Fracture Mechanics of Concrete and Concrete Structures -
High Performance, Fiber Reinforced Concrete, Special Loadings and Structural Applications- B. H. Oh, et al. (eds)

Design concept of spliced holed web post-tensioned concrete girders

M.Y. Han & Y-S. Jeon
Ajou University, Suwon, Korea

S. Choi* & H.K. Kim
* *Corresponding author, Kookmin University, Seoul, Korea*

ABSTRACT: Post-tensioned concrete girders have been popular for the superstructures of bridges because of simple design and low maintenance cost. Nevertheless, the traditional I-type PSC girders are limited in their girder length due to allowable stress limitations at each loading step. Prestressing force which is large enough to compensate the total external service loads can't be implemented in the girder at the initial prestressing stage since stresses in concrete which are larger than the allowable stresses should not be developed at subsequent loading steps. In order to design longer PSC I-type girders, several aspects should be considered and overcome. Three important and different design concepts were implemented in this work to achieve bridge spans up to about 70 meters; 1) Girders are divided into several pieces. Girders can be precast at plants and transported to the construction site without being deterred by transportation problem in Korea. In this way, concrete quality can be ensured, and construction period at the site will be reduced dramatically as well. 2) A numerous number of holes was made in the web of the girder. Some of the anchorage devices were moved from the girder ends into the holes, and the magnitude of negative moment and compressive stresses developed at the girder ends were reduced. 3) Prestressing force was introduced through multiple stages. This concept of incremental prestressing overcomes the prestressing force limit restrained by the allowable stresses at each loading stage, and maximizes the magnitude of applicable prestressing force. A full scale girder was fabricated. Five pieces of concrete girder members were cast and assembled by post-tensioning to build a 50 meter long full scale girder. Test results showed that the spliced holed web post-tensioned concrete girder design concept worked well and would replace steel box girders in competitive span length

1 SCOPE

1.1 *Introduction*

PSC girders are very competitive in the market due to their cost advantage, and many researchers have conducted projects to improve the performance (Alexander *et al*., 1997, Francis, 1971). Three important design concepts are combined to develop PSC I-type girders that are longer than 50m. Those three concepts are the incremental prestressing method, the introduction of holes in the web, and the splicing method. A full scale girder with the length of 50m was fabricated and tested to verify the performance of newly designed girder.

1.2 *Incremental prestressing*

The factor which determines the girder capacity is the allowable stresses of concrete at each loading step. By introducing prestressing forces through multiple steps, larger moment capacity in the girder can be achieved (Han & Hwang, 2002, Han *et al*, 2003). At the initial stage, prestressing force which compensates only self-weight was introduced. After the concrete deck slab is cast and hardened, second stage prestressing force was applied to compensate the total design loads. In this way, final load carrying capacity is increased a lot comparing traditional one-time prestressing method.

1.3 *Holes in the web*

When multiple holes are introduced in the web, the total girder weight is reduced by about 8%. Even though this number is not small, there are other important issues related to the hole. About half of the anchorage devices which were located at girder ends can be moved into the holes. In this way, the magnitude of compressive stresses developed at girder ends was reduced, and the thickness of web at girder ends can be reduced to the same thickness of web. Prestressing moment introduced through the girder length is more efficient. In other words, negative moment at girder ends are reduced. And also the girders with holes are aesthetically more attractive.

1.4 *Spliced girders*

Concrete girder segments which are longer than about 20m cannot be delivered conveniently to construction site due to transportation difficulties in Korea. When girders are spliced into several pieces several advantages can be achieved. First of all, they can be precast at factory and concrete quality can be ensured. Secondly, transportation problem can be resolved. Thirdly, some land space at site which is required for girder fabrication is not required. And also working hours at site are reduced a lot. After all segments are transported to the bridge construction site, they will be assembled using the first stage of prestressing, and lifted and installed on bridge piers.

2 FABRICATION OF HOLED WEB SPLICED GIRERS

2.1 *Girder design and fabrication*

Total length of the test girder is 50m and it consists of five 10m segments. The height of the girder is 2m, and diameter of a hole is 1m. The center to center distance between two adjacent holes is 2.5m. The width of deck slab is 2.4m and the thickness is 24cm. It was designed based on the allowable stress design method. But allowable stresses were checked for each separate prestressing stage. Shear was designed based on classical beam shear design since no instant design method was available for the current holed web prestressed girder. Self-consolidating concrete was used, and the strength of concrete was 55MPa and 30MPa for girder and deck, respectively. Prestressing wire used was SWPC 7B.

2.2 *Finite element analysis for reinforcement*

Researches about the design of structures that contain holes are very rare (Mansur, 1999), and well-established method is not available. After finite element analysis, it was recognized that tensile stresses are developed near holes. Various hole diameters were analyzed. Even though the diameter of the hole was chosen as 1m, the variation in the magnitude of tensile stresses was minor. Shear reinforcement in the web was placed based on the analysis around the hole.

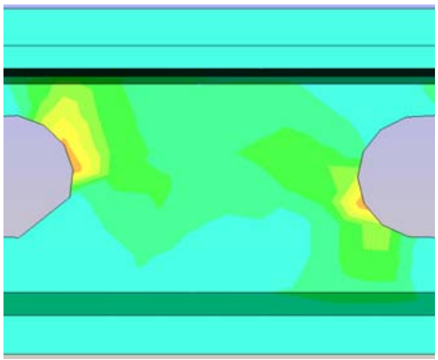

Figure 1. Principal tensile stresses developed near holes, dia.=80cm.

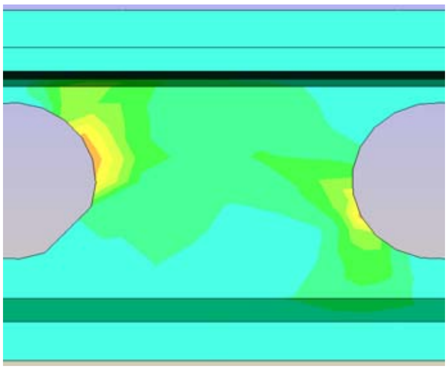

Figure 2. Principal tensile stresses developed near holes, dia.=100cm.

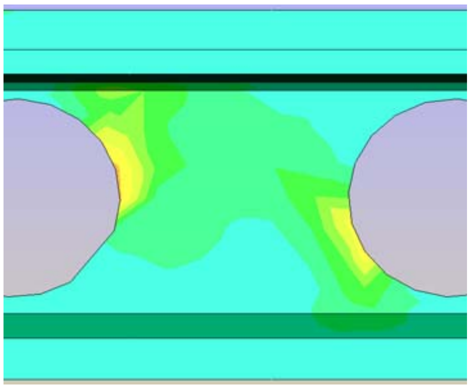

Figure 3. Principal tensile stresses developed near holes, dia.=120cm.

2.3 *Experimental procedure*

A third point loading test was conducted. Two actuators, which are located at the center of the girder and 5m apart each other, are used for loading. Each actuator has the capacity of 2,000kN. Lots of displacement transducers and strain gages are installed at various locations to get data. Figure 4-11 shows the procedure of girder fabrication and testing.

Figure 4. Assemblage of formworks.

Figure 5. Reinforcement details.

Figure 6. Casting of deck slab.

Figure 7. First stage of prestressing for the spliced girder.

Figure 8. Anchorage devices at each hole.

Figure 9. Shear keys at a joint.

Figure 10. During loading process.

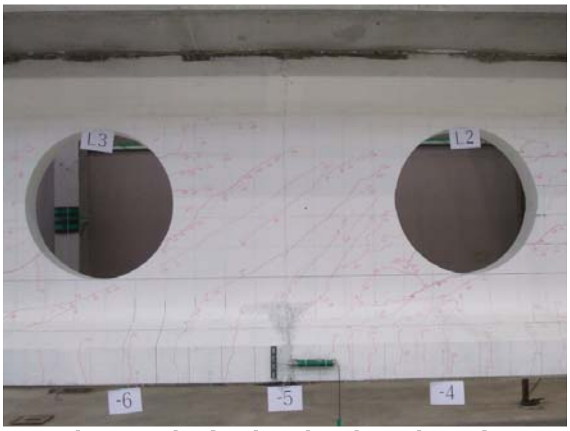

Figure 11. Shear cracks developed in the web at a later stage.

2.4 *Experimental observation*

At about 1,000kN of total load, shear cracks are observed by naked eye for the first time between two holes. Some stains near a hole showed large jump in deformation at about 1,900kN. But some strain gages attached on vertical stirrups showed sudden increase from about 800kN (Fig. 14). Factored shear load from the design live load was about 400kN.

The neutral axis started to move up after about 1,400kN (Fig. 13), which means large amount of flexural cracks formed at this stage. But the hairline flexural cracks observed by naked eye started from as early as 1,000kN.

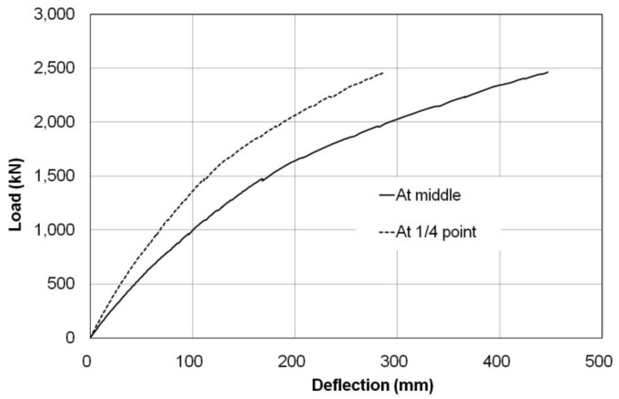

Figure 12. Load displacement curves.

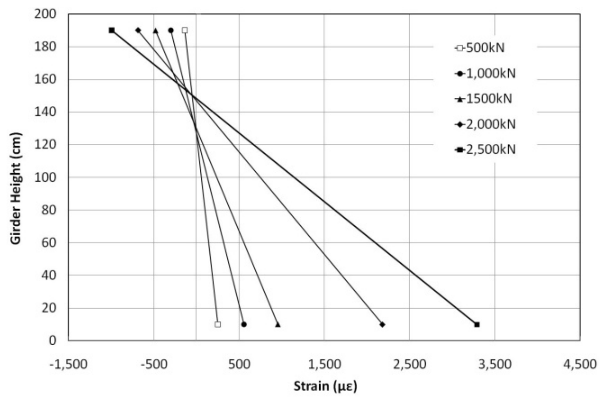

Figure 13. Longitudinal strains at flanges.

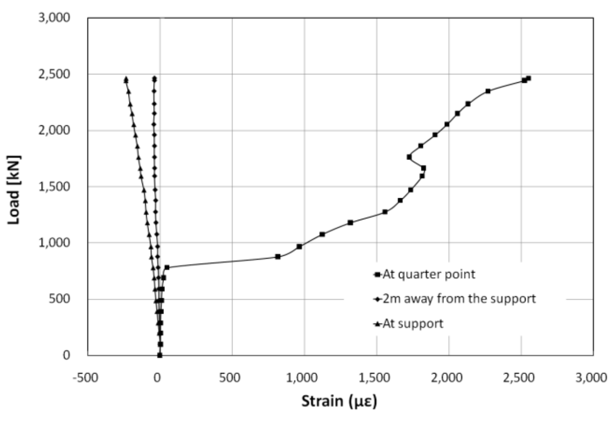

Figure 14. Steel strains at vertical stirrups.

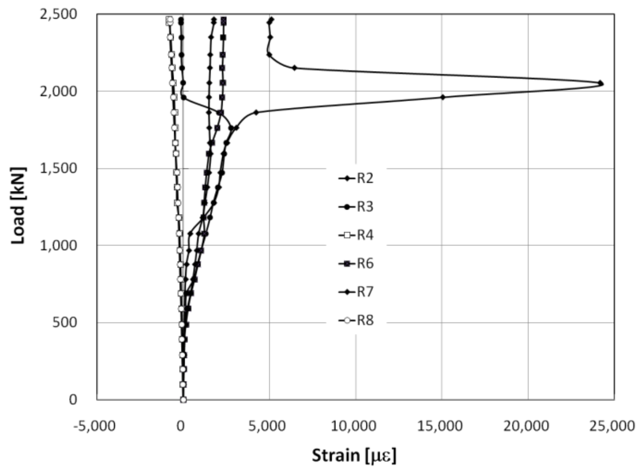

Figure 15. Steel strains near holes.

Final failure was shear failure for the current girder design. Even though current reinforcing arrangement satisfies design load, flexural failure can be ensured when horizontal and vertical reinforcements are increased more to increase the shear resistance for the area between two holes.

3 CONCLUSIONS

Three innovative design concepts are combined for the design of I-type PSC girders to achieve long span length that is more than 50m.

1) Unified girder design concept that combines the holed web concept, the incremental prestressing method, and the splicing girder method is very promising in overcoming various construction issues such as concrete quality assurance, traffic problem, and maximizing the performance of girder design.

2) Splicing method solves several issues including transportation problem, quality assurance of concrete, and the usage of high strength self-consolidating concrete. The construction period at site also reduces significantly.

3) Negative moment can be introduced more efficiently in the girder if some anchorages can be removed from the girder ends for simple span bridge design, and moved into the holes. Consequently, thick end diaphragm can be reduced too.

4) Since the incremental prestressing method develops concrete stresses sufficient only enough to compensate each loading stage, longer span length can be achieved with the same girder depth.

5) Current test girder was designed to satisfy the DL-24 live load (similar to AASHTO truck load) of Korean Highway Bridge Design Speicification. But, more shear reinforcement is required in the web in order to ensure ductile flexural failure.

Holed web prestressed concrete girder design is a revolutionary design method that has many advantages against conventional I-type concrete girders. It will make longer spans possible for I-type PSC girders and economically very competitive against other types of girders such as steel box girders in Korea.

4 ACKNOWLEDGMENTS

This research was supported by a grant from Construction Technology Innovation Program (CTIP, 05' D02-01) funded by Ministry of Land, Transportation and Maritime Affairs (MLTM) of Korean government.

REFERENCES

Alexander, K. B., Seraderian, R. L., & Culmo, M. P. 1997. Design, Fabrication and Construction of the New England Bulb-Tee Girder. *PCI Journal*, Nov.-Dec.

Francis J. J. 1971. Study of Long Span Prestressed Concrete Bridge Girder. *PCI Journal*, Mar.-Apr. 24-42.

Han, M.Y. & Hwang E.S. 2002. Development of Longer and Economical Incrementally Prestressed Concrete (IPC) Girder. *The 1st fib Congress*, Osaka, Japan, 87-88.

Han, M.Y., Hwang, E.S., & Lee, C. 2003. Prestressed Concrete Girder with Multistage Prestressing Concept. *ACI Structural Journal* 100(6): 731.

Mansur, M.A., Tan, K.-H., & Wei W. 1999. Effects of Creating an Opening in Existing Beams. *ACI Structural Journal* 96(6): 899-905.