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Analytical Study on the Shape of T-type Girder Modular Bridge Connection by Using Parameter

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***Abstract*—**Recently, to cope with the rapidly changing construction trend with aging infrastructures, modular bridge technology has been studied actively. Modular bridge is easily constructed by assembling standardized precast structure members in the field. It will be possible to construct rapidly and reduce construction cost efficiently. However, the shape of the transverse connection of T-type girder newly developed between the segmented modules is not verified. Therefore, the verification of the connection shape is needed. In this study, shape of the modular T-girder bridge transverse connection was analyzed by finite element model that was verified in study which was verified model of transverse connection using Abaqus. Connection angle was chosen as the parameter. The result of analyses showed that optimal value of angle is 130 degree.

***Keywords*—**Modular bridge, optimal transverse shape, parameter, FEM.

I. Introduction

RECENTLY, according to the aging of the bridge, the necessary of maintenance, repair and reconstruction has been increased. In addition, the various methods about the minimization of traffic jam, cost reduction and environmental protection have been required. And the accelerated construction of the bridge has been studied variously. Therefore, the commercialization research of the modular bridge is proceeding in order to preoccupies the new market in the whole global trend change, acquires the modular technology with the advanced technique and improves existing bridge technology. If the modular bridge is applied to practice construction, it is expected improvement safety, quality, durability, economy and environmental issues efficiently. Despite of advantage in modular bridges, it has a lot of connection that was weak between segmented modules and cause unstable in whole structure. In order to ensure its safety and durability, RIST [1], proposed detail connection shape and verified optimal that of size. Developed modular bridges were classified as a slab and T-type girder bridge according to the classification by type. Slab-type modular bridge has one connection of transverse that was placed high performance mortar in shear keys and applied prestressing through transverse direction. On the other hand, T-type girder bridge has two connection of longitudinal and transverse. As to the longitudinal connecting of the T-type girder bridge, PSC was introduced and the analytical research was progressed. But the transverse connection of flange is composed of the lapped splice and UHSC (Ultra high strength concrete) that has 120MPa only theoretically [2].

Although, the cross-sectional shape of the diamond form which has a 113 degree was introduced for the structure of resisting the interactive shear force, the design basis is not clear. This shape is out of the application for fields because it has to be equipped with the manufacturing factory in the close range of fields. It acts on the original intention of the modular bridge disadvantageously. In addition, variety of cross-sectional shapes analytical verification is insufficient. Consequently, study on optimal section of transverse connection to T-type girder module bridge is needed.

Research on the precast concrete connection using prestressing was studied various way such as shear key, non-shrink mortar and loop joint. The various connection construction methods of precast concrete PSC segment beam bridge were analyzed. It proposed the optimal connection system using the analysis and evaluated the junction behavior through the field loading experiment of the actually built segment beam bridge [3]. To evaluate the structural performance of PCS (Prestressed Concrete Segment) junctions, the section including the post-tension, bar and shear key was performed as experimental study. The fracture behavior, cracking aspect, strain rates, and maximum strength and ductility of specimen were evaluated. Then, the detail shape which is the field applicable was proposed [4]. The shear behavior of the shear key and shear strength characteristic was studied experimentally and drew the best suited shape, which presented the design guide and analytical basis [5]. KICT [6] determined the parameter that was consisted of the number of shear keys, width, height, angle of inclination and connection width for longitudinal connection shape. Then experimental and analysis study was performed by considering cracking load and efficiency factor [7].

In this research, the parameter was set for the optimal shape of the transverse connection of the modular T-type girder bridge and the finite-element analysis was performed with using the FE model proved in the research. To compare to experimental results which was ahead and limit research scoop, only cross-sectional angles were set to the parameter with maintaining the existing shape that previous study [2]. The crack width and deflection was compared for optimal cross-sectional shape.

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II. Modular Bridge

Modular bridge has the feature that can expand and assemble simply each segmented module to the section, width, length in order to correspond to the various field conditions, like Lego®.

As to the modular bridge, the connection design of whole structure is completed through the standard module D/B and assembling simulation, then the assembly is built in the field after being purchased and circulated through the standard module supply chain. The standard module is manufactured by the off-the-shelf unit module in which the assembling is possible. And there is the advantage that expansion of the cross-section, width and length easily, so it can correspond to the various field conditions. Also it has the other advantages of improvement of productivity, profitability improvement through the inputted manpower reduction, quality stability through using standardization product application, period of construction shortening through the design with the standard goods and module products circulation. Lastly, easily maintenance by changing damaged module to new one.

However, in order to commercialize, integral technology on the field is needed. And safety examination about the connecting has to be preceded.

A. Transverse Connection of T-girder Modular Bridge

The transverse connection of the modular T-girder bridge is comprised of the connection between the flange. With lapped splices are exposed at the outside, the segmented flange is manufactured and simply assembled in the field. As to the connection shape, the angle in diamond is 113 degree. And strength of steel bars is 400MPa and UHSC that is the standard design compressive strength (120MPa) has been placing. The specification is shown the Fig. 1 [2], [8].

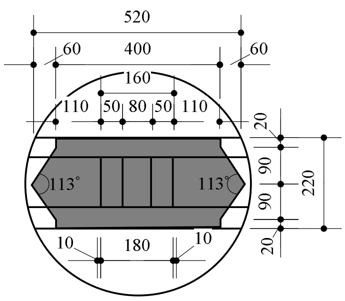

Fig. 1 Specification of transverse connection

B. Static Behavior of Transvers Connection

In previous study, the verification for the modular T-type girder transverse connection was performed. Third point loading was used. Specimen specification and result was shown Fig. 2 and Table I.

One integral specimen and three module specimens were fabricated with using 50MPa for integral and module segments and 120MPa for connection part. Average load of module specimens was 94% maximum loads relative to integral one. However, there is the difficulty to the pre-production of precast members which has the diamond shape of the angle, 113 degree and in addition it has the problem that the application property in the field becomes difficult.

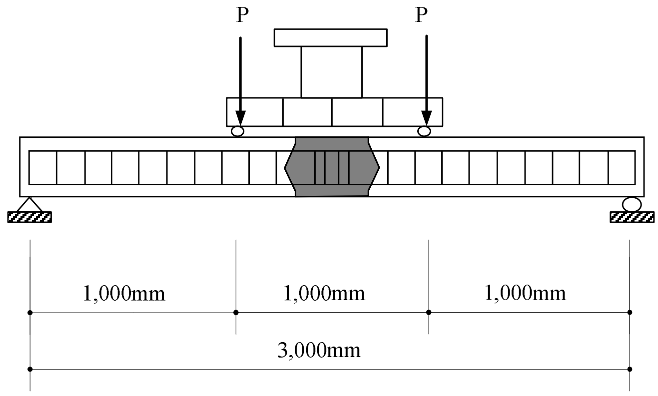

Fig. 2 Specification of specimen for static

TABLE I
Result of Static Behavior Experiment

Specimen name	Maximum Load(kN)	Ratio
Continue-4P	263.8	1
Connect-4P(1)	244.6	0.93
Connect-4P(2)	251.6	0.95
Connect-4P(3)	248.8	0.94

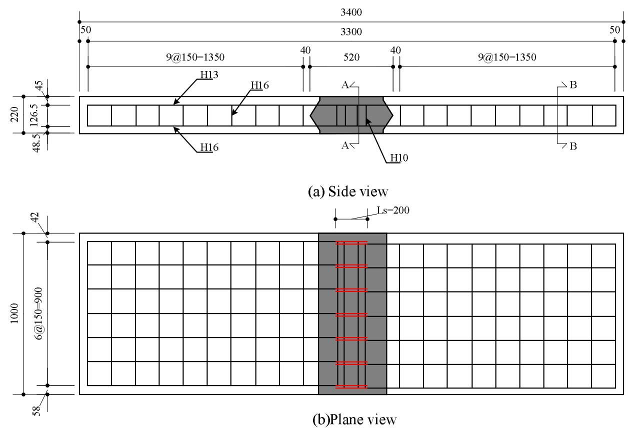

Fig. 3 Specification of segmented model

III. Analysis Model

A. Model

In the performed research, the integral and segmented module specimen model using the general analysis program ‘Abaqus ver. 6.10’was developed and it compared with the experimental result. As to the analysis model, the segmented module model was used for analysis study. The specimen was premised that it was insensible to loading speed, which was controlled to minimize inertial forces and kinetic energy. And at the same time to obtain reasonable results, the generation time of the behavior in this model was artificially reduced. Load was 158.28kN that was 60% of integral specimen maximum load shown Table I, uniform load was distributed the contact area as possible. The specification was same like Fig. 3 and the hinge and roller were applied the support of the both ends.

B. Parameter

To evaluate constructability and performance, angle of diamond shape was set to parameter with range; 10 ~ 180 degree. And EXP-value (113 degree) was analyzed for comparison. This was shown Table II and Fig. 4.

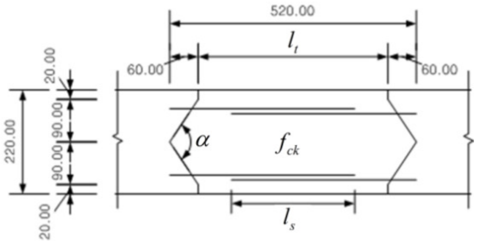

Fig. 4 Specification of parameter

TABLE II
RANGE OF PARAMETER

Parameter	EXP-value	Range	Interval
angle(α°)	113°	10°~180°	10°

IV. RESULT

A. Deflection

The flexural behavior according to the connection cross-sectional angles was analyzed in order to draw the optimal shape. Fig. 5 shows the load-deflection curve according to the angular variation. Nonlinearity was shown from cracking load to maximum load (152.28kN) and the biggest deflection was identified at 10 degree. While the angle increased, deflection was decreased irregularly. Table III shows the deflection value each angle. Maximum deflection was generated at 10 degree (18.81mm) which was that 1.5 times as high as that of PA113. Minimum deflection was shown at 130 degree (11.55mm) which was 3% smaller than that of PA113. There was a difference between maximum and minimum deflection, 7.25mm. Also the distinct difference was expected when it was compared to the failure behavior.

TABLE I
RESULT OF DEFLECTION BY ANGLE

Model	Angle(°)	Deflection(mm)	Ratio	Remark
PA010	10	18.81	1.57	Max.
PA020	20	11.68	0.98	
PA030	30	13.18	1.10	
PA040	40	12.12	1.01	
PA050	50	11.89	0.99	
PA060	60	11.88	0.99	
PA070	70	11.69	0.98	
PA080	80	12.08	1.01	
PA090	90	11.91	1.00	
PA100	100	12.17	1.02	
PA110	110	12.02	1.00	
PA113	113	11.96	1.00	EXP-value
PA120	120	11.64	0.97	
PA130	130	11.55	0.97	Min.
PA140	140	13.83	1.16	
PA150	150	14.23	1.19	
PA160	160	13.26	1.11	
PA170	170	14.21	1.19	
PA180	180	14.49	1.21	

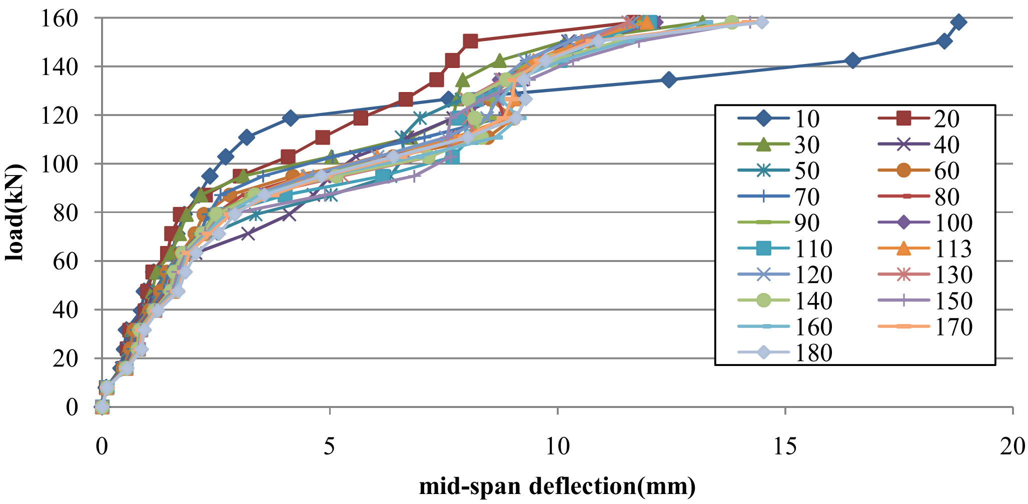

Fig. 5 Load and deflection curves

Fig. 6 shows the tendency towards deflection on each angle, deflection was decreasing at first and increasing later. Both 10 ~ 20 and 160~ 180 degree had irregular changes, but 30 ~ 150 degree had a convergence aspect with 130 degree which had a minimum deflection.

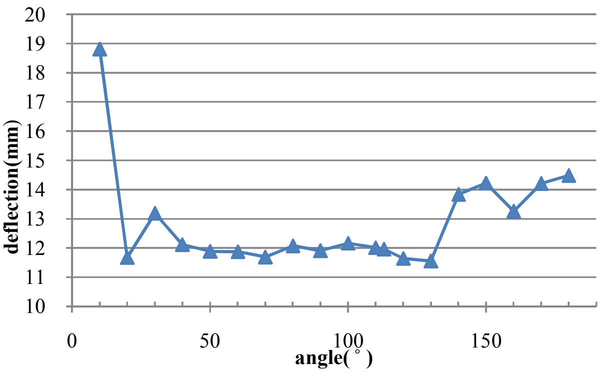

Fig. 6 Tendency of Deflection

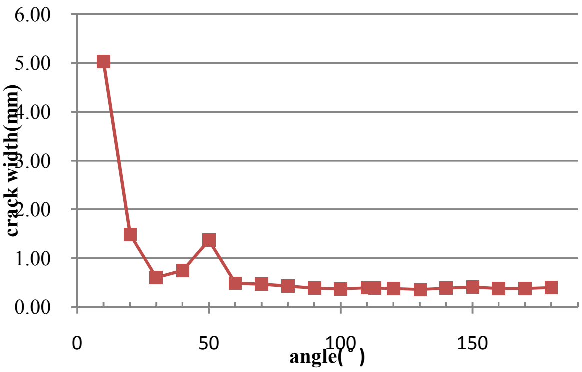

Fig. 7 Tendency of crack width

B. Crack Width

Table IV shows result of crack width on each angle, tendency of maximum and minimum widths were identical to the result of deflection one. Maximum crack width was generated at 10 degree (5.025mm) which was 13 times as high as that of PA113. Minimum crack width was 0.366mm and 6% smaller than that of PA113. There was a difference between maximum and minimum crack width, 4.66mm. Also the distinct difference was expected when it was compared to the failure behavior.

TABLE IV
RESULT OF CRACK WIDTH BY ANGLE

Model	Angle(°)	Crack width (mm)	Ratio	Remark
PA010	10	5.025	12.96	Max.
PA020	20	1.493	3.85	
PA030	30	0.607	1.57	
PA040	40	0.754	1.94	
PA050	50	1.372	3.54	
PA060	60	0.490	1.26	
PA070	70	0.473	1.22	
PA080	80	0.433	1.12	
PA090	90	0.388	1.00	
PA100	100	0.377	0.97	
PA110	110	0.398	1.03	
PA113	113	0.388	1.00	EXP-value
PA120	120	0.383	0.99	
PA130	130	0.366	0.94	Min.
PA140	140	0.388	1.00	
PA150	150	0.414	1.07	
PA160	160	0.381	0.98	
PA170	170	0.383	0.99	
PA180	180	0.403	1.04	

Fig. 7 shows the tendency towards crack width each angle and it was decreasing constantly. Irregular tendency was shown until 50 degree. And after 60 degree, tendency was constant with few variations that were small between 94% to 126% ranges. After 130°, unlike deflection tendencies, it had smooth variation. The crack width change was irregular between 10 and 50 degree and it was generated because the flange bottom fell off irregularly.

After 60 degree, very small variation range was shown and the tendency was consistently maintained. Therefore, beyond 60 degree, angle had no affected on the crack width.

C. Discussion

Although deflection and crack have difference result with value and relative sizes, those are the core items to be together considered as the priority to satisfying safety.

Fig. 8 shows the deflection tendency with crack one. Minimum value was shown at the 130 degree. The deflection and crack width tendency were differently developed. Deflection value of variation was higher than that of crack width after 130 degree. Because of many hair crack being generated and distributing the load, module specimen has the efficient structural behavior.

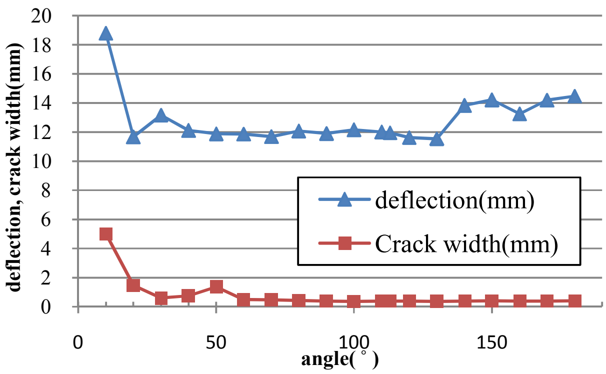

Fig. 8 Comparison with results

Fig. 9 shows the attachment collapse of the lower part of connection. This phenomenon has the disadvantageous of behavior which is generated when the flange bottom was failed to resist the moment. Also it showed that deflection of each segmented module is higher than that of center.

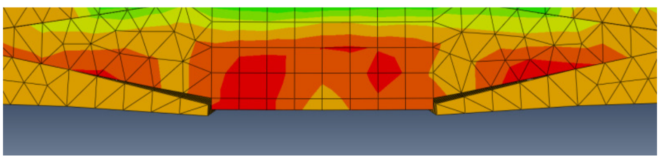

Fig. 9 Attachment collapse at 20 degree

The outside of connection is the flange of the T-type girder which was manufactured as the precast concrete. As to this part, in case the angle is very small (10 ~ 50 degree), manufacture of module segment is difficult and the connection can be easily damaged because of low stiffness. In addition, construction is difficult by using the material that has low workability placing in small angle connection.

On the other hand, in case the angle is high (160 ~ 180 degree), it was expected to be the most disadvantageous at the normal load condition, the tendency to be similar to the expected that deflection is increasing.

Therefore, in case the range (60 ~ 150) was stability, and the best optimal cross-sectional angle on the transverse flange of the modular T-type girder bridge was determined 130 degree.

V. Conclusion

In this study, analytical research was performed on the connection of T-type girder modular bridge. To determine the optimal cross-section angle of diamond shape, deflection and crack width was analyze.

1) Deflection result shows the tendency that was minimum value at 130 degree. It was 11.55mm that was 4% smaller than basic model and was shown the range 57% increasing and decreasing in the analysis.
2) Crack width result shows the tendency that was minimum value at 130 degree. It was 0.38mm that was 6% smaller than basic model and was shown the range 1196% increasing and decreasing in the analysis.
3) Therefore, it was determined that cross-sectional angle was enough to resist the shear with angle of 130 degree. In addition, safety, performance, constructability will be satisfying in field and factory manufacture environment.
4) To construct using T-type girder modular bridge, flange will be manufactured as the precast concrete that has various angles of diamond shape. In addition, it'll be determined the optimal value if the parameter of angle that has remarkable interval and ranges, which affect the result and have more accurate shape. Also it will expect to enhance the reliability of the analysis model when considering comparable reinforcing rod, concrete strain rates, experimental data as parameter. Later, the result of this research is expected to be used as basic data in supplementing the transverse connection shape of the modular bridge and making the allowable standard for modular structure.

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