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Biaxial Hollow Slab Under Seismic Load

Abstract: - In reinforced concrete building structures, the slab is the component with the largest volume of concrete of all the superstructure components. Various innovations were carried out. Currently, the use of Hollow Core Slab (HCS) to reduce the load on building superstructures is widely used in Indonesia. Another type of slab is Biaxial Hollow Slab (BHS) as an alternative to reduce slab concrete volume. BHS is considered capable of reducing concrete consumption by up to 30% -50% of conventional concrete without reducing the performance of the slab itself. It could be reducing the load on the working superstructure can reduce the influence of seismic loads on the foundation. Indonesia is a country with an earthquake zone, so the use of BHS must be considered with seismic design categories that are appropriate to the earthquake zones in Indonesia. This research is focused on giving information about the numerical study of application BHS in 10th story building with design seismic category D. The thickness used in this study is equivalent thickness of BHS to solid slab. The absence of beams in weak axis and the present of perimeter beam by utilization BHS, gives the result BHS has sufficient capacity to carry the workload.

Keywords: BHS; HCS; Seismic Load; Slab; Earthquake

1. INTRODUCTION

The slab is part of a building component that has the largest concrete volume when compared to other components such as beams or columns. This causes innovation to be needed to optimize the volume of concrete in the slab without reducing the performance of the slab (Teja et al., 2012). First of the innovation is the Hollow Core Slab (HCS). The current HCS is a one-way slab system. For slabs with a 2 (two) way system, there is another alternative that continues to be developed, namely Biaxial Hollow Slabs (BHS). BHS replaced concrete with bubbles in the middle of the thickness slab (Figure 1). This type of slab can reduce concrete volume by 30% - 50% from conventional slabs (Quraisyah et al., 2020).

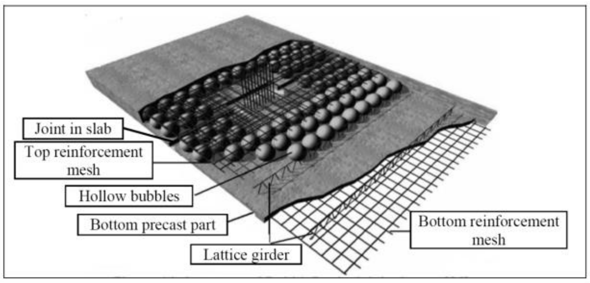

Figure 1. Illustration section of BHS (Ali and Kumar, 2017)

Biaxial hollow slabs consist of 3 (three) important components, namely concrete, reinforcement, and filler balls (Tiwari and Zafar et al., 2016). The concrete used is standard concrete with a maximum aggregate size of 20 mm. For reinforcement, 2 (two) layers of reinforcement are used to support the balls made from recycled polyethylene or HDPE material. The concept is to fill the hollow part of the slab to reduce the weight using a spherical ball made of recycled plastic material. This volume reduction is in line with the reduction in CO2 gas emissions from concrete because 1 kg of recycled plastic can replace up to 100 kg of concrete and reduce the slab's weight by up to 50% (Quraisyah et al., 2020).

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This structure, which has been applied abroad, uses a flat slab system. If this structure is used in a moderate or high earthquake area, the flat slab system is very vulnerable to lateral loads so it must be combined with a lateral force-resisting system (Dovich and Wight, 2015). The documentation of a diaphragm failure that occurred in the parking structure at Northridge Fashion Centre during the Northridge earthquake In January 1994 (Figure 2).

Figure 2. Diaphragm failure in the parking structure at the Northridge Fashion Centre during the January 1994 earthquake in Northridge, California (James, 2019)

The Northridge earthquake is a tragic example of the dangers of using hollow core precast slabs, which are poorly designed even though they can reduce the weight of structures up to 40% less than conventional slabs, resulting in catastrophic and even fatal damage when designed without comprehensive earthquake engineering analysis and design (Fleischman et al., 1998). The structural response that occurred during the Northridge earthquake was controlled by the diaphragm, this being the weakest link in the entire structural system, because it was not designed and detailed properly (Wood et al., 2000).

Thus, further research is needed to increase understanding of the behaviour of this slab as a diaphragm capable of distributing lateral loads due to earthquakes and how far the potential for utilization is using a flat slab system with the addition of perimetric beams, especially for high earthquake areas.

This means that proper design and analysis must be ensured to measure the strength and influence of seismic effects on the behaviour of BDS as diaphragms, especially in Indonesia for seismic categories D, E, and F which require details for structural diaphragms. Although experimental testing is an ideal way to assess actual behaviour, it is expensive and time-consuming and is often limited in the number of specimens that can be tested. Considering this, to provide a more practical and accurate approach, the numerical method was used to evaluate the behaviour of the BHS as a diaphragm.

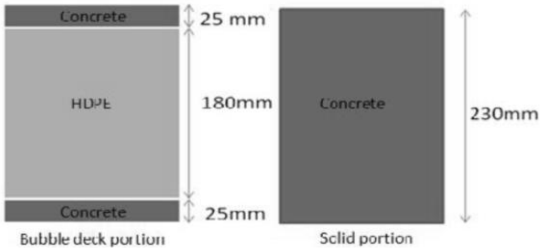
2. LITERATURE REVIEW

BHS is a slab where part of the concrete is replaced by balls or bubbles which are generally made from recycled HDPE (High-Density Polypropylene) material. This material is usually made from nonporous material that does not react chemically with concrete or reinforcement. This type of material can support. This type of material can support the load safely when pouring concrete because this type of material has sufficient strength and stiffness. The shape of the balls or bubbles used can be spherical or ellipsoidal (Sethkar dan Hance, 2015).

The concrete used in BHS is made from Portland cement with a maximum aggregate dimension of 20 mm. The concrete specifications used are not less than M30 (Ali and Kumar, 2017). The thickness of the slab will determine the dimensions of the bubble that will be used. This bubble will be placed between 2 (two) layers of reinforcement. The reinforcement provided is 2 (two) directions for both lateral and transverse.

BHS consists of 3 (three) production stages. The first stage is precast concrete which is produced in the factory for bottom mould, namely concrete with a thickness of 60 mm - 80 mm, 2 (two) direction reinforcement in the bottom layer, and 1/3 bubble embedded in the bottom layer of concrete is used to ensure the position of the bubble does not change or remains in place (Bubbledeck UK, 2007). The second stage is placing the first stage of precast concrete as the bottom formwork of the BHS which is then given additional reinforcement in the top layer and other reinforcement for connections between the first stage of precast. The third stage is pouring concrete to the BHS plan height (Bubbledeck UK, 2008).

BHS was first studied in Denmark by Jorgen Bruenig regarding its structural behaviour (John and Varghese, 2015). Then research on BHS was developed by many experts using various types of cavity-filling materials. Quite complete research was in 2012 examining the comparison of structural behaviour between BHS and conventional plates. The comparison of dimension BHS and solid slab used in the research (Figure 3). The properties studied were bending behaviour, shear, durability, deflection, sound insulation, vibration, and fire resistance, then analysed using the finite element method using the SAP2000 program to obtain different responses from the two types of slabs (Teja et al., 2012).



(a) BHS (b) Solid slab

Figure 3. Comparison dimensions of BHS and solid slab models

The results obtained for the bending stress value of bubble deck plates were 6.43% lower than conventional plates. Due to the reduced stiffness of the bubble deck plate due to the bubble replacing the concrete in the middle of the plate, the resulting deflection is 5.88% higher than conventional plates. The resulting shear resistance is 0.6 times that of conventional plates with the same plate thickness. However, this can be overcome by providing vertical reinforcement. This statement also states that due to the reduced concrete volume will also reduce the BHS's shear resistance (Churakov, 2014).

Experimental research in 2015, full-scale experiments in the laboratory to determine the behaviour of BHS, tests were carried out on the same plate size, but using 2 different bubble dimensions with 2 different types of concrete shown in Table 1 (Sethkar and Hance, 2015). From the modelling of this experimental setup (Figure 4), the results obtained show that the B.BD.3 test object with the highest failure pattern is the flexural test object with the highest ultimate loading value of all the test objects studied. Meanwhile, the smallest deflection value was obtained in test object A.BD.2 where the bubble used was small with a concrete quality of 35 MPa.

Table 1. Dimension of specimens

Compression strength		Dimension 1900x800x230 mm		
		BD 186 (no links)	BD 240-180 (no links)	BD 240-280 (have link)
A	B25	A.BD.2	A.BD.3	A.BD.4
B	B35	B.BD.2	A.BD.3	

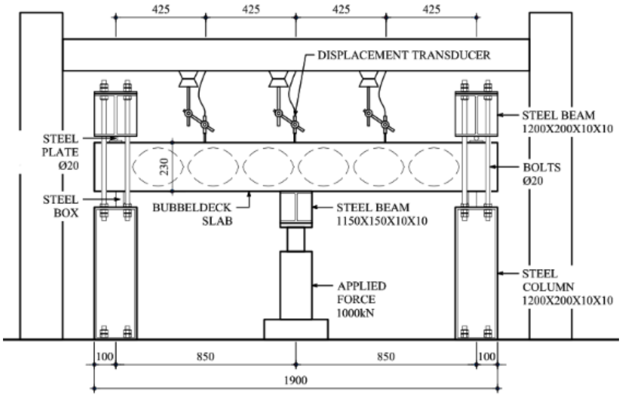


Figure 4. Set up experimental [8]

Analysis using the Finite Element Method (FEM) about BHS, that the materials used in the calculations are normal concrete and HDPE material originating from India. Modeling was also carried out for conventional plates to obtain comparative values from the analysis results of the two. The results obtained were that the weight of the bubble deck plate was 15% lighter than the conventional plate, while the deflection of the conventional plate was 18% better than the bubble deck plate because the conventional plate was stiffer (Pandey and Srivastava, 2016).

In another experiment, regarding the comparison between conventional slabs and BHS, for the BHS type, 2 (two) types of spherical ball placement patterns were made, and one continuous bubble deck (completely equipped with round balls). The results from the three test objects show that the placement of the spherical balls also influences the performance of the plate itself. The bearing capacity obtained increased by 11% and 6% compared to conventional plates but was smaller than the bearing capacity value of BHS (Fatma et al., 2018).

3. METHOD

The structural modelling used in this research is a preliminary geometric proposal by considering reasonable column spacing with a slab thickness that is still possible. The tool used for structural modelling is SAP2000 software. The structural modelling of the building is shown in Figure 5. The dimension of a typical grid is 8 m x 6 m in length with no irregularity. The Panel of the slab is shown in Figure 6 for the detail of the side view with the detailed join of BHS is presented in Figure 7.

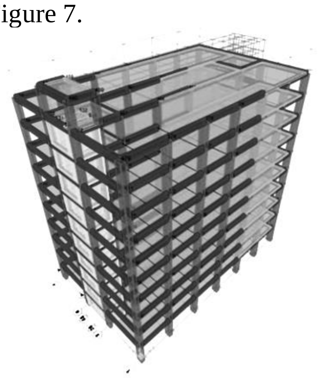
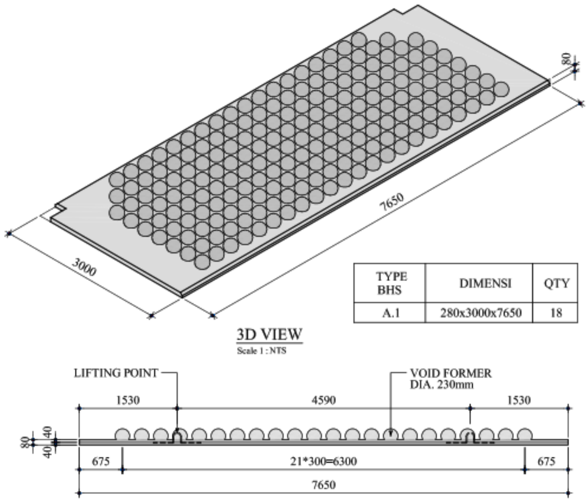


Figure 5. Structure model of the building



TYPE BHS	DIMENSI	QTY
A.1	280x3000x7650	18

Figure 5. Dimension of precast BHS

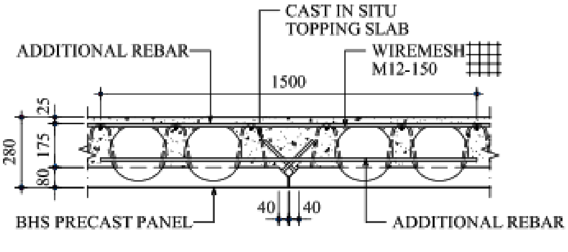


Figure 6. Detail joint of BHS

The modelling of this structure is a 10th-story building with a shear wall with the absence of beams at the weak axis. The dimension of each member of the structure components is described in Table 2. The BHS is converted to the thickness of the solid slab. BHS is used in this model with 280mm thickness of slab with spherical ball diameter 230mm for void former of the slab. The conversion of the dimension of BHS is 235 mm of solid slab. The expected output from this step is to ensure that the slab dimensions meet the requirements of the structural needs.

Table 2. Dimension of structure components

No.	Components	Dimension
1.	Column	1000 mm x 600 mm
2.	Beam	400 mm x 800 mm
3.	BHS thickness	225 mm

The planned earthquake loading can be reviewed using scaled response spectrum analysis with equivalent static analysis. The earthquake area used is the Jakarta City area and the spectrum response graph for this city is obtained from software that is available online at the website provided by the Minister for Public Works and Housing (https://rsa.buatkarya.pu.go.id/2021/). The KDS planning determined in this research is shown in Table 3. Based on the parameters mentioned in SNI 1726:2019, the values in the table show that the planning is at seismic design category D (0.5 ≤ SDS and 0.2 ≤ SD1).

Table 3. Parameters for determining seismic design category in research

No.	Description	Value
1.	Building Type	Apartment building
2.	Risk Category	II
3.	Location	DKI Jakarta
4.	Type of Soil	Medium (SD)
5.	S_{DS}	0.62

4. RESULT

Dynamic earthquake load analysis control, the analysis is permitted to include a minimum number of variances to achieve a combined variance mass of at least 90% of the actual mass in each orthogonal horizontal direction of the response considered by the model. The result is 92% which meets the requirements.

If the combined response of the base shear force resulting from the analysis of variance is less than 100% of the shear force calculated using the equivalent static method, then the force must be multiplied by V/Vt, where V is the calculated equivalent static base shear force and Vt is the base shear force obtained from the results of a combination analysis of variance (ASCE 7-16). The calculation of the requirement of base reaction is shown below (Table 4).

Table 4. Base reaction calculation

Base Shear	Dynamic (V_D) (kN)	Static (V_S) (kN)	85% Static (V_S) (kN)	Scale Factor	Note
Dir. x	3274.51	3852	3274.51	1.00	OK
Dir. y	3274.51	3852	3274.51	1.00	OK

For static earthquake load, inter-story drift result, this building still meets the requirements for the inter-story limits (Figure 6).

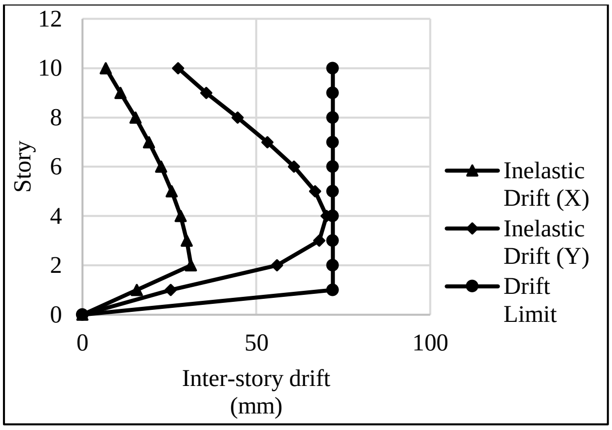


Figure 6. Inter-story drift result

Focused on earthquake load, the components slab itself, due to dynamic load, at the 7th story of the building, at panel selected at typical dimension, shown in Table 5 for the axial and bending moment.

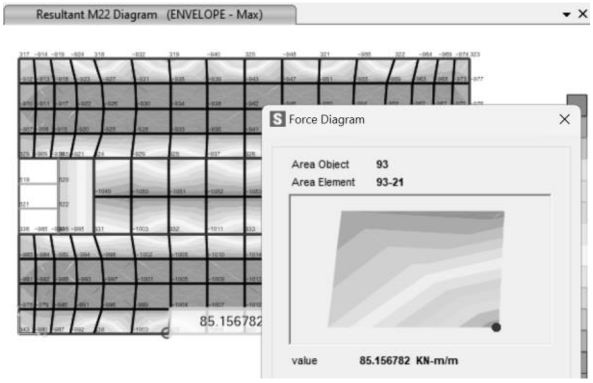
Table 5. Bending moment and shear result due to dynamic earthquake load

EQ	M11 kN.m/m	M22 kN.m/m	V13 kN/m	V23 kN/m
EQD-X	4.51	0.93	1.61	1.04
EQD-Y	2.91	11.75	1.20	4.19

The maximum result of the internal force that happens to the building is due to envelope combination, bending moment, shear, and axial at the typical panel slab, shown in Table 6. Figure 7 and Figure 8, represent the bending moment and shear that occurs at the slab (M22 and V23). The reinforcement of the slab using wire mesh WM12-150 mm. From the calculation, this reinforcement meets the requirement due to the moment ultimate in the slab. It is shown in the calculation of the shear capacity, punching shear, and bending moment of the slab is shown in Table 7, Table 8, and Table 9 sequentially.

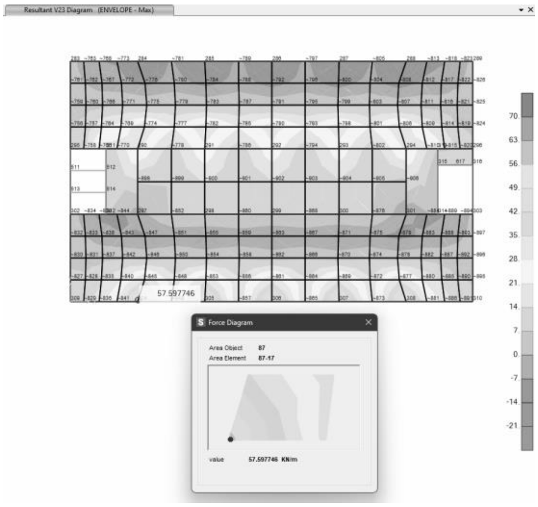
Table 6. Bending moment and shear result due to maximum envelope combination

Envelope	M11 kN.m/m	M22 kN.m/m	V13 kN/m	V23 kN/m
Max	24.20	85.16	19.32	57.60
Min	-12.76	-35.68	-19.44	-56.43



Area Object 93
Area Element 93-21
value 85.156782 KN-m/m

Figure 7. M22 envelope combination



Area Object 87
Area Element 87-17
value 57.597746 KN/m

Figure 8. V23 envelope combination

Table 7. Calculation checks of bending moment

Dir.	Zone	Mu (kNm)	Eff. thickness (mm)	Ø Mn (kNm)	Note
X dir.	Max	24.20	249	85.94	OK
	Min	12.76	249	85.94	OK
Y dir.	Max	85.16	249	85.94	OK
	Min	21.58	249	85.94	OK

Table 8. Calculation checks of shear force

Dir	Zone	d (mm)	Vu (kN)	Vc (kN)	Ket.
X dir.	Max	204	19.32	189.95	OK
	Min	204	-19.44	189.95	OK
Y dir.	Max	204	57.60	189.95	OK
	Min	204	-56.43	189.95	OK

The calculation of punching shear has to be calculated since the shear at the corner of the slab and column has a critical issue (Schnellenbach-Held and Pfeffer, 2002). The calculation is based on the column dimensions 1000mm x 800mm. The working loads applied are dead load 5.53 kN/m, live load 4.79 kN/m, and the superimpose dead load 1.19 kN/m (SNI 2847-2019). Table 7 shows that the capacity of BHS meets the requirement.

Table 9. Check of punching shear

Direction	Vu (kN)	Ø Vc (kN)			
X Dir.	286.54	916.47			OK
Y Dir.	273.92	916.47			OK
Two ways	648.58	1146	1031	1042.7	OK

5. DISCUSSION

The overall calculation results obtained, show that the use of BHS in a 10-story building structure that has no primary beam in X direction (only perimeters beam exist) has sufficient capacity to carry the workload under conditions of seismic design category type D. However, further research needs to be carried out regarding the behaviour of BHS as a diaphragm to get an idea of the curvature and load deflection moments that occur in the BHS panels below based on axial load effected to the slab due to seismic loads.

6. CONCLUSION

From the result of calculation using numerical software, the absence of beams at the weak axis and the use of BHS although it converted to modeling as a solid slab with thickness, at seismic design category D give us information that this building with BHS as a slab has sufficient capacity to carry the workload.

Further research is needed to analyze the performance of BHS as a structural diaphragm in buildings, both in the form of numerical and experimental studies to ensure its performance under the influence of seismic load.

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