INDIAN INSTITUTE OF TECHNOLOGY

Tirupati, A.P. -517619

ADVANCED DESIGN OF CONCRETE STRUCTURES

TERM PROJECT

ANALYSIS AND DESIGN OF CABLE-STAYED BRIDGE.

DESIGN BASIS REPORT (DBR)

FACULTY IN CHARGE

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CONTENTS **PAGE NO.**

1.0 GENERAL INFORMATION

NAME OF THE PROJECT – ANALYSIS AND DESIGN OF CABLE-STAYED BRIDGE

BRIDGE CONFIGURATION – TWO NEEDLE PYLONS, SEMI-FAN SHAPED CABLES, AND PSC BOX GIRDER.

TYPE OF ROADWAY – TWO-LANE ROAD

SPAN OF THE BRIDGE – 238M

LOCATION OF SEISMIC ZONE – II

LOCATION OF SOIL – HARD ROCK OR HARD SOIL

2.0 PROJECT BRIEF

2.1 PROJECT DESCRIPTION

It is proposed to develop the design of cable cable-stayed bridge for the vehicles movement a river having a seismic zone II and hard soil at the foundation level. This cable-stayed bridge is designed for two-lane traffic.

2.2 BRIDGE DESIGN DATA

Span of the bridge 238 m

Middle span – 112m

Both back span – 63m

Width of the deck – 16m

Width of the carriageway – 14m

Height of the pylon

3.0 BASIC STRUCTURAL SYSTEM OF THE CABLE STAYED BRIDGE

3.1 Components of cable stayed bridge

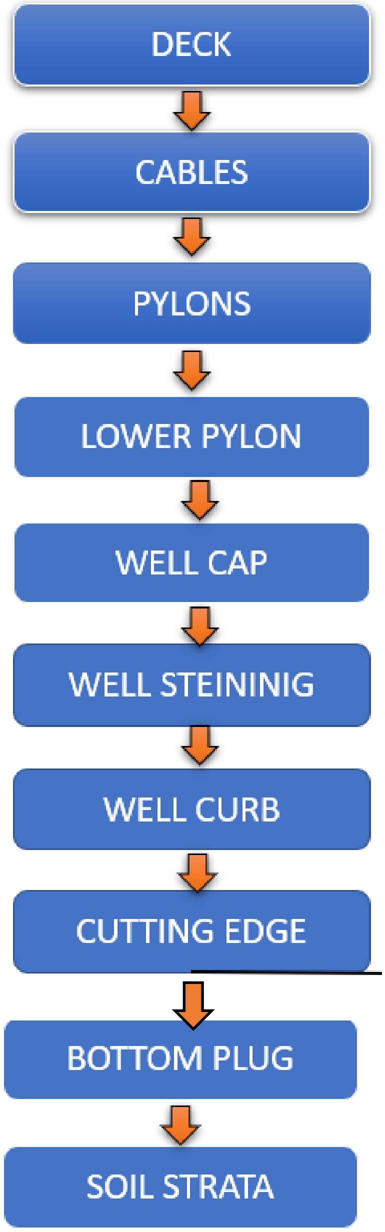
- Upper pylon
- Lower pylon
- Pier table
- Bridge deck
- Cables
- Tendons
- Foundation
- Bearings

3.2 Load transfer mechanism in cable-stayed bridge

The load transfer mechanism in a cable-stayed bridge, as depicted in the diagram, begins at the deck, which carries the traffic loads (live and dead loads). These loads are first transferred to the stay cables, which are tension members. The cables then transmit these loads to the pylons, creating both vertical and horizontal components of force. The pylons, acting in compression, transfer the vertical load further downward into the lower pylon section and subsequently to the well foundation system.

The load continues from the well cap to the well steining, which is the vertical shaft of the well foundation. From there, it is transferred through the well curb, and finally down to the cutting edge, which makes contact with the soil strata. The bottom plug beneath the well acts to seal the base and helps distribute the load effectively into the surrounding soil.

The load transfer path for the cable stayed bridge is:



This hierarchical path ensures that loads from the superstructure are safely transmitted to the subsoil, maintaining the structural integrity and stability of the bridge

4.0 STRUCTURAL DESIGN CRITERIA

4.1 MODELING OF THE BRIDGE

Cable stayed bridge is modelled in Midas Civil software. Bridge sections are approximated according to the experience in design of cable-stayed bridges in the past. A symmetric section is chosen for analysis of the bridge. Preliminary analysis is done to check whether the approximation is under the acceptable criteria for deflection and shear. As per the provision of the code using the following method. Deflection and stress variation are determined in each stage of Construction. Adjustment in cable forces and length of the cable according to the deformed profile obtained in each stage until the desired profile is achieved. The initial cable forces are determined from the different methods as given below

- Traditional "Zero Displacement" Method
- Force Equilibrium Method
- Force Method
- Unknown Load Factor in Midas Civil
- Tuning of Cables

From the above methods Unknown Load Factor in Midas Civil mostly used to determine the initial cable forces.

4.2 Basic assumptions

Bearings are assumed as elastic link. Foundation is assumed as a series of elastic links.

Grades of the concrete for the different components are taken as follows

- Lower pylon concrete M60
- Upper pylon concrete M60
- Deck M60
- Well M40
- Well steining M30
- For the anchor cables and tendons, steel is used.

5.0 METHOD OF ANALYSIS AND DESIGN

5.1 Types of Analysis performed in midas civil

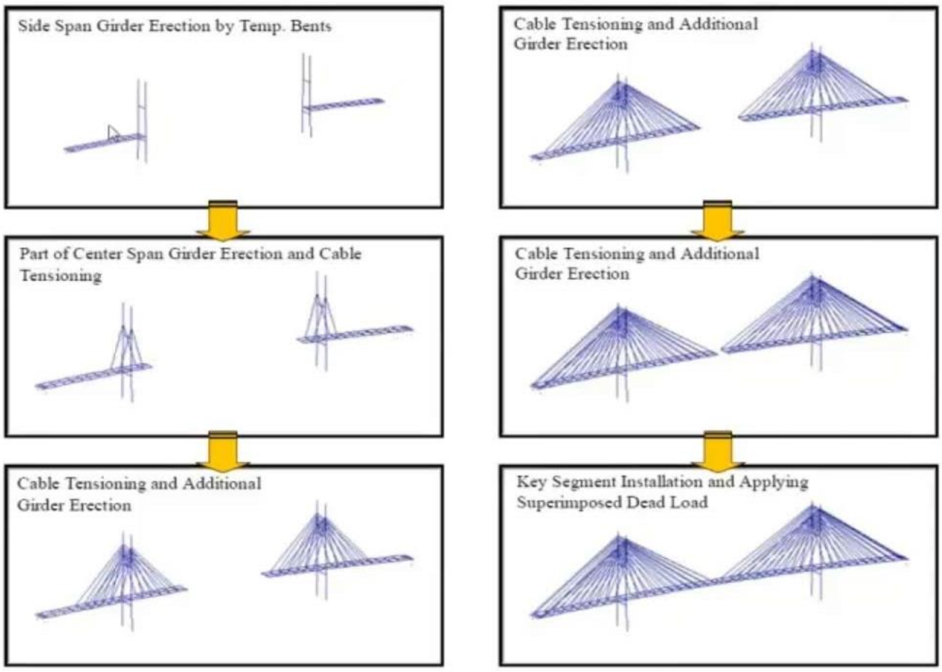
5.1.1 Construction stage analysis

Construction stage analysis in **Midas Civil** is performed to accurately simulate real-world construction processes and understand how structures behave at different stages of construction. This type of analysis is essential for large-scale and complex structures, such as bridges, high-rise buildings, and staged excavation projects.

Construction stage analysis consists of two types of analysis

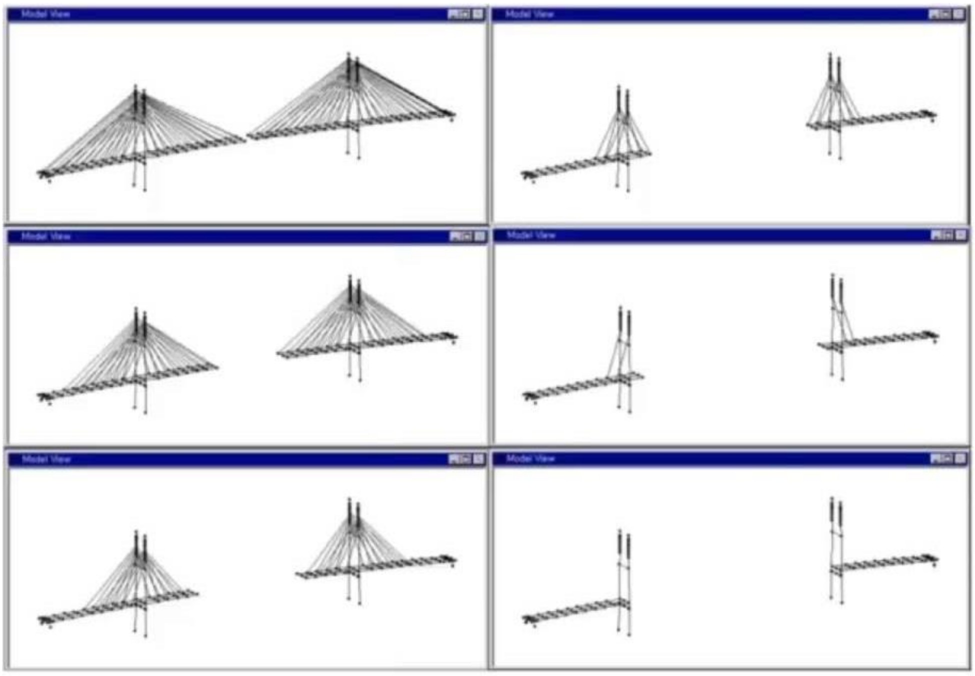
1. Backward analysis
2. Forward analysis

1. Backward analysis



- Useful in finding cable force during execution
- Does not account for time-dependent effects

2. Forward analysis.



- Useful to confirm backward analysis results when creep and shrinkage are not considered.
- Can account for the time-dependent effects.

5.1.2 Static Analysis

Static analysis is a method used to determine the response of structures under constant or slowly varying loads over time. It assumes that the structure is in equilibrium, meaning the sum of forces and moments is zero.

- Considers dead loads, live loads, wind loads, and prestressing/cable forces (in cable-stayed bridges).
- Ignores time-dependent effects like inertia and damping (unlike dynamic analysis).
- Useful for calculating:
    - Displacements
    - Reactions at supports
    - Internal forces (axial, shear, bending moments)

5.1.3 Response Spectrum – Short Note

Response Spectrum Analysis is a seismic analysis method used to estimate the peak structural response (displacement, velocity, or acceleration) to earthquake ground motion.

- Based on the response of a Single Degree of Freedom (SDOF) system to a range of vibration periods.
- The response spectrum curve shows maximum response vs. natural period or frequency for a given damping ratio (commonly 5%).
- Used for linear dynamic analysis of multi-degree structures

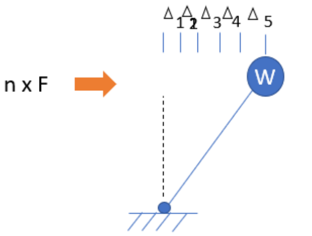
5.1.4 Pushover Analysis.

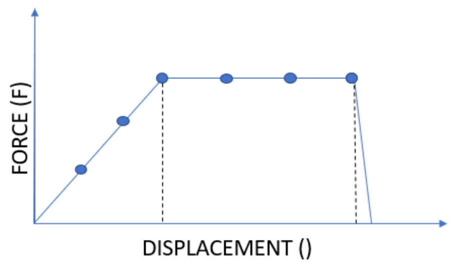
Pushover Analysis is a nonlinear static analysis method used to evaluate the seismic performance of a structure by applying gradually increasing lateral loads until failure.

- Simulates the building's behavior beyond elastic limits.
- Applies a predefined lateral load pattern (e.g., uniform or mode shape based) incrementally.
- Captures plastic hinge formation, stiffness degradation, and ultimate capacity.

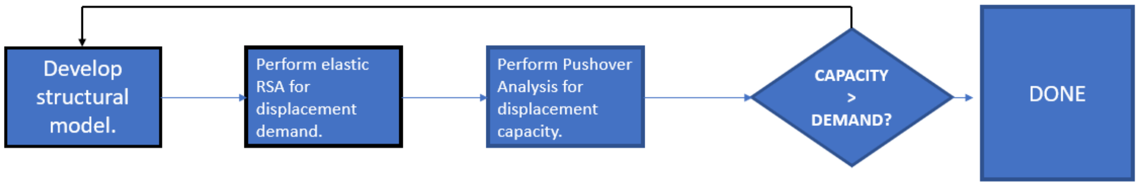
5.1.4.1 Purpose of Pushover Analysis in Midas Civil (Bridges):

- Seismic Vulnerability Assessment
- Performance-Based Design (PBD)
- Determining Plastic Hinge Formation
- Capacity Curve Generation
- Checking Ductility and Failure Modes
- Retrofit Evaluation





OVERALL PROCEDURE



6.0 DESIGN

Limit state method of design has been adoted to concrete elements according to irc 112. Along with the dead load and live load analysis, seismic and wind analysis is carried out for the super and substructure of the cable-stayed bridge.

7.0 LOADS AND LOAD COMBINATIONS

7.1 Load types considered in bridge design

- Dead load
- SIDL fixed
- SIDL variable
- Live load (vehicle load
- Wind load
- Seismic load
- Temperature load
- Breaking force
- Pretension

7.2 Load combinations

7.2.1 Limit state of strength

Table 4 of IRC:6-2017

Load Type	Leading (γf1)	Accompanying (γf2)
DL, SIDL	1.35	1.0
LL	1.5	1.15

Wind	1.5	0.9–1.5 (case based)
Temp	0.9–1.5	
Braking Force	1.5	
Seismic Load	1.2	

7.2.2 Limit state of servability.

Serviceability Load Factors (IRC:6-2017 Table 4)

Load Type	Partial Safety Factor (γf)
Dead Load (DL)	1.0
SIDL Fixed/Var.	1.0
Live Load (LL)	1.0
Wind Load (WL)	1.0
Temperature	1.0
Braking Force	1.0
Seismic (EQ)	1.0

8.0 SERVICEABILITY CHECKS

8.1 For the deflection.

- Mid tower displacement less or equal $\frac{H}{350}$
- Deck displacement less or equal $\frac{L}{540}$

8.2 For the stress.

- Cable stress (dead load and live load) should be less than or equal to 0.4% of the cable strength

8.2 For cracking

- Limiting crack width is taken as 0.3 mm

9.0 COMPUTER ANALYSIS

- Midas Civil – for the modelling and analysis of the bridge.
- Astra pro – for the design of structural elements.
- Oyasis adsec – for the design of the pylon section.
- Excel – cross verification of calculation.
- Auto cad – to prepare structural drawings

10. DESIGN LOAD DATA

Loads are calculated according to IRC 6 2017

Load Type	Clause No.	Description
Dead Load (DL)	203.1	Self-weight of structural components
Superimposed Dead Load (SIDL)	203.2	Wearing course, railings, footpaths, etc.
Live Load (LL)	204.1	IRC Class A, Class 70R, etc. vehicular loads
Impact Factor (Dynamic Load)	204.2	Dynamic amplification due to moving vehicles
Braking Force	204.4	Longitudinal force due to vehicle braking
Traction Force	204.4.2	Opposite of braking, considered for acceleration
Wind Load	205	Lateral and vertical wind forces on superstructure and vehicles
Temperature Effects	207	Uniform temperature and temperature gradient
Shrinkage and Creep	207.3	Time-dependent deformation in concrete
Seismic Load	208	Earthquake forces (zone factor, response spectra, etc.)
Longitudinal Force (Train/Traffic)	209	Includes frictional and braking loads from vehicles and trains
Earth Pressure / Backfill	211	For abutments and retaining walls

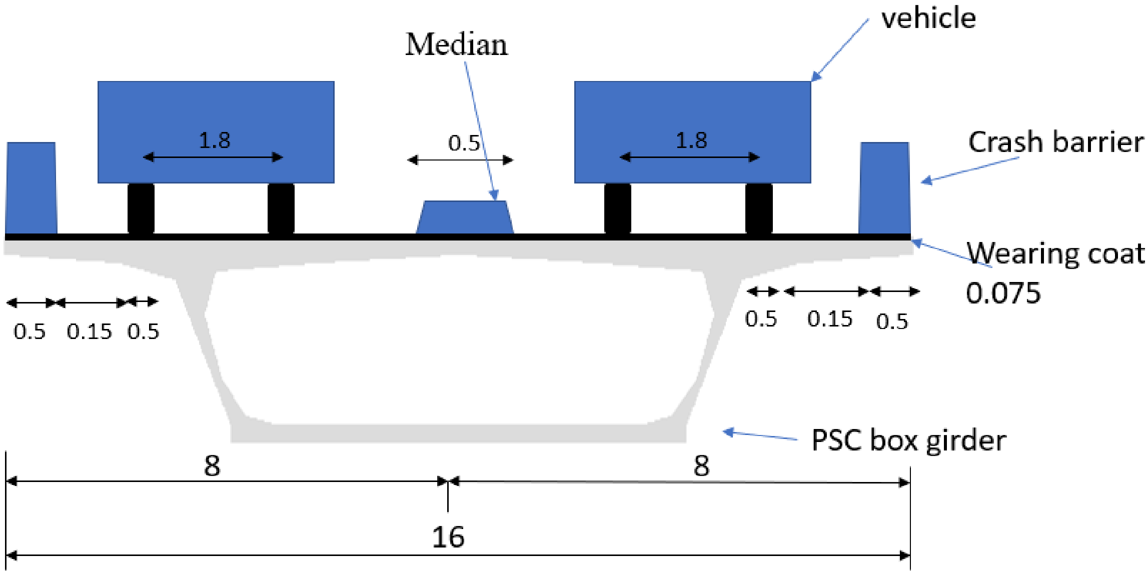
10.2 DEAD LOADS

- Density of reinforced concrete – 2kn/m3
- Density of steel for cables and tendons is 7850 kg/m^3
- Density of wearing course is 2300 kg/m^3
- Railings
- Light towers
- Median
- Footpath

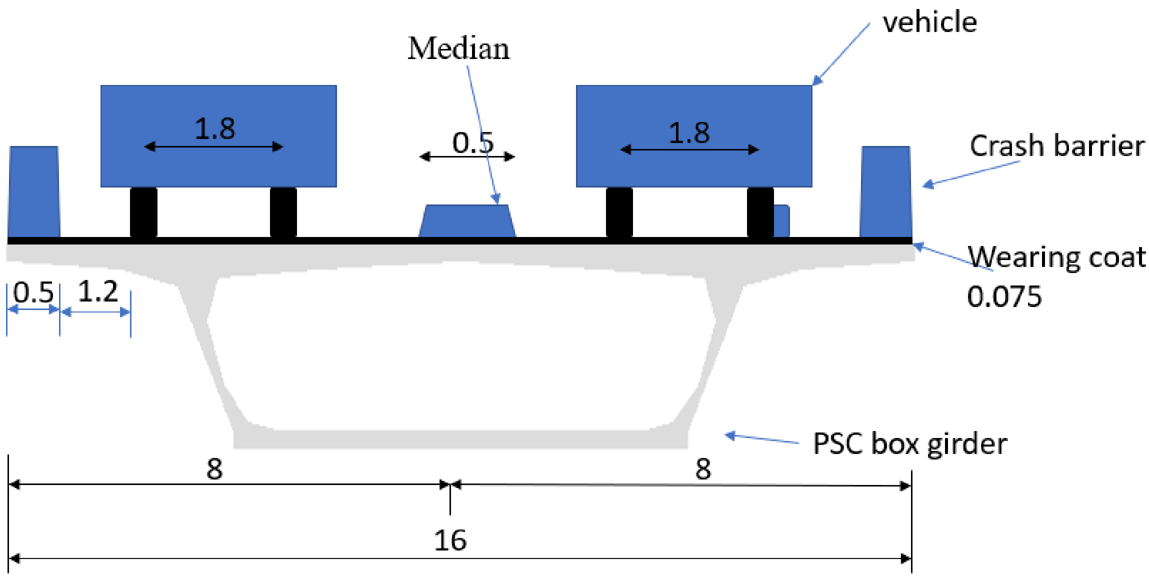
10.3 Live load

Class a1 and a2. Class 70R loading considered.

10.3.1 Class A LOADING



10.3.2 class 70R loading



10.4 WIND LOAD

RC:6 prescribes the method to calculate wind loads for bridges under two main scenarios:

- **Without Live Load**
- **With Live Load**

Wind load components include:

- Transverse Load (Ft) – acting horizontally, perpendicular to bridge axis
- Longitudinal Load (Fl) – usually taken as 25% of transverse
- Vertical Uplift (Fv) – due to aerodynamic lift

10.4.1 Wind Load Without Live Load

10.4.1.1 Transverse Wind Load (Ft)

$$Ft = P_z \times A \times G \times C_d$$

- **Pz**: Hourly mean wind pressure in N/m² at deck height (from Clause 209.3.2)
- **A**: Exposed area of the superstructure in elevation (m² per meter length)
- **G**: Gust Factor (from Clause 209.3.3) – usually taken as 2.0 for highway bridges
- **Cd**: Drag Coefficient (typical value = 1.28 for standard deck shapes)

10.4.1.2 Longitudinal Component (Fl)

Per IRC:6-2017, Clause 209.3.5:

$$Fl = 0.25 \times Ft$$

10.4.1.3 Vertical/Uplift Load (Fv)

From **Lift formula**:

$$Fv = P_z \times A_v \times G \times C_L$$

Where:

- Av : Plan area (deck width × unit length)
- CL: Lift coefficient (0.75 for standard decks)

10.4.1.4 Wind Load With Live Load

Live load (vehicles) must be considered when wind speed is **below 36 m/s**. Vehicles are subject to transverse wind pressure and drag as well.

- Deck height = 14.55 m → Pz = 480 N/m²
- Deck height = 16.0 m → Pz = 510 N/m²

10.4.1.5 Superstructure Wind Load:

10.4.1.6 Wind Load on Vehicles (Live Load)

Formula:

$$Ft = P_z \times A \times G \times C_d$$

- Pz = 510 N/m²
- A = 1.45 m²/m (projected area of vehicles per meter)
- G = 1 (since live load gust considered normal)
- Cd = 1.28

10.1.7 Wind Load on Substructure (Piers/Columns)

Clause 209.3.6 gives method for **wind on substructures**, such as piers, columns.

- P = 463.7 N/m² (wind pressure at lower height)
- A = Area of pier (varies)
- Cd = 1.05 – 1.425 (drag coefficient depending on shape)
- G = 2.0

10.5 SEISMIC LOAD

Seismic Definition Inputs (Based on IRC:SP:114-2018)

Parameter	Explanation
Design Spectrum	IRC:SP:114-2018 – Seismic guidelines for bridges in India.
Seismic Zone (Z)	Zone II (0.10), III (0.16), IV (0.24), V (0.36) per IRC 6 / IS 1893.
User Defined Z	Option to manually input seismic zone factor.
Soil Type	I (Rock/Hard), II (Medium), III (Soft) – affects spectral shape.
Damping (%)	Typically 5% for concrete bridges.
Damping Factor (β)	Often taken as 1.0 unless special conditions exist.
Importance Factor (I)	Usually 1.5 for important bridges.
Response Reduction Factor (R)	Depends on ductility and structure type (e.g., 2.5 for regular RC bridge).
Max. Period (sec)	Maximum vibration period considered (e.g., 6s).

10.5.2 PARAMETERS GIVEN IN THE MIDAS SEISMIC DEFINATION.

- Design Spectrum: IRC:SP:114-2018
- Seismic Zone: II (Zone factor, Z = 0.10)
- Soil Type: Type I (Rock or Hard Soil)
- Damping (%): 5%
- Damping Multiplying Factor: 1.0
- Importance Factor (I): 1.0
- Response Reduction Factor (R): 2.5
- Maximum Period: 6 seconds

11.0 FOUNDATION

Well foundation is chosen for the cable stayed bridge.

11.1 CODES FOR THE WELL FOUNDATION.

IRC 45:1972	*Recommendations for Estimating the Resistance of Soil Below the Maximum Scour Level in the Design of Well Foundations*
IS 3955:1967	*Criteria for Design of Well Foundations*

11.2 COMPONENTS OF WELL FOUNDATION.

Component	Purpose
Well Cap	Transfers loads from pier to well
Steining	Main structural body; resists loads
Well Curb	Supports steining, guides sinking
Cutting Edge	Aids in soil penetration
Bottom Plug	Seals the bottom, supports sand fill
Sand Filling	Adds dead weight, stabilizes well
Top Plug	Closes top and anchors the structure

12.0 DESIGN CODES AND REFERENCES

• **IRC: 112- 2020**, *Code of Practice for Concrete Road Bridges (Limit State Design)*, Indian Roads Congress, New Delhi.

• **IRC:136**, *Guidelines for the Design, Construction and Maintenance of Cable-Stayed Bridges*, Indian Roads Congress, New Delhi.

• **IRC:6-2017**, *Standard Specifications and Code of Practice for Road Bridges, Section II – Loads and Stresses*, Indian Roads Congress, New Delhi.

• **IRC:18-2010**, *Design Criteria for Prestressed Concrete Road Bridges (Post-tensioned System)*, Indian Roads Congress, New Delhi.

• **IS: 1343- 2012**, *Code of Practice for Prestressed Concrete*, Bureau of Indian Standards, New Delhi.

• **IRC:83 (Part I & II)**, *Specifications and Guidelines for Bearings for Road Bridges*, Indian Roads Congress, New Delhi.

• **IRC: SP:114-2018**, *Guidelines for Seismic Design of Road Bridges*, Indian Roads Congress, New Delhi.

• **IRC:45-1972**, *Recommendations for Estimating the Resistance of Soil Below the Maximum Scour Level in the Design of Well Foundations*, Indian Roads Congress, New Delhi.

• **IS: 3955- 1967**, *Criteria for Design of Well Foundations*, Bureau of Indian Standards, New Delhi.