Structural behavior of incrementally prestressed concrete girders

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Abstract

Due to the simple design and construction, along with the cheap cost of maintenance and repair, the prestressed concrete (PSC) I-type girders are widely used in superstructures of bridges. But the traditional PSC I-type girders are restricted in size when applied in long span bridges. In Korea, PSC I-type girders are only applied in short and medium span bridges. However, using the concept of incremental prestressing, long span PSC I-type girder can be used without increasing the height of the girder. In this study, bending test of incrementally prestressed concrete (IPC) girder is performed to prove the validity of design concept and to find out structural behavior of IPC girder. Two full scale specimens (bracket type and coupler type), with span length of 30m, are designed, manufactured and tested up to failure. During the test, strains of reinforcing steel and concrete and deflections are measured. Cracks are also marked during the test.

Test results show good agreement with theoretical values in terms of stresses, deflections, cracking moment and ultimate strength. The ultimate strength of IPC girder is about 30\% higher than the traditional PSC girder. Deflections are observed within the design limit. It can be concluded that the IPC girder has full safety and ductility and can be used as long span bridge girders.

1 Introduction

Due to the simple design and construction, along with the cheap cost of maintenance and repair, the prestressed concrete (PSC) I-type girders are widely used in superstructures of bridges. In Korea, 11\% of all bridges are PSC I-type
Table 1: Design condition of girders

<table>
<thead>
<tr>
<th>Type</th>
<th>Span length</th>
<th>Girder height</th>
<th>Girder spacing</th>
<th>Slab thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple</td>
<td>30m</td>
<td>100cm</td>
<td>200cm</td>
<td>22cm</td>
</tr>
</tbody>
</table>

Table 2: Material properties of IPC girders

<table>
<thead>
<tr>
<th></th>
<th>Prestressing Tendon</th>
<th>Reinforcing Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Ultimate strength</td>
<td>Diameter</td>
</tr>
<tr>
<td>SWPC 7B</td>
<td>19,178 kg/cm²</td>
<td>15.2mm</td>
</tr>
</tbody>
</table>

In this study, bending test of IPC girder is performed to prove the validity of design concept and to find out structural behavior of IPC girder. Two specimens (one with bracket type and the other with coupler type), with span length of 30m, are designed according to bridge design code of Korea [2] and fabricated using the concept of incremental prestressing. During the test, strains of reinforcing steel and concrete and deflections are measured. Cracks are also marked during the test.

2 Test

2.1 Specimen

Two full scale specimen are manufactured. They are designed under the same condition (Table 1) but different from the method of second prestressing and type of anchorage. One is using the bracket (IPC-B) and the other is using the coupler (IPC-C). Girder sections are designed according to the code [2] and shown in Figure 1.

Concrete compressive strengths of girder and slab are 500kg/cm² and 300kg/cm² each. Steam curing is used for 12 hours after casting to avoid the effect of the shrinkage. Material properties for prestressing tendon and reinforcing steel are in Table 2.

The shape of the girder cross section is determined as a bulb-tee type considering the section of Nebraska University Bulb Tee (NUBT) [3] and New England Bulb Tee (NEBT) [4].
The procedure for manufacturing the specimen is in Figure 2. Only difference between the traditional and IPC girder is the addition of second prestressing just after the slab concrete casting.

2.2 Loading and Measurement

The static loading is applied on the simply supported specimen. Two loading points are 2m away each from the center as shown in Figure 3. During the test, structural behavior is measured as shown in Figure 4. Strain gauges are installed on reinforcing steel at upper and lower flanges, stirrups and main reinforcing steel in the slab. Displacements are measured at mid and quarter span in vertical and horizontal directions.

3 Test results

3.1 Load-deflection

The load-deflection diagrams at midspan are shown in Figure 5 and summarized and compared with theoretical values in Table 3.

In case of IPC-C girder, there is a change of the slope at about 50ton possible due to cracking. The first crack by naked eye was actually found at 44ton, which is close to theoretical cracking load of 39.8ton. Since design live load including the impact load is 28.1ton, it can be considered that the girder has enough safety margin. Deflection at midspan was measured as 18.1mm at the design load level (28.1ton) comparing the theoretical value of 26.2mm. The difference may be due to reinforcement not included in the calculation and actual strength of concrete. At cracking load, measured deflection was 30mm, which is 19.1% less than theoretical value of 37.1mm.
Girder Manufacturing

- Fabrication of reinforcing steel for IPC girder
- Placement of sheath
- Forming
- Casting of girder concrete
- Curing of girder
- 1\textsuperscript{st} prestressing & placing girder on supports

Slab Manufacturing and 2nd Prestressing

- Forming of slab & reinforcing steel placement
- Casting of slab concrete & 2\textsuperscript{nd} prestressing
- Curing of slab
- Load test

Figure 2: Procedure for manufacturing IPC girder

Figure 3: Loading of specimen

Yield strength of the specimen is measured as 135.8ton, which is very close to theoretical value of 132.9ton. It was measured that the prestressing tendon yield at about 140ton. Deflection at midspan was measured as 29.6cm. The specimen was unloaded after yielding and deflection of 5.7cm remains. The specimen is loaded again up to its failure. Measured ultimate strength is almost the same as theoretical value of 165ton, which is almost 30\% larger than that of the traditional PSC girder [5].
Figure 4: Location of strain gauges and LVDTs

Table 3. Comparison of design values and results

<table>
<thead>
<tr>
<th>Girder Type</th>
<th>Loading (ton)</th>
<th>Deflection (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stage</td>
<td>Measured</td>
</tr>
<tr>
<td>IPC-C</td>
<td>Design</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Cracking</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td>135.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ultimate</td>
<td>165</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Cracking</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td>143.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ultimate</td>
<td>167</td>
</tr>
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</tr>
</tbody>
</table>
In case of IPC-B girder, measured deflection at design load level and cracking load were 23.7mm and 34.1mm each, which is 8.1% and 25.9% less than theoretical values and also less than design limit of 37.5mm. The nominal ultimate strength of the specimen is 160ton. At loading of 167ton, compressive failure of slab occurred and the loading stops. Deflection was measured as 57.2cm.

From the various test results, it can be concluded that IPC girder has enough load carrying capacity (about 5 times of design load) and ductility (deflection of more than 30cm at yielding).
3.2 Load-strain

Figure 6 shows the relation between the load and strain along the height of midspan section. Figure 7 and 8 show measured strains from various strain gauges. They show that as the load increases, slab and upper flange are in compression and the lower flange is in tension, as expected.

The load-strain diagram of reinforcing steel in lower flange show the rapid increase of strain at about 52ton, which is the cracking load and yielded at about 80ton. The reinforcing steel in slab (compression zone) also yields at about 110ton. There is almost no increase of strain of stirrups at supports.
In case of IPC-B girder, there is a similar trend as in IPC-C girder: rapid increase of strain of reinforcing steel in tension zone at about 55ton, yielding at about 100ton. Yielding of reinforcing steel in slab at about 147ton.

### 3.3 Crack pattern

Figure 9 shows the crack patterns developed in IPC-C girder. The first crack occurred in center part at the load level of about 44ton. At the load level of about
80ton, shear cracks start to develop and shear crack at web occurred at the load level of about 120ton. As the load increases, there are more shear cracks rather than flexural cracks. The IPC-B girder show the similar results.

4 Conclusions

This paper deals with the experimental study on the structural performance of IPC girder. Following conclusions can be made from the full scale test of two types of 30m long IPC girder composite with the slab.
IPC girder has enough safety, stiffness and ductility so that can be applied to longer span bridges.

- Ultimate strength of IPC girder is about 30% larger than the conventional prestressed concrete girder.
- Measured ultimate strength of the girder is close to theoretical value (less than 5% error) but error in deflection is rather large.
- Measured and theoretical deflections at design load level satisfy the design limit.
- The first crack occurred at the load level of 44ton (IPC-C) and 45ton (IPC-B), which is about 1.6 times of design load level.
- After unloading, most of deflections are recovered, which shows that the girders have good ductility and restoration capability.

References