COMPARISON OF PIER CAP ANALYSIS AND REHABILITATION USING AASHTO AND LRFD SPECIFICATIONS

Mohammad Yousef Dastajani Farahani¹, Dr. K Rama Mohan Rao², Mahdi Hosseini³

¹,²,³Departments of Civil Engineering, Jawaharlal Nehru Technological University Hyderabad (JNTUH), Hyderabad, Andhra Pradesh, India

ABSTRACT

A bridge is a structure built to span physical obstacles such as a body of water, valley, or the road, for the purpose of providing passage over the obstacle. The components of a bridge can be split up into three parts, namely, foundation, sub-structure, super-structure. AASHTO, LRFD bridge specification (1998) incorporated the strut-and-tie modeling procedure for the analysis and design of deep reinforced concrete members where sectional design approaches are not valid. In most instances, hammerhead piers can be defined as deep reinforced concrete members and therefore, should be designed using the strut-and-tie modeling approach. However, little has been done to develop a consistent approach to the design of hammerhead pier caps employing the strut-and-tie modeling method. The present study is focused on developing a uniform design procedure for applying the strut-and-tie modeling method to hammerhead piers. In addition to developing a design procedure, a survey of all fifty state transportation departments was conducted to ascertain the degree of implementation of the AASHTO, LRFD bridge specifications for substructure design.

Keywords: AASHTO, LRFD, Pier Cap, Structure and Tie Modeling.

INTRODUCTION

The first bridges were made by nature itself as simple as a log fallen across a stream or stones in the river. The first bridges made by humans were probably spans of cut wooden logs or planks and eventually stones, using a simple support and crossbeam arrangement. Some early Americans used trees or bamboo poles to cross small caverns or wells to get from one place to another. A common form of lashing sticks, loge, and deciduous branches together involved the use of long reeds or other harvested fibers woven together to form a connective rope which was capable of binding and holding
in place materials used in early bridges. The science of bridge engineering developed with varied
degrees in different countries. Some of the Roman bridges in Italy are among the finest bridges of the
past in the eighteen century. France was the most powerful country of continental Europe and
because of its prosperity and taste in art, it has produced numerous and finest bridge during this
period. It is really a pleasure to see the existing eighteenth century bridges in France. The bridge over
the river Nile built by means, the king of Egypt about 2650 BC was the earliest bridge on record.
After five centuries, Anthers Bridge was built by queen smiramio of Babylon across the river
Euphrates. The oldest existing arch dating back to about 350 BC and consisting of 20 pointed arches,
each of 7.5 m span is at khorsbad in Babylonia. The earliest construction of permanent bridges
started around 400 BC. The lake dwellers of Switzerland are said to be the pioneers of timber-trestle
construction. The Indians also developed the prototype of the modern suspension bridge at
eighteenth century. The first iron bridge of 30.5 m span was built in 1779 over the Severn at
Coalbrookdale, England. The arch bridges were developed simultaneously by the romans and chines.
Condition assessment of concrete bridge pier caps using the general shear provisions of the
AASHTO LRFD bridge design specification has caused the Georgia Department of Transportation
(GDOT) to post a large number of bridges in the state of Georgia. Posting of bridges disrupts the free
flow of goods within the region served by the bridge and has a negative economic impact. To prevent
structural deterioration, diagonal cracking or failure of concrete pier caps in shear, the GDOT
employs an in situ strengthening technique that utilizes an external vertical post-tensioning system.
However, the fundamental mechanics of this system and its effectiveness under service load have not
examined previously. This research examines the behavior of reinforced concrete pier caps that
utilize the above strengthening system in a combined analytical and experimental program. In the
experimental part of the study, two groups of full-scale reinforced concrete deep beam specimens
were tested. The first ground consisted of six deep beams with shear span/depth ratios of
approximately 1.0, which is typical of bridge pier caps; of these six, two included the external post-
tensioning system. In the second group, nine deep beam specimens that included a segment of the
column representing the pier were tested; four of those tests included the external post-tensioning
system. The tests revealed that the shear capacity computed using the AASHTO LRFD bridge design
specifications provided a conservative estimate of the specimen capacity in all but one case when
compared to the experimental results. However, the AASHTO strut and tie provisions were found to
provide a much closer assessment of the load carrying mechanism in the pier cap than the general
shear provisions. In that they were able to predict the load at which yielding of the tension
reinforcement occurred as well as the angle of the compression strut. The presence of the failure
mechanism developed in the specimen near ultimate load. The stress concentration at the re-entrant
corner between the pier cap and column interface served as an attractor for the formation of diagonal
shear cracks, a mechanism not observed in previous deep beam tests in shear. The research has led to
recommendations for improving the design of pier caps and the external post-tensioning system,
where required, based on fundamental mechanics which is consistent with the results of the
experimental program.

MATERIALS AND METHODOLOGY

This work states about reinforcing concrete substructure analysis and design, the method used
is as an integrated module with LEAP bridge. LEAP RC-PIER is an integrated tool for the AASHTO
Standard and LRFD analysis and design of reinforced concrete bridge substructures and foundations.
By incorporating both LFD and LRFD specification in one interface, LEAP RC-PIER makes the
transition to LRFD simple and efficient. LEAP RC-PIER allows users to design multi-column and
hammerhead piers, straight, tapered or variable caps, and circular, rectangular (tapered and non-
tapered) or drilled-shaft columns. Footing types include isolated or combined, supported on either
soil or piles. There is no limit to the number of loads, Bearings and piles that may be included in the design. Analysis results are presented in a variety of easy-to-view formats. Strut-and-tie modeling is an analysis and design tool for reinforced concrete element which assumes that internal stresses are transferred through a truss type mechanism. The tensile ties and compressive struts serve as truss members connected by nodal zones. The internal truss idealized by the strut and-tie model implicitly accounts for the distribution of both flexure and shear. In 1998, the AASHTO LRFD bridge specification (1998) incorporated the strut-and-tie modeling procedure for the analysis and design of deep reinforced concrete members where sectional design approaches are not valid. In most instances, hammerhead piers can be defined as deep reinforced concrete members and therefore, should be designed using the strut-and-tie modeling approach. However, little has been done to develop a consistent approach to the design of hammerhead pier caps employing the strut-and-tie modeling method.

The present study is focused on developing a uniform design procedure for applying the strut-and-tie modeling method to hammerhead piers. In addition to developing a design procedure, a survey of all fifty state transportation departments was conducted to ascertain the degree of implementation of the AASHTO LRFD bridge specifications for substructure design. A design study was conducted using four hammerhead piers that were previously designed using the strength design method specified by the AASHTO standard specifications in order to evaluate strut-and-tie modeling procedures. The four pier caps were designed using the strut-and-tie modeling procedure and the results compared to the result of the sectional design method. For each hammerhead pier cap, the strut-and-tie method required more flexural steel than the sectional method. Based on the design studies, a well-defined procedure for designing a hammerhead pier utilizing the strut-and-tie model was established that may be used by bridge engineers.

COMPARISON OF PIER CAP ANALYSIS AND REHABILITATION USING AASHTO AND LRFD SPECIFICATIONS

These specifications give design clauses for the three piers reinforced concrete cap of the I-77 over I-480 bridge supports 4 bearings, one on each cantilever and one between each column. Bridge Inspectors recently reported cracks in the cantilever near the bearing. The cap section was adequate as cracks in the one cantilever near the bearing. The cap section was adequate as per the AASHTO Standard Specifications. However, when the cantilever was analyzed as a corbel using the AASHTO Standard Specifications and using the strut and tie module as specified in the LRFD coda, the top reinforcement was found to be inadequately anchored and the distribution reinforcing was found to be inadequately anchored and the distribution reinforcement was deficient. There were several possible solutions, including post-tensioning, FRP repair, steel jacketing, and concrete repair, but the most feasible ways to widen the existing column and redistribute the bearing load, reducing the tie force the tie force requirement and the stress in the area of the crack.

THREE DIMENSIONAL STRESS ANALYSES

Soiled or three dimensional element enables the solution of the problem for a general three dimensional stress analysis. There are many problems such as concrete dams, stress distribution in solids and rocks, ring beams, bridge piers, pipe intersections, stresses around opening, machine components, etc. Where three dimensional stress analysis is required. For such problems, finite element analysis is required. For such problems, finite element analysis provides a powerful tool getting numerical solution.
THREE DIMENSIONAL SOLID ELEMENTS

Three dimensional solid elements can be broadly grouped under “tetrahedral, triangular prism, and hexahedral family of elements”.

1. Tetrahedral element
   The simplest element of the tetrahedral family is a four nodded tetrahedron. The linear shape function for this element can be expressed as:

   \[(N3)T=(L1, L2, L3, L4)\]

   Where \(L\) is defined as, \(L_i = \frac{v_i}{V}\)

   \(V_i\) is the volume of the sub-element and \(V\) is the total volume of the element.
   The strain variation is linear within the element.
   Three other types of eight and ten and twenty nodded tetrahedral elements are shown in fig.
The main disadvantages of tetrahedral family of elements are:-

a) It require small and costly subdivision.

b) The division of a space volume into individual tetrahedron sometimes presents difficulties of visualization and could lead to errors in nodal numbering and element connectivity in data preparation.

2. Triangular prism Isoperimetric elements

The simplest triangular prism element is a six nodded element. The polynomial function in natural curvilinear coordinates “r,s,t” describing the geometry and the variation of displacement over the element is \((Q3)T=(I, r, s, t, rs, st)\). The six nodes from a solid bounded by two triangles and three quadrilateral faces and the sides are non-intersecting. When quadratic variation is required, fifteen nodded triangular prism can be used. The fifteen nodes form a solid bounded by two curved or straight sided quadrilateral faces. Neither the faces nor the edges should intersect each other.
3. Hexahedral Isoperimetric Elements

The eight nodded element is the simplest hexahedral element. The polynomial function defining the geometry and displacement variation is \((Q3)_T = (I, r, s, t, rs, st)\). The twenty nodded element are shown in fig, has eight corner nodes and twelve nodes located at the midpoints of the edges thus accommodating curved boundaries.

RESULTS

Comparing
Table 1

<table>
<thead>
<tr>
<th>Stress</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1</th>
<th>1.1</th>
<th>1.2</th>
<th>1.3</th>
<th>1.4</th>
<th>1.5</th>
<th>1.6</th>
<th>1.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASE 1</td>
<td>2965200</td>
<td>2407100</td>
<td>2151500</td>
<td>1859700</td>
<td>1500200</td>
<td>1374400</td>
<td>1295400</td>
<td>1200000</td>
<td>1163200</td>
<td>1088100</td>
<td>1049800</td>
<td>1000700</td>
<td></td>
</tr>
<tr>
<td>CASE 2</td>
<td>702440</td>
<td>686220</td>
<td>590590</td>
<td>557990</td>
<td>504565</td>
<td>438560</td>
<td>406860</td>
<td>396770</td>
<td>354010</td>
<td>338710</td>
<td>318060</td>
<td>303370</td>
<td></td>
</tr>
<tr>
<td>CASE 3</td>
<td>527800</td>
<td>468630</td>
<td>438080</td>
<td>411820</td>
<td>299770</td>
<td>286230</td>
<td>264240</td>
<td>251110</td>
<td>246130</td>
<td>239850</td>
<td>223790</td>
<td>205450</td>
<td></td>
</tr>
<tr>
<td>CASE 4</td>
<td>1243100</td>
<td>1095800</td>
<td>976420</td>
<td>860200</td>
<td>759850</td>
<td>684960</td>
<td>625040</td>
<td>569430</td>
<td>523400</td>
<td>483250</td>
<td>449160</td>
<td>419830</td>
<td>393760</td>
</tr>
<tr>
<td>CASE 5</td>
<td>2893900</td>
<td>2143700</td>
<td>1737500</td>
<td>1468200</td>
<td>1217400</td>
<td>1056900</td>
<td>968020</td>
<td>893820</td>
<td>754400</td>
<td>703400</td>
<td>681080</td>
<td>638180</td>
<td>604560</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Normal Elasticity Strain</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1</th>
<th>1.1</th>
<th>1.2</th>
<th>1.3</th>
<th>1.4</th>
<th>1.5</th>
<th>1.6</th>
<th>1.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASE 1</td>
<td>1.17E-05</td>
<td>1.12E-05</td>
<td>6.08E-06</td>
<td>4.83E-06</td>
<td>4.03E-06</td>
<td>3.59E-06</td>
<td>3.18E-06</td>
<td>3.0E-06</td>
<td>2.85E-06</td>
<td>2.49E-06</td>
<td>2.35E-06</td>
<td>2.26E-06</td>
<td>2.15E-06</td>
</tr>
<tr>
<td>CASE 2</td>
<td>6.76E-06</td>
<td>5.65E-06</td>
<td>4.19E-06</td>
<td>3.4E-06</td>
<td>2.82E-06</td>
<td>2.5E-06</td>
<td>2.3E-06</td>
<td>2.16E-06</td>
<td>2.04E-06</td>
<td>1.94E-06</td>
<td>1.87E-06</td>
<td>1.81E-06</td>
<td>1.75E-06</td>
</tr>
<tr>
<td>CASE 3</td>
<td>4.6E-06</td>
<td>3.58E-06</td>
<td>2.38E-06</td>
<td>2.12E-06</td>
<td>1.49E-06</td>
<td>1.43E-06</td>
<td>1.38E-06</td>
<td>1.35E-06</td>
<td>1.33E-06</td>
<td>1.31E-06</td>
<td>1.29E-06</td>
<td>1.29E-06</td>
<td>1.27E-06</td>
</tr>
<tr>
<td>CASE 4</td>
<td>9.95E-06</td>
<td>9.77E-06</td>
<td>9.33E-06</td>
<td>9.04E-06</td>
<td>8.46E-06</td>
<td>7.06E-06</td>
<td>6.11E-06</td>
<td>5.44E-06</td>
<td>4.85E-06</td>
<td>4.43E-06</td>
<td>4.1E-06</td>
<td>3.82E-06</td>
<td>3.6E-06</td>
</tr>
<tr>
<td>CASE 5</td>
<td>1.59E-05</td>
<td>1.1E-05</td>
<td>8.68E-06</td>
<td>6.85E-06</td>
<td>5.87E-06</td>
<td>5.31E-06</td>
<td>4.86E-06</td>
<td>4.56E-06</td>
<td>4.35E-06</td>
<td>4.23E-06</td>
<td>3.98E-06</td>
<td>3.82E-06</td>
<td>3.26E-06</td>
</tr>
</tbody>
</table>
Shear Stress

CASE 1

CASE 2

CASE 3

CASE 4

CASE 5

Shear Elastic Strain
Shear Elastic strain

<table>
<thead>
<tr>
<th>CASE</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1.0</th>
<th>1.1</th>
<th>1.2</th>
<th>1.3</th>
<th>1.4</th>
<th>1.5</th>
<th>1.6</th>
<th>1.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>2.77E-05</td>
<td>2.34E-05</td>
<td>1.87E-05</td>
<td>1.48E-05</td>
<td>1.42E-05</td>
<td>1.35E-05</td>
<td>1.33E-05</td>
<td>1.3E-05</td>
<td>1.15E-05</td>
<td>9.88E-06</td>
<td>9.21E-06</td>
<td>9.15E-06</td>
<td></td>
</tr>
<tr>
<td>CASE 2</td>
<td>1.85E-05</td>
<td>1.65E-05</td>
<td>1.42E-05</td>
<td>1.34E-05</td>
<td>1.21E-05</td>
<td>1.09E-05</td>
<td>9.76E-06</td>
<td>9.52E-06</td>
<td>8.5E-06</td>
<td>8.13E-06</td>
<td>7.63E-06</td>
<td>7.28E-06</td>
<td></td>
</tr>
<tr>
<td>CASE 3</td>
<td>1.27E-05</td>
<td>1.12E-05</td>
<td>1.05E-05</td>
<td>9.88E-06</td>
<td>7.24E-06</td>
<td>7.19E-06</td>
<td>6.87E-06</td>
<td>6.34E-06</td>
<td>6.03E-06</td>
<td>5.91E-06</td>
<td>5.76E-06</td>
<td>5.65E-06</td>
<td></td>
</tr>
<tr>
<td>CASE 4</td>
<td>2.98E-05</td>
<td>2.63E-05</td>
<td>2.34E-05</td>
<td>2.06E-05</td>
<td>1.82E-05</td>
<td>1.64E-05</td>
<td>1.5E-05</td>
<td>1.37E-05</td>
<td>1.26E-05</td>
<td>1.16E-05</td>
<td>1.08E-05</td>
<td>1.01E-05</td>
<td></td>
</tr>
<tr>
<td>CASE 5</td>
<td>2.53E-05</td>
<td>2.06E-05</td>
<td>1.63E-05</td>
<td>1.41E-05</td>
<td>1.22E-05</td>
<td>1.07E-05</td>
<td>9.86E-06</td>
<td>9.02E-06</td>
<td>8.75E-06</td>
<td>8.57E-06</td>
<td>8E-06</td>
<td>7.54E-06</td>
<td></td>
</tr>
</tbody>
</table>

Total deformation

<table>
<thead>
<tr>
<th>Case</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1.0</th>
<th>1.1</th>
<th>1.2</th>
<th>1.3</th>
<th>1.4</th>
<th>1.5</th>
<th>1.6</th>
<th>1.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 B</td>
<td>0.0001</td>
<td>8.4E-05</td>
<td>7.2E-05</td>
<td>6.4E-05</td>
<td>5.9E-05</td>
<td>5.5E-05</td>
<td>5.2E-05</td>
<td>4.9E-05</td>
<td>4.8E-05</td>
<td>4.6E-05</td>
<td>4.5E-05</td>
<td>4.4E-05</td>
<td>4.4E-05</td>
</tr>
<tr>
<td>2 B</td>
<td>6E-05</td>
<td>5.6E-05</td>
<td>5E-05</td>
<td>4.6E-05</td>
<td>4.4E-05</td>
<td>4.2E-05</td>
<td>4E-05</td>
<td>3.9E-05</td>
<td>3.8E-05</td>
<td>3.8E-05</td>
<td>3.7E-05</td>
<td>3.7E-05</td>
<td>3.7E-05</td>
</tr>
<tr>
<td>3 B</td>
<td>4.9E-05</td>
<td>4.1E-05</td>
<td>3.5E-05</td>
<td>3.4E-05</td>
<td>2.7E-05</td>
<td>2.7E-05</td>
<td>2.8E-05</td>
<td>2.7E-05</td>
<td>2.8E-05</td>
<td>2.8E-05</td>
<td>2.8E-05</td>
<td>3.2E-05</td>
<td>3.2E-05</td>
</tr>
<tr>
<td>4 B</td>
<td>0.00027</td>
<td>0.0002</td>
<td>0.00016</td>
<td>0.00013</td>
<td>0.00011</td>
<td>9.5E-05</td>
<td>8.6E-05</td>
<td>7.7E-05</td>
<td>7E-05</td>
<td>6.5E-05</td>
<td>6E-05</td>
<td>5.7E-05</td>
<td>5.4E-05</td>
</tr>
<tr>
<td>5 B</td>
<td>0.00018</td>
<td>0.00014</td>
<td>0.00011</td>
<td>9.7E-05</td>
<td>8.6E-05</td>
<td>7.8E-05</td>
<td>7.2E-05</td>
<td>6.7E-05</td>
<td>6.3E-05</td>
<td>5.8E-05</td>
<td>4.7E-05</td>
<td>3.7E-05</td>
<td>3.1E-05</td>
</tr>
</tbody>
</table>
DISCUSSION AND CONCLUSION

It is evident from the observing result deformation has been occurred in cap over hollow cylinder due to load which transverse from super-structure to the pier and sub-structure. This leads to variation in the moment and its nature as indicated in the results and charts. It is also observed that shear force increases at the junction of pier and cap with the increase in diameter of well. It is evident from the deformation results that shell bending is evident in cap because of stiffness transferred by pier through cap. Case 5 and case 3 has lesser deformation comparing by other cases. Shear stress and shear elasticity strain was more affected in 3 comparing to other cases and result of case 5 was much near to case3 in all size on cap. Stress in normal (N) or equal size of cap and hollow cylinder is having more reduction as in increasing the thickness of cap in case5 and case1.

REFERENCES

2. Finite Element Analysis by S.S Bhavikati.
5. Bridge Engineering by Punosowamai.
17. Behaveior of cable Truss Web Elements of Prestressed Suspension Bridge.


AUTHOR’S DETAIL

Mohammad Yousef Dastajani Farahani, Post Graduate Student, Dept. of Civil Engineering, Jawaharlal Nehru Technological University Hyderabad (JNTUH), Hyderabad, Andhra Pradesh, India.

Dr.K Rama Mohan Rao, Professor, Dept. of Civil Engineering, Jawaharlal Nehru Technological University Hyderabad (JNTUH), Hyderabad, Andhra Pradesh, India.

Mahdi hosseini, Post Graduate Student, Dept. of Civil Engineering, Jawaharlal Nehru Technological University Hyderabad (JNTUH), Hyderabad, Andhra Pradesh, India.