NCHRP 12-71
Design of Horizontally Curved Concrete Box Girder Highway Bridges

by

Richard V. Nutt, Robert Dameron, Toorak Zokaie,
Kent Cordtz, Charles M. Redfield and Robert N. Valentine

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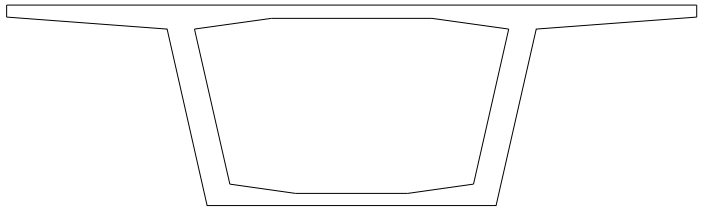
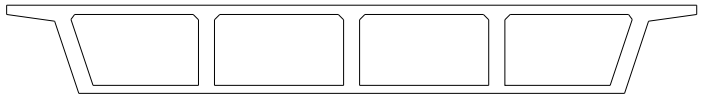
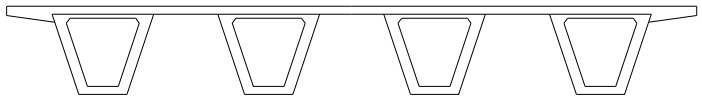
Box-Girder Types



Single-cell Box Girder



Multi-cell Box Girder



Spread Box Beams

Problems Experienced with Curved Box-Girder Bridges

- Bearing Failures
- Concrete Cracking
- Unanticipated Distortions
- Prestress Tendon Breakout

Example of Bearing and Distortion Problem

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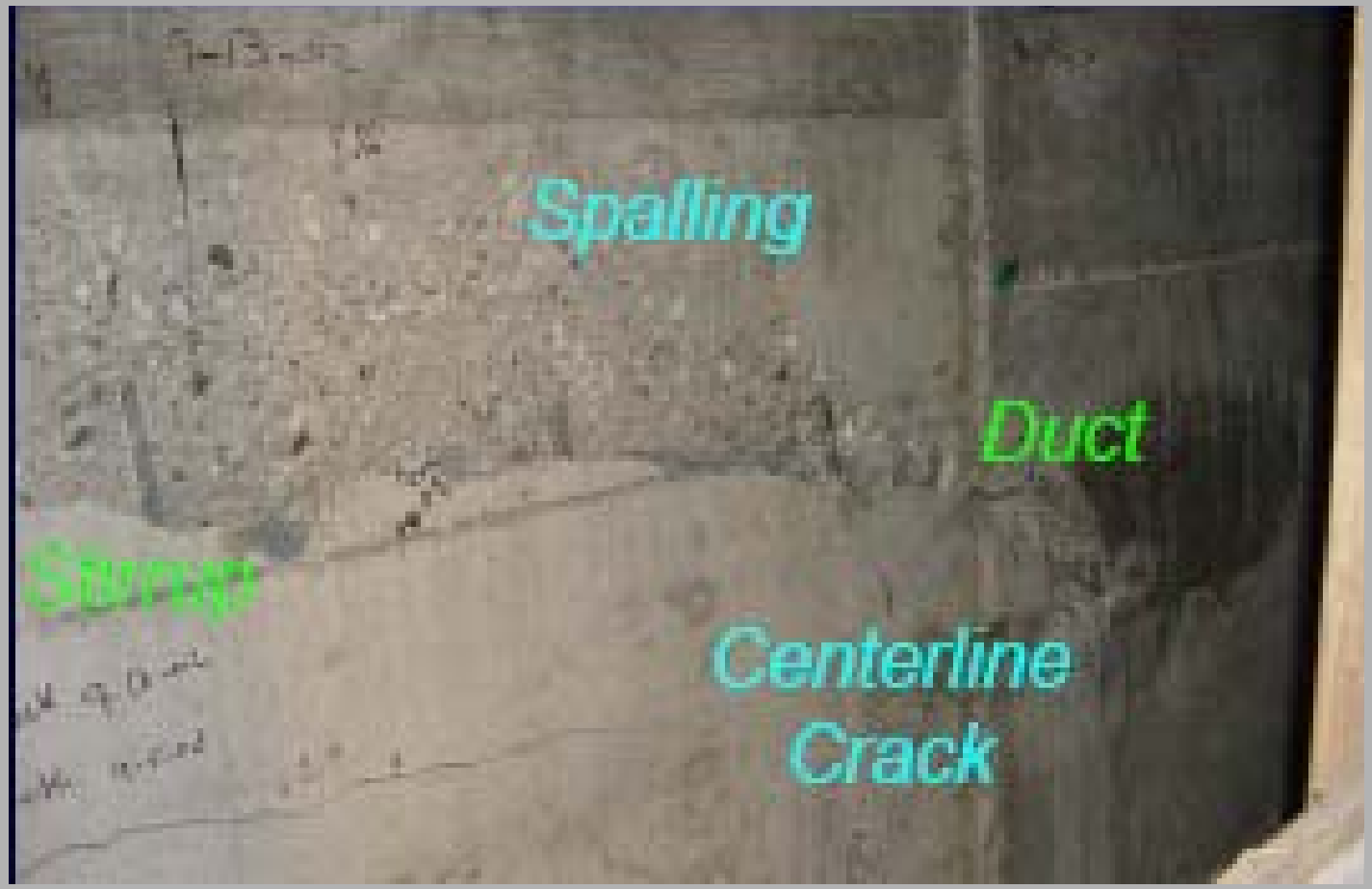
Example of Prestress Tendon Breakout Failure



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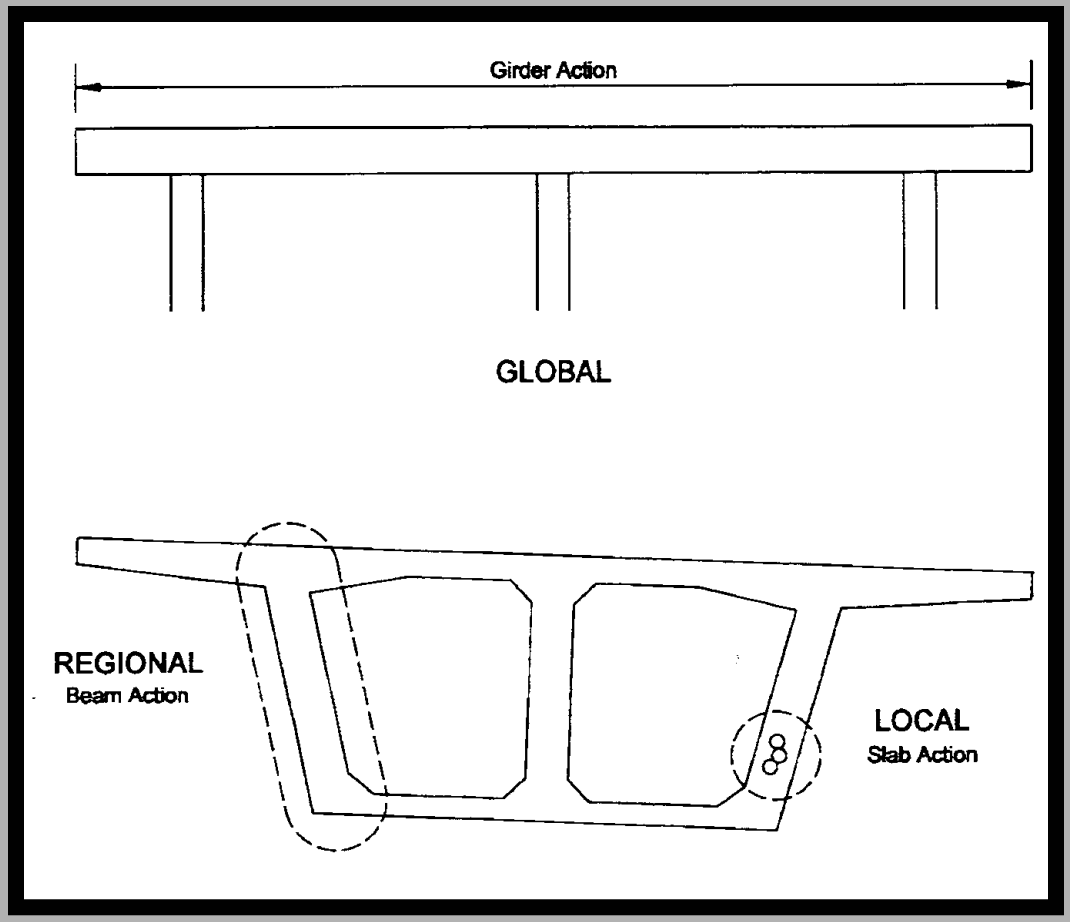
Response of Curved Box-Girder Bridges



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Global Response Analysis

- Model Verification
- Parameter Studies
- Special Studies
  - Diaphragms
  - Bearings
  - Skew
  - Creep

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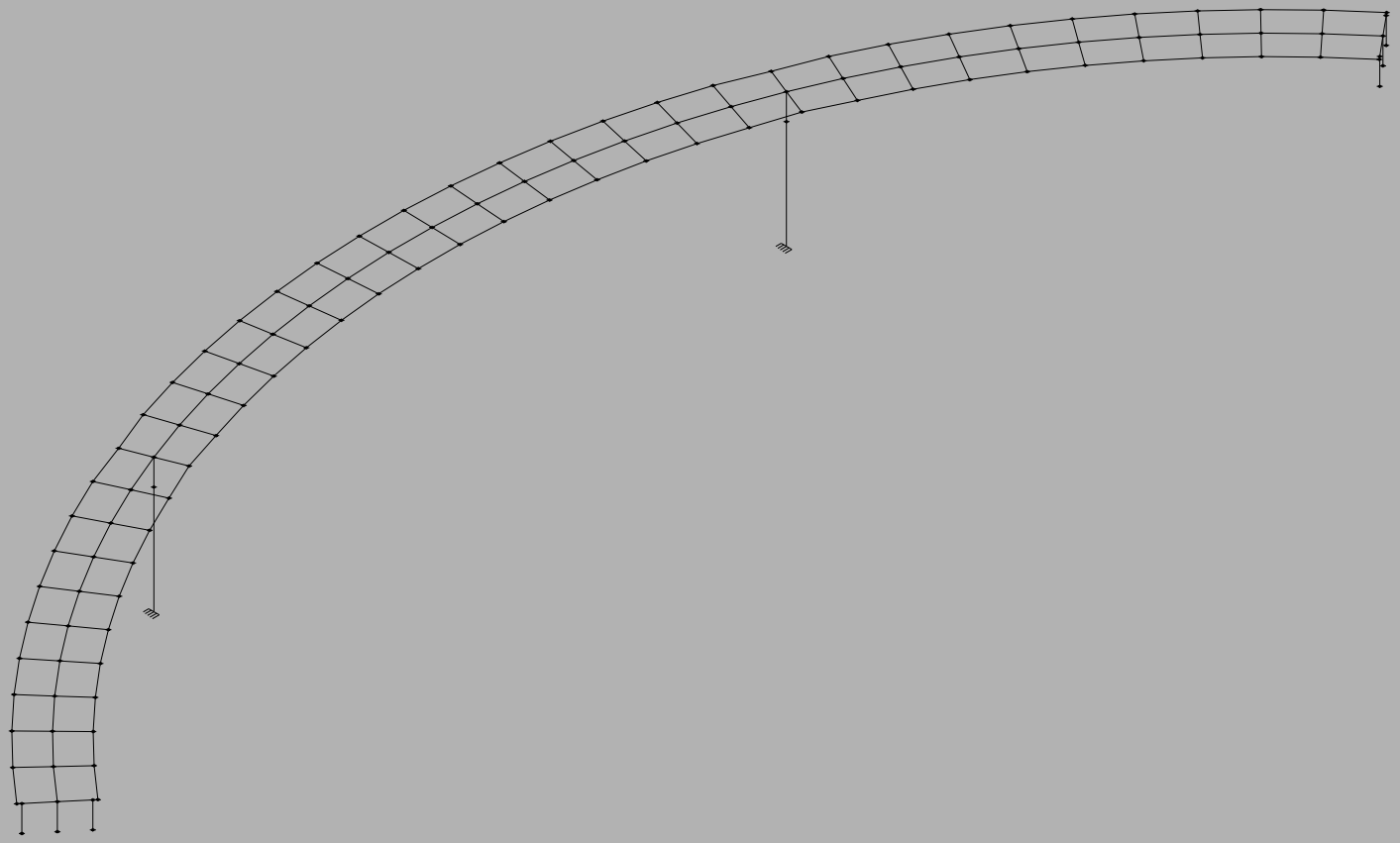
Grillage Model



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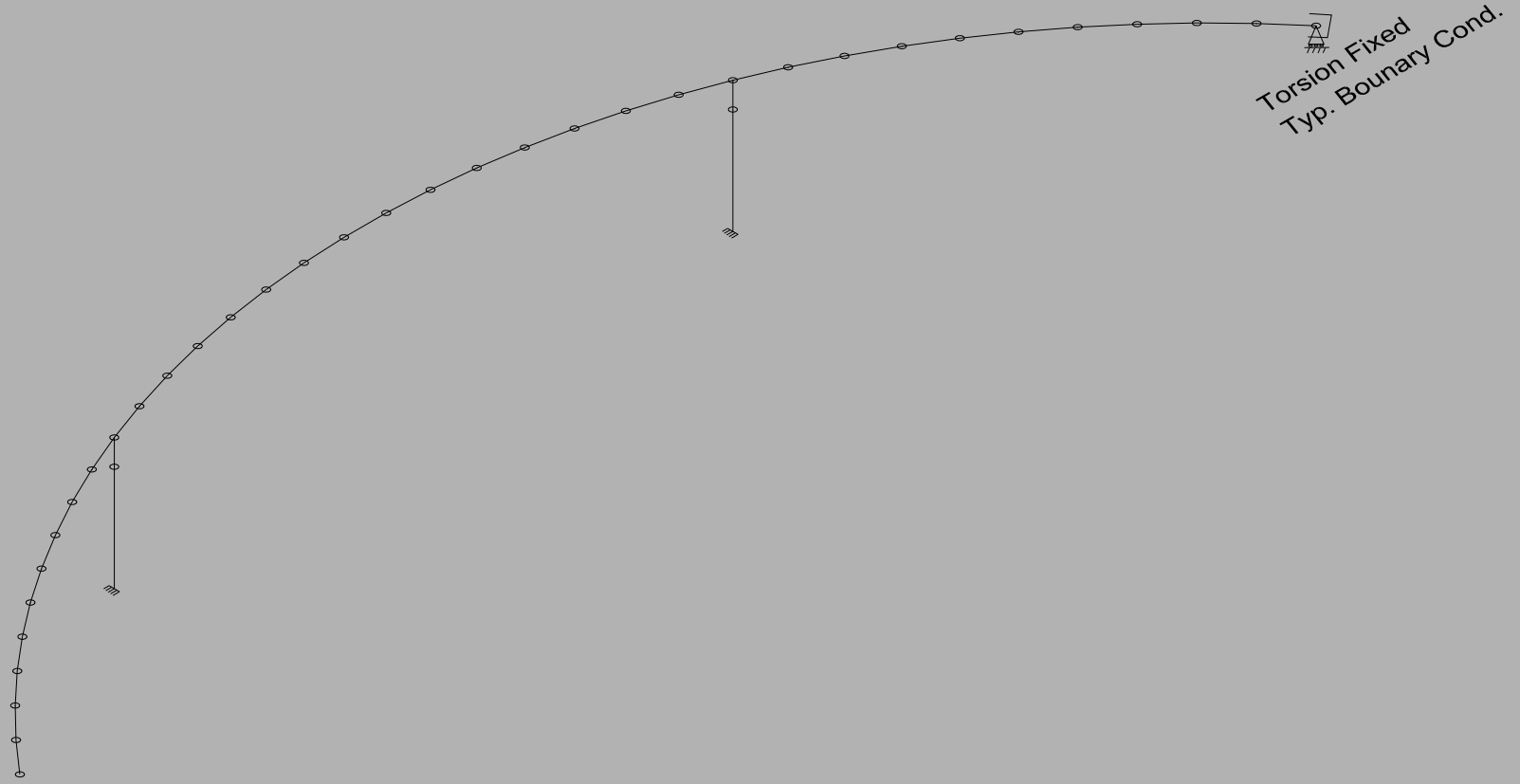
Spine Model



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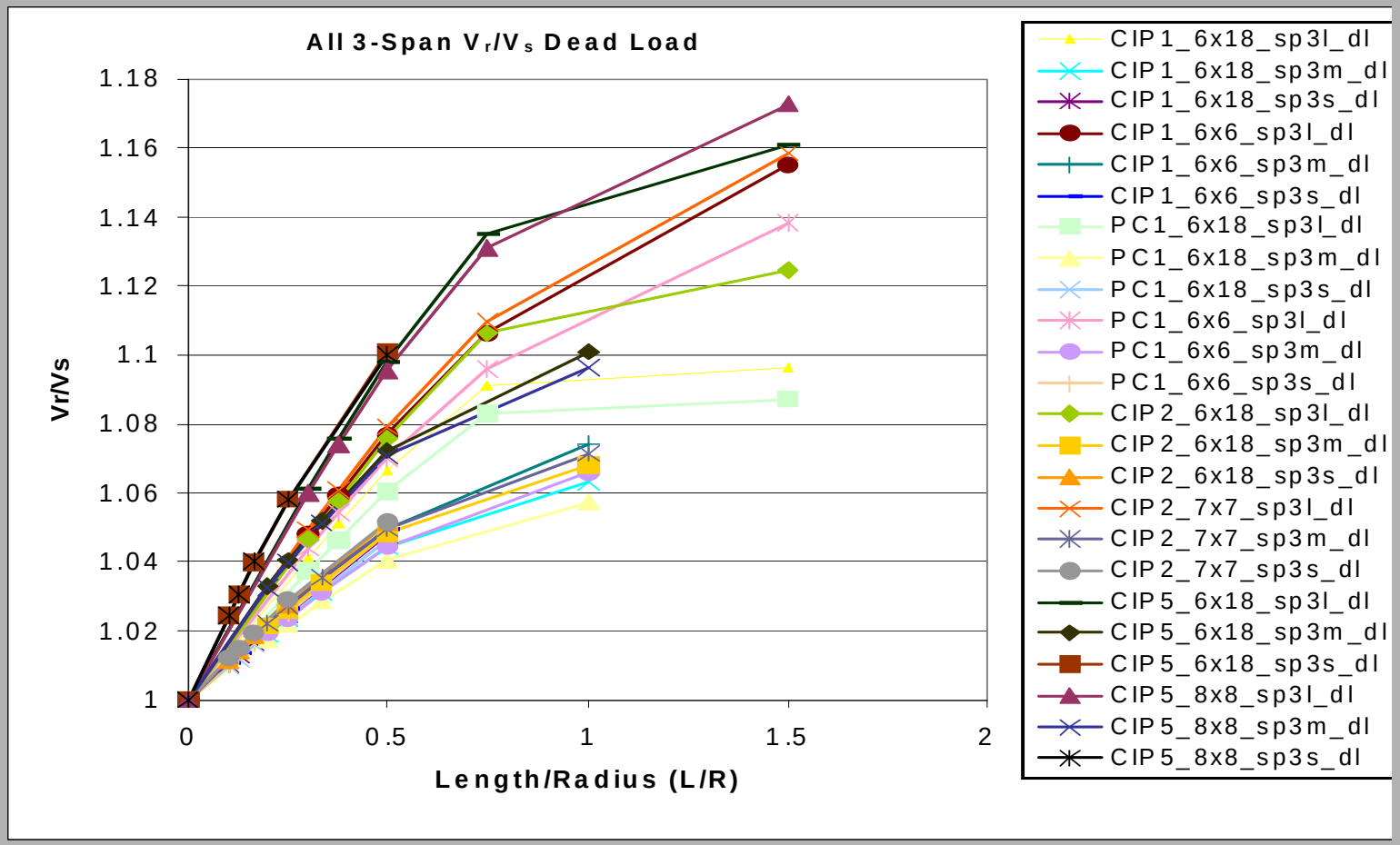
Parameter Studies

- Span Configuration
- Span Length
- Cross-Section Geometry and Type
- Pier Type
- Radius of Curvature

Dead Load Shear in Outside Web (Curved vs. Straight)



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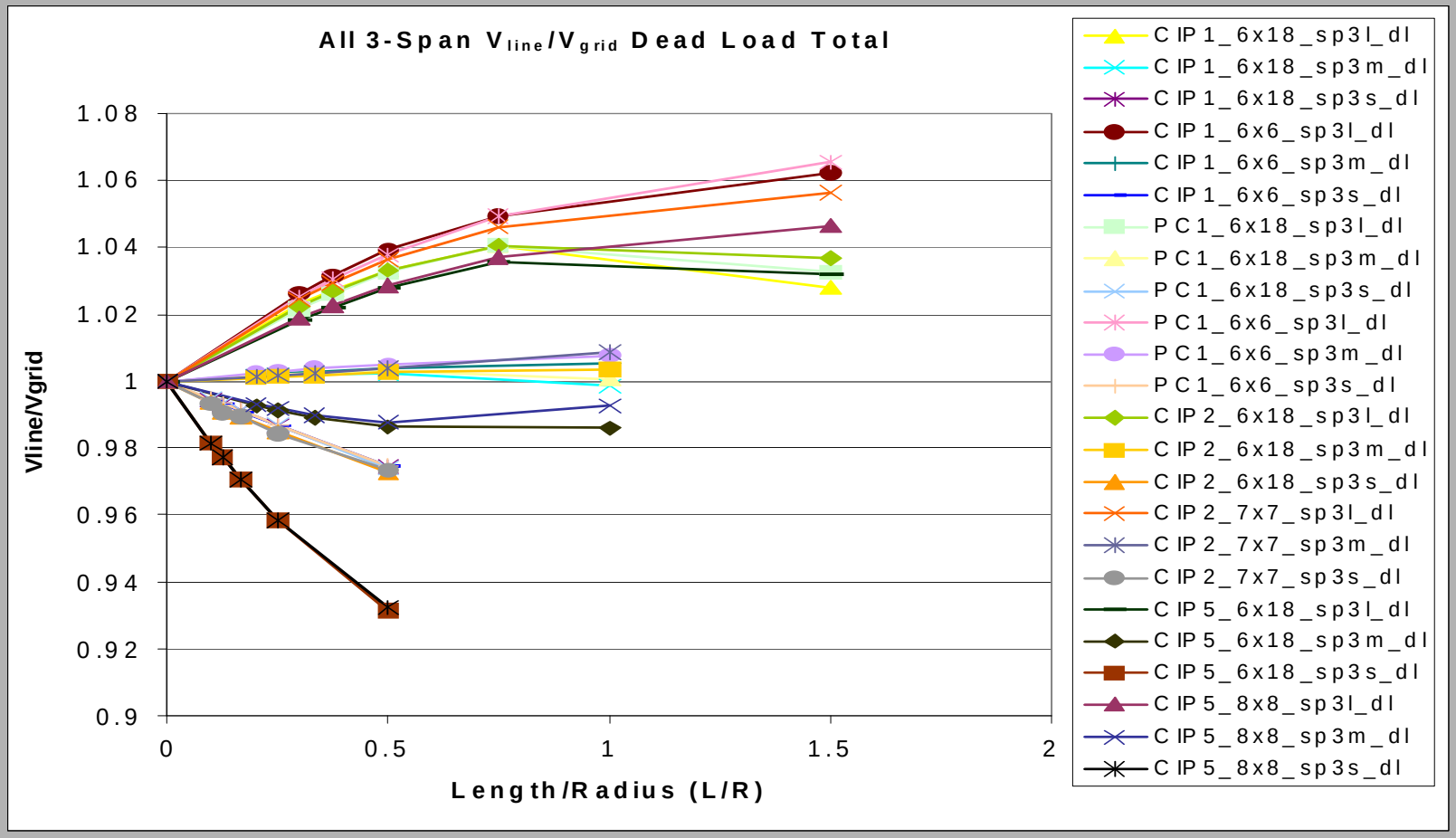
Dead Load Shear in Outside Web (Spine vs. Grillage)



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Conclusions of Parameter Studies

- Plane Frame Acceptable if L/R < 0.2
- Spine Model Acceptable if L/R < 0.8 and L/W > 2.0
- Detailed 3D Analysis Required when L/R > 0.8 and/or L/W < 2.0
- Effect of Torsion must be considered for Design of Bearings and Web Shear

Conclusions of Special Studies

- Interior Diaphragms have Minimal Effect on Global Response
- Modelling Recommendations are Equally Applicable for Integral and Non-integral Bent Caps
- Skew does not have a Special Effect on Curved Bridges
- Consider Long-Term Creep when Designing Bearings

Regional and Local Response Analysis

- Model Validation
- Parameter Studies for Multi-Cell Box Girders
- Parameter Studies for Single-Cell Box Girders

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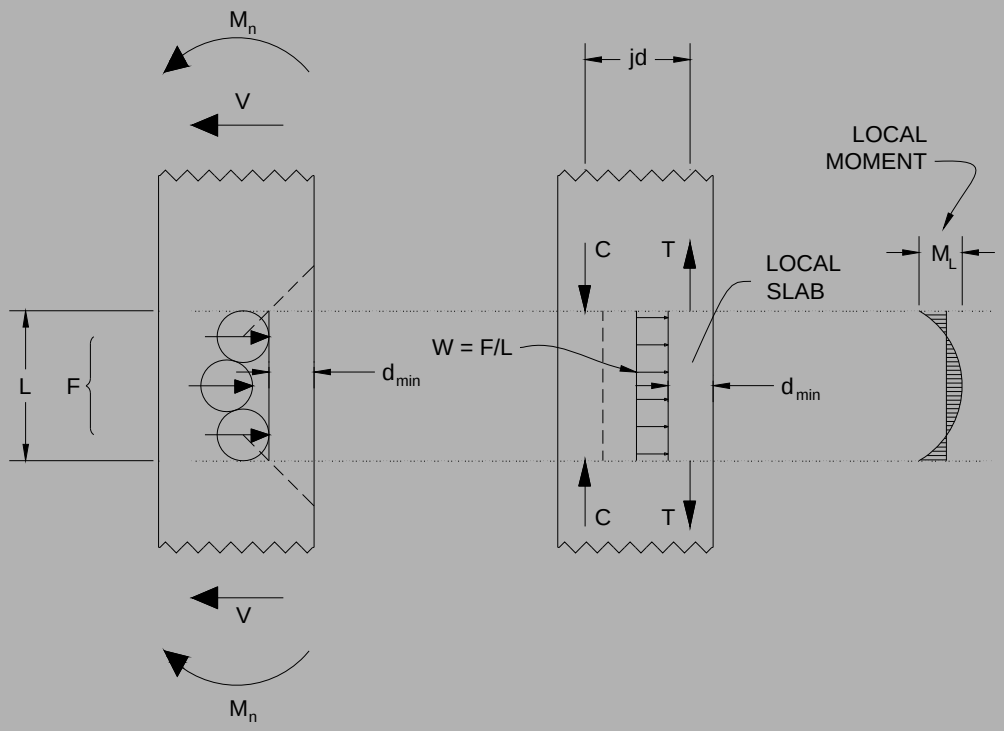
Features of FEM Analysis

- ABAQUS
  - Widely used nonlinear FE program
  - Includes smeared cracking & rebar subelements
  - 20 years experience with program
- Extensive experimental validation
- Widely applied to RC bridge components
- Used on I-405/55 HOV forensic studies

Regional and Local Actions



V ~ F/2 T ~ M_n /(jd) M_L ~ FL/12

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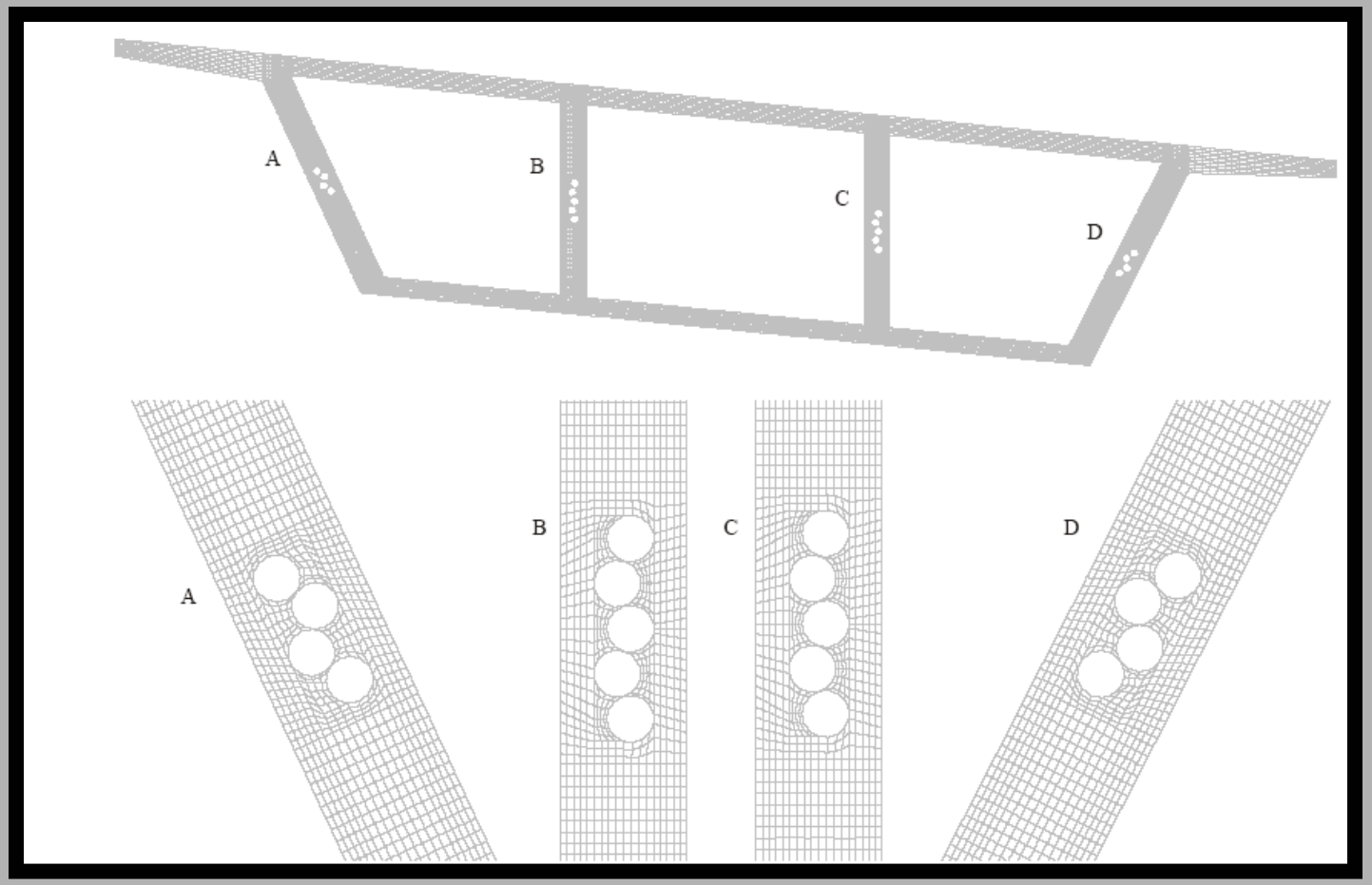
Finite Element Mesh for Multi-cell Box Girder



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Conclusions of Parameter Study

- Radial Prestressing Force
  - Breakout failures dependant on radial forces
- Web Depth
  - Regional moments increase with web depth
- Web Thickness
  - Increase in resistance to breakout failure increases with web thickness
  - Locating ducts toward outside of curve increases resistance to breakout failure

Conclusions of Parameter Study

- Exterior vs Interior Webs
  - Exterior webs have larger regional moments
- Web Slope
  - Most of the reduction in web resistance to breakout failure of sloped webs is attributed to their being exterior webs
  - A slight increase in the resistance of sloped webs on the inside of the curve vs. those on the outside of the curve was observed

Conclusions of Parameter Study

- Cover Thickness
  - Greater stirrup cover increases local resistance to breakout failure but reduces resistance to regional transverse web bending
- Number and Configuration of Ducts
  - Vertical duct separation increases breakout resistance
  - Number of vertically stacked ducts without space should be limited to three

Conclusions of Parameter Study

- Number and Configuation of Duct Ties
  - Web/duct ties are very effective in resisting breakout failure
- Vertical Location of Ducts
  - Ducts located at 1/4 height of the web or near the bottom (or top) of the web fail at a lower radial force

Conclusions of Parameter Study

- Stirrups
  - Stirrups have a major effect on regional web failures but are not very effective in preventing local breakout failure
- Concrete Material Properties
  - Increased concrete strength effective in preventing local breakout failures only if web/duct ties are not provided

Regional Transverse Bending

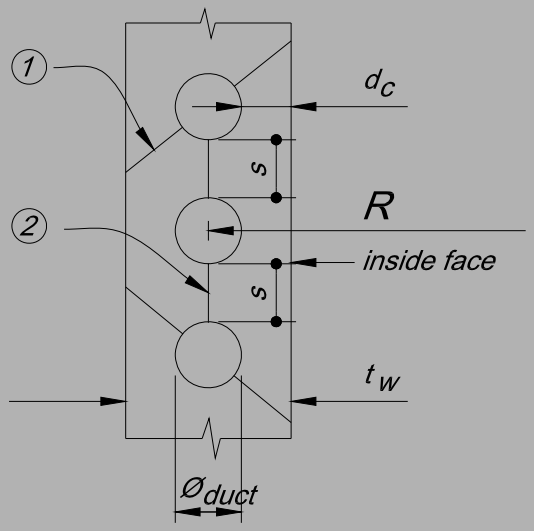
$$M_u = (\text{Load Factor})\ (\text{Moment Fixity Factor})\ (1/4)\ (Pj/R)\ h_c$$

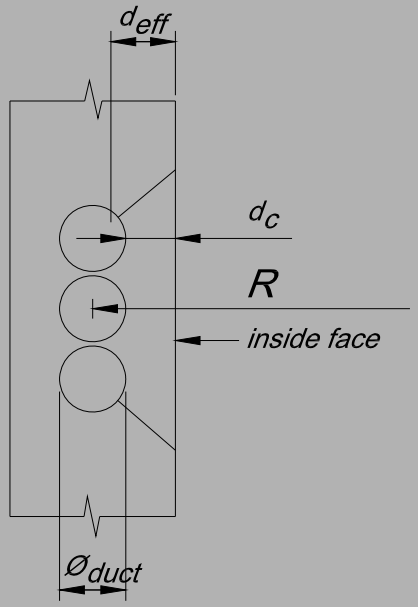
Local Lateral Shear

$$V_d = P_j/R \div 2$$

$$V_c = \phi 24 \, d_{eff} \sqrt{f'_c}$$

Definition of d_{eff}





For "s" ≥ Ø duct

d_{eff} = lesser of :

① $d_{eff} = t_w - \frac{Ø_{duct}}{2}$

② $d_{eff} = d_c + \frac{Ø_{duct}}{4} + \frac{\Sigma s}{2}$

For Single Ducts or for "s" < Ø duct

$d_{eff} = d_c + \frac{Ø_{duct}}{4}$

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Cover Concrete Cracking

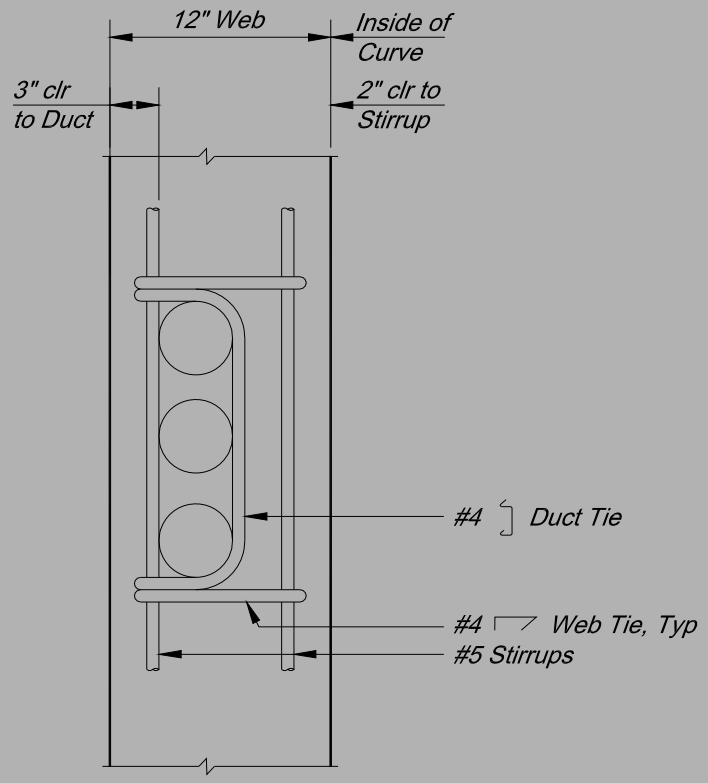
$$M_{ends} = \frac{wL^2}{12} = (\mathrm{Pj/R} / L)L^2 / 12$$

$$M_{center} = \frac{wL^2}{24}$$

L is the height of the duct bank

$$\mathrm{I} = \frac{bd_c^3}{12}$$

Web/Duct Tie Detail



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References

- NCHRP Report 620
- Appendix A - LRFD Specifications and Commentary
- Appendix B - Example Problems
- Appendix C - Global Analysis Guidelines
- Appendix D - State of Practice Survey Results
- Appendix E - Detailed Global Analysis Results
- Appendix F - Detailed Local Analysis Results
- TRB Website - http:/trb.org/news/blurb_detail.asp?id=9596