Key Construction Technology of Large-span Prestressed Beam

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Abstract

In recent years, large-span prestressed construction technology in the construction industry develops rapidly, continuously extends in application scope, with advantages becoming increasingly evident. This paper briefly introduced the prestressed construction scheme and key technical aspects of this project, and made corresponding analysis and explanation for the key points of quality control, it was proved that this technology met the requirements of design and use, and provided reference for the smooth construction of future similar projects.

Keywords: Large-span beam, prestress, quality control, post-tensioned method

1. INTRODUCTION

With the development of building technology, prestressed design and construction is widely used in large-span and large-space building (Shen, 2012), bridge, and nuclear power plant. Its theory and technology development also tends to be perfect and mature (Hu, 2010), and its strong vitality and attraction has been demonstrated by looking back upon constructed projects. However, further study with respect to construction quality control (Hu, 2010) is needed. For bounded post-tensioned prestressed technology, prestressed reinforcement and concrete are able to form a whole bond (Dai et al., 2012) after grouting and anchor seal, and can still work properly despite of anchorage failure. In addition, it has more safety reserve (Dai et al., 2012) in seismic resistance. This technology can be a very good solution to deflection and crack resistance (Zhao, 2010) of large-span beam under high load. This paper introduced examples of the large-span prestressed beam, listed key points of quality control of the prestressed beam, and identified three factors influencing the elongation dissatisfaction of the prestressed reinforcement, thus, the quality of this project was ensured.

2. PROJECT OVERVIEW

This project is located in Main Urban Zone, Xianyang city, Shaanxi province, including Science and Technology Museum, Publicity and Education Center for Disaster Reduction Propaganda, Women and Children’s Activity Center, Youth Palace, Library, Archives, Exhibition Hall for Public Art and Intangible Cultural Heritage, City Planning Exhibition Hall, and Theatre. The theatre is the core building venue, designed into cast-in-place reinforced concrete frame shear structure, with six floors above ground, one underground. It covers an area of 36,982 m², with a longitudinal axis length of 76.0 m, horizontal axis length of 76.0 m, indoor and outdoor height difference of 1.80 m, and building height of 45.0 m. A total of three prestressed beams were constructed on the roof with 38.0 m elevation, all of which employed the bonded post-tensioned prestressed technology, as shown in Figure 1.

The strength grade of the three prestressed beams was C40. For prestressed beams WYKL1 and WYKL2, both of their sectional dimensions were 800 mm×2, 500 mm, and effective span was 29.2 m, with two rows of prestressed reinforcements, upper and lower rows of 2-11Φs15.2, arranged inside them, where the linear parameter of the lower row was (300, 400, 300), as shown in Figure 2; the linear parameter of the lower row was (500, 200, 500), as shown in Fig. 3. For prestressed beam WYKL3, its sectional dimension was 700 mm×1, 800 mm, and effective span was 24 m, with one row of prestressed reinforcements 2-9Φs15.2 arranged inside it, where the linear parameter was (300, 200, 300), as shown in Figure 4. All the prestressed beams were four connecting parabolas, with a prestressed strut set every other 1.0 m in them, and the inflection point was 0.10 Ln1 (Ln1 was the clear span of the prestressed beams) from the inner edge of the bearing.
Figure 1. Three Prestressed Beams

Figure 2. Line Shape of the Prestressed Reinforcements of the Upper Row of the Prestressed Beams WYKL1 and WYKL2 with 38 m Elevation in the Theatre

Figure 3. Line Shape of the Prestressed Reinforcements of the Lower Row of the Prestressed Beams WYKL1 and WYKL2 with 38 m Elevation in the Theatre

Figure 4. Line Shape of the Prestressed Reinforcements of the Prestressed Beam WYKL3 with 38 m Elevation in the Theatre
3. CONSTRUCTION MATERIALS AND TECHNOLOGY

3.1 Material and equipment

3.1.1 Prestressed reinforcement

Grade 1860 Φs15.2 high-strength low-relaxation bonded prestressed steel strand was employed, with a nominal diameter of 15.2 mm, an elasticity modulus of 1.95×10^5 MPa, a single cross section area of 140 mm^2, and a relaxation ≦ 3.5%. The control stress for the tensioning of the prestressed reinforcement was 1, 302 MPa < 0.75 fptk (1, 395 MPa).

3.1.2 Grouting cement

Ordinary Portland Cement Grade 42.5 was employed, and chlorine-free high efficiency water reducer was added during the grouting.

3.1.3 Anchorage

OVM series anchorage was employed, with specifications of 15-X and 15P-X. Clip type anchorage was employed for the tensioning end; extruding anchorage was employed for the anchored end; as shown in Figure 5 and 6, respectively.

3.1.4 Bellow

Steel bellow was employed, with internal diameters Dn of 80 mm and 90 mm (80 mm was employed for 9-bundle prestressed reinforcement, and 90 mm for 11-bundle prestressed reinforcement).

![Figure 5. Anchorage at the Tensioning End](image)

![Figure 6. Extruding Anchorage at the Fixed End](image)
3.1.5 Major equipment

Wire cutting machine, high-pressure oil pump, 250 T through-type jack, 25 T through-type jack, prestressed extruder, high-pressure grouting pump, cement mixer, and electric welder were employed.

3.2 Construction technology

Construction technological process of the three prestressed beams:

4. ANALYSIS AND QUALITY CONTROL

4.1 Key points of quality control

4.1.1 Positioning and laying of bellow

The prestressed reinforcement curve was formed by positioning bellow pre-layed in the beam, the beam column joints, in particular, was difficult (Liu et al 2009; Li, 2012) for accurate positioning because of dense reinforcement. Before laying of bellow, non-prestressed reinforcements were bound in accordance with dimensions in the drawing. Spacer bar was set with elevation according to the control point of curve in the drawing for linear control, and its highest and lowest points should be marked with dimensions for construction in strict accordance with the drawing, and the elevation error of the highest and lowest points was less than 5 mm and 10 mm, respectively. Construction practices: first, the spacer bar fabricated from $\phi 12$ reinforcement was welded on the beam stirrup by using spot welding to ensure the curve positioning of the prestressed reinforcement. Then, the bellow was penetrated into the beam to fall on the fabricated spacer bar. Finally, the bellow was rang with U-shaped reinforcement fabricated from $\phi 6$ plain round bar, and welded on the spacer bar for horizontal position, as shown in Figure 7.

During the laying of bellow, priority should be given to the prestressed duct position when non-prestressed reinforcement conflicted with prestressed duct position, especially when the elbow anchored end of the longitudinal reinforcement of the upper row of the prestressed beam on the column joint of the prestressed tensioning end influenced the prestressed duct position, the elbow anchored end can anchor upward inside the beam in order to avoid prestressed duct position. When the bellow was penetrated into the column, the vertical
reinforcement in the position of the bellow should be cut if the vertical reinforcement of the column cannot be displaced, and the vertical reinforcement should be rearranged to meet the requirements of lapped length after the laying of bellow was completed.

4.1.2 Installation of anchor plate

Anchor plate at the tensioning end was pre-installed on the tensioning end of the beam, and poured together with the bellow along with the beam, and hidden in structure concrete at the tensioning end. The anchor plate was welded on the reinforcement at the end of tensioning node by using spot welding perpendicular to the bellow, after the anchor plate at the tensioning end was fixed at the tensioning end of the beam, operating space of tensioning should be inspected, and spiral reinforcement should be installed in the position close to the anchor plate, and exhaust hole with 20 mm aperture was reserved on the anchor plate.

Extrusion anchor plate at the fixed end was welded on the nonprestressed stirrups by using spot welding perpendicular to the bellow, the end of the prestressed steel strand used as extrusion anchor head was penetrated from the anchor plate at the fixed end, through restriction ring and bellow to tensioning end, with restriction ring sealed with cotton. Finally, the exhaust hole with 20 mm aperture was set at the highest point and two ends of the bellow. During the installation of the anchorage at the fixed end, extrusion anchorage should be close to bearing plate which should be free from overlapping, with spiral reinforcement arranged at the restriction ring.

4.1.3 Docking of bellow

The standard length of each bellow was 6 m, for bellow with length of greater than 6 m, docking should be conducted by using the bellow (400 mm long, 150 mm screwed in per side) of the same form and one size larger (3~5 mm larger), and sealed with yellow tape, as shown in Figure 8.

![Docking diagram of bellow](image)

Figure 8. Docking diagram of bellow

4.1.4 Bundling of prestressed reinforcement

Bundling of prestressed reinforcement was performed by artificial means, during the bundling, steel strand end should be wound or ground with adhesive tape, after bundling was completed, the bellow should be checked for damage, and wrapped with waterproof tape if damaged.

4.1.5 Pouring of concrete

Pouring of concrete was conducted in 5 layers, with each layer of 500 mm (volume was approximately 10 m³), and the pouring of next beam should be started immediately after the pouring of the first layer of one beam was completed. Only after circular pouring of four layers in turn was completed can the pouring of other regional structures from south to north be started, after 4 to 6 hours, the pouring of the fifth layer was started; during the pouring of concrete in layers, the insertion depth of vibration rod in the lower concrete should not exceed 50 mm so as to eliminate the seams between the two layers.

4.1.6 Tensioning of prestress
Tensioning was started after the concrete strength reached 80% (providing report of concrete test block of the beam) of design strength. Whole-bundle anchor group tensioning using a 250T through-type jack was employed for the tensioning of prestress. When it was unable to install the 250T jack due to insufficient tensioning space, a 25T jack was employed for single anchor tensioning. Before tensioning, a safe and reliable working platform of approximately 1 m below the tensioning top should be set; during the tensioning and within 2 hours after anchoring, it was prohibited that person stood on the end of the prestressed reinforcement.

Tensioning was conducted from the lower layer to the higher layer; for each layer, tensioning was conducted by starting from one direction to all prestressed beams one by one, and supplementary tensioning was conducted for the other end; for a single prestressed beam, tensioning was carried out one by one in line with the principle of symmetrical tensioning. At the end of tensioning, the excess steel strand was cut using a wire cutting machine, and the length of exposed steel strand should not be less than 30 mm.

The blanking length of the prestressed reinforcement was calculated as follows: L=Lc+H1+H2+L0

where: L - blanking length;
L4 - length of effective prestressed steel strand calculated according to the drawing (i.e. length of the duct);
H1 and H2 - thickness of work anchor and stopper;
L0 - clamping length of the jack (to ensure the requirements of the operating space of the jack, L0=1m)

The prestress tensioning adopted the stress control method, and checked by theoretical value of elongation. The control stress for the tensioning of the prestressed reinforcement was: σcon=0.7 fptk=1, 302 Mpa, with an ultra-tensioning of 3%. The control range of actual elongation value should be in the scope of calculated theoretical value of elongation of -6%→+6%. Tensioning procedure was: 0→20% σcon (initial measured value)→103% σcon→maintaining for 2 minutes→final measured value→anchoring.

Common problems in the process of tensioning of the prestressed reinforcement: 1) In case of broken or slipped prestressed reinforcement, its number should not exceed 3% of the total number of the prestressed reinforcement on the same section, and the number of each bundle of steel wire should not exceed one. When an exception occurred, the anchorage should be first pulled out and then replaced with a reliable anchorage depending on the situation of the broken or slipped prestressed reinforcement, and the broken prestressed reinforcement can be added with false steel wire to assist tool anchor for clamping, after tensioning force was reduced, the tensioning was started again. 2) In case of harmful crack in the tensioning end after hole collapsing or tensioning, the anchorage should be first pulled out and strengthening treatment was performed for the concrete with collapsed hole or cracked concrete, after the treated concrete strength met the requirements, the tensioning was started again. 3) In case of abnormal tensioning due to duct leakage caused by pouring and tamping of concrete, component should be timely chiseled open to clean up the leakage portion, after the repair was completed, the tensioning was started again.

4.1.7 Grouting of duct

Grouting can achieve effective bonding between the prestressed reinforcement and the concrete, increase integrity, reduce the load of anchorage on the beam end, and protect steel strand from corrosion. Grouting cement adopted Ordinary Portland Cement Grade 42.5, with water cement ratio of not greater than 0.45. To improve the fluidity of cement slurry and ensure the compactness of the grouting, the cement slurry was uniformly stirred for 2-3 minutes, and added with appropriate amount of chlorine-free high efficiency water reducer. Before the grouting, first, excess steel strand outside of the anchorage should be cut using a grinder at a place of not less than 30 mm from the anchorage, then, the clip gap was sealed with neat cement viscous slurry, only after cement setting can the grouting be started.

During the grouting, the cement slurry was stirred uninterruptedly, and filtered with a screen mesh. Grouting for each duct should be completed once, during which the nozzle shall stay at the outlet of the duct in order to prevent air entering into the pipe to produce bubbles. After cement slurry outlet of the grouter and grout pipe...
were tightly connected and confirmed, the grouting pump was started and pressurized to grout cement slurry, the cement slurry outlet was inspected one by one from near to far, after dense cement slurry flowed from each cement slurry outlet, all the cement slurry outlets were closed one by one to the last one which was closed and continued to be pressurized to 0.5-0.7 MPa for 1-2 minutes. finally, the cement slurry inlet valve was closed, and the bleeding cement and sundries were cleaned up timely. If any gap was found in the grout pipe, it should be filled with cement slurry carefully. If the grouting of the duct was blocked, displaced or interrupted, the duct should be flushed timely or other measures should be taken for re-grouting.

4.1.8 Anchor seal of prestressed reinforcement end

After tensioning and grouting, concrete surrounding the anchorage should be roughened and rinsed well, the anchorage and exposed prestressed reinforcement were coated with epoxy resin. The convex type anchor head was collocated with steel mesh and sealed with C40 micro-expansive inflatable concrete including thin stone.

4.2 Analysis of construction effect

4.2.1 Investigation and analysis of quality

<table>
<thead>
<tr>
<th>Inspection items</th>
<th>Total points/pcs</th>
<th>Unqualified points/pcs</th>
<th>Qualification ratio/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensioning elongation dissatisfaction</td>
<td>80</td>
<td>10</td>
<td>87.5</td>
</tr>
<tr>
<td>Cracked concrete at the tensioning end</td>
<td>80</td>
<td>2</td>
<td>97.5</td>
</tr>
<tr>
<td>Stress loss of steel strand</td>
<td>80</td>
<td>2</td>
<td>97.5</td>
</tr>
<tr>
<td>Slipped or broken bundled steel wires</td>
<td>80</td>
<td>1</td>
<td>98.7</td>
</tr>
<tr>
<td>Total</td>
<td>320</td>
<td>15</td>
<td>95.3</td>
</tr>
</tbody>
</table>

**Table 2. Statistical Table of Control Deficiencies in Prestress Tensioning Construction**

<table>
<thead>
<tr>
<th>Inspection items</th>
<th>Frequency count</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensioning elongation dissatisfaction</td>
<td>10</td>
<td>66.7</td>
</tr>
<tr>
<td>Cracked concrete at the tensioning end</td>
<td>2</td>
<td>13.3</td>
</tr>
<tr>
<td>Stress loss of steel strand</td>
<td>2</td>
<td>13.3</td>
</tr>
<tr>
<td>Slipped or broken bundled steel wires</td>
<td>1</td>
<td>6.7</td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>100</td>
</tr>
</tbody>
</table>

By Tables 1 and Table 2, it can be found that tensioning elongation dissatisfaction, cracked concrete at the tensioning end, stress loss of steel strand and slipped or broken bundled steel wires were the four factors influencing the prestressed construction quality, of which, the tensioning elongation dissatisfaction was the main influencing factor. So as long as the tensioning elongation dissatisfaction of the prestressed reinforcement was controlled well, the tensioning quality can be ensured. By inspecting the quality of instruments and equipment and the prestressed reinforcement, analyzing the tensioning of the prestressed beam at both ends, tensioning operation and environmental factors, it was found that three minor factors influencing the tensioning elongation dissatisfaction, thus, control measures should be taken to ensure the quality of the follow-up project.

1) Improper jack used for initial stress tensioning

By asking, the construction team conducted 20% of whole-bundle initial stress tensioning using a Grade 2, 500 KN jack. By calculation, the tensioning force of 2-9φs15.2 and 4-11φs15.2 prestressed reinforcements was 656.208 KN and 1, 604.064 KN, respectively. Since 656.208KN was not within the scope of 1/2-3/4 of 2, 500 KN, thus leading to large error. For 2-9φs15.2 prestressed reinforcement, it was more appropriate to choose four sets of 25 T jacks for initial stress tensioning, and choosing a Grade 2, 500 KN jack can not completely meet the requirements.

2) Location inaccuracy of reserved duct
After investigation, because the reinforcement at the junction of the prestressed beam and column was thick, densely arranged, therefore, the corrugated duct can not be installed in the position 100 percent according to the design requirements, which influenced the position of the reserved duct and the size of the angle theta (sum of partial tangents of curve duct), thus influencing the theoretical length and friction coefficient of the steel strand, finally influencing the tensioning elongation. During the construction, the control point position of the bellow was determined in strict accordance with the design, person was sent to carefully check to ensure accurate location.

3) Blockage of reserved duct

The blockage of the reserved duct caused by disrepair and leakage of the bellow not only affected the bundling and tensioning of the prestressed reinforcement, but also affected the grouting of the duct. Therefore, special attention needed to be paid to the joint of the bellow and the process of reinforcement penetrating. When the duct was blocked, it should be washed timely. Pre-control measures for the blockage of the reserved duct should be carried out when the pouring of the prestressed frame beam was conducted. During the laying of bonded prestressed bellow, special attention needed to be paid to the leak-tightness of the bellow, when the disrepair and leakage of the bellow occurred, the bellow should be closed or replaced timely.

5. CONCLUSION

This paper conducted analysis of the construction difficulties of the three large-span prestressed concrete beam of this project and performed quality control. The successful application of the bounded post-tensioned prestressed technology not only met the design of the prestressed beam, but also greatly reduced the size of the beam section, as well as the dosage of the concrete and reinforcement. It identified three factors influencing the construction quality of the prestressed beam, thus, the quality of this project was ensured by taking control measures. This showed that this scheme was reasonable and feasible. Strict quality control was the key to the successful construction of this project, which saved costs, created good social benefits, and provided reference for the smooth construction of future similar projects.

ACKNOWLEDGEMENTS

The work was supported by Natural Science Basic Research Planning Project of Shaanxi (2014JM2-5079).

REFERENCES

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