

Behaviour of BH Girder Composed of CIP and Precast concrete Subjected to Flexural Loading

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Abstract. This paper presents the behaviour of reinforced BH girder which is made of precast, and cast in place (CIP) subjected to flexural loading (bending). The girder is made of two types of concrete materials, precast and cast in place (CIP), which has different strengths. The girder is simply supported and loading force is given at the mid span of the beam during analysis. The main objective of the analysis and modelling is to studying the combined effect of CIP, precast and the reinforcing materials. Modelling process is carried out using Rigid-Body-Spring-Network (RBSN) and Abaqus commercial software. Cracking and failure behaviour of the girder is investigated. Performance of the BH girder (precast and CIP) is estimated based on the load carrying capacity. Deflection of the composite is measured along the span of the girder. From the analysis result; the ductility, load carrying capacity and crack initiation and crack propagation behaviour of BH girder is investigated.

1. Introduction

The widely increasing demand of infrastructure facilities initiates engineers of construction industry to develop an easily fabricated, environmental friendly and good workability structural members. In respond to this rapidly growing needs of infrastructure facilities such as development of railway bridges, leads the construction company researchers to develop BH girder (Bulb-T& Half Slab) like developed and owned by Taewoong co.ltd in Korea, a technology that meets the design standards of highway bridges. Because of its low cost of manufacture and ease of maintenance, the pre-stressed concrete girders have been attracting many researchers and company owners in comparison to other types of girder such as those made of steel [1].

Precast concrete BH girder (Bulb-T Half Slab) systems offer significant savings in construction time and labor because the structural components are fabricated off-site (Pre-cast part) and are efficiently assembled onsite with the cast in place (CIP) component. Other advantages of precast concrete girders are the elimination of deck placement which increases product quality as a result of factory-controlled conditions. The elimination of the joints could provide for an improved riding surface and the continuity could help to provide reserve load capacity in the event of an overload condition [2]. Proper design and construction of the joints between girders, however, must be addressed to ensure adequate system performance [3]. The main concept of BH girder system is to reduce the number of anchor at the end of the beam and move it to the intermediate beam at the outlet position, so it can optimize the use of anchor in the support area and the efficiency in the use of strand cable [4].



Over the past few years, many research and construction companies in Korea, such as Taewoong Institute of Construction Technology and GS E & C Research Institute have figured out the advantages of BH girders and have successfully designed and implemented it in a construction site. The purpose of this study is then to investigate the overall behavior of precast and cast-in-place Bulb-Tee girder by rigid-body-spring-network (RBSN) lattice modeling technique. The RBSN is a network of spring elements interconnected and placed at a location of nodes with rigid body constraints.

Our aim in this numerical simulation is that to study the fracture property of the BH girder by figuring out the conditions of crack initiation, where the crack starts and how it propagate through the beam using lattice modeling. Lattice models originated in the field of computational physics and have been

applied to modelling fracture in a variety of materials in computational engineering fields [5-9]. This modelling techniques has been attracting many researchers of concrete structures and widely used to simulate concrete fracture behaviour because of its ability to show the crack propagation between Voronoi cells. The concrete low fracture energy, which leads to quasi-brittle failure, is easily shown when Voronoi cells are separated. In the RBSN the separation of Voronoi cells are the crack of the concrete structure. Because of its low fractural energy (low tensile strength), usually concrete needs reinforcement to overwhelm its weakness of tensile stress resistance by placing a rebar in tension side of the concrete structure. Generally, reinforcement entails the use of steel reinforcing bars (rebar), which are placed into the tension side of concrete structures to resist the propagation of cracks that causes the structure to fail.

2. Control specimen discretization

The three dimensional domain discretization of BH girder is carried out based on lattice modelling approach. RBSN modelling technique is the core element for the simulation. In RBSN, concrete is treated as a collection of rigid cells, named as Voronoi cells that interconnected to each other by spring cells. Discretization of the domain begins with meshing the target area using Voronoi cells. The control specimen shown in figure 1 is set up and prepared for both numerical simulation and experimental test.

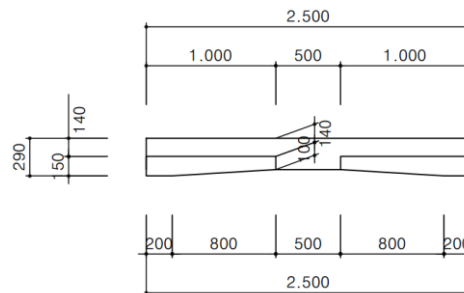


Figure 1. Control specimen layout.

2.1. Voronoi diagram construction

For numerical simulation, the BH girder is first discretized using Voronoi diagram to prepare the girder for RBSN simulation work. To get Voronoi cells, three main process can be carried out. The first step is, lattice cell discretization to obtain nodal value of the Voronoi cells from semi-random point generation. The entire domain of the girder first is saturated by randomly placed points. The point placement in the domain of beam (girder) is governed by minimum allowable length constraints. When the beam fully saturated by nodal points, the second step, which is Delaunay triangle construction follows. Lastly, Voronoi diagram can be constructed from the Delaunay triangle. Even though there are many ways to generate Voronoi diagram from the nodal points, the Delaunay triangulation is the efficient way to generate Voronoi diagram [10]. Figure 2 shows this process.

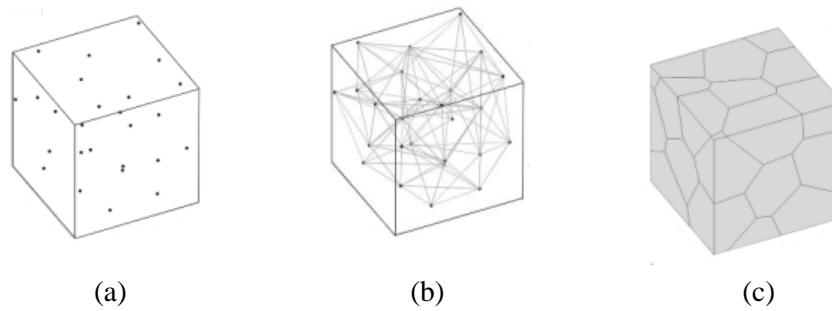


Figure 2. Domain discretization: (a) point generation; (b) Delaunay triangulation; and (c) Voronoi diagram construction.

2.2. Stiffness element matrix formulation

Voronoi diagram is a key component of RBSN in modeling and discretizing the structure to be analyzed. The element stiffness matrix can be formulated from Voronoi cell centroid and vertex information as indicated on figure 3.

To establish the element stiffness matrix, first the vertex coordinate and centroid of the Voronoi facet should be determined. Voronoi diagram construction process carried out by mesh generation provide full information the facet. As indicated by the equation 1 to 3, the term Y_c and Z_c enable us to determine the centroid where as S_y and S_z used to find the moments about the y' and z' axis [11]. Using equation 4 and 5 which can be used to find moments of inertia, it is possible to find the principal direction, θ on the facet of Voronoi cell as depicted by equation 7.

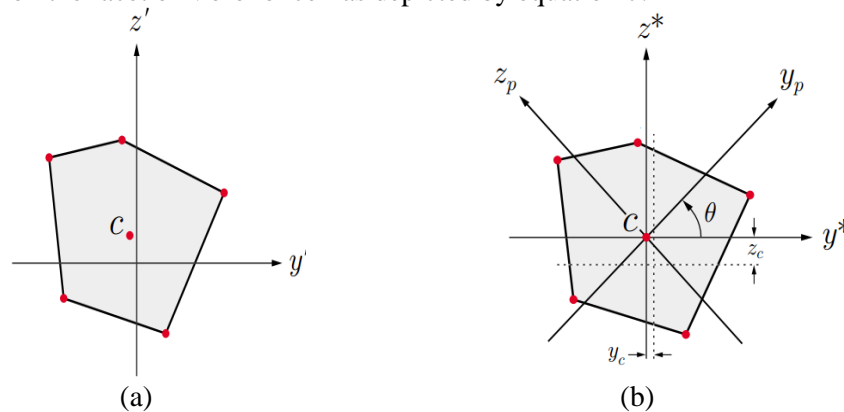


Figure 3. Voronoi facet: (a) initial coordinate and (b) coordinate origin at c.

$$Y_c = \frac{S_z}{A} ; Z_c = \frac{S_y}{A} \quad (1)$$

$$S_y = \int_A z' dA \quad (2)$$

$$S_z = \int_A y' dA \quad (3)$$

$$I_{yy} = \int_A (z^*)^2 dA \quad (4)$$

$$I_{zz} = \int_A (y^*)^2 dA \quad (5)$$

$$I_{yz} = \int_A (y^*)(z^*) dA \quad (6)$$

$$\theta = \frac{1}{2} \arctan \frac{-2I_{yz}}{I_{yy} - I_{zz}} \quad (7)$$

The application of external force causes deformation of the beam domain resulting in the relative displacements of adjacent nodes with the activation of corresponding networks of springs placed at the centroid of the Voronoi cell. The displacement and rotation at any cell can be obtained which help us to construct the stiffness matrix of the element using equation 8.

$$\delta = Bd \quad (8)$$

Where B is 6×12 matrix and d is 12×1 vector.

3. Analysis

The discretized BH girder on the figure 4 was prepared for simulation and analysis using RBSN modelling. The length, depth and width of the beam are 2500mm, 290mm and 1500mm respectively. The rebar was discretized by discrete reinforcement method. Total eleven (11) longitudinal rebars are used for simulation. In the actual beam test for flexural, all transversal and longitudinal rebars are used during laboratory test by three point bending. The material properties and bilinear curve parameters for both concrete types (precast and cast-in-place) is given on Table 1 and Table 2, while the rebar properties are listed on Table 3.

The simulation result shown on the figure 5 shows how the crack initiated at the tension side of the BH girder when it was subjected to flexural loading and the crack patterns and crack initiation points are similar to the experimental test. On figure 6 the fractural shape of experimental BH girder control specimen is indicated. The beam was tested for three point bending during simulation and analysis. The load applied at the mid span of the beam at 1250mm from the end of the girder. The support condition are 200mm away from the end of the beam in both side.

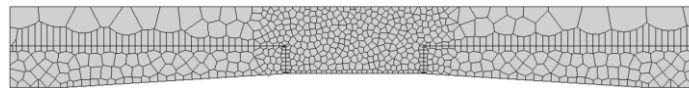


Figure 4. Specimen discretization using Voronoi diagram.

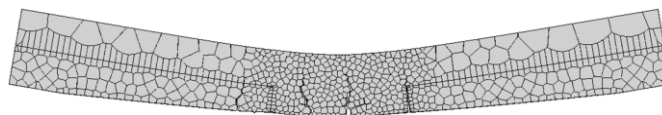
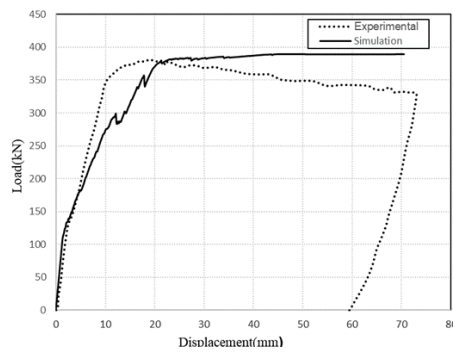


Figure 5. Fracture shape of experimental control specimen.



Figure 6. Simulation and analysis result with crack.

**Figure 7.** Load-displacement curve.**Table 1.** Material properties of concrete.

Material	Elastic modulus (GPa)	Poisson's ratio	Strength (MPa)	
			Compressive	Tensile
^a Conc A	25.743	0.19	30	3
^b Conc B	33.234	0.19	50	5

^a Cast-in-place (CIP) concrete which is prepared at construction site .^b Precast concrete made at factory level and transported to the construction site.**Table 2.** Bilinear curve parameters.

Material	Toughness (N/m)	βW_c (mm)	W_c (mm)	$\alpha \sigma_t$ (MPa)
^a Conc A	81	0.03	0.3	0.75
^b Conc B	103	0.05	0.5	1.25

 ^{β} Assumed to be 0.25 as calibrated by Yip et al.(206) . ^{α} Assumed to be 0.1.**Table 3.** Material properties of rebar.

Material	Elastic modulus		Yield strength (MPa)	Diameter (mm)
	(GPa)	Poisson's ratio		
^c R	200	0.3	400	16

^c Total number of rebars used are 11 for simulation purpose. Only the longitudinal rebars are considered in this simulation

4. Conclusion

The BH girder of given cross-section was tested for flexural test both in laboratory and RBSN simulation. The simulation result was compared with the experimental result. The load-displacement curve indicated on figure 7 agrees with the one obtained by the laboratory test with slightly small difference. The miss-match of the result in the load-displacement curve is that because we considered the longitudinal direction rebars only. Secondly, the mesh used in simulation is not fully three dimensional. Random generation of nodal points was carried out along the depth and length of the beam keeping the generation of nodal points constant along the width of the beam. The crack initiated

at the lower tension side of the beam and propagates toward the applied load as expected from the experimental test.

Acknowledgments

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