Comparision study on the mechanical properties between Steel Reinforce Concrete Beam and Prestressed Steel Reinforced Concrete Beam

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Abstract: Eight prestressed steel reinforced concrete beam (PSRCB) and six steel reinforced concrete beam (SRCB) have been done with different compressive strength of concrete, rebar ratio, cover thickness, steel cover thickness and degree of prestressing. A compared study on the mechanical properties between PSRCB and SRCB were carried out, which included flexural capacity, deflection and maximum crack width. Experimental study indicates that PSRCB has better mechanical performance, higher flexural capacity, larger stiffness and better resistance to crack.

1. Introduction
Steel reinforce concrete beam (SRCB) has a better flexural strength contrast to reinforce concrete beam, but its serviceable performance is not improved obviously.

Prestressed steel reinforced concrete beam (PSRCB) make full use of prestressing technique to improve mechanical performance. The H-section steel inside can increase the flexural strength and the prestressing technique can improve it’s working performance. PSRCB has expansive application in structures.

An experimental comparision study between SRCB and PSRCB has been done through the test of Six SRCB and seven PSRCB specimens with different compressive strength of concrete, rebar ratio and cover thickness, steel cover thickness and degree of prestressing.

The development of flexural capacity, deflection and maximum crack width have been observed, which can provide experimental and theoretical foundation for practical application of PSRCB.

2. Experimental program
In order to study further mechanical properties of PSRCB by contrast with SRCB, specimens of SRCB are designed corresponding to PSRCB. The following aspects are taken into account, including different compressive strength of concrete, rebar ratio and cover thickness, steel cover thickness and degree of prestressing.

Fourteen specimens were designed, including six SRC beams and eight PSRC beams(As is shown in Table 1). All specimens were 4000mm long with H-section steel (HN200×100×5.5×8)inside, area of specimens were 200 mm×350 mm and stirrups were φ8@100. Tension reinforcement for SRCB4
and PSRCB4 were 2 Φ20, and the other were 2 Φ14. Low relaxation strand $\phi_{15.2}$ ($f_{ptk}=1860$ N/mm²) was used in the test and control stress for prestressing was 0.75 $f_{ptk}$.

Table 1. Detail of specimens

| specimens   | $c_s$ (mm) | $c_{as}$ (mm) | concrete | specimens   | $c_s$ (mm) | $c_{as}$ (mm) | concrete |
|-------------|------------|---------------|----------|-------------|------------|---------------|----------|
| SRCB1       | 25         | 80            | C40      | PSRCB1      | 25         | 80            | C40      |
| SRCB2       | 25         | 100           | C40      | PSRCB2      | 25         | 100           | C40      |
| SRCB3       | 50         | 80            | C40      | PSRCB3      | 50         | 80            | C40      |
| SRCB4       | 25         | 80            | C40      | PSRCB4      | 25         | 80            | C40      |
| SRCB5       | 25         | 80            | C50      | PSRCB5      | 25         | 80            | C50      |
| SRCB6       | 25         | 80            | C60      | PSRCB6      | 25         | 80            | C60      |
| PSRCB6'     | 25         | 80            | C40      | PSRCB7      | 25         | 80            | C40      |

Note: PSRCB2 was destroyed and abandoned during its construction process.

3. Contrast of flexural capacity between PSRCB and SRCB

The failure model of PSRC beams are all flexural failure model (Fig-1). As is shown in Fig-2, PSRCB can obtain better flexural capacity by contrast to SRCB.

4. Contrast of deflection between PSRCB and SRCB

As is shown in Fig-3, increase of tensile rebar area, compressive strength of concrete and effective stress of prestressing strand can all contribute to improving flexural rigidity of PSRC beam.

The development of deflection for PSRC beam can be classified into three phases: elastic phase, serviceable phase and failure phase.

The first phase: elastic phase. This phase is before $M$ reaches $M_{cr}$. There is a reverse deflection before load is applied to PSRC beam, which can bring a beneficial effect to its working performance. PSRC beam has a longer elastic phase by contrast with SRC beam, because $M_{cr}$ of the former is bigger than that of the latter.

The second phase: serviceable phase. This phase is from $M_{cr}$ to yield of tension reinforcement and tensile flange of H-section steel. Concrete in tension zone lose its effect in cracking section after $M_{cr}$, which make the flexural rigidity decrease slightly. However, there is no obvious turning point in the M-f curve, which is because the concrete losing effect in cracking section contributes little to the flexural rigidity of PSRC beam. Therefore, in this phase, M-f curve approximately keeps a line, which indicates a better working performance.

The third phase: failure phase. This phase is from yield of tension reinforcement and tensile flange of H-section steel to ultimate failure of beam. Strains of tensile rebar and tensile flange of H-section increase drastically after their yield strengths, which make flexural rigidity decrease rapidly. Therefore, there is a turning point in the M-f curve, which indicates that deflection increases more quickly. The reason is that concrete near the outer compressive fiber is crushed and flexural rigidity decreases
further when $M$ reaches $M_u$. But PSRC beam has a good ductile property because of its H-section steel inside.

Before load is applied to PSRC beam, there is a reverse deflection, which brings a beneficial effect to its working performance. After $M$ reaches $M_{cr}$, the flexural rigidity decreases slightly and there is no obvious turning point in the $M$-$f$ curve for both PSRC beam and SRC beam. PSRC beam has a higher flexural rigidity but the ultimate deflection is smaller by contrast with SRC beam. The flexural rigidity of PSRCB6 is higher than that of PSRCB6’, because the effective stress of prestressing strand for the former is higher than that for the latter. However, the ultimate deflection of PSRCB6 is smaller by contrast with PSRCB6’. In addition, after $M$ reaches $M_u$, the flexural rigidity of the PSRC beam with high compressive concrete strength decreases more rapidly and there is a more obvious turning point in $M$-$f$ curve.

5. Contrast of crack width between PSRCB and SRCB
Cracking moments $M_{cr}$ of PSRCB is from 18.41 percent to 27.61 percent ultimate moment $M_u$, and average is 22.25 percent, which indicate a better resistance to crack. With the increase of bending moment, the crack further develop along the across section. However, the height and crack width of PSRCB decrease more obviously by contrast with that of SRCB under the same $M/M_u$. With the decrease of load, the crack width become smaller than that of SRCB and what is more important is that the distribution of crack width become more even, which indicate that PSRCB has a better crack closing performance. The ultimate heights of cracks develop lower than that of SRCB. The height and width of cracks in shear span develop more slowly than that of cracks in the bending span.

Residual bending deflection and residual crack width of PSRCB is evidently smaller than that of SRCB after the experiment. Actually, most crack widths cannot be observed by our eyes after the test, except those of the portion where the compressive concrete is crushed.

As is shown in Fig 4, the development of PSRCB $w_{\text{max}}$ can also be classified into three phases: linear development, faster development and unstable development.

a) The first phase: linear development. From the cracking moment to the yield of tension reinforcement and low flange of H-section steel, it is evidently that the beginning of the phase is higher than that of SRCB which indicate a better resistance to crack. In this phase, $w_{\text{max}}$ increase linearly with the bending moment, which indicate a better working performance.
b) The second phase: Faster development. Above eighty percent $M_u$, $w_{\text{max}}$ develop faster than that of the first phrase.

The third phase: unstable development. $w_{\text{max}}$ develop drastically with little increment of bending moment in this phrase.

Prestressing technique can improve the SRCB working performance under the same $M/M_u$. But the effective stress of prestressing strand should not be too low, where the value is about 0.40 $f_{\text{ptk}}$.

The conclusion can be reach from the above test results that the tensile strength and ratio of tensile rebar and the cover thickness of tensile rebar can influence obviously on the development of $w_{\text{max}}$.

Cracking moments $M_{cr}$ of SRCB is from 12.25 percent to 18.91 percent ultimate moment $M_u$. The maximum crack widths $w_{\text{max}}$ reach 0.2mm, when the moment is about seventy percent $M_u$. $w_{\text{max}}$ reach 0.3mm while the moment is around eighty percent $M_u$. The ultimate heights of cracks develop to the up flange of H-section steel. The height and width of cracks in shear span develop more slowly than that of cracks in the bending span. Residual bending deflection and residual crack width of SRCB is obviously after the experiment.

6. Conclusions
1) Prestressing technique contributed to utilization of flexural strength of PSRC beam.
2) PSRC beam has better serviceable performances by contrast with SRC beam: better resistance to crack and smaller deflection.
3) The development of SRCB or PSRCB $w_{\text{max}}$ can be classified into three phases: linear development, faster development and unstable development.
4) The development of deflection for SRCB or PSRCB can be classified into three phases: elastic phase, serviceable phase and failure phase.

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