panels regularly and another seven states were trying the method through bidding options or were developing details prior to trial projects. The panels are used as a composite part of the completed deck. They replace the main bottom (positive moment) transverse deck reinforcement and also serve as a form surface for the cast-in-place concrete upper layer that contains the top of deck (negative moment) reinforcement.

The use of precast panels has proven to be both economical and convenient. Generally, when a deck is cast in place for its full depth, timber forms must be installed and later removed. This is expensive, time consuming and in many locations causes safety concerns to roadway traffic or pedestrians under them construction. On high level crossings, placing and removing deck slab forms is a safety concern to the workers.

Principle of Prestressing

The function of prestressing is to place the concrete structure under compression in those regions where load causes tensile stress. Tension caused by the load will first have to cancel the compression induced by the prestressing before it can crack the concrete. Figure shows a plainly reinforced concrete simple-span beam and fixed cantilever beam cracked under applied load. Figure shows the same unloaded
beams with prestressing forces applied by stressing high strength tendons. By placing the prestressing low in the simple-span beam and high in the cantilever beam, compression is induced in the tension zones; creating upward camber.

Figure shows the two prestressed beams after loads have been applied. The loads cause both the simple-span beam and cantilever beam to deflect down, creating tensile stresses in the bottom of the simple-span beam and top of the cantilever beam. The Bridge Designer balances the effects of load and prestressing in such a way that tension from the loading is compensated by compression induced by the prestressing. Tension is eliminated under the combination of the two and tension cracks are prevented. Also, construction materials (concrete and steel) are used more efficiently; optimizing materials, construction effort and cost.

![Comparison of Reinforced and Prestressed Concrete Beams](image)

Prestressing can be applied to concrete members in two ways, by pretensioning or post-tensioning. In pretensioned members the prestressing strands are tensioned against restraining bulkheads before the concrete is cast. After the concrete has been placed, allowed to harden and attain sufficient strength, the strands are released and their force is transferred to the concrete member. Prestressing by post-tensioning involves installing and stressing prestressing strand or bar tendons only after the concrete has been placed, hardened and attained a minimum compressive strength for that transfer.

**Post-Tensioning Operation**

- Compressive forces are induced in a concrete structure by tensioning steel tendons of strands or bars placed in ducts embedded in the concrete. The tendons are installed after the concrete has been placed and sufficiently cured to a prescribed initial compressive strength.
A hydraulic jack is attached to one or both ends of the tendon and pressurized to a predetermined value while bearing against the end of the concrete beam. This induces a predetermined force in the tendon and the tendon elongates elastically under this force.

After jacking to the full, required force, the force in the tendon is transferred from the jack to the end anchorage.

Tendons made up of strands are secured by steel wedges that grip each strand and seat firmly in a wedge plate. The wedge plate itself carries all the strands and bears on a steel anchorage.

The anchorage may be a simple steel bearing plate or may be a special casting with two or three concentric bearing surfaces that transfer the tendon force to the concrete. Bar tendons are usually threaded and anchor by means of spherical nuts that bear against a square or rectangular bearing plate cast into the concrete. For an explanation of post-tensioning terminology and acronyms, see Appendix A.

After stressing, protruding strands or bars of permanent tendons are cut off using an abrasive disc saw. Flame cutting should not be used as it negatively affects the characteristics of the prestressing steel.

Approximately 20mm (¾ in) of strand is left to protrude from wedges or a certain minimum bar length is left beyond the nut of a bar anchor. Tendons are then grouted using a cementitious based grout. This grout is pumped through a grout inlet into the duct by means of a grout pump. Grouting is done carefully under controlled conditions using grout outlets to ensure that the duct anchorage and grout caps are completely filled.

Post-Tensioning Systems

Many proprietary post-tensioning systems are available. Several suppliers produce systems for tendons made of wires, strands or bars. The most common systems found in bridge construction are multiple strand systems for permanent post-tensioning tendons and bar systems for both temporary and permanent situations. Refer to manufacturers' and suppliers' literature for details of available systems. Key features of three common systems (multiple-strand and bar tendons).
Typical Post-Tensioning Anchorage Hardware for Strand Tendons

Typical Post-Tensioning Bar System Hardware.

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7. Draw neat sketches showing the typical cross sections of post tensioned PSC bridge decks.
8. What are the general aspects of prestressed concrete bridges and its advantages over RC bridges? (MAY/JUNE 2013)

Prestressed concrete is a method for overcoming concrete's natural weakness in tension. It can be used to produce beams, floors or bridges with a longer span than is practical with ordinary reinforced concrete. Prestressing tendons (generally of high tensile steel cable or rods) are used to provide a clamping load which produces a compressive stress that balances the tensile stress that the concrete compression member would otherwise experience due to a bending load. Traditional reinforced concrete is based on the use of steel reinforcement bars, rebars, inside poured concrete.

1. High-strength concrete and high-tensile steel, besides being economical make for slender sections, which are aesthetically superior.
2. Prestressed concrete bridges can be designed as Class 1 type structures without any tensile stresses under service loads, thus resulting in a crack free structure.
3. In comparison with steel bridges, prestressed concrete bridges require very little maintenance.
4. PSC is ideally suited for composite bridge construction in which precast prestressed girders support the cast in-situ slab deck

Prestressed concrete is ideally suited for the construction of medium and long span bridges. Solid slabs are used for the span range of 10 m to 20 m. While T beam slab decks are suitable for spans in the range of 20 m to 40m.

Single or multicell box girders are preferred for large spans of the order of 30 m to 70 m.

Prestressed concrete is ideally suited for long span of the order continuous bridges in which precast box girders of variable depth are used for spans exceeding 50 m.

- Precast segmental construction for prestressed concrete bridges has been widely used in the world. This method has many advantages, such as quality-guaranteed standard precast segments, fast speed construction time and the least site work. Lots of prestressed concrete bridges in the world were built by precast segmental construction method in recent 20 years.

- Although more and more precast segmental bridges have been successfully built in China, this construction method is still relatively new. One reason is that the precise control of the dimensions of the bridge makes the construction much more complicated.

- Another reason is that the precast segmental construction method, originated from the contractor system, is not well followed in time by design codes.

- This construction method even well influences the structural design including the profiles of internal and external prestressing tendons, the detail dimensions of segments and the arrangements of segments and deviators, etc.

- Due to these reasons, lack of the regarding specified design codes usually causes owners and even designers to hesitate to use this construction method.

- A cantilever bridge is a bridge built using cantilevers, structures that project horizontally into space, supported on only one end. For small footbridges, the cantilevers may be simple beams; however, large cantilever bridges designed to handle road or rail traffic use trusses built from structural steel, or box girders built from prestressed concrete.

- The steel truss cantilever bridge was a major engineering breakthrough when first put into practice, as it can span distances of over 1,500 feet (460 m), and can be more easily constructed at difficult crossings by virtue of using little or no falsework.

![Cantilever Bridge Diagram](civilsoftwares.com)
A common way to construct steel truss and prestressed concrete cantilever spans is to counterbalance each cantilever arm with another cantilever arm projecting the opposite direction, forming a balanced cantilever; when they attach to a solid foundation, the counterbalancing arms are called anchor arms.

Thus, in a bridge built on two foundation piers, there are four cantilever arms: two which span the obstacle, and two anchor arms which extend away from the obstacle. Because of the need for more strength at the balanced cantilever's supports, the bridge superstructure often takes the form of towers above the foundation piers.

The Commodore Barry Bridge is an example of this type of cantilever bridge. Steel truss cantilevers support loads by tension of the upper members and compression of the lower ones.

Commonly, the structure distributes the tension via the anchor arms to the outermost supports, while the compression is carried to the foundations beneath the central towers.

Many truss cantilever bridges use pinned joints and are therefore statically determinate with no members carrying mixed loads. Prestressed concrete balanced cantilever bridges are often built using segmental construction.

10. State and explain the forces to be considered in PSC bridges.

(MAY/JUNE 2012)

Currently, the prediction and the control of prestressing force and camber are designed deterministically in the design of cable-stayed bridges or prestressed concrete bridges.

However, the variation of qualities of materials and external loads have different types of probabilistic distributions, which could make additional errors in the prediction and the control of errors. Therefore, the uncertainties in the resistance and loads should have to be considered in a probabilistic manner.

To develop a probabilistic risk assessment technique in prestressed concrete box girder railway bridges, the important random variables are determined by an analytical hierarchy process (AHP) method, which are selected for the risk assessment of the target PSC box girder bridge constructed by a MSS method.
The limit state functions are determined to investigate the risk of tensile cracks in upper and lower flange concrete, just after the moving of scaffolding, and the risks of the prestressing loss at each construction stage. For composing the implicit limit state function, Response Surface Method (RSM) is selected to evaluate the reliability of the implicit limit states of complex structures.

The basic RSM could diverge depending on the nonlinearity of the limit states. For the improved convergence, iterations are performed to find the more probable failure points, which are closer to the limit states by updating design matrix, the input data to compose the response surfaces of considered systems. For maximizing the adaptation of RSM, a diagonal weighting matrix is used, which accelerates the convergence of reliability. Accordingly in the target PSC Railway Bridge, the linear adaptive weighted response surface method combined with advanced first order second moment method have been used for the evaluation of reliabilities of the considered limit states. Consequently, risk assessments have been performed for the limit states of the response of the target bridge, as a resistance term using the ultimate stress and prestress loss with the load term using the rupture stress and expected prestress loss, based on the Korean design specifications and ACI specification for each construction stages of PSC box girder bridges built by Movable Scaffolding Method.
Design of post tensioned PC slab bridge decks.

Data:
- Clear span
- Width of bearing
- Clear width of roadway, footpath, kerbs, check of wearing coat, live load, type of structure.

Materials:
- M20 grade concrete, trim φ HRSP
- Ultimate tensile stress = 1500 N/mm²

ii) Compressive stress @ transfer, \( f_{td} = 35 \text{ N/mm}^2 \)
\[ \gamma = 0.8 \]
\[ LR = 0.85; IR = 0.85; IRL = 0.6, IRL - 21 \text{ yrs.} \]

iii) Permissible stress, \( f_{ct} = 0.95f_{td} \)
\[ \gamma = 0.8 \]

iv) Depth of slab \& Effective span:
Assume thickness of slab @ 50mm per metre of span for highway bridge decks.

v) Dead load, D:\n- Dead weight = \( \gamma \times \text{width} \)
- Total dead load

vi) Live load, B:\n- Impact factor for class B = 3.5, for span 10.4m span
  10.5 for 10.9m span

[link to civilsoftwares.com]
Effective width of slab $b_2 = k_x x \left[ 1 - \frac{w_{/2}}{x} \right] + b_0$

from Table A1-2.

max. not due to live load.

(vi) shear due to class AA tracked vehicle.

Effective width $= b_2 = k_x x \left[ 1 - \frac{w_{/2}}{x} \right] + b_0$

(vii) check for minimum section modulus:

moment: $m_0, m_g$

$Z_t = Z_b = Z = \frac{b_0 t}{d}$

minimum section modulus $= Z_b = \left[ \frac{m_0 + m_g}{F_{bt}} \right]$

(viii) minimum prestressing force:

$p = \left[ \frac{R_e \left[ m_0 + m_g \right] + f_{ub} \cdot Z_t}{Z_t + P_t} \right]$