MIDAS Elite Engineer Talk

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Spanning Bridges Using Extradosed Cables
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1. Introduction
2. General Structural Considerations
3. Examples
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5. Design Example
1. Introduction

**CONCEPT**

- EXTRADOSED BRIDGE – ORIGINATED FROM FRENCH WORD “EXTRADOS” WHICH MEANS TOP FIBER
- EXTRADOSED MEANS THAT PRESTRESSING TENDONS ARE PASSING ABOVE THE TOP FIBER

First Extradosed Bridge (Ganther br- In Switzerland) by Christian Menn
# 1. Introduction

## Structural Characteristics

<table>
<thead>
<tr>
<th>Type Of Bridge</th>
<th>Figure</th>
<th>Ratio of Pylon Height to Central Span Length</th>
<th>Overtension Due To Frequent Live Load</th>
<th>Vibration Due To Wind</th>
<th>Ratio of Superstructure Depth to Central Span Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girder Bridge (Economical upto 100m Span)</td>
<td><img src="image" alt="Girder Bridge Diagram" /></td>
<td>-</td>
<td>About 15% for external prestressing</td>
<td>No</td>
<td>1:40 to 1:50 to 1:15 to 1:20</td>
</tr>
<tr>
<td>Extradosed Bridge (Economical - 80m to 200m Span)</td>
<td><img src="image" alt="Extradosed Bridge Diagram" /></td>
<td>h/L=1/9 to 1/10</td>
<td>About 50 MPa</td>
<td>Negligible</td>
<td>1:40 to 1:50 to 1:30 to 1:40</td>
</tr>
<tr>
<td>Cable Stayed Bridge (Economical - 175m to 400m span)</td>
<td><img src="image" alt="Cable Stayed Bridge Diagram" /></td>
<td>h/L= 1/5</td>
<td>About 100 MPa</td>
<td>Yes</td>
<td>1.5m to 2.5m depth</td>
</tr>
</tbody>
</table>
1. Introduction

ADVANTAGES

STRUCTURAL
Similar to Girder Bridge - No Vibration Problem
-No Fatigue Problem

AESTHETIC
Improved Aesthetics - Looks similar to cable stayed bridges
-Sleeker superstructure than girder bridge

CONSTRUCTION
Ease in Construction - Lesser Tower height than cable stayed bridge
- Simpler Superstructure

ECONOMICS
Less Material consumption of superstructure - Nearly 30% lesser than girder bridge
Less load on foundation-Saving in foundation
2. General Structural Considerations

GENERAL STRUCTURAL CONSIDERATIONS FOR EXTRADOSED BRIDGES

STAY CABLE
- STAY CONFIGURATION- SINGLE PLANE OR DOUBLE PLANE (Governed by Roadway Width & Configuration)
- STAY LAYOUT – FAN SHAPED OR SEMI FAN SHAPED OR HARP SHAPED (Governed by number of cables in a Plane & economics of stay system)

SUPERSTRUCTURE
- CENTRAL SUPPORTED SUPERSTRUCTURE (BOX GIRDER)
  - SINGLE CELL (WITH INTERNAL STRUT) BOX GIRDER WITH WIDE CANTILEVER
  - SINGLE CELL SPINE BOX GIRDER WITH EXTERNAL STRUTS TO SUPPORT WIDE CANTILEVER
  - SINGLE CELL SPINE BOX GIRDER (WITH INTERNAL STRUTS ALONG WITH EXTERNAL STRUTS TO SUPPORT WIDE CANTILEVER
- LATERALLY SUPPORTED SUPERSTRUCTURE (BOX GIRDER)
  - SINGLE CELL BOX GIRDER
  - MULTIPLE CELL BOX GIRDER
- LATERALLY SUPPORTED STIFFENED SLAB CROSS-SECTION

PIER SUPERSTRUCTURE CONNECTION
- THROUGH BEARINGS
- MONOLITHICS (INTEGRAL)

PYLON & PIER CONFIGURATION
- Single Pier
- Twin bladed piers

(Governed by Ease of Construction, Strain induced effects, Seismic regions)

(Central or lateral Suspension of superstructure, cable configuration, Strain induced effects, Seismic regions)
3. Examples

**Single Plane Of Stay- Harp Shaped**

- Single Plane Of Stay- Harp Shaped
- Centrally Supported -Single Cell Box Girder With Wide cantilever (Deck Transversally Prestressed)
- Single Pylon With Single Pier , Monolithic with Superstructure
3. Examples

**Single Plane Of Stay- Semi-Fan Shaped**

- Single Plane Of Stay- Semi-Fan Shaped
- Centrally Supported Superstructure-Single Cell Box Girder With Wide Cantilever Supported by External Struts(Deck Transversally Pre-stressed)
- Single Pier , Superstructure supported on bearing
3. Examples

**Double Plane Of Stays- Semi-Fan Shaped**

- Double Plane Of Stays- Semi-Fan Shaped
- Laterally Supported Single Cell Box Girder
- Single Pier, Superstructure Integral to pier
3. Examples

**Double Plane Of Stays- Semi-Fan Shaped**

- Double Plane Of Stays- Semi-Fan Shaped
- Laterally Supported Single Cell Box Girder
- Single Pier , Superstructure resting on bearing
3. Examples

**Double Plane Of Stays- Semi-Fan Shaped**

- Double Plane Of Stays- Semi-Fan Shaped
- Laterally Supported Single Cell Box Girder
- Single Pier, Superstructure resting on bearing
4. Hardware

COMPLETE STAY ASSEMBLY
4. Hardware

Strands, Semi bonded individual sheath & Outer Duct

- Greased or Wax Strands – Climatic Condition
- Galvanization=190gm/m² (Min)
  =350gm/m² (Max)
- Greased Quantity /strand=5 to 12gm/m
- PE thickness of individual sheath=1.5mm (min)
- Min Friction Sheath & Strand=160 N /m Length

- HDPE stay pipe shall consist of a co-extruded high-density polyethylene, with a colored external layer and a black internal layer.
- Minimum thickness=6mm or dia/36
## 4. Hardware

### STRAND ALONE - Physical Properties

<table>
<thead>
<tr>
<th>Material Characteristics</th>
<th>EURONORM EN 10337</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Diameter (mm)</td>
<td>15.3</td>
</tr>
<tr>
<td>Minimum specified Ultimate stress (MPa)</td>
<td>1860</td>
</tr>
<tr>
<td>Nominal Area (mm^2)</td>
<td>140</td>
</tr>
<tr>
<td>Modulus Of Elasticity (MPa)</td>
<td>195000 +/- 5%</td>
</tr>
<tr>
<td>Fatigue &amp; Static Strength</td>
<td></td>
</tr>
<tr>
<td>Nos Of Cycle</td>
<td>2 millions</td>
</tr>
<tr>
<td>Upper Stress</td>
<td>0.45 U.T.S</td>
</tr>
<tr>
<td>Stress Range (MPa)</td>
<td>300</td>
</tr>
<tr>
<td>Minimum Fatigue Strength</td>
<td>Tensile force &gt;= 95% MUTS</td>
</tr>
</tbody>
</table>
4. Hardware

M/S VSL - STAY CABLE ANCHORAGE

Stay Anchorages - 12 nos to 121 nos of strands
4. Hardware

M/S DYWIDAG SYSTEM INTERNATIONAL-STAY CABLE ANCHORAGE

Stay Anchorages- 4 nos to 127nos of strands
4. Hardware

Selection Of Saddle (Over Pylon)

Design Objectives

• Passage of Extradosed Stay Cable Over Pylon
  (should be able to transfer radial forces to pylon with minimal horizontal forces)

• Should be able transfer unbalance force in stay on either side of pylon
  (without movement/slippage of strand inside saddle)

• Strand by Strand replacement is possible even during restricted movement of traffic
  (minimal Residual compressive stress required to be maintained in deck)

• Minimal force transferred to pylon in case of accidental breakage of stay

• It should be compact in size
4. Hardware

Selection Of Saddle (Over Pylon)

Fretting Corrosion

- It occurs due to contact between materials of comparable hardness subjected to transverse pressure.
- Small relative movement between adjacent materials
- Availability Of Oxygen
4. Hardware

SELECTION OF SADDLE

Single Tube Type

Multi-Mono Tube

Anchor Box Type
4. Hardware

SADDLE-STAY-ANCHORAGE LOAD TESTING

Saddle fatigue and tensile testing – Acc to fib Bulletin 30
4. Hardware

SINGLE TUBE - SADDLE
4. Hardware

M/S VSL-Patent Saddle System
4. Hardware

M/S VSL-Patent Saddle System
4. Hardware

FREYSSINET INTERNATIONAL-PATENT SADDLE SYSTEM
4. Hardware

M/s DYWIDAG –SYSTEM INTERNATIONAL–SADDLE PATENT SYSTEM

- Interstices filled with Grout
- Individual, curved Recess Pipes
- Curved Saddle Pipe
4. Hardware

 GENERIC-STEEL BEAM
4. Hardware

Stay Anchorage Anchored On Either Side Of Pylon
4. Hardware

GENERIC-STEEL BEAM
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

BARAPULLAH EXTRADOSED BRIDGE OVER RIVER YAMUNA, NEW DELHI
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

LONGITUDINAL ELEVATION & PLAN

LONGITUDINAL ELEVATION OF BRIDGE

PLAN OF BRIDGE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

CROSS-SECTION AT PIER LOCATION
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

TYPICAL CROSS-SECTION

[Diagram of typical cross-section showing dimensions and annotations such as "SLOPE 2.0%", "DECK SLAB WIDTH", "CARRIAGEWAY", and "CYCLE TRACK & PEDESTRAIN".]
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

STAY GEOMETRY
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

HINGE BEAM

- ACTIVE BEARING DURING SAGGING MOMENT
- ACTIVE BEARING DURING HOGGING MOMENT
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

ANALYTICAL MODEL OF EXTRADOSED BRIDGE

Solid Views
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

BRIDGE LOADING
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

Construction stage
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

AT END OF CONSTRUCTION STAGE (INFINITY)

STRESS DIAGRAM-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

PRESTRESS PRIMARY EFFECT

BM DIAGRAM-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

PRESTRESS PRIMARY EFFECT

AXIAL EFFECT DIAGRAM-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

PRESTRESS PRIMARY EFFECT

STRESS DIAGRAM-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

PRESTRESS SECONDARY EFFECT

BM DIAGRAM-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

PRESTRESS SECONDARY EFFECT

AXIAL EFFECT DIAGRAM-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

PRESTRESS SECONDARY EFFECT

STRESS DIAGRAM-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

DIFFERENTIAL SETTLEMENT OF PIER

BM ENVELOPE-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

DIFFERENTIAL SETTLEMENT OF PIER

STRESS ENVELOPE-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

IRC-6:-VEHICULAR LIVE LOAD-VERTICAL LOAD EFFECT

**CLASS-A FORWARD-Two Trains**

Direction Of movement Of Train

**CLASS-A BACKWARD-Two Trains**

Direction Of movement Of Trains
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

IRC-6: VEHICULAR LIVE LOAD-VERTICAL LOAD EFFECT

Direction Of movement Of Train

CLASS-70R WHEEL FORWARD - Two trains

TRAIN NO-1 = 13.4 Length

17.0 17.0 17.0 17.0 12.0 12.0 8.0

TRAIN NO-2 = 13.4 Length

17.0 17.0 17.0 17.0 12.0 12.0

CLASS-70R WHEEL BACKWARD - Two trains

TRAIN NO-1 = 13.4 Length

8.0 12.0 12.0 17.0 17.0 17.0

TRAIN NO-2 = 13.4 Length

8.0 12.0 12.0 17.0 17.0 17.0
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

IRC-6:-VEHICULAR LIVE LOAD-ERTICAL LOAD EFFECT

Direction Of movement Of Trains

70t

4.57m

Train No-1

30.0
(min)

Train No-2

70t

4.57m

IRC:6-Class 70R Track
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

IRC-6:-VEHICULAR LIVE LOAD-VERTICAL LOAD EFFECT

THREE LANES OF CLASS-A (TRANSVERSAL PLACEMENT)
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

IRC-6:-VEHICULAR LIVE LOAD-VERTICAL LOAD EFFECT

ONE LANE OF 70R-WHEELED/TRACKED + ONE LANE OF CLASS-A (TRANSVERSAL PLACEMENT)
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

IRC-6:-VEHICULAR LIVE LOAD-VERTICAL LOAD EFFECT

IMPACT FACTOR AND LANE FACTOR

APPROPRIATE IMPACT FACTOR TO BE TAKEN INTO ACCOUNT
(AS PER CLAUSE 208 OF IRC:6-2014)

APPROPRIATE LANE FACTOR TO BE TAKEN INTO ACCOUNT
(AS PER CLAUSE 205 OF IRC:6-2014)
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

POSITION OF VEHICLE-MOVING TRACER

MAX SAGGING MOMENT AT CENTER OF PENULTIMATE SPAN
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

POSITION OF VEHICLE-MOVING TRACER

MAX HOGGING MOMENT AT INTERIOR SUPPORT
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

IRC-6: VEHICULAR LIVE LOAD-VERTICAL LOAD EFFECT

BM ENVELOPE-SUPERSTRUCTURE

LIVE LOAD (INCL IMPACT) - VERTICAL - ENVELOPE OF BM DIAGRAM IN SUPERSTRUCTURE - (MAX / MIN)
(BM Is Drawn On Tension Side)
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

IRC-6:-VEHICULAR LIVE LOAD-VERTICAL LOAD EFFECT

STRESS ENVELOPE-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

IRC-6:-VEHICULAR LIVE LOAD-BRAKING / TRACTIVE EFFECT

STRESS ENVELOPE-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

IRC-6:- FOOTPATH LIVE LOAD EFFECT

BM ENVELOPE-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

IRC-6:- FOOTPATH LIVE LOAD EFFECT

STRESS ENVELOPE-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

IRC-6:-GLOBAL TEMP FALL/RISE(Thermal Effect)

BM ENVELOPE-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

IRC-6:-GLOBAL TEMP FALL/RISE(Thermal Effect)

STRESS ENVELOPE-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

IRC-6: DIFFERENTIAL TEMP GRADIENT FALL/RISE (Thermal Effect) ACROSS DEPTH OF SUPERSTRUCTURE

STRESS ENVELOPE - SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

PTI: STAY SUPERSTRUCTURE DIFFERENTIAL TEMP ALL/RISE (Thermal Effect)

BM ENVELOPE-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

PTI:-STAY SUPERSTRUCTURE DIFFERENTIAL TEMP ALL/RISE (Thermal Effect)

STRESS ENVELOPE-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

PTI: PYLON DIFFERENTIAL TEMP FALL/RISE GRADIENT (Thermal Effect)

BM ENVELOPE-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

PTI: Pylon Differential Temp Fall/Rise Gradient (Thermal Effect)

STRESS ENVELOPE - SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

THERMAL LOAD EFFECTS

STRESS ENVELOPE-SUPERSTRUCTURE

[Graph showing thermal load stresses and envelope of stresses in superstructure with various stress levels and locations along the half length of the bridge.]
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

IRC-6 RARE LOAD COMBINATION (Service Condition)
(LIVE LOAD – LEADING WITH THERMAL LOAD ACCOMPANYING)

STRESS ENVELOPE - SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

IRC-6 RARE LOAD COMBINATION (Service Condition)
(LIVE LOAD – LEADING WITH THERMAL LOAD ACCOMPANYING)

STRESS ENVELOPE-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

IRC-6 RARE LOAD COMBINATION (Service Condition)
THERNAL LOAD—LEADING WITH THERMAL LOAD ACCOMPANYING)

STRESS ENVELOPE-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

IRC-6 RARE LOAD COMBINATION (Service Condition)
(WIND LOAD –LEADING WITH THERMAL LOAD ACCOMPANYING)

STRESS ENVELOPE-SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

IRC-6 RARE LOAD COMBINATION (Service Condition)

STRESS ENVELOPE-SUPERSTRUCTURE

SLS-1 ENVELOPE OF ALL RARE LOAD COMBINATION STRESSES IN SUPERSTRUCTURE \((\text{MAX/\text{MIN} - \text{TOP}/\text{BOT FIBRE})\) AS PER TABLE 3.3 OF ANNEX B OF IRC-6

HALF LENGTH OF BRIDGE (m)

- \(C_{b1} - \text{Max (TOP FIBRE)}\)
- \(C_{b3} - \text{Max (BOTTOM FIBRE)}\)
- \(C_{b1} - \text{Min (TOP FIBRE)}\)
- \(C_{b3} - \text{Min (BOT FIBRE)}\)
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

SEISMIC ANALYSIS

- Multi Model Response Spectrum Analysis
  - Linear Analysis
  - Response spectrum defines acceleration of structure relative to period of oscillation
  - Response spectrum as per IRC-6:-2014
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

SEISMIC ANALYSIS

- Multi Modal Response Spectrum Analysis
  - Individual modes of vibration determined by Midas
    - Period of oscillation
    - Mass participation
  - For each mode acceleration is determined from the response spectrum
    - Force effects determined based on mass and acceleration
  - Effects of all considered modes combined
    - Method determined by standard
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

SEISMIC ANALYSIS

Predominant Mode- Longitudinal (X-Direction)

Mode-2
(T=1.1 Sec)
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

SEISMIC ANALYSIS

Predominant Mode - Vertical (Z-Direction)

Mode-5
(T=0.92 Sec)
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

SEISMIC ANALYSIS

Predominant Mode - Transverse (Y-Direction)

Mode-14
(T = 0.37 Sec)
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

ACCIDENTAL CHECKS-SETRA

14.2.8 Accidental cable-stay breakage

The action resulting from accidental breakage of one cable stay at a time should be taken into account. Breakage is represented by a force exerted at both anchorages in the direction opposite to cable-stay tension, and weighted by a dynamic amplification factor of between 1.5 and 2.0 (to be substantiated).

The dynamic amplification factor depends on the type of breakage (vehicle impact, corrosion, etc.) and on the dynamic response of the structure. A dynamic amplification factor of 2.0 is a particularly severe envelope value corresponding to the improbable case of sudden failure of the entire cable. There is a detailed analysis of the dynamic effects of bridge cable-stay breakage in [17].

For cable stays made up of independent MTEs (PSC, PWC), since it is highly unlikely that all the MTEs would break simultaneously, the amplification factor can be reduced to 1.5.
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

ACCIDENTAL CHECKS

LOSS OF STAY CABLES
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

MULTIPLE STRESSING OF STAYS

DESIGN CONSIDERATIONS

- SIMULTANEOUS STRESSING OF STAYS ON EITHER SIDE OF PYLON (IF STRUCTURE IS HAVING TWO PLANE OF STAYS, BOTH THE PLANES SHALL BE STRESSED SIMULTANEOUSLY).
- MINIMUM STRESS LEVEL IN STAY AT FIRST JACKING.
- MINIMUM ELONGATION OF STAY TO BE ACHIEVED AFTER EACH STRESSING OF STAY.
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

EXTRADOSED STAYS

SERVICEABLE CHECK FOR STAYS

SETRA -

\[ F_{sls} \ll 0.46 \left( \frac{\Delta F_{Freq}}{140} \right)^{-0.25} \]

JAPANESE

\[ f_a = \begin{cases} 
0.6f_{pu} & \Delta \sigma_L \leq 70\text{MPa} \\
(1.067 - 0.00667\Delta \sigma_L)f_{pu} & 70\text{MPa} \leq \Delta \sigma_L \leq 100\text{MPa} \\
0.4f_{pu} & \Delta \sigma_L \geq 100\text{MPa} 
\end{cases} \]

PTI = 0.45 Fpu
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

EXTRADOSED STAYS

ULTIMATE LIMIT STATE CHECK REQUIREMENT-SETRA

14.8.1 Ultimate limit states

The tension of an extradosed prestressing tendon under the effect of fundamental ULS combinations must prove:

\[ F_{ULS} \leq \frac{F_{GUTS}}{\gamma_m \gamma_{m2}} \]

If the extradosed prestressing system has been qualified by the category B mechanical test defined in Chapter 11, partial safety factor \( \gamma_m \) is 1.15. If not, \( \gamma_m \) is 1.30. Because of the limited sensitivity to wind effects, partial safety factor \( \gamma_{m2} \) is 1.15 for extradosed prestressing tendons.

<table>
<thead>
<tr>
<th>Category of utilization</th>
<th>Category B (cable stay)</th>
<th>Category A (extradosed prestress, etc.)</th>
<th>External prestress (for reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial range ( \Delta \sigma )</td>
<td>200 MPa</td>
<td>140 MPa</td>
<td>80 MPa</td>
</tr>
<tr>
<td>Angular range ( \Delta \alpha )</td>
<td>10 mrad</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>( \sigma_{max} )</td>
<td>0.45 ( f_{class} )</td>
<td>0.55 ( f_{class} )</td>
<td>0.65 ( f_{class} )</td>
</tr>
<tr>
<td>( \alpha_{max} )</td>
<td>10 mrad</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>( \sigma_{min} )</td>
<td>0.45 ( f_{class} ) - 200 MPa</td>
<td>0.55 ( f_{class} ) - 140 MPa</td>
<td>0.65 ( f_{class} ) - 80 MPa</td>
</tr>
<tr>
<td>( \alpha_{min} )</td>
<td>0 mrad</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSEd BRIDGE

EXTRADOSEd STAYS

Stay Cable - ULS & SLS Check

<table>
<thead>
<tr>
<th>Stay Cable</th>
<th>ULS Stresses in Stay</th>
<th>SLS Stresses in Stay</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>0.60 U.T.S</td>
<td>0.75 U.T.S</td>
</tr>
<tr>
<td>S2</td>
<td>0.60 U.T.S</td>
<td>0.75 U.T.S</td>
</tr>
<tr>
<td>S3</td>
<td>0.60 U.T.S</td>
<td>0.75 U.T.S</td>
</tr>
<tr>
<td>S4</td>
<td>0.60 U.T.S</td>
<td>0.75 U.T.S</td>
</tr>
<tr>
<td>S5</td>
<td>0.60 U.T.S</td>
<td>0.75 U.T.S</td>
</tr>
<tr>
<td>S6</td>
<td>0.60 U.T.S</td>
<td>0.75 U.T.S</td>
</tr>
</tbody>
</table>
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

CONSTRUCTION STAGE LOAD EFFECTS

DIFFERENTIAL DEAD LOAD (G)

DIFFERENTIAL DEAD LOAD (G)
(By having differential ULS load factor on left side of cantilever & right side of cantilever.)
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

CONSTRUCTION STAGE LOAD EFFECTS

CONSTRUCTION LIVE LOAD (qca, qcb & Fcb)

- Fcb = 100 kN
- qca = 0.48 kN/m² x 20.8 m = 9.984 kN/m
- qcb = 0.2 kN/m² x 20.8 m = 4.16 kN/m
- qca = 0.24 kN/m² x 20.8 m = 4.992 kN/m

CONSTRUCTION LIVE LOAD (qca, qcb & Fcb)

(a) HAVING DIFFERENT CONSTRUCTION LIVE LOAD (qca) ON LEFT SIDE OF CANTILEVER & RIGHT SIDE OF CANTILEVER.
(b) ADDITIONAL DISTRIBUTED LOAD (qcb) COVERING NEARLY FOUR SEGMENTS ON LEFT SIDE OF CANTILEVER.
(c) ADDITIONAL CONSTRUCTION EQUIPMENT LOAD (Fcb) AT TIP OF LEFT SIDE OF CANTILEVER.
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

CONSTRUCTION STAGE LOAD EFFECTS

LIFTING GANTRY WT + COUNTER WT + RAIL WT. ($Q_{cc}$)
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

CONSTRUCTION STAGE LOAD EFFECTS

Accidental Release (Fa) Of Precast Segment

ACCIDENTAL RELEASE (Fa) OF PRECAST SEGMENT (SEG-S16 ON RIGHT SIDE OF CANTILEVER)
(100% REVERSE IMPACT TAKEN ON RIGHT SIDE OF CANTILEVER WHILE SEGMENT ON LEFT SIDE OF CANTILEVER IS HELD BY LIFTER)
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

TRANSVERSE MODEL OF SUPERSTRUCTURE

2D Model - For Superstructure - For DL, SIDL, FPLL, Pre-stressing Effects
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

TRANSVERSE MODEL OF SUPERSTRUCTURE

2D MODEL-Tendon Primary / Secondary Diagram

Tendon Primary

Tendon Secondary
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

TRANSVERSE MODEL OF SUPERSTRUCTURE
3D FEM MODEL - FOR LIVE LOAD EFFECTS
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

SPAN FEM MODEL

3D FEM MODEL - STAY STRESSING EFFECT OF SUPERSTRUCTURE
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

SEGMENT FEM MODEL

3D FEM MODEL - LIFTING OF SEGMENT
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

FEM MODEL

3D FEM MODEL-SADDLE-Von-Mises Stresses
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

SUPERSTRUCTURE STAY JUNCTION

DECK CABLE – WEB CABLE- STAY CABLES PROFILE-CLASHING
5. DESIGN EXAMPLE - BARAPULLAH EXTRADOSED BRIDGE

SUPERSTRUCTURE STAY JUNCTION
CABLE STAY BLISTER
THANK YOU