# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>SECTION</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXECUTIVE SUMMARY</td>
<td>ii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>iv</td>
</tr>
<tr>
<td>LIST OF ILLUSTRATIONS</td>
<td>xii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>vii</td>
</tr>
<tr>
<td>1.0 INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2.0 STATEMENT OF PROBLEM/SCOPE OF WORK</td>
<td>2</td>
</tr>
<tr>
<td>3.0 OBJECTIVES</td>
<td>2</td>
</tr>
<tr>
<td>3.1 Geotechnical Databases</td>
<td>2</td>
</tr>
<tr>
<td>3.2 Site Specific Earthquake Hazards Assessments</td>
<td>3</td>
</tr>
<tr>
<td>4.0 MISSOURI DEPARTMENT OF TRANSPORTATION GEOTECHNICAL DATABASE</td>
<td>3</td>
</tr>
<tr>
<td>4.1 Design</td>
<td>3</td>
</tr>
<tr>
<td>4.1.1 Design Approach</td>
<td>4</td>
</tr>
<tr>
<td>4.1.2 A Geotechnical Generic Example</td>
<td>5</td>
</tr>
<tr>
<td>4.1.3 Analysis and Data Structure</td>
<td>6</td>
</tr>
<tr>
<td>4.2 Implementation</td>
<td>8</td>
</tr>
<tr>
<td>4.3 Link to Spatial Database (GIS)</td>
<td>8</td>
</tr>
<tr>
<td>5.0 SITE CHARACTERIZATION PROCEDURES</td>
<td>8</td>
</tr>
<tr>
<td>5.1 Field Investigations</td>
<td>8</td>
</tr>
<tr>
<td>5.1.1 Drilling and Sampling</td>
<td>9</td>
</tr>
<tr>
<td>5.1.2 Test Pits</td>
<td>9</td>
</tr>
<tr>
<td>5.1.3 Cone Penetrometer Testing</td>
<td>9</td>
</tr>
<tr>
<td>5.1.4 Surface Mapping</td>
<td>9</td>
</tr>
<tr>
<td>5.1.5 Interviews with Local Personnel</td>
<td>10</td>
</tr>
<tr>
<td>5.2 Laboratory Investigations</td>
<td>10</td>
</tr>
<tr>
<td>5.2.1 Missouri Department of Transportation Laboratory Soil Testing</td>
<td>10</td>
</tr>
<tr>
<td>5.2.2 University of Missouri-Rolla Laboratory Soil Testing</td>
<td>10</td>
</tr>
<tr>
<td>5.2.2.1 Consolidated Undrained (CU) Triaxial Tests</td>
<td>11</td>
</tr>
<tr>
<td>5.2.2.2 Cyclic Triaxial Tests</td>
<td>11</td>
</tr>
<tr>
<td>5.3 Base Rock Motion Determination</td>
<td>11</td>
</tr>
<tr>
<td>5.3.1 Current Peak Ground Acceleration</td>
<td>11</td>
</tr>
<tr>
<td>5.3.2 Magnitudes and Distances for the Recommended Acceleration Values</td>
<td>12</td>
</tr>
<tr>
<td>5.3.3 Time Histories</td>
<td>12</td>
</tr>
<tr>
<td>Section</td>
<td>Title</td>
</tr>
<tr>
<td>---------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>5.4</td>
<td>Seismic Response of Soil</td>
</tr>
<tr>
<td>5.4.1</td>
<td>Wave Propagation Analysis</td>
</tr>
<tr>
<td>5.4.2</td>
<td>Liquefaction Analysis</td>
</tr>
<tr>
<td>5.5</td>
<td>Slope Stability of Abutment Fills</td>
</tr>
<tr>
<td>5.5.1</td>
<td>Soil Property Estimation</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Groundwater Elevation Selection</td>
</tr>
<tr>
<td>5.5.3</td>
<td>Design Horizontal and Vertical Earthquake Accelerations</td>
</tr>
<tr>
<td>5.5.4</td>
<td>Flood Hazard Analysis</td>
</tr>
<tr>
<td>6.0</td>
<td>PROCEDURES FOR SEISMIC CONDITION ASSESSMENT OF BRIDGES AND ABUTMENTS</td>
</tr>
<tr>
<td>6.1</td>
<td>Global Performance Goals</td>
</tr>
<tr>
<td>6.1.1</td>
<td>American Association of State Highway and Transportation</td>
</tr>
<tr>
<td>6.1.2</td>
<td>Bridges Along US 60</td>
</tr>
<tr>
<td>6.2</td>
<td>Engineering Performance Criteria</td>
</tr>
<tr>
<td>6.2.1</td>
<td>Performance Assessment</td>
</tr>
<tr>
<td>6.2.2</td>
<td>Seismic Demand</td>
</tr>
<tr>
<td>6.2.3</td>
<td>Seismic Capacity</td>
</tr>
<tr>
<td>6.2.4</td>
<td>Acceptable Damage</td>
</tr>
<tr>
<td>6.3</td>
<td>Analysis Procedures</td>
</tr>
<tr>
<td>6.3.1</td>
<td>Computer Modeling of Bridges</td>
</tr>
<tr>
<td>6.3.1.1</td>
<td>Design Ground Motions</td>
</tr>
<tr>
<td>6.3.1.2</td>
<td>Analysis Procedure</td>
</tr>
<tr>
<td>6.3.2</td>
<td>Computer Modeling of Abutments</td>
</tr>
<tr>
<td>7.0</td>
<td>REGIONAL GEOLOGY AND GEOTECHNICAL DATA</td>
</tr>
<tr>
<td>7.1</td>
<td>Regional Geology</td>
</tr>
<tr>
<td>7.2</td>
<td>Summary of Field and Laboratory Data</td>
</tr>
<tr>
<td>8.0</td>
<td>RESULTS OF SITE SPECIFIC STUDIES</td>
</tr>
<tr>
<td>8.1</td>
<td>St. Francis River Bridge Site</td>
</tr>
<tr>
<td>8.1.1</td>
<td>Site Geology</td>
</tr>
<tr>
<td>8.1.2</td>
<td>Selected Base Rock Motion</td>
</tr>
<tr>
<td>8.1.3</td>
<td>Seismic Response of Soil</td>
</tr>
<tr>
<td>8.1.3.1</td>
<td>Horizontal Seismic Response of Soil</td>
</tr>
<tr>
<td>8.1.3.2</td>
<td>Resulting Ground Motion Time Histories</td>
</tr>
<tr>
<td>8.1.3.3</td>
<td>Vertical Seismic Response of Soil</td>
</tr>
<tr>
<td>8.1.4</td>
<td>Liquefaction Potential Analysis</td>
</tr>
<tr>
<td>8.1.4.1</td>
<td>Cyclic Stress Ratio (CSR), Cyclic Resistant Ratio (CRR) and Factor of Safety (FOS)</td>
</tr>
<tr>
<td>8.1.5</td>
<td>Slope Stability of Abutment Fills</td>
</tr>
<tr>
<td>8.1.6</td>
<td>Flood Hazard Analysis Results</td>
</tr>
<tr>
<td>8.1.7</td>
<td>Structure Response of Bridges and Abutments</td>
</tr>
<tr>
<td>8.1.7.1</td>
<td>New St. Francis River Bridge</td>
</tr>
<tr>
<td>8.1.7.1.1</td>
<td>Bridge Description</td>
</tr>
<tr>
<td>8.1.7.1.2</td>
<td>Bridge Model and Analysis</td>
</tr>
</tbody>
</table>
8.1.7.1.3 Detailed Description of Bridge Evaluation  76
8.1.7.1.3.1 Load Combination Rule  77
8.1.7.1.3.2 Minimum Support Length and C/D Ratio for Bearing  77
8.1.7.1.3.3 C/D Ratios for Shear Force at Bearings  77
8.1.7.1.3.4 C/D Ratios for Columns/Piers  78
8.1.7.1.3.5 C/D Ratios for Hooked Anchorage in Columns  84
8.1.7.1.3.6 C/D Ratios for Splices in Longitudinal Reinforcement  84
8.1.7.1.3.7 C/D Ratio for Transverse Confinement  85
8.1.7.1.3.8 C/D Ratio for Column Shear  85
8.1.7.1.3.9 C/D Ratio for Diaphragm and Cross-Frame Members  87
8.1.7.1.3.10 Ratio for Abutment Displacements  88
8.1.7.1.4 Summary of Problem Areas  89
8.1.7.1.5 Time History Analysis vs. Response Spectrum Analysis  90
8.1.7.1.6 Comparison of AASHTO Response Spectrum vs. Site-Specific Response Spectrum  96
8.1.7.2 Old St. Francis River Bridge  97
8.1.7.2.1 Bridge Description  97
8.1.7.2.2 Bridge Model and Analysis  98
8.1.7.2.3 Bridge Evaluation  99
8.1.7.2.3.1 Load Combination Rule  102
8.1.7.2.3.2 Minimum Support Length and C/D Ratio for Bearing  102
8.1.7.2.3.3 C/D Ratios for Shear Force at Bearing  103
8.1.7.2.3.4 C/D Ratios for Columns/Piers  103
8.1.7.2.3.5 C/D Ratios for Reinforcement Anchorage in Columns  104
8.1.7.2.3.6 C/D Ratios for Splices in Longitudinal Reinforcement  104
8.1.7.2.3.7 C/D Ratio for Transverse Confinement  104
8.1.7.2.3.8 C/D Ratio for Column Shear  105
8.1.7.2.3.9 C/D Ratio for Diaphragm and Cross-Frame Members  105
8.1.7.2.3.10 C/D Ratio for Abutment Displacements  105
8.1.7.2.4 Summary of Problem Areas  106
8.1.7.2.5 Time History Analysis vs. Response Spectrum Analysis  107
8.1.7.2.6 Structural Response of Abutments  109
8.1.7.2.6.1 Calculated Time Dependent Displacements of Abutment  109

8.2 Wahite Ditch Bridge Site  113
8.2.1 Site Geology 113
8.2.2 Selected Base Rock Motion 114
8.2.3 Seismic Response of Soil 114
  8.2.3.1 Horizontal Seismic Response of Soil 117
  8.2.3.2 Resulting Ground Motion Time Histories 123
  8.2.3.3 Vertical Seismic Response of Soil 124
8.2.4 Liquefaction Potential Analysis 140
  8.2.4.1 Cyclic Stress Ratio (CSR), Cyclic Resistant Ratio (CRR) and Factor of Safety 140
8.2.5 Slope Stability of Abutment Fills 140
8.2.6 Flood Hazard Analysis Results 142
8.2.7 Structure Response of Wahite Ditch Bridges and Abutments 142
  8.2.7.1 New Wahite Ditch Bridge 142
    8.2.7.1.1 Bridge Description 142
    8.2.7.1.2 Bridge Model and Analysis 144
    8.2.7.1.3 Description of Bridge Evaluation 148
      8.2.7.1.3.1 Load Combination Rule 148
      8.2.7.1.3.2 Minimum Support Length and C/D Ratio for Bearing 148
      8.2.7.1.3.3 C/D Ratios for Shear Force at Bearings 148
      8.2.7.1.3.4 C/D Ratios for Columns/Piers 149
      8.2.7.1.3.5 C/D Ratios for Reinforcement Anchorage in Columns 150
      8.2.7.1.3.6 C/D Ratios for Splices in Longitudinal Reinforcement 150
      8.2.7.1.3.7 C/D Ratio for Transverse Confinement 150
      8.2.7.1.3.8 C/D Ratio for Column Shear 150
      8.2.7.1.3.9 C/D Ratio for Diaphragm Members 150
      8.2.7.1.3.10 C/D Ratio for Abutment Displacements 150
    8.2.7.1.4 Summary of Problem Areas 150
    8.2.7.1.5 Comparison of AASHTO Response Spectrum vs. Site-Specific Response Spectrum 151
  8.2.7.2 Old Wahite Ditch Bridge 153
    8.2.7.2.1 Bridge Description 153
    8.2.7.2.2 Bridge Model and Analysis 154
    8.2.7.2.3 Bridge Evaluation 158
      8.2.7.2.3.1 Load Combination Rule 158
      8.2.7.2.3.2 Minimum Support Length and C/D Ratio for Bearing 158
      8.2.7.2.3.3 C/D Ratios for Shear Force at Bearings 158
      8.2.7.2.3.4 C/D Ratios for Columns/Piers 158
      8.2.7.2.3.5 C/D Ratios for Reinforcement Anchorage in Columns 159
      8.2.7.2.3.6 C/D Ratios for Splices in Longitudinal Reinforcement 159
      8.2.7.2.3.7 C/D Ratio for Transverse Confinement 159
9.0 CONCLUSIONS

9.1 Summary

9.2 Geotechnical GIS Databases

9.3 Site Specific Earthquake Hazards Assessments

9.3.1 Francis River Bridge Site

9.3.1.1 Liquefaction

9.3.1.2 Slope Stability

9.3.1.3 Flood Hazard

9.3.1.4 Structural Response of St. Francis River Bridges

9.3.1.4.1 New St. Francis River Bridge

9.3.1.4.2 Old St. Francis River Bridge

9.3.1.4.3 Old St. Francis River Bridge Abutment

9.3.2 Wahite Ditch Bridge Site

9.3.2.1 Liquefaction

9.3.2.2 Slope Stability

9.3.2.3 Flood Hazard

9.3.2.4 Structural Stability of Wahite Ditch Bridges

9.3.2.4.1 New Wahite Ditch Bridge

9.3.2.4.2 Old Wahite Ditch Bridge

9.3.2.4.3 Old St. Francis River Bridge Abutment

10.0 RECOMMENDATIONS

10.1 Protocol

10.1.1 Determination of Site-Specific Strong Rock Motion

10.1.2 Determination of Liquefaction Potential

10.1.3 Determination of Slope Stability

10.1.4 Determination of Potential for Flooding in Response to Strong Ground Motion

10.1.5 Evaluation of Flooding Potential

10.1.6 Determination of Structural Stability

10.1.6.1 Evaluation of Abutment Stability

10.1.6.2 Evaluation of Stability of Integrated Bridge Abutments

10.1.6.3 Evaluation of Stability of Structural Members

10.2 Further Work

10.2.1 Proposed Study: Retrofit of Critical Structures along Designated Emergency Access Routes
10.2.2 Proposed Study: Site Specific Earthquake Assessments along MO 100 176
10.2.3 Proposed Study: Regional Liquefaction Hazard Analysis 177
10.2.4 Proposed Study: Geo-Referencing of Boring Locations 178
10.2.5 Proposed Study: Regional Prioritization for Future Earthquake Hazards Assessments 178
10.2.6 Proposed Study: Laboratory Testing of Truss-Type Diaphragms or Cross Frames and Effective Retrofitting Techniques 178
10.2.7 Proposed Study: Integration of LOGMAIN Surficial Materials Information 178
10.2.8 Proposed Study: Long Term Strategic Plan 178

11.0 BIBLIOGRAPHY 179

12.0 LIST OF SYMBOLS 183
LIST OF ILLUSTRATIONS

Figure                                      Page

2.1  Study Site Locations                   2
4.1  System Design: Top-Down vs. Bottom-Up  4
4.2  Organization of Missouri Department of Transportation Subsurface Data  5
4.3  Example of an Object Oriented Geotechnical Database Model (Luna and Frost, 1995)  7
5.1  Seismicity in The 1974 - 1995 Time Period in The Vicinity of The St. Francis River Bridge Site (SF) and the Wahite Ditch Site (WD). (Herrmann, (2000))  13
5.2  The Selected Base Rock Motion for the St. Francis River Bridge Site
   5.2a  PE 10% in 50 Years, Magnitude 6.2  16
   5.2b  PE 10% in 50 Years, Magnitude 7.2  17
   5.2c  PE 2% in 50 Years, Magnitude 6.4  18
   5.2d  PE 2% in 50 Years, Magnitude 8.0  19
5.3  The Selected Base Rock Motion for The Wahite Ditch Bridge Site
   5.3a  PE 10% in 50 Years, Magnitude 6.4  20
   5.3b  PE 10% in 50 Years, Magnitude 7.0  21
   5.3c  PE 2% in 50 Years, Magnitude 7.8  22
   5.3d  PE 2% in 50 Years, Magnitude 8.0  23
5.4  Simplified Base Curve Recommended for Calculation of CRR From SPT (N1)60 Data Along With Empirical Liquefaction Data for M=7.5 (From Seed et. al., 1971, Modified by Youd and Idriss, 1997)  26
5.5  St. Francis River Bridge Site Topography, Cross-Sections and Boring Locations  27
5.6  Wahite Ditch Bridge Site Topography, Cross Sections and Boring Locations  28
6.1  The Typical Highway Bridge Abutment Supported on Piles  36
6.2  Translation and Rotation Movement of Bridge Abutment Forces Acting on the Bridge Abutment  36
6.3  Forces Acting on the Bridge Abutment  37
7.1  Extent of Mississippi Embayment  39
7.2  Cross-Section of Regional Geology  40
8.1  St. Francis River Bridge Site Topography, Cross-Section and Boring Locations  42
8.2  Cross-Section of St. Francis River Bridge Site Geology  43
8.3  Soil Profile St. Francis River Bridge Site Boring B-1  44
8.4  Acceleration Time Histories for St. Francis River Bridge Site
   8.4a  PE 10% in 50 Years Magnitude = 6.2  46
   8.4b  PE 10% in 50 Years Magnitude = 7.2  47
   8.4c  PE 2% in 50 Years, Magnitude = 6.4  48
   8.4d  PE 2% in 50 Years, Magnitude = 8.0  49
8.5  Peak Ground Acceleration vs. Depth for PE 10% in 50 Years Magnitudes 6.2 and 7.2 St. Francis River Bridge Site  51
8.6  Peak Ground Acceleration vs. Depth for PE 2% in 50 Years Magnitudes 6.4 and 8.0 St. Francis River Bridge Site  52
8.7  Surface Ground Acceleration at the St. Francis River Bridge Site
8.7a  PE 10% in 50 years, Magnitude = 6.2
8.7b  PE 10% in 50 years, Magnitude = 7.2
8.7c  PE 2% in 50 years, Magnitude = 6.4
8.7d  PE 2% in 50 years, Magnitude = 8.0

8.8  Ground Acceleration at the St. Francis River Bridge Abutment
8.8a  PE 10% in 50 years, Magnitude = 6.2
8.8b  PE 10% in 50 years, Magnitude = 7.2
8.8c  PE 2% in 50 years, Magnitude = 6.4
8.8d  PE 2% in 50 years, Magnitude = 8.0

8.9  Ground Acceleration at the St. Francis River Bridge Pier
8.9a  PE 10% in 50 years, Magnitude = 6.2
8.9b  PE 10% in 50 years, Magnitude = 7.2
8.9c  PE 2% in 50 years, Magnitude = 6.4
8.9d  PE 2% in 50 years, Magnitude = 8.0

8.10 Soil Profile, CSR, CRR and Factor of Safety Against Liquefaction at the St. Francis River Bridge Site for PE 10% in 50 years and M=6.2
8.11 Example Slope Stability Results for St. Francis River Bridge Site
8.12 Estimated Flooding Zone Due to Wappapello Dam Failure
8.13 Region of Potential Flooding
8.14 Bridge General Elevation (New St. Francis River Bridge)
8.15 Mode 1, Period 0.2519 Seconds (New St. Francis River Bridge)
8.16 Mode 2, Period 0.2295 Seconds (New St. Francis River Bridge)
8.17 Mode 3, Period 0.1421 Seconds (New St. Francis River Bridge)
8.18 Mode 4, Period 0.0901 Seconds (New St. Francis River Bridge)
8.19 Mode 5, Period 0.0896 Seconds (New St. Francis River Bridge)
8.20 Shear Force Calculations
8.21 Calculations of Axial Loads and Column Shears
8.22 Calculations for Hooked Anchorage in Columns
8.23 Calculations for Splices in Longitudinal Reinforcement
8.24 Calculations for Transverse Confinement
8.25 Calculations for Column Shear
8.26 Calculations for Diaphragm Cross-Frame Members
8.27 Calculations for Abutment Displacements
8.28 Comparison of AASHTO Response Spectrum & Site Specific Response Spectrum
8.29 Bridge General Elevation (Old St. Francis River Bridge)
8.30 Mode 1, Period 1.3173 Seconds (Old St. Francis River Bridge)
8.31 Mode 2, Period 0.4773 Seconds (Old St. Francis River Bridge)
8.32 Mode 3, Period 0.3673 Seconds (Old St. Francis River Bridge)
8.33 Mode 4, Period 0.2065 Seconds (Old St. Francis River Bridge)
8.34 Mode 5, Period 0.1501 Seconds (Old St. Francis River Bridge)
8.35 Old St. Francis River Bridge Plans
8.36 Time Histories of Sliding, Rocking and Total Permanent Displacement of the Old St. Francis River Bridge Abutment PE 10% in 50 Years, Magnitudes 6.2 and 7.2
8.37 Time Histories of Sliding, Rocking and Total Permanent Displacement of the Old St. Francis River Bridge Abutment PE 2% in 50 Years, Magnitudes 6.4 and 8.0
8.38 Cross-Section of Wahite Ditch Bridge Site Geology
8.39 Acceleration Time Histories for the Wahite Ditch Bridge Site
8.39a PE 2% in 50 Years Magnitude = 6.4
8.39b PE 10% in 50 Years Magnitude = 7.0
8.39c PE 2% in 50 Years, Magnitude = 7.8
8.39d PE 2% in 50 Years, Magnitude = 8.0
8.40 Wahite Ditch Bridge Site Topography, Cross-Section and Boring Locations
8.41 Soil Profile B-1 Wahite Ditch Bridge Site
8.42 Peak Ground Acceleration vs. Depth for PE 10% in 50 Years Magnitudes 6.4 and 7.0 Wahite Ditch Bridge Site
8.43 Peak Ground Acceleration vs. Depth for PE 2% in 50 Years Magnitudes 7.8 and 8.0 Wahite Ditch Bridge Site
8.44 Surface Ground Acceleration at the Wahite Ditch Bridge Site
8.44a PE 10% in 50 years Magnitude = 6.4
8.44b PE 10% in 50 years Magnitude = 7.0
8.44c PE 2% in 50 years Magnitude = 7.8
8.44d PE 2% in 50 years Magnitude = 8.0
8.45 Ground Acceleration at the Abutment Wahite Ditch Bridge
8.45a PE 10% in 50 years Magnitude = 6.4
8.45b PE 10% in 50 years Magnitude = 7.0
8.45c PE 2% in 50 years Magnitude = 7.8
8.45d PE 2% in 50 years Magnitude = 8.0
8.46 Ground Acceleration at the Wahite Ditch Bridge Pier
8.46a PE 10% in 50 years Magnitude = 6.4
8.46b PE 10% in 50 years Magnitude = 7.0
8.46c PE 2% in 50 years Magnitude = 7.8
8.46d PE 2% in 50 years Magnitude = 8.0
8.47 Soil Profile, CSR, CRR and Factor of Safety Against Liquefaction at the Wahite Ditch Bridge Site for M=6.4
8.48 Example Slope Stability Results for Wahite Ditch Bridge Site
8.49 Bridge General Elevation (New Wahite Ditch Bridge)
8.50 Mode 1, Period 0.2686 Seconds (New Wahite Ditch Bridge)
8.51 Mode 2, Period 0.2558 Seconds (New Wahite Ditch Bridge)
8.52 Mode 3, Period 0.0915 Seconds (New Wahite Ditch Bridge)
8.53 Mode 4, Period 0.0854 Seconds (New Wahite Ditch Bridge)
8.54 Mode 5, Period 0.0729 Seconds (New Wahite Ditch Bridge)
8.55 Bridge General Elevation (Old Wahite Ditch Bridge)
8.56 Mode 1, Period 0.5641 Seconds (Old Wahite Ditch Bridge)
8.57 Mode 2, Period 0.3518 Seconds (Old Wahite Ditch Bridge)
8.58 Mode 3, Period 0.1809 Seconds (Old Wahite Ditch Bridge)
8.59 Mode 4, Period 0.1229 Seconds (Old Wahite Ditch Bridge)
8.60 Mode 5, Period 0.1025 Seconds (Old Wahite Ditch Bridge)
8.61 Bridge General Elevation (Old Wahite Ditch Bridge)
8.62 Plan and Cross-Section of Old Wahite Ditch Bridge Abutment
8.62a Plan of Old Wahite Ditch Bridge Abutment
8.62b Cross Section of Old Wahite Ditch Bridge Abutment
8.63 Time Histories of Sliding, Rocking and Total Permanent Displacement of the Old Wahite Ditch Bridge Abutment PE 10% in 50 Years, Magnitudes 6.4 and 7.0 167

8.64 Time Histories of Sliding, Rocking and Total Permanent Displacement of the Old Wahite Ditch Bridge Abutment PE 2% in 50 Years, Magnitudes 7.8 and 8.0 168
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Example of Data Structure Input to Database</td>
</tr>
<tr>
<td>5.1</td>
<td>Peak Ground Acceleration (Herrmann, 2000) (Source; USGS 1996 Seismic Hazard Maps)</td>
</tr>
<tr>
<td>5.2</td>
<td>Magnitude and Distances for Selected Earthquakes, (Herrmann, 2000)</td>
</tr>
<tr>
<td>5.2a</td>
<td>St. Francis River Bridge Site</td>
</tr>
<tr>
<td>5.2b</td>
<td>Wahite Ditch Bridge Site</td>
</tr>
<tr>
<td>5.3</td>
<td>Design Horizontal and Vertical Earthquake Accelerations</td>
</tr>
<tr>
<td>5.3a</td>
<td>St. Francis River Bridge Site</td>
</tr>
<tr>
<td>5.3b</td>
<td>Wahite Ditch Bridge Site</td>
</tr>
<tr>
<td>8.1</td>
<td>Detail of Synthetic Ground Motion at the Rock Base of St. Francis River Bridge Site With Corresponding Maximum Peak Horizontal Ground Acceleration</td>
</tr>
<tr>
<td>8.1a</td>
<td>PE 10% in 50 Years</td>
</tr>
<tr>
<td>8.1b</td>
<td>PE 2% in 50 Years</td>
</tr>
<tr>
<td>8.2</td>
<td>Detail of Peak Ground Motion Used at the St. Francis River Bridge Site Rock Base, Ground Surface, Bridge Abutment and Pier</td>
</tr>
<tr>
<td>8.2a</td>
<td>PE 10% in 50 Years</td>
</tr>
<tr>
<td>8.2b</td>
<td>PE 2% in 50 Years</td>
</tr>
<tr>
<td>8.3</td>
<td>The Different Zones of Soil Liquefaction for Different Factors of Safety</td>
</tr>
<tr>
<td>8.4</td>
<td>Soil Properties used for the Slope Stability Analysis, St. Francis River Bridge Site</td>
</tr>
<tr>
<td>8.5</td>
<td>Slope Stability Results for the St. Francis River Bridge Site</td>
</tr>
<tr>
<td>8.6</td>
<td>Natural Periods and Their Corresponding Vibration Modes (New St. Francis River Bridge)</td>
</tr>
<tr>
<td>8.7</td>
<td>Elastic Moments Due to Transverse Acceleration</td>
</tr>
<tr>
<td>8.8</td>
<td>Elastic Moments Due to Longitudinal Acceleration</td>
</tr>
<tr>
<td>8.9</td>
<td>Elastic Moments Due to Vertical Acceleration</td>
</tr>
<tr>
<td>8.10</td>
<td>Summary of All Moment Demands</td>
</tr>
<tr>
<td>8.11</td>
<td>Summary of Moment C/D Ratios for Columns</td>
</tr>
<tr>
<td>8.12</td>
<td>Summary of All C/D Ratios for Structure</td>
</tr>
<tr>
<td>8.13</td>
<td>Summary of C/D Ratios for All Earthquakes on New St. Francis River Bridge</td>
</tr>
<tr>
<td>8.14</td>
<td>Comparison of Moments for Time History and Response Spectrum Analysis for Column 2 New St. Francis River Bridge</td>
</tr>
<tr>
<td>8.15</td>
<td>Comparison of Moments for Time History and Response Spectrum Analysis for Column 5 New St. Francis River Bridge</td>
</tr>
<tr>
<td>8.16</td>
<td>Comparison of Displacements for Time History and Response Spectrum Analysis for Maximum Abutment Displacement. New St. Francis River Bridge</td>
</tr>
<tr>
<td>8.17</td>
<td>Comparison of AASHTO Response Spectrum vs. Site Specific Response Spectrum (New St. Francis)</td>
</tr>
<tr>
<td>8.18</td>
<td>Natural Periods and their Corresponding Vibration Modes (Old St. Francis River Bridge)</td>
</tr>
<tr>
<td>8.19</td>
<td>Summary C/D for Various Components of the Old St. Francis River Bridge for all Earthquakes</td>
</tr>
</tbody>
</table>
8.20 Comparison of Moments for Time History and Response Spectrum Analysis for Column 2 Old St. Francis River Bridge

8.21 Comparison of Moments for Time History and Response Spectrum Analysis for Column 5 Old St. Francis River Bridge

8.22 Comparison of Displacements for Time History and Response Spectrum Analysis for Maximum Abutment Displacement. Old St. Francis River Bridge

8.23 Displacement at Top of Old St. Francis Bridge Abutment

8.24 Detail of Peak Ground Motion at Wahite Ditch Bridge Site, Rock Base, Soil Surface, Bridge Abutment and Pier
   8.24a PE 10% in 50 Years
   8.24b PE 2 % in 50 Years

8.25 Detail of Peak Ground Motion Used at the Wahite Ditch Bridge Site Rock Base, Ground Surface, Bridge Abutment and Pier
   8.25a PE 10% in 50 years
   8.25b PE 2% in 50 years

8.26 The Different Zones of Soil Liquefaction for Different Factors of Safety

8.27 Soil Properties Used for the Slope Stability Analysis, Wahite Ditch Bridge Site
   Slope Stability Analysis

8.28 Slope Stability Results, Wahite Ditch Bridge Site

8.29 Natural Periods and Their Corresponding Vibration Modes (New Wahite Ditch Bridge)

8.30 Summary of all Earthquakes for New Wahite Ditch Bridge

8.31 Comparison of AASHTO Response Spectrum vs. Site Specific Response Spectrum (New Wahite)

8.32 Natural Periods and their Corresponding Vibration Modes (Old Wahite Ditch Bridge)

8.33 Summary of all Earthquakes for Old Wahite Ditch Bridge

8.34 Comparison of Column Moments for Old Wahite Ditch Bridge

8.35 Displacement at Top of Old Wahite Ditch Bridge Abutment
D.1 Time Series for Study Sites

D.2 Magnitude and Distance for Design Earthquakes

D.3 St. Francis River 10% Probability of Exceedance in 50 Years

D.4 St. Francis River 2% Probability of Exceedance in 50 Years

D.5 Wahite Ditch 10% Probability of Exceedance in 50 Years

D.6 Wahite Ditch 2% Probability of Exceedance in 50 Years
APPENDICES

A.  FIELD DATA
A.1 Symbols Used on Boring Information A1
A.2 St. Francis River Bridge Site Test Pits A3
A.3 St. Francis River Bridge Site Boring Logs A6
A.4 St. Francis River Bridge Site Cone Penetrometer Logs A13
A.5 Wahite Ditch Bridge Site Test Pits A19
A.6 Wahite Ditch Bridge Site Boring Logs A24
A.7 Wahite Ditch Bridge Site Cone Penetrometer Logs A30

B.  LABORATORY DATA
B.1 Cyclic Stress Test Results A35
B.2 St. Francis River Bridge Site Laboratory Results A37
B.3 Wahite Ditch Bridge Site Laboratory Results A43

C.  SOFTWARE DESCRIPTION
C.1 SHAKE91 and SHAKEDIT A48
C.1.1 SHAKE91 A48
C.2.2 SHAKEDIT A48
C.2 Modified DDRW2 Program A48
C.3 PCSTABLE5 A49
C.4 SAP2000 49

D.  DETAILS OF SYNTHETIC GROUND MOTION
D.1 Task A51
D.2 Overview of problem A51
D.3 Defining earthquakes A51
D.4 Discussion A56

E.  DATABASE FOR EARTHQUAKE ANALYSIS A89

F.  BRIDGE ABUTMENT AND PIER SUPPORTED ON A PILE GROUP A90
F.1 Stiffness and Damping Factors of Single Pile A90
F.1.1 Vertical Stiffness (k_z) and Damping Factors (c_z) A90
F.1.2 Torsional Stiffness (k_ψ) and Damping Factors (c_ψ) A90
F.1.3 Sliding and Rocking Stiffness and Damping Factors A93
F.2 Group Interaction Factor A94
F.3 Group Stiffness and Damping Factors A98
F.3.1 Vertical Group Stiffness (k_z^g) and Damping Factors (c_z^g) A98
F.3.2 Torsional Group Stiffness (k_ψ^g) and Damping Factors (c_ψ^g) A98
F.3.3 Sliding and Rocking and Cross Coupled group Stiffness and Damping Factors A99
F.4 Strain-Displacement Relationships A100
F.5 Solution Technique for Displacement Dependent k”s and c’s A101
F.6 Equations of Motion A104
G. LIQUEFACTION ANALYSIS

H. MOMENT-ROTATION CURVE OF PILE FOUNDATIONS