Structural Behaviour of Spherical Hollow Reinforced Concrete Beam under Flexural Loading

by Suryawan Murtiadi

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Abstract

This research was conducted with aims to determine and understand the behaviour of spherical hollow reinforced concrete beam. Five hollow reinforced concrete beams were tested with variations of 1, 3, 5, 7 and 9 spheres resulted the volume ratios of 99%, 98%, 97%, 95% and 94%, respectively. Beams dimension were 200 x 300 mm with effective length of 3000 mm. Steel reinforcements were 3D13 in tension and 2D10 in compression linked together with D10-20 stirrups. The concrete strength of 22 MPa and steel yield-strength of 390 MPawas considered. In addition, one solid beam was also tested as a standard beam. Flexural static loads were applied according to SNI testing standardmethod with two points of loading. Test results indicated that the fracture pattern of all specimens was classified as bending cracks. The presence of spherical hollow has insignificant effect to the structural behaviour of reinforced concrete beam. Cracking moments has 83% decreased and the ultimate moment has only95% decreased. Ductility of the hollow beams was also decreased but it is still acceptable since the ductility ≥2. Therefore, in order to reduce self-weight of reinforced concrete, the use of spherical hollow beam is highly recommended.

Keywords: Concrete beam, hollow sphere, structural behaviour, moment capacity, ductility

1. Introduction

Concrete is a very popular building material in the construction industry because of its strength to withstand high compressive forces. However, the concrete has a weakness with low tensile strength and its need to be combined with other materials such as steel reinforcement. Another weakness is its heavy self-weights which is necessary to have an innovation to the structure by reducing its own weight. The reinforced concrete structural element with the hollow is a structure that is effective enough to reduce its own weight. This research was conducted in the laboratory of Materials and Building Department of Civil Engineering University of Mataram. This study aims to determine and understand the behavior ofspericalhollow reinforced concrete beam structure. While the specific purpose of this study is to obtain the form of geometry modeling hollow cross section that supports the ductility of an element of reinforced concrete structure.

The world consumption for concrete is about 8.8 million tons annually. This consuming material will continues to increase from year to year in line with the increasing needs of basic human facilities and infrastructure. From the increasing use of concrete materials, there are two important aspects to note i.e durability of the concrete material itself and the environmental disturbance caused by Portland cement production. Besides abrasion and landslide by the use of coarse aggregate material, excess sand is also a problem to be prevented. Therefore, the optimization and limitation of the use of concrete materials is essential.

Concrete slab with Bubble Deck system developed by Netherlands (1997) is an innovation of hollow concrete plate elements with no beam (flat plate) and column head (drop panel). This system can be used as floor slab, roof and floor plate. One of the structural advantages of this system is to have a load-bearing capacity that is as good as a massive plate, but with a smaller thickness. This brings the advantages of saving plate construction materials up to 40% to 50%. With the reduction of the plate's own weight, other structural elements will also retain less weight of the plate, and will reduce the required column and foundation dimensions, resulting in a 50% overall material saving for the whole building.

Rahadyanto (2013) conducted experimental hollow beam with the utilization of PET bottle waste. The experimental test was divided into three types, solid beam K-400, K-400 hollow beam and K-300 hollow block. The reasonably stable maximum loads occur in solid beam K-400 with K-300 hollow beam of 77.33 kN and maximum holding moment of 46.40 kN.m. The solid strength ratio of K-400 and the K-300 hollow to the K-400 hollow beam is 1.017. While Ali and Wahid (2008) state that massive blocks reach cracks at higher loads than hollow blocks. The hollow beam has a failure of press with the plan load while the massive block is able to withstand the load greater than the load of the plan.

Canonica (2013) divides the structural form in two levels i.e. global-form (whole form) and local-form (element form/component detail structure). At the global level-form structural efficiency is produced by a form-active structure while at local-form level structural efficiency is obtained by forming a cross-sectional configuration of structural components formed to produce the moment of inertia (I) as large as possible with the least amount of material possible. For structural receiving moment of efficiency can be done by placing the most material on the outermost side of the cross section of the structural component in order to obtain maximum inertia. Correspondingly, Canonica (2013) has also thought to pierce the cross section of the beam in order to reduce its own weight without reducing its flexural strength.

2. Materials and Methods

2.1. Materials

All beams have dimension of 200 mm x 300 mm x 3200 mm and placed on a simple supported position with a clean span of 3000 mm. The beam is planned to fail to carry the load through flexural failure. Three types of modelling are used on beam test specimens with under reinforced reinforcement ratios. Concrete cover between reinforcement is 22.5 mm for all surfaces. The three types of the beam and detail of steel reinforcement shown in the Figure 1.

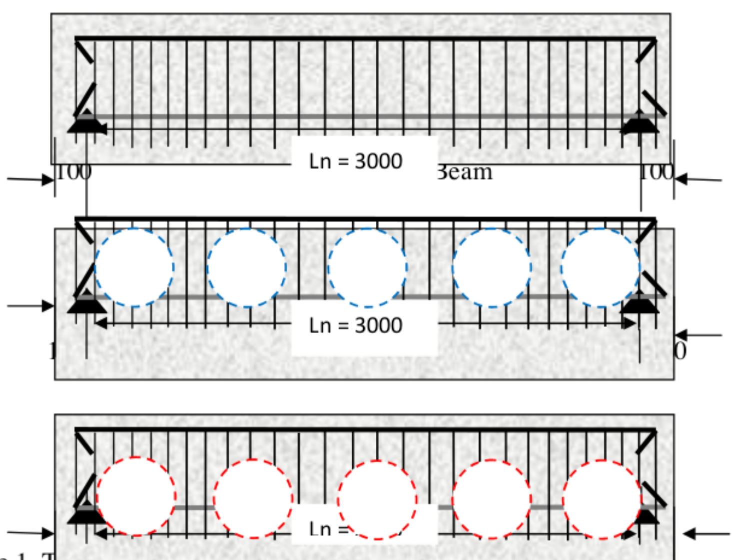

Figure 1. Types of Beams

2.2. Methods

Ten hollow concrete beams were tested by varying the number of balls and the position of the ball in a reinforced concrete beam section. The number of spheres consisted five variations of 1, 3, 5, 7, and 9 balls resulted the beam volume ratios of 99%, 98%, 97%, 95% and 94%, respectively. The cross section of the beam is rectangular with width b = 200 mm and height h = 300 mm with effective span L = 3000 mm. Two tensile reinforcements type of 3D13 and 2D10 were applied with Ø10-20 mm stirrups. The quality of concrete is fc'22 MPa while steel reinforcement isfy = 390 MPa. For comparison, a solid beam of the same size and reinforcement is also tested as a standard beam. The static bending load is carried out following the SNI testing standard with two points of loading. The load cell is placed in the middle of the span and distributed to two points through the steel profile. Hydraulic jack capacity of 50 tons as a load source connected with load cell. Vertical deflection measurements in the center of the landscape are recorded with LVDT.Load-deflection relationships were recorded until the test specimens collapse. The position of loading beam at the experimental test is shown in Figure 2.

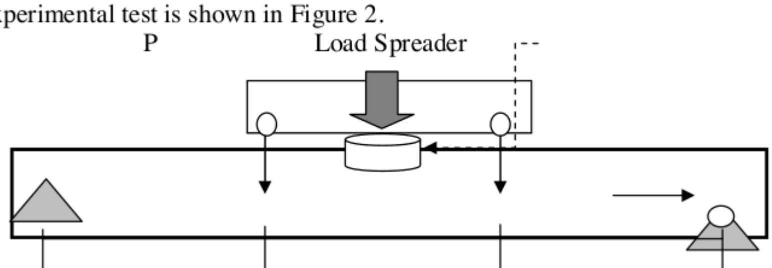

Figure 2. Loading of the beam

3. Results and Discussions

3.1 Flexural Behavior

Behavior of the beam when given a load indicates that when the load is still small the beam is relatively strong to withstand the load marked by the small deflection of the beam. The increased load is increased resulting in cracks starting to appear on the extreme part of the concrete beam. The cracks continue to propagate in the vertical direction as the load increases. Over time, the number of cracks that occur also increases which not only the old cracks become larger and longer but also new cracks are shifted from the initial crack position towards the outside. Pattern of crack that happened also is characteristic of crack bending that is direction of crack perpendicular axis cross section. Finally after the crack appears more and more then the beam loses its strength to withstand the outside load or be said the beam has experienced failure.

3.2 Load-Deflection Relationship

It is seen in the Load-Deflection diagram in the laboratory tests that all test specimens have structural behaviour and capacities of not much different. It is also seen that solid beams (without cavities) have the ability to withstand the best load. The upward curve at the start of the test indicates a slope which is the stiffness of the beam before the first crack occurs. Hence the first crack value greatly determines the behaviour of the bending test object. In addition to obtaining cracked moment values, service moments and ultimate moments, this diagram is also useful for determining ductility of the beam.

The test result values for all specimens are shown in Table 2 showing the load and deflection at the service load and the collapsed load (ultimate) of each specimen.Seen from Table 2 the ductility of the beam with the cavity decreased compared to the less hollow block. However, this decline is considered insignificant. The lowest ductility experienced by the beam with the cavity occurred on the specimen with 9 (nine) hollows of 2.28. Compared to the solid beam with the ductility of 2.78, the ductility of the hollow beam decreased to 82%.

3.3 Structural Behaviour

The magnitude of the first cracking moment (Mr), the service moment (My) and the ultimate moment (Mu) of the experimental results are shown in Table 2. It is seen in the table that the experimental results are larger than the theoretical calculations. This is because in the theoretical calculations the ability of concrete is considered zero when the concrete starts to crack. Also shown in the table, there is a decrease in the strength of a hollow block rather than a cavity beam. Compared to cavity blocks, the hollow beam ability with 9 balls in carrying loads decreased by 94%, 95%, and 95% respectively for Mr, My, and Mu. The magnitude of this decline is considered insignificant so that the use of this hollow ball beam can be recommended for application in the field.

Table 2. Structural Capacity

Series	Beam	Fc' (MPa)	Mr (kN.m)	My (kN.m)	Mu (kN.m)	Δy (mm)	Δu (mm)	Ductility Δu/Δy
1	V-0AB	22,43	10,085	45,04	47,25	14,04	38,98	2,78
2	V-2A	21,57	8,628	42,78	45,41	14,36	35,80	2,49
3	V-3A	23,21	10,415	44,60	46,78	15,36	37,76	2,46
4	V-5A	22,08	8,970	39,56	46,36	15,14	36,76	2,41
5	V-7A	22,42	9,210	42,84	45,36	15,74	36,50	2,32
6	V-9A	22,68	9,785	42,19	45,75	16,50	37,68	2,28
7	V-2B	22,31	9,165	42,95	46,90	12,08	31,23	2,58
8	V-3B	21,95	8,783	43,47	45,34	12,42	30,06	2,42
9	V-5B	22,91	9,915	42,63	45,62	12,32	31,36	2,55
10	V-7B	21,11	8,424	42,87	46,36	12,65	33,05	2,61
11	V-9B	22,49	9,51	42,99	44,78	13,50	34,40	2,55

4. Conclusions

Based on the results of the analysis, several points can be concluded in the following:

1. Test results indicated that the fracture pattern of all specimens was classified as bending cracks.
2. The presence of spherical hollow has insignificant effect to the structural behavior of reinforced concrete beam. Cracking moments has 83% decreased and the ultimate moment has only 95% decreased.
3. Ductility of the hollow beams was also decreased but since the ductility ≥ 2 it is still acceptable for structural element.
4. Therefore, in order to reduce its self-weight of reinforced concrete beam, the use of spherical hollow beam is highly recommended.

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