Behavior of Segmental Precast Post-Tensioned Bridge Pier

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Abstract

In seismic areas, bridges are designed so that the piers will yield rather than the superstructure. Powerful earthquakes cause residual displacement of the Pier. This permanent deformation can be difficult to repair. Un-bonded post-tensioning solves the problem of residual displacement, since strain is distributed equally throughout the tendon, it does not yield easily, and residual displacements are small. After adding pre-stressing load, tensile stresses are reduced and compressive stresses are increased upto its permissible limits. In this study the effects of the pre-stressed tendon ratio and prestressing force, the longitudinal reinforcement ratio is made by non-linear static pushover analys in SAP2000, from Pushover Analysis is obtained that the yield strength & ultimate strength is improved when the pre-stressing force is applied to the Pier. From Cyclic Analysis (Hysteresis) it is found that hysteresis loop area will improve hence, energy dissipating capacity will be improved when pre-stressing load applied to the pier. Probability of complete damage is reduced for Pre-stressed Pier as compared with normal pier.

Keywords: Segmental Precast Post-tensioned Bridge Pier, cyclic analysis Pushover Analysis, hysteresis loop, Fragility Curves

I. INTRODUCTION

In the Kobe earthquake in 1995, about one-fifth of common reinforced concrete piers did not show any need of reconstruction because of excessive residual plastic deformation. Therefore, international research made by mass tests and theoretical research on high ductility and low-residual displacement pier. Supported by the Japanese Prestressed Concrete Engineering Association, according to the disadvantages of low energy dissipation capacity and poor ductility performance of pure prestressed concrete (PRC) pier and large residual plastic deformation of pure common reinforced concrete pier, De Felice put forward an assumption of the mixed use of common reinforcement and prestressed tendon in a pier. The vertical prestressed tendon can decrease residual plastic deformation of pier. In addition, the common reinforcement can increase ductility capacity and energy dissipation capacity and control the crack of pier body. Pier is designed with and without prestressing force and stresses are checked. In this paper the effects of the pre-stressed tendon ratio, the longitudinal reinforcement ratio, and the stirrup reinforcement ratio is studied by Pushover Analysis, hysteresis loop, Fragility Curves and appropriate ratios are suggested

II. ANALYTICAL MODELLING

A. Analytical Modelling of Post-tensioned Bridge Pier:

- Piers are modelled using nodes and frame element:
- Steel reinforcement properties were represented by a built-in model in SAP2000.
- A vertical force at the top of the column was assigned as the axial dead load and horizontal loads are assigned on the same node.
- Plastic hinge properties are inserted to Pier using auto-hinge command which is a built-in feature in SAP2000.
- Post-tensioned tendons modelled using link element. The parameter used for tendon element were force and stiffness. A link element was then placed at the tendon location within the model. The tendons continued along the length of the column and were anchored at the location of the top of the loading head.
- A body constraint was then used to connect the top of the column with the end of the four tendons, to insure that the tendons and column moved together as one unit. To initially stress the tendons (link elements), a frame element was created and referred to as a “Tendon Bar” in the model (see Fig. 1).
- The tendon bar was connected between the base of each tendon, and below the footing. The base of this frame element was assigned as fixed constraint and the base of this link element was assigned as pinned constraint.
B. Bridge Pier Details:

A Post-tensioned reinforced concrete pier is 10m high and the rectangular section of size 3m x 8m, subjected to vertical load of 7760 kN, horizontal load of 510 kN (longitudinal), horizontal load of 150 kN (transverse) and different pre-stressing load (minimum 648 kN), materials used Fe 415 steel, M50 concrete and A416 grade 250 tendon (see Fig. 2)

III. Pushover Analysis (Monotonic Loading)

A. Comparison between Normal Pier and Prestressed Pier

Two frame element models are consider, which are the same except the values pre-stressed of tendon and prestressing force. The configuration of pre-stressed tendon is 12Φ12.7 with pre-stressing load of 1537kN. The pushover curve is obtained from the plastic hinge area at the bottom of pier (see Fig. 2).

B. The Effect of Pre-stressed Tendon

Five frame element models are consider, which are the same except the number of pre-stressed tendon and pre-stressing force. The configuration of prestressed tendon are 12Φ12.7, 19Φ12.7, 27Φ12.7, 137Φ12.7, and 55Φ12.7 with pre-stressing load of 1537kN, 2434kN, 3458kN, 4739kN and 7045kN respectively. The pushover curve is gotten from the section of plastic hinge area at the bottom of pier (see Fig. 3)
C. The effect of the Ratio of Longitudinal Reinforcement

Five frame element models are established, they are all the same except the ratio of longitudinal reinforcement; the configuration of longitudinal reinforcement are 76Φ35, 88Φ35, 130Φ35, 148Φ35, and 220Φ35. The pushover curve is gotten from the section of plastic hinge area at the bottom of pier (see Fig. 4).

D. The effect of the Ratio of transverse Reinforcement

Five frame element models are established, which are all the same except the ratio of stirrups. The configuration of transverse Reinforcement are Φ10@30cm, Φ10@25cm, Φ10@20cm, Φ10@15cm and Φ10@10cm. The pushover curve is gotten from the section of plastic hinge area at the bottom of pier (see Fig. 5).
E. The effect of the Slenderness Ratio

Five frame element models are established, which are all the same except the height of column. The configuration was 8m, 9m, and 10m height of column. The pushover curve is gotten from the section of plastic hinge area at the bottom of pier (see Fig. 6).

![Fig. 6: Pushover Analysis Curve of PRC pier with slenderness ratio](image)

F. The effect of the Aspect Ratio

Five frame element models are established, which are all the same except the aspect ratio. The configuration was (2x8x10),(2.5x8x10) and (3x8x10) area of column. The pushover curve is gotten from the section of plastic hinge area at the bottom of pier (see Fig. 7).

![Fig. 7: Pushover Analysis Curve of PRC pier with Aspect ratio](image)

IV. CYCLIC LOAD ANALYSIS (HYSTERESIS)

A time history of “A time history of “EL-CENTRO” was used in the analytical model to estimate energy dissipation and residual displacements (see Fig. 8).

![Fig. 8: Time history function of El-centro earthquake](image)
A. Comparison between normal Pier and prestressed Pier

Two frame element models are established, which are the same except the pre-stressed tendon and prestressing force. The configuration of pre-stressed tendon are 12Φ12.7 with pre-stressing load of 1537kN. The pushover curve is gotten from the section of plastic hinge area at the bottom of pier (see Fig. 9 and Fig. 10).

![Hysteresis Curve of PRC pier with pre-stressing tendons](image)

Fig. 9: Hysteresis Curve of PRC pier with pre-stressing tendons

B. The Effect of Pre-stressed Tendon

Five frame element models are established, which are the same except the number of pre-stressed tendon and pre-stressing force. The configuration of prestressed tendon are 12Φ12.7, 19Φ12.7, 27Φ12.7, 137Φ12.7, and 55Φ12.7 with pre-stressing load of 1537kN, 2434kN, 3458kN, 4739kN and 7045kN respectively. The pushover curve is gotten from the section of plastic hinge area at the bottom of pier (see Table 1).

<table>
<thead>
<tr>
<th>Transverse Reinforcement</th>
<th>Transverse Reinforcement Ratio</th>
<th>Minimum force (kN)</th>
<th>At Displacement (m)</th>
<th>Maximum force (kN)</th>
<th>At Displacement (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Φ10 @ 30 cm</td>
<td>0.012</td>
<td>-15120</td>
<td>0.01005</td>
<td>14610</td>
<td>-0.00641</td>
</tr>
<tr>
<td>Φ10 @ 25 cm</td>
<td>0.014</td>
<td>-15120</td>
<td>0.01005</td>
<td>14610</td>
<td>-0.00641</td>
</tr>
<tr>
<td>Φ10 @ 20 cm</td>
<td>0.018</td>
<td>-15120</td>
<td>0.01005</td>
<td>14610</td>
<td>-0.00641</td>
</tr>
<tr>
<td>Φ10 @ 15 cm</td>
<td>0.024</td>
<td>-15120</td>
<td>0.01005</td>
<td>14610</td>
<td>-0.00641</td>
</tr>
<tr>
<td>Φ10 @ 10 cm</td>
<td>0.036</td>
<td>-15120</td>
<td>0.01005</td>
<td>14610</td>
<td>-0.00641</td>
</tr>
</tbody>
</table>

C. The effect of the Ratio of Longitudinal Reinforcement

Five frame element models are established they are all the same except the ratio of longitudinal reinforcement; the configuration of longitudinal reinforcement are Φ32, 88Φ32, 130Φ32, 148Φ32, and 220Φ32. The pushover curve is gotten from the section of plastic hinge area at the bottom of pier (see Table 2).

<table>
<thead>
<tr>
<th>Longitudinal Reinforcements</th>
<th>Longitudinal Reinforcement Ratio</th>
<th>Minimum force (kN)</th>
<th>At Displacement (m)</th>
<th>Maximum force (kN)</th>
<th>At Displacement (m)</th>
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</thead>
<tbody>
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<td>106 nos. of Φ 32</td>
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</tr>
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<td>156 nos. of Φ 32</td>
<td>0.521</td>
<td>-15120</td>
<td>0.01005</td>
<td>14610</td>
<td>-0.00641</td>
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<tr>
<td>178 nos. of Φ 32</td>
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<td>-15120</td>
<td>0.01005</td>
<td>14610</td>
<td>-0.00641</td>
</tr>
<tr>
<td>266 nos. of Φ 32</td>
<td>0.880</td>
<td>-15120</td>
<td>0.01005</td>
<td>14610</td>
<td>-0.00641</td>
</tr>
</tbody>
</table>

D. The effect of the Ratio of transverse Reinforcement

Five frame element models are established, which are all the same except the ratio of stirrups. The configuration was Φ10@30cm, Φ10@25cm, Φ10@20cm, Φ10@15cm and Φ10@10cm. The pushover curve is gotten from the section of plastic hinge area at the bottom of pier (see Table 3).
Table - 3
Hysteresis Curve result comparison of PRC pier with different Transverse Reinforcements

<table>
<thead>
<tr>
<th>Transverse Reinforcements</th>
<th>Transverse Reinforcement Ratio</th>
<th>Minimum force (kN)</th>
<th>At Displacement (m)</th>
<th>Maximum force (kN)</th>
<th>At Displacement (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Φ10 @ 30 cm</td>
<td>0.012</td>
<td>-15120</td>
<td>0.01005</td>
<td>14610</td>
<td>-0.00641</td>
</tr>
<tr>
<td>Φ10 @ 25 cm</td>
<td>0.014</td>
<td>-15120</td>
<td>0.01005</td>
<td>14610</td>
<td>-0.00641</td>
</tr>
<tr>
<td>Φ10 @ 20 cm</td>
<td>0.018</td>
<td>-15120</td>
<td>0.01005</td>
<td>14610</td>
<td>-0.00641</td>
</tr>
<tr>
<td>Φ10 @ 15 cm</td>
<td>0.024</td>
<td>-15120</td>
<td>0.01005</td>
<td>14610</td>
<td>-0.00641</td>
</tr>
<tr>
<td>Φ10 @ 10 cm</td>
<td>0.036</td>
<td>-15120</td>
<td>0.01005</td>
<td>14610</td>
<td>-0.00641</td>
</tr>
</tbody>
</table>

V. CONCLUSION

Pier is checked for different pre-stressing loads, it is observed that after addition of pre-stressing forces tensile stresses got reduced and compressive stresses increased, and increased compressive stresses are in permissible limits. From Pushover Analysis is obtained that the yield strength & ultimate strength is improved when the pre-stressing force is applied to the Pier. From Cyclic load Analysis (Hysteresis) it is obtained that hysteresis loop area will improve hence, energy dissipating capacity will be improved when pre-stressing load applied to the pier. Probability of complete damage is reduced for Pre-stressed Pier as compared with normal pier. Following are the appropriate ratios for prestressed tendon ratio-12 Φ 12.7, the longitudinal reinforcement ratio-220 Φ 35, and the transverse reinforcement ratio-Φ10 @ 30.

REFERENCES