The Behavior of Two-Way Sandwich Concrete Slab with Aspect Ratios Variation Subjected to Central Point Load

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Abstract. The self-weight of the concrete slab in high-rise building construction significantly affects the risk of structural failure in earthquake-prone areas as the earthquake force is directly proportional to the mass of the building. To reduce the building mass then the sandwich concrete slab is introduced. This study focuses on variations of aspect ratio effect on the slab behavior under central point loading. The aspect ratios are set at 1.0, 1.26, 1.5, and 2.0. A normal concrete slab with an aspect ratio of 1 as the control specimen is prepared. Tension reinforcement of D10-150 is placed in both x- and y-direction. While the compression reinforcement of P8-200 for both directions is used. The slabs were supported on four edges and tested under a central point load. Results found that the slab with an aspect ratio of 2.0 has a greater stiffness than other slabs as well as the resistance load capacity. The slab with an aspect ratio less than 2.0 behaves similarly with no significant differences. Generally, the slab ductility index decreases with increasing the aspect ratio. All slabs have ductile behavior which is indicated by both the strain measurement and the relationship of the load-deflection curves. An aspect ratio of 2.0 as the limit used by the Standard for distinguishing one-way and two-way slab elements is proven valid and acceptable.

Keywords: Two-Way Slab · Sandwich · Concrete · Aspect Ratio · Deflection

1 Introduction

The superstructure of a high-rise building consists of three main components, namely columns, beams, and slabs. The slabs weigh almost 30% of the weight of the other components in the building system. The magnitude of the earthquake resisted by the building is directly proportional to the mass of the building. Therefore, to reduce the mass of the building, the dominant structural components are engineered in such a way as to be sandwich components with lightweight material cores to reduce the total weight of the building. Efforts to reduce the self-weight of structural components, especially

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concrete slabs, have been carried out, among others by using pumice powder, putting the plastic ball in the core of the slab, using EPS materials, foam materials, etc. [1] [4].

The number of studies on lightweight concrete beams indicates the view of researchers who have a strong desire to reduce the total weight of the building, reduce the load, and increase the safety of the structure, especially in receiving earthquake loads. Therefore, this research activity on sandwich construction with a lightweight pumice concrete core was carried out. It has been said previously that in the concrete construction system, the volume of beams and slabs occupies almost half of the volume of the concrete, therefore changing a homogeneous concrete cross-section into a heterogeneous section is expected to reduce the structural load significantly. In addition, the slab/beam components are designed not to receive lateral loads, referring to the design concept of a weak beam with a strong column, where the slab is an integral part of the beam. Thus, for loading the sandwich slab, it is considered representative of using static loads in building the flexural model.

The flexural elements of one-way sandwich concrete structures represented by beams have been studied by the authors under static loading and even testing for their fire-resistant [5, 6]. However, the sandwich section using pumice concrete in the two-ways slab system still lacks study. Therefore, it is needed to further study. This study aims to learn how the two-way sandwich slabs behave under central point loading. The two-way slab system is defined by slab aspect ratio or the ratio of the longer span to the shorter span (ly/lx) higher than two [7, 8].

1.1 Review of Previous Study on the Two-Way Slab

Many researchers have studied two-way reinforced concrete slab systems for model improvement. The important things to study were the serviceability of the slab section which represent by the measurement of deflection and crack width [9]–[11]. Manish et al. found that short-term deflections determined based on the provision for two-way RC slabs are not comparable with experimental values [10]. Adan et al. examine the effects of cracking on two-way slab deflection and serviceability [11]. An attempt has been made by Hossain to produce simplified design charts to estimate immediate deflection for different end conditions and aspect ratios. These charts have been found to produce a realistic estimation of short-term deflection similar to finite element analysis as well as experimental results [12]. Two closed-form expressions were obtained which describe the relation between the bending moments and all factors that affect it (the span ratio, the dimensions ratio of the loaded area and the ratio between the short span to the parallel length of the loaded area) [13]. to investigate how fibers affect structural behavior such as the possibility for redistribution, crack patterns, and load-carrying capacity. The investigation was conducted through experiments on two-way octagonal slabs, simply supported on four edges, centrically loaded with a point load [14].

From these literature reviews, there was no sandwich slab composed of layers with different materials studied. Therefore, the two-way sandwich-section slab which is the focus of this study composed of outer layers of reinforced concrete with specified reinforcement, and the core is filled with lightweight pumice concrete. The variable considered in this study is the slab aspect ratio.

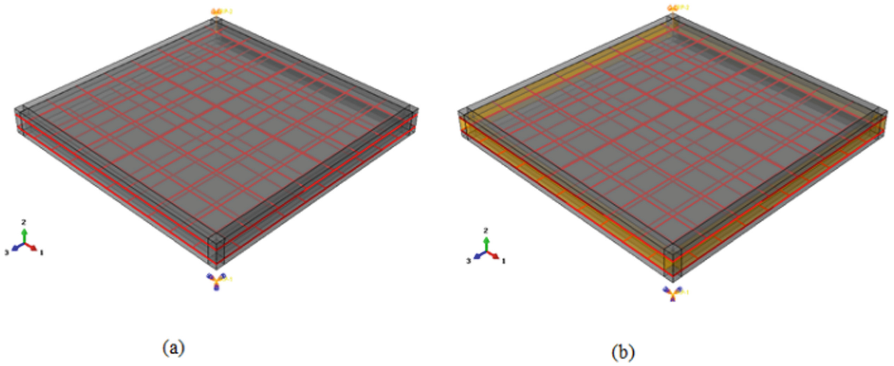

Fig. 1. FE modeling of (a) NC slab and (b) SWC slab.

1.2 FEA Analysis

The capacity and behavior of the slab specimens were analyzed using Finite Element modeling in the ABAQUS student version [15]. The concrete and steel materials were modeled as concrete damage plasticity (CDP) and bi-linear behavior in the elastic and plastic range available in the ABAQUS respectively. The element model used for the concrete was the brick element C3D8R and the truss element T3D2 model was used for steel reinforcement. The bond between steel reinforcement and concrete is simulated using the embedded interaction technique. As the specimen were symmetrical in geometry and load applied then for more convenience one-fourth of both elements are only considered as shown in Fig. 1.

2 Experimental Program

Before testing of the slab specimen is carried out, it is ensured that the concrete constituents are evaluated to meet the desired concrete compressive strength. For this reason, the details are explained in the following section.

2.1 Concrete Material and Mix Proportions

Materials used in this study are Portland cement type I brand Tiga Roda, pumice with a maximum size of 10 mm, sand that passes through sieve number 4 (with a maximum grain size of 5 mm), 20 mm maximum size of coarse aggregate, and clean water available in the Structural Laboratory of Engineering Faculty, University of Mataram.

Normal weight concrete and lightweight concrete strength set in this study are 25 MPa and 15 MPa respectively. For 1 m3 concrete mixture for both concrete grades is presented in detail in Table 1.

2.2 The Design of the Specimen

To achieve the objectives of this study, it was designed the specimens consisted of sandwich slabs with 4 variations of aspect ratio (α). The aspect ratios are 1.0, 1.26,

Table 1. Concrete mixture for $1m^3$.

No.	Materials (kg)	LWC	NC
1	Cement	406	342
2	Water	203	205
3	Pumice	458	-
4	Sand	560	747
5	Gravel	-	1121

Table 2. Specimen details.

Designation	l_y (m)	l_x (m)	α	Tension reinforcement	Compression reinforcement
SN-1.00	3	3	1.00	D10-150 (both directions)	P8-200 (both directions)
SW-1.00	3	3	1.00		
SW-1.26	3	2.4	1.26		
SW-1.50	3	2	1.50		
SW-2.00	3	1.5	2.00		

1.5, and 2.0. In addition, a normal concrete slab with an aspect ratio of 1 as the control specimen is prepared. For all specimens, tension reinforcement of D10–150 with f_y of 400 MPa was placed in both the x- and y-direction. While the compression reinforcement of P8-200 for both directions was used with a f_y of 250 MPa. The slab thickness was 150 mm with 35 mm thick skin and 80 mm core. Table 2 shows detail of the specimen considered in this study.

The designation in Table 2 explains that the letter SW and SN represents the sandwich concrete slab and the normal concrete slab respectively while the number after the letter shows the slab aspect ratio.

2.3 Manufacturing and Curing Specimens

Reinforcement cages were prepared and placed in a slab mold. Strain gauges were attached to the tension steel located at the center of the slab. The first concrete layer of slabs was cast followed by the casting of the second layer (core) as shown in Fig. 2. Casting between layers was arranged in such a way, that after finishing the first layer, casting is then allowed to dry until approximately 2 h and then followed by casting of the second layer. Finally, the third layer (skin) was cast. Figure 2(a) shows the process of installing a strain gauge on the reinforcement that has been prepared in the mold before casting and Fig. 2(b) and 2(c) show the slab under casting and has been finished in cast respectively. Strain gauge cables are then secured in such a way as to avoid unexpected disturbances. Cylinder specimens were also cast together with the casting of the slab specimen.

Fig. 2. (a) Strain gauge installation, (b) casting, and (c) slab specimen.

Fig. 3. Slab test set-up.

After the cast slab is finished, the specimens are covered with wet burlap sacks and wetting is carried out continuously until the age of 28 days. While the mold cylindrical specimen is opened after one day, then the specimen is immersed in a soaking bath. This specimen will be removed from the tub one week before its age reaches 28 days with the intention that when testing the water contained in the test specimen can come out perfectly so that the weight measurements and others become following the conditions of the slab specimen. Testing the compressive strength of concrete cylinders with a diameter of 150 mm and a height of 300 mm is based on ASTM C39-72 using a Compression Testing Machine.

2.4 Testing Setup

The slab specimen is placed on the test frame as shown in Fig. 3. 2. A hydraulic jack, load cell, and five LVDTs were prepared. Four LVDTs (50 mm capacity) were placed in the support area and one LVDT (100 mm capacity) was placed in the center of the slab specimen.

Two types of strain gauges were used. The embedded type was attached to the surface of reinforcing steel and the other was mounted on a concrete surface (slab cross-sectional zone). The whole equipment was then connected to the 8 channels data logger available. The data logger of Tokyo Sokki trademark type TDS-630 was used to record data with the Auto mode which was set to record readings every 10 s. The load is given incrementally with a load increment of ±5 kN. At each load increment given, the slab specimen was observed for cracks. When cracks occur, they were marked and given a load number. This method continues until the slab specimen fails.

3 Results and Discussion

3.1 Mechanical Properties of Materials

The cylindrical compressive strength tests of the above concrete mixture are presented in Table 3. Meanwhile, the average split tensile strength test result obtained was 1.61 MPa.

Reinforcing steel used consists of two types, namely deformed bar (D) and plain bar (P). A deformed bar is used as a tensile reinforcement with a diameter of 10 mm and a design yield strength of 400 MPa. While the reinforcement on the compressive zone uses a plain bar of 8 mm diameter with a design yield strength of 250 MPa. Specimen test results for these two types of steel are presented in Table 4.

The average yield strength of the deformed bar obtained is 409 MPa. This result is close to the design strength of 400 MPa. The average yield strength of the plain bar obtained was 355 MPa exceeding the design yield strength of 400 MPa. The results of this test have shown that the steel material used has met the target strength. Furthermore,

Table 3. Cylinder compressive strength.

Designation	α	f_c' (NC) MPa	f_c' (LWC) MPa
SN-1.00	1.00	26.16	0
SW-1.00	1.00	25.67	11.76
SW-1.26	1.26	24.96	11.92
SW-1.50	1.50	25.23	12.46
SW-2.00	2.00	25.92	12.28

Table 4. Tensile test of steel reinforcement.

Specimen	Designation	Yield strength MPa	Ultimate strength MPa
Plain bar	P8_1	357.00	504.00
	P8_2	355.00	586.00
	P8_3	353.00	498.00
	Average	355.0	529.33
Deformed bar	D10_1	410.00	547.00
	D10_2	400.00	555.00
	D10_3	418.00	587.00
	Average	409.33	563.00

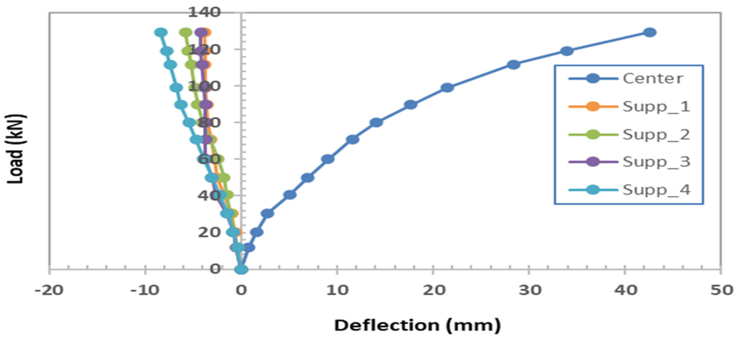

Fig. 4. Load deflection of SN-1.0 at various places (x-direction).

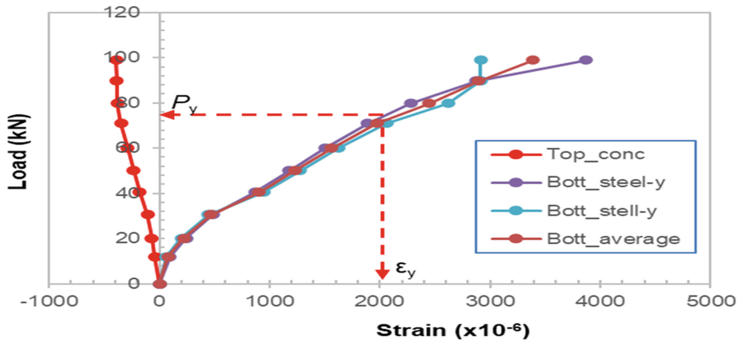

Fig. 5. The strain of steel reinforcement and concrete surfaces on SN-1.0.

for data analysis, actual test results that have been rounded down will be used. In addition to the yield strength of the steel reinforcement, the ultimate strength was also obtained of 563 MPa and 529.33 MPa for deformed and plain bars respectively.

3.2 Flexural Behavior of Two-Way Slab

To study the behavior of a two-way slab loaded with P in the center of the slab span, the following plots are presented between the incremental load and the deflection that occurs at the center of the span, and the deflection at each support for normal concrete specimens as shown in Fig. 4. In the figure, it can be said that generally, the greater the load, the greater the deflection.

Figure 4 shows the slab in the middle experienced a greater deflection as the load increased compared to deflection at the support in the opposite direction.

At the same time as deflection reading time, the amount of strain that occurs At the same time as the deflection reading time, the amount of strain that occurs every 10 s is recorded according to the data logger settings. The amount of strain that occurs in the tensile zone and the compression zone of the plate specimen is presented in Fig. 5.

The tensile test results of the deformed bar produce average yield stress of 409.33 MPa (see Table 4). This value produces a steel yield strain (εy) of 409.33/200000

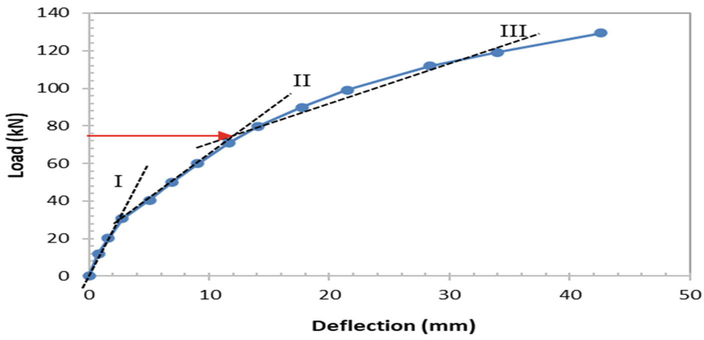

Fig. 6. Simplified load-deflection curve as the bilinear line of SN-1.0.

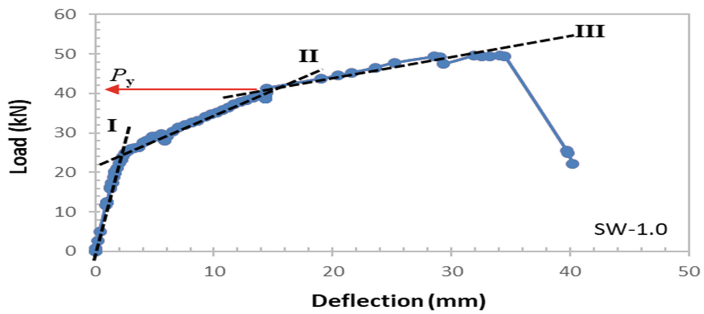

Fig. 7. Simplified load-deflection curve as the bilinear line of SW-1.0.

= 0.002. When this value is plotted on the x-axis (Fig. 5) and drawn on a line parallel to the y-axis, then this strain corresponds to a load of 76 kN called yield load (Py).

If the load-deflection curve (Fig. 4) is simplified in the form of a bilinear line (in this case into 3 segments) as shown in Fig. 6 and then the Py value is drawn parallel to the x-axis, it is obtained that this P value meets the point intersect between linear line-II and –III. This indicates that the use of the load-deflection curve simplification approach to obtain the yield load Py is acceptable [16]. Meanwhile, the intersection of the linear lines-I and -II indicates the first crack occurred, this is following the results observed during the test.

A typical sandwich slab (SW-1.0) with the same aspect ratio as the control slab (SN-1.0) was tested and produced a load-deflection curve as shown in Fig. 7. Similar to the discussion above, if this curve is simplified into 3 segments of the linear line as shown in Fig. 7 then a P_y value of 40 kN is obtained.

This value is the same as that obtained when using the strain readings on the tensile reinforcement (corresponding to 0.002), which is 40 kN as shown in Fig. 8. The concrete strain when the load reaches the maximum P = 50 kN is 0.00016. This value is far below the maximum concrete strain of 0.003. This means that the concrete slab undergoes failure that is preceded by the yield of the steel before the concrete reaches its maximum strain. This behavior of slabs is called an under-reinforced condition.

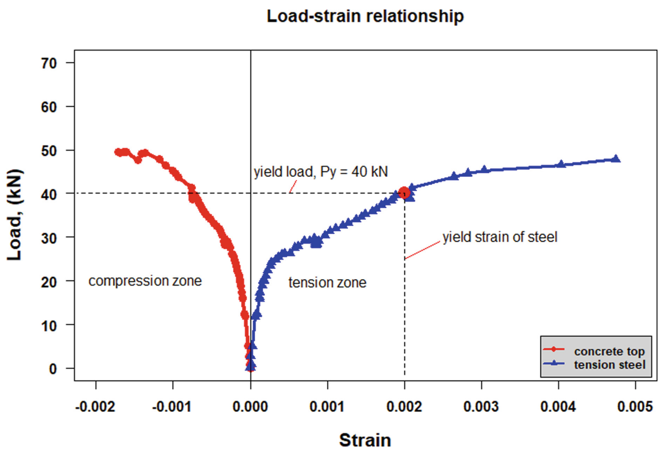

Fig. 8. The strain of steel reinforcement and concrete surfaces on SW-1.0

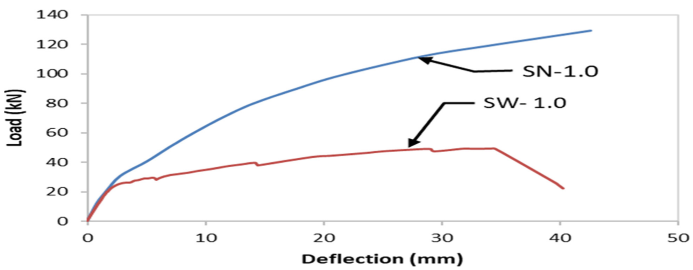

Fig. 9. Comparison of SN-1.0 and SW-1.0. slabs.

From the two typical slabs described above, it can be concluded that the yield load P_y may be taken from the load corresponding to the point of intersection between the two lines, namely the linear line-II and line-III on the load-deflection curve as in Fig. 7. This approach is considered valid because it is proven by the approach using strain measurements as shown in Fig. 8.

Comparison of SN and SW Slabs. The comparison between a normal concrete slab and a sandwich concrete slab is presented in Fig. 9. In the figure it is clear that the curves coincide with each other between the two slab specimens and begin to change direction after the specimens are cracked.

In normal slabs (SN-1.0), although it has cracked, it is still quite stiff compared to sandwich slabs (SW-1.0). The initial crack load P_{cr} for each specimen from the curve (Fig. 9) is 26 kN and 24 kN for normal and sandwich slabs respectively. Meanwhile, yield loads P_y obtained are 76 kN and 42 kN for the normal slab and sandwich slab, respectively. Similarly, the ultimate load of 129 kN and 49.3 kN are obtained.

Analytical and Experimental Comparison of Slabs. As mentioned previously the analysis of these slabs was carried out using Abacus on a finite element basis to predict

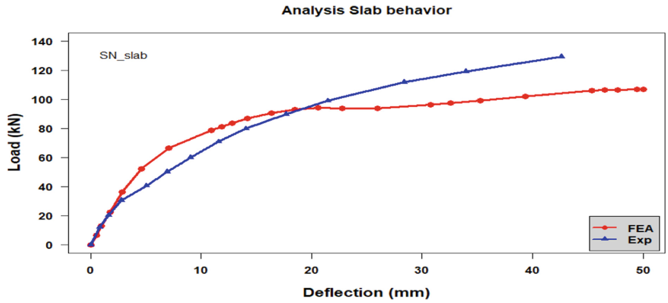

Fig. 10. FEA and experimental results for SN-1.0.

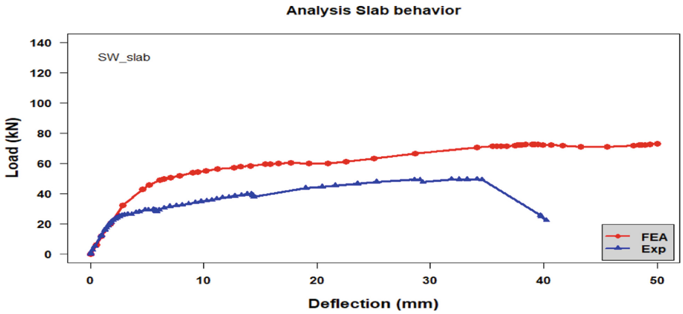

Fig. 11. FEA and experimental results for SW-1.0.

the load capacity and behavior of the slabs. The predicted value is plotted alongside the experimental one as shown in Fig. 10 and Fig. 11 for SN-1.0 and SW-1.0 slabs respectively.

As demonstrated in Fig. 10, there is little difference in the SN-1.0 behavior between the two results. Both results are equivalent in the early stages up to the load reaching about 30 kN. The FEA indicates increasing load capacity predictions once the load exceeds 35 kN to 90 kN, and these estimates tend to remain constant with greater deflection. In contrast, the experimental results show load capacity still increases after 90 kN and reach a maximum of 130 kN with a smaller deflection than the estimated one.

Figure 11 shows quite similar behavior between experimental and FEA prediction for SW-1.0, Both results are similar in the early stages in terms of load and deflection until the load reaches about 30 kN. The FEA indicates increasing load capacity predictions once the load exceeds 30 kN until 60 kN. These estimates tend to remain constant with greater deflection. Meanwhile, the findings of the experiment indicate that load capacity is continuing to increase slightly up to a maximum of 40.

Effect of Aspect Ratio on Sandwich Slab. The test results obtained of the four aspect ratio variations of sandwich slab specimens are presented in Fig. 12. The load-deflection curves for all types of slabs are almost the same when the slabs have not cracked, in the load range between 0 and 20 kN. The curve starts to vary at loads above 20 kN.

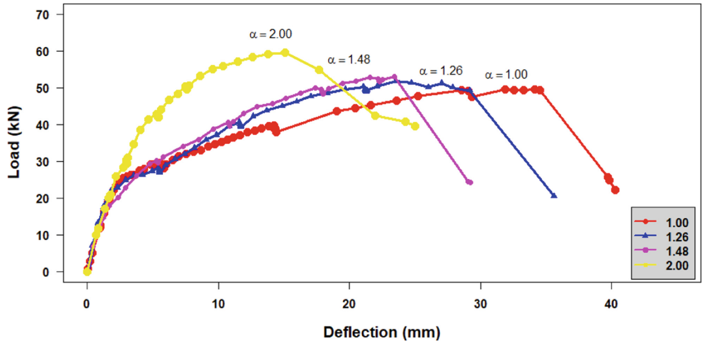

Fig. 12. Test results for various variations of SW slabs.

Table 5. Cracked and yield load observation.

Designation	P_{cr} (kN)	Normalized P_{cr}	P_y (kN)	Normalized P_y	Ratio P
SN-1.00	31.00	1.00	76.00	1.00	0.41
SW-1.00	25.00	0.81	42.00	0.55	0.63
SW-1.26	22.00	0.71	44.00	0.58	0.50
SW-1.50	22.00	0.71	46.00	0.61	0.48
SW-2.00	26,00	0.84	47.00	0.63	0.55

Based on Fig. 12, it can be said that for sandwich slab aspect ratio below 2.0, the sandwich slabs behave almost similarly. There are no significant differences among them in terms of load capacity. The slab with an aspect ratio of 2.0, however, has stiffness higher than the other sandwich slab. This is much similar to the behavior of the RC beam which presents a one-way element [5, 6]. Therefore, using 2.0 as the upper limit for the definition of one-way and two-way slab elements is acceptable.

In general, the slab ductility index decreases with an increasing slab aspect ratio. Further detailed descriptions of the important values of these slabs are discussed in the following subsections.

Yield Load and Initial Cracking. As discussed in the previous section, the load-deflection relationship curve can be used to interpret the value of the load when the reinforcement begins to yield or when the concrete first cracks occur. Table 5 presents the interpretation results for all slab types.

From the table, it can be seen that the crack load for all sandwich-slab ranges from 22 to 26 kN except for normal concrete slabs of 31 kN. When the crack load of the sandwich slab is normalized to the normal slab, the value of the crack load varies from 0.71 to 0.84. While normalization of yield load Py the value varies from 0.48 to 0.63.

Ultimate Capacity Resistance of the Slab. The ultimate capacity of slab sections is defined as the limit of the ability of concrete slabs to withstand the maximum load

Table 6. Ultimate load and deflection observation.

Designation	P_u (kN)		Ratio	δ (mm)		Ratio
	FEA	Exp		FEA	Exp	
SN-1.00	94.00	129.37	1.38	20.62	42.62	2.07
SW-1.00	72.70	49.53	0.68	38.90	34.14	0.88
SW-1.26	78.50	53.05	0.68	36.50	23.54	0.64
SW-1.50	86.50	59.39	0.69	33.60	23.44	0.70
SW-2.00	100.66	59.53	0.59	28.99	15.08	0.52

indicated by the failure during the test. From the test results, it has been obtained the capacity of the ultimate cross-section slab resistance and presented in Table 6.

Based on Table 6 it can be seen that the predicted load capacity of a normal slab (SN-1.0) is lower than the experimental results showing a safety factor of 1.38. But not the case for all sandwich slabs (SW) where the predicted load capacity is higher than the experimental one meaning no factor of safety is available. This indicates the model to calculate the deflection or bending of the two-way slab section to be reviewed, especially when applying to the sandwich concrete slab.

4 Conclusion

The use of pumice lightweight concrete as the core material of a two-way sandwich concrete slab element has prospects for development.

The load-carrying capacity of the sandwich slab is lower than that of the normal slab for the aspect ratio of 1. In general, the aspect ratio on the sandwich slab gives an insignificant effect in terms of load-carrying capacity.

The sandwich slabs with an aspect ratio below 2.0 behave almost the same with slightly different in terms of ductility index. The lower the aspect ratio the bigger the ductility index. The aspect ratio of 2.0 set by the standard as the limit for distinguishing between one-way and two-way slab elements is valid and acceptable.

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