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# BENDING PERFORMANCE OF HALF-SLAB STYROFOAM MORTAR WITH GLAZED NYLON FIBER

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**Abstract**

This paper scrutinizes bending performance of light weight half-slab mortar against bending and punching load. To produce the slab, 30 % round bud Styrofoam was used as fine aggregate substitution. Besides, glazed nylon fiber was applied to increase its tension strength and cavities at tension area of slab were also created. This method results in the significant reduction of self-weight of half-slab, while the cavities do not affect its bending performance and the fiber increases its ductility. Furthermore, the lower result of punching test should not to be a disadvantage as the slab is primarily to be used as a formwork.

**Keywords:**

Half-slab,
Light-weight mortar;
Styrofoam;
Fiber;
Cavities.

## 1 Introduction

The application of precast concrete in building construction has generally been accepted around the world as it provides solution for on-site rapid construction process. In comparison to on-site concrete casting, the precast concrete reduces some processes, at least, the process of formwork preparation and removal as well as curing stage all of which resulting in the shortening of the construction duration. In addition, the use of the genre of concrete has advantages which include reducing duration of construction and making supply reliable — made in purpose-built factories and not weather affected. High level performance in thermal comfort, durability, acoustic separation, and resistance to fire [1, 2].

One type of precast concretes namely half-slab is a thin precast concrete system which is installed on beam and continued with casting in situ concrete as the topping to form a full slab concrete for building. This method of concrete slab casting will reduce the utilization of formwork leading to the reduction of construction duration and construction cost as well. In comparation to casting in situ slab, half-slab can reach 1.7 times higher productivity than the conventional concrete slab. This is because the application of this method needs less crew to finish the slab construction. Besides, as half-slab is only used as formwork, the design strength of the slab is focused on receiving both self-weight of concrete and its live load during installation [3, 4].

Precast concrete is usually produced at central plan and transported into the construction site; however, the high density of the concrete makes the process of transportation and erection a challenging process. Therefore, light weight concrete becomes solution to produce lightweight precast concrete to deal with problem of transportation and installation. The normal concrete has the density about 2,400 kg/m$^3$, whereas lightweight concrete has the density below 1,760 kg/m$^3$ and can even be

lower than the density of water. If the lightweight concrete will be used as a structural element it should have minimum compressive strength of 17 MPa and minimum density of 1120 kg/m$^3$ [5].

The lightweight concrete (LWC) could be produced by substituting the aggregate deploying porous lightweight aggregate or introducing large voids within the concrete or mortar mass (aerated, cellular, foamed or gas concrete) [6]. Previous light weight concrete research by utilization of manufactured plastic aggregate reached a conclusion that at a replacement level of 25 %, concrete can produce moderate strength and ductility concrete that can be used in structural and non-structural applications [7]. Another lightweight aggregate possibly used is Styrofoam, a largely used material in industry for packaging process. However, the Styrofoam waste is not allowed to put in recycle bin due to contamination risk and its large volume [8]. Hence, the suggested treatment for the Styrofoam waste is reusing it for example as aggregate substitution to produce lightweight concrete.

A previous study has shown that it is possible to manufacture lightweight mortar by using Styrofoam as partially fine aggregate substitution with strength of [9]. Although Styrofoam mortar has low compressive strength, it can still be used as nonstructural element e.g. brick or roof tile and its contribution to reduce industrial waste becomes a credit point to this kind of concrete. Nevertheless, as Styrofoam has very low density that leads to some problems in casting process, an application of Self Compacting Concrete (SCC) method is possible to make the Styrofoam concrete become homogenous concrete matrix.

Self-Compacting Concrete was first time developed at University of Tokyo Japan in 1980s referring to a type of concrete that does not need external mechanical vibration for compaction process of fresh concrete after pouring into formwork. The self-compaction is possible due to high flowability and its self-weight of this type of concrete that can fill up the formwork even for thin concrete size or high congestion of concrete reinforcement [10]. The high flowability of this concrete should meet with the following properties i.e.: filling ability, passing ability and resisting segregation. The typical mix proportion of self-compacting concrete is described as lower coarse aggregate contents, higher binder contents, lower water/binder ratios and significant superplasticizer dosages [11].

In correspond to other common concrete constituents, fiber has been used in concrete matrix and has mainly act as surface crack controller. The controller works on the improvement of concrete strain, improves bending tensile stress, and reduces its deflection especially when the concrete elements are subject to flexure, shear and torsion load. Moreover, after the first micro crack on concrete, the improvement of concrete strain and bending tensile stress can still be figured out [12, 13]. The types of fiber include steel fiber, natural fiber, synthetic fiber and polypropylene fiber. In comparison to steel fiber and polypropylene fiber, nylon fiber has not been widely used in concrete referring to the small exploration on this area available in published papers [14]. Nylon fiber was introduced in October 1938 classified as synthetic fiber which resists to abrasion but is degraded by ultraviolet light. However, provided that the fiber is protected inside the concrete, this type of fiber enhance effectively split tension strength of concrete due to crack bridging effect of the fiber.

Considering the advantage of using half-slab lightweight concrete in building construction and the lack of information about utilization of lightweight panel for half-slab, an investigation into the employment of Styrofoam and glazed nylon fiber in producing half-slab light weight concrete panel was conducted. This paper presents the results of experimental program on bending performance and punching performance of lightweight half-slab by using monotonic load application.

## 2 Research method

The experimental program for this study was conducted at Civil Engineering Laboratory Universitas Muhammadiyah Surakarta which comprised material testing, mortar half-slab casting, specimens curing and concrete half-slab bending as well as punching testing. Material testing was conducted for fine aggregates and the test included mud content test, organic content test, fine aggregate gradation test and density test of fine aggregate.

Prior to casting the specimens, mix proportions of light weight mortar which was comply with requirement of self-compacting concrete was prepared. To produce lightweight mortar, 30 %, rounded Styrofoam bud was used as partially fine aggregate replacement by its volume. In addition, a variation of 0.5 % and 1.0 % glazed nylon fiber was used as mortar strengthening. Mix proportion per m$^3$ of light weight mortar was described at Table 1.

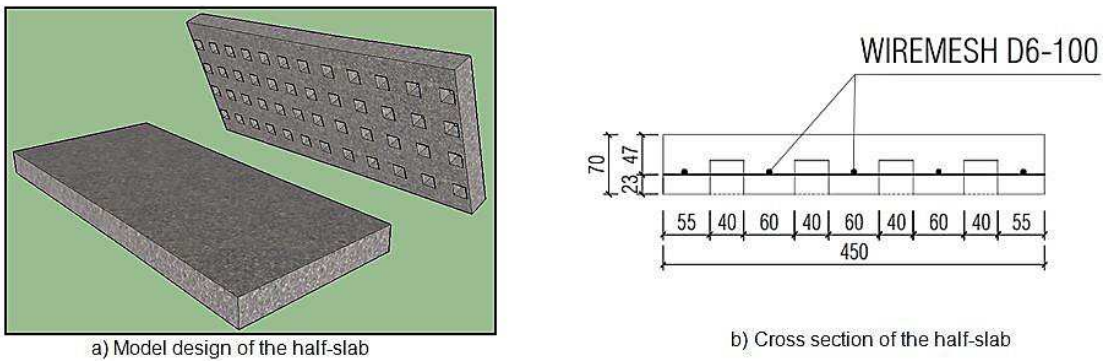
Table 1: Mix proportion of concrete per $m^3$.

| Specimen's code | Cement [kg] | Styrofoam [kg] | Sand [kg] | Plasticizer [l] | Fiber [g] | Total [kg] |
|---|---|---|---|---|---|---|
| GNF-0.5 | 570.5 | 2.205 | 1,081.2 | 5.725 | 432.9 | 1.659 |
| GNF-1.0 | | | | | 865.8 | |

In addition to the use of plasticizer to produce self-compacting concrete, the mix proportion also utilized discontinue glazed nylon fiber as the fiber effectively enhances concrete toughness [15]. Based on Table 1, it can be predicted that total concrete material will produce concrete with density of 1,659 kg/$m^3$ which belongs to light weight concrete criteria. Moreover, the amount of glazed nylon fiber was added based on concrete volume i.e.: 0.5 % (GNF-0.5) and 1.0 % (GNF-1.0) by volume of concrete.

Prior to the casting of half-slab mortar, a test called slump flow test was conducted to check whether the mix proportion satisfied the requirement as self-compacting concrete. This test was needed as thin half-slab would be produced in order that the fresh mortar fill up formwork easily with minimum compaction work. Slump flow test was conducted by filling up abrams cone with fresh mortar followed by lifting up the cone vertically. Once the cone was lifted up, the fresh mortar spreads evenly on the base of the cone and the measurement of fresh mortar diameter could be completed. The result shows that the diameter of slump flow for GNF-0.5 is 72 cm whereas the one for GNF-1.0 the slum flow is 65 cm. Both of them satisfy the requirement value of slum flow test for self-compacting concrete i.e. between 55 – 85 cm [16].

In casting half-slab, wooden form works were used to cast Styrofoam concrete half-slab with the dimension of 450 x 1100 x 70 mm. In addition, 40 x 40 x 40 mm Styrofoam cubes were used to create cavity at the bottom of the slab, Fig. 1. Furthermore, diameter 6 mm and spacing of 100 mm wire mesh were used as slab reinforcement. Beside the slab, Styrofoam concrete cylinder with diameter of 150 mm and height of 300 mm were casted for density test and compression strength test. After casting, water immersion curing method was applied to all of specimens for the duration of 28 days, which then followed by testing stage which consisted of bending test and punching test to analyze flexural behavior and punching shear of the half-slab.




a) Model design of the half-slab

b) Cross section of the half-slab

Fig. 1: Design of the half-slab.

## 3 Result and discussion

### 3.1 Concrete cylinder test

Concrete cylinder specimens with diameter of 150 mm and height of 300 mm were tested at 28 days to analyze its density and compression strength. The compression strength test was carried out by using compression test machine which gave constant load to the specimens until failure whereas the density was obtained by calculating the ratio between the weight and the volume of specimen. The following table shows the result of average of four specimens to find compressive strength and density of Styrofoam mortar cylinder specimens.

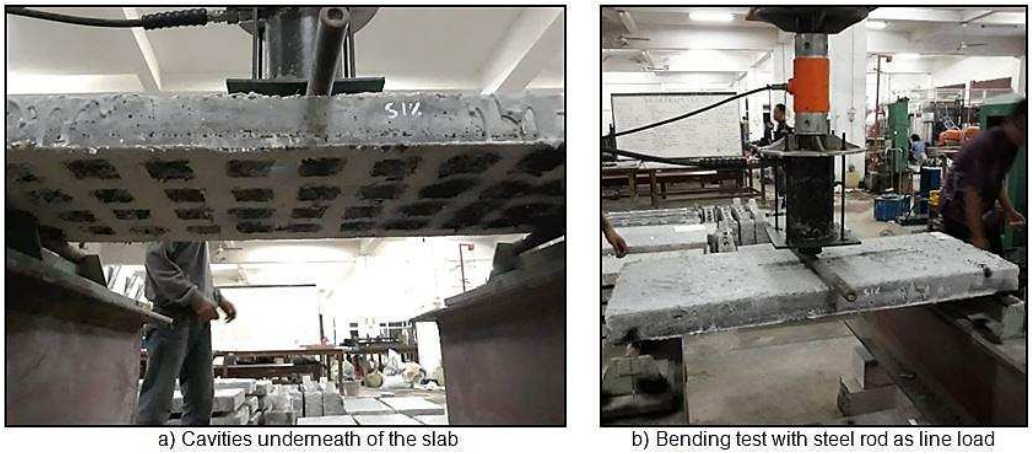
Table 2: Compressive strength and density and test result.

| No | Specimen's code | Compressive strength [MPa] | Density [kN/$m^3$] |
|---|---|---|---|
| 1 | GNF-0.5 | 13.02 | 1.634 |
| 2 | GNF-1.0 | 15.03 | |

As presented in table 2, there was a slightly increase on compressive strength when higher fiber content was used since the presence of fiber in concrete matrix possibly became confinement in concrete to increase its compressive strength. Ezeldin and Perumalsamy [17] reported that the more steel fiber is used the higher the compressive strength is due to the transverse confinement effect of the steel fibers. Therefore, this result agrees with the previous research reporting that the presence of fiber can increase concrete compressive strength. Correspondingly, as the density of mortar less than 1760 kg/ $m^3$, the mortar belongs to lightweight concrete criteria [5].

### 3.2 Bending test result

Bending test specimen for half-slab had dimension of 70 x 450 x 1100 mm, in which clear span of 1000 mm was used as shown in Fig. 2. In the middle of the slab, a steel rod was placed on the top of slab which acted as a line load where hydraulic pump was used to apply static constant load with loading rate of 10 kN/minutes. To record load and deflection data, load cell and dial gauge device was utilized.



a) Cavities underneath of the slab b) Bending test with steel rod as line load

Fig. 2: Bending test of specimen.

The data of load and deflection was then presented in Fig. 3 that showed the load and deflection diagram for both specimens glazed nylon fiber 1.0 % and 0.5 %.

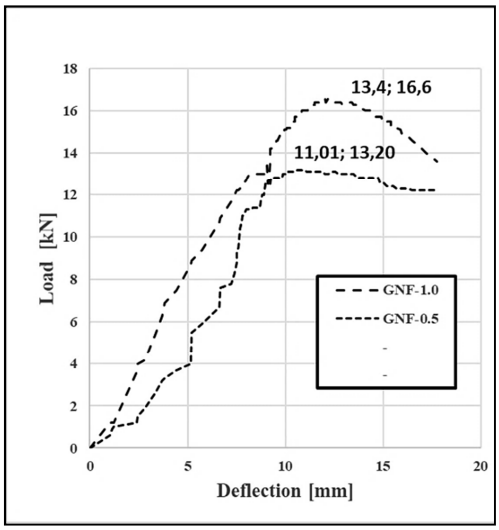


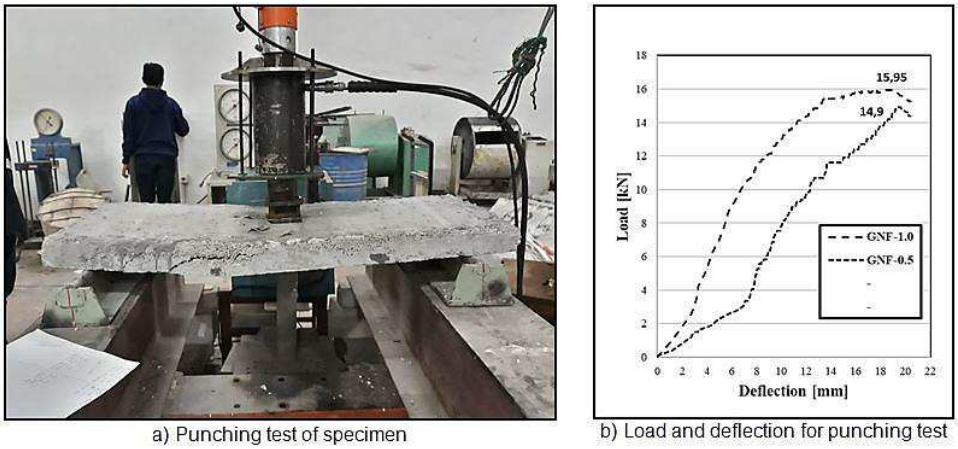

Fig. 3: Load and deflection graph for bending test.

Based on load and deflection graph in Fig. 3, utilization glazed nylon fiber (GNF) of 1 % increased the maximum bending load at about 26 % in comparison to additional glazed nylon fiber (GNF) of 0.5 %. In addition, the more fiber inside the concrete increased the deflection to reach the maximum load, which indicated the increase of half-slab ductility. The increase of maximum bending load and ductility when additional fiber was used seemed similar to the result of compressive strength

test in which higher content of fiber led to higher strength of concrete. This result is mostly caused by the presence of fiber in cement matrix which reduced the crack width and increased the ultimate strain of material. Consequently, these led to the increase its strength and ductility [18, 19]. Further, the presence of fiber was beneficial to increase bending performance and ductility of concrete which was shown in higher bending load and higher deflection.

### 3.3 Punching test result

Punching test is an important test for reinforced concrete slab subject to concentrate load to determine whether the thickness of slab is adequate against two shear failure [20, 21]. The punching test was conducted on specimen with dimension of 70 x 450 x 1100 mm supported on two sides at length direction of the slab. On surface center of the slab. steel block with area of 10 x 10 $cm^2$ was used as concentrated load where hydraulic pump was used to apply static constant load. This two-side support testing setup nested in previous research of punching test deploying two supporting desks. During the test, load and deflection data was recorded. The maximum load of each specimen was presented in Fig. 4.




a) Punching test of specimen b) Load and deflection for punching test

Fig. 4: Punching Test result.

Load – deflection on Figure 5 showed the maximum load for both specimen with the same thickness of 70 mm in which the presence of 1 % glazed nylon fiber slightly increased maximum punching load of 7.05 % in comparison to 0.5 % content of glazed nylon fiber. This result indicated that the punching strength was influenced more by the thickness of the slabs rather than by the fiber content of specimen as there was no significant difference of maximum punching load for those specimens. This result approves the previous research conducted by Birkle and Dilger [22] and Urban et.al [23] in which for thick concrete slab, the decrease of shear stress resistance was small, meaning that shear stress resistance was affected more by slab thickness rather by external factor such as shear reinforcement.

## 4 Analysis of bending and punching performance

When bending and punching test were finished, the performance of both tests in experiment and in analysis was compared. For bending and punching analysis, the thickness of the slab was calculated as uniform thickness without cavities at the bottom of the slab. Moment for bending test experiment $M_u$ could be calculated based on first crack load $P$, self-weight of the slab $q$ and length of the slab $L$ deploying the formula:

$$M_u = {}^1\!/_4\, PL + {}^1\!/_8\, qL^2 \,. \tag{1}$$

The result of moment from bending test experiment was then compared to that from the analysis of design moment $M_D$ applying the formula:

$$M_D = 0.9\left[A_s\, f_y\left(d - {}^1\!/_2\, a\right)\right], \tag{2}$$

where: $A_s$ is area of longitudinal tension reinforcement in $mm^2$, $f_y$ is specified yield strength of reinforcement in MPa, and *a* is depth of rectangular stress block in $mm^2$. Moreover, the comparison of punching performance between experiment and analysis was conducted by comparing first crack punching load to punching shear of concrete $V_c$ as described in the following formula [24]:

$$V_c = \phi(0{,}33.\lambda.\sqrt{f'_c}.b_0.d), \quad (3)$$

where $\phi$ is strength reduction factor i.e.: 0.9, $\lambda$ is modification factor correlation strength between lightweight concrete to normal weight concrete i.e.: 0.75, $f'_c$ is specified concrete compressive strength in MPa, $b_o$ is perimeter of critical section of two way shear in slab in mm, and *d* is distance from extreme compression fiber to center of longitudinal tension reinforcement in mm. By referring to previous research on load deflection of slab that first crack load is 67 % of maximum load [25] and uniform self-weight of the slab is 0.408 kN/m, comparison between experiment and analysis was shown in Table 3.

Table 3: Maximum moment comparison between experiment and analysis.

| Speciment | Experiment | Analysis |
|---|---|---|
| Moment analysis for bending test | | |
| GNF-0.5 | 1.774 kN·m | 1.388 kN·m |
| GNF-1.0 | 2.217 kN·m | 1.395 kN·m |
| Concentrated load analysis for punching test | | |
| GNF-0.5 | 7.778 kN | 18.510 kN |
| GNF-1.0 | 8.326 kN | 19.888 kN |

Self-weight comparison analysis showed that half-slab Styrofoam mortar with cavities underneath was superior in comparison to normal half-slab concrete. With the thickness of 7 cm, normal concrete had self-weight of 168 $kg/m^2$ whereas half-slab Styrofoam mortar with cavities underneath had self-weight of 90.7 $kg/m^2$. It is important to note that significant self-weight reduction of 46 % would attract more stake holders in building construction to use this half-slab for their construction.

In Table 3, analytical result shows no significant difference in analytical calculation for both bending and punching of GNF-0.5 and GNF-1.0 as analytical calculation was conducted based on the compressive strength result. Nevertheless, a slight difference was observed in experimental program for both bending and punching of GNF-0.5 and GNF-1.0.

In addition, the experimental bending test of half-slab had 1.5 times as much as the analysis strength test. This result showed that even though cavity at the bottom of the slab was created, it did not affect its flexural strength. This was because the cavities were located at the tension region of the slab where the tension strength was held by wire mesh as steel reinforcement. Further analysis of bending strength test could obtain maximum length of light weight half-slab i.e. with the length of 2.39 m for 0. % glazed nylon fiber content and 2.99 m for 1 % glazed nylon fiber content.

However, due to the presence of cavity at the bottom of the slab that reduced the effective depth of the slab, there was a significant decrease of 58 % in the ability of the slab to hold concentrated load in comparison to uniform thickness of the slab. Correspondingly, this does not seem to be a disadvantage as the slab was primarily to be used as a formwork in which the punching strength will be increased once in situ toping concrete added. Therefore, half-slab could satisfy as lightweight formwork for concrete slab with additional consideration on the concentrated load reduction.

## 5 Conclusion

The experimental program on bending performance of lightweight Styrofoam half-slab mortar has confirmed the significant reduction of its self-weight and the fulfillment of half-slab requirement. Further, the study demonstrates that:

a) Mix proportion of mortar consisting of cement, sand, water plasticizer, Styrofoam and glazed nylon fiber can produce homogenous mortar and satisfy the requirement as self-compacting concrete in which the slump flow for GNF-0.5 is 72 cm and for GNF-1.0 the slum flow is 65 cm. Both compositions are ready to cast in thin size formwork mortar with minimum compaction work.

b) The formation of cavities at the bottom of the slab, which makes the slab lighter, essentially leads to the reduction of its self-weight in comparison to normal half-slab by 46 %. Correspondingly, the process of transportation and installation is also easier.

c) Moreover, the presence of cavities underneath the slab does not affect its bending performance in comparison to analytical calculation of solid half-slab. Meanwhile, the presence of glazed nylon fiber increases half-slab ductility that increases the performance of building especially related to dynamic load.

d) Compared to theoretical calculation analysis, the punching test is reduced by 58 %, however; as the slab is mainly used as a formwork, this should not be a hurdle.

e) Further research needs to be conducted to study the utilization of small size crushed rock aggregate to introduce mix proportion of lightweight concrete and to open the possibility to increase the maximum length of the slab.

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## References

[1] ADMIN.: Precast Concrete in Building (A Guide to Design and Construction). Camberley, UK: The Concrete Centre, 2007.
[2] NUNALLY, S. W.: Construction Method and Management. 7th edition, New Jersey, USA: Pearson Education, 2007.
[3] CHO, K. - SHIN, Y. - KIM, T.: Effects of Half-Precast Concrete Slab System on Construction Productivity. Sustainability, Vol. 9, No. 7, 2017, pp. 1-15. doi: 10.3390/su9071268.
[4] LEE, Y. L. – KARIM, A. T. A. – ISMAIL, A. R. – CHAI, T. J. – KOH, H. B. - NAGAPAN, S. – YEOH, D.: Deflection Of Reinforced Concrete Half-Slab. Int. J. Constr. Technol. Manag., Vol. 1, Jun., 2013, pp. 2289–4454.
[5] ACI 213R-03.: Guide for Structural Lightweight-Aggregate Concrete. American Concrete Institute, Farmington Hills, MI, USA, 2003.
[6] GILANI, H. G. - SAMPER, K. G. - HAGHI, R. K.: Advanced Process Control and Simulation for Chemical Engineers. Florida, U.S.A.: Apple Academic Press, 2013.
[7] ALQAHTANI, F. K. - GHATAORA, G. - KHAN, M. I. - DIRAR, S.: Novel lightweight concrete containing manufactured plastic aggregate. Constr. Build. Mater. Vol. 148, Sep. 2017, pp. 386–397. doi: 10.1016/j.conbuildmat.2017.05.011.
[8] ADMIN.: The Rundown on Plastic #6 (Styrofoam). American Disposal Services. https://americandisposal.com/blog/the-rundown-on-plastic-6-styrofoam/ (accessed Dec. 12, 2019).
[9] SOLIKIN, M. - WIDIYANTO, R. - ASRONI, A. - SETIAWAN, B. - ASNAN, M. N.: High content Styrofoam as partial substitution for fine aggregate in SCC lightweight concrete brick. AIP Conference Proceedings, June 2019, pp. 030022-1 - 030022-6. doi: 10.1063/1.5112426.
[10] NAIK, T. R. - KUMAR, R.: Self-Compacting Concrete (SCC) or Selfleveling Concrete (SLC). Madison, USA: Department of Civil Engineering and Mechanics College of Engineering and Applied Science The University Of Wisconsin - Milwaukee, 2001.
[11] DE SCHUTTER, G. – GIBBS, J - DOMONOE, P.: Self-compacting Concrete. Whittles Publishing, Scotland, UK. 2008.
[12] MARCALIKOVA, Z. - CAJKA, R.: Determination of Mechanical Properties of Fiber Reinforced Concrete for Numerical Modelling. Civ. Environ. Eng., Vol. 16, No. 1, 2020, pp. 86–106. doi: https://doi.org/10.2478/cee-2020-0010.
[13] YOO, D. Y. - YOON, Y. S.: A Review on Structural Behavior, Design, and Application of Ultra-High-Performance Fiber-Reinforced Concrete. Int. J. Concr. Struct. Mater., Vol. 10, No. 2, 2016, pp. 125–142. doi: 10.1007/s40069-016-0143-x.
[14] LEE, S.: Effect of Nylon Fiber Addition on the Performance of Recycled Aggregate Concrete. Applied Sciences , Vol. 9, No. 4. 2019, pp. 1-14. doi: 10.3390/app9040767.
[15] YOO, D. Y. - BANTHIA, N.: Impact resistance of fiber-reinforced concrete – A review. Cem. Concr. Compos., Vol. 104, 2019, pp. 1 - 22 doi: https://doi.org/10.1016/j.cemconcomp. 2019.103389.

[16] SKH-1.7.23.: Spesifikasi Khusus - Interim Skh-1.7.23 Beton Memadat Sendiri (in English: Special specification for Self Compacting Concrete). Jakarta: Kementerian Pekerjaan Umum Dan Perumahan Rakyat Republik Indonesia Direktorat Jenderal Bina Marga, 2017.
[17] EZELDIN, A. S. - PERUMALSAMY, B. N.: Normal- and High-Strength Fiber-Reinforced Concrete under Compression, J. Mater. Civ. Eng., Vol. 4, No. 4, Nov. 1992, pp. 415–429. doi: 10.1061/(ASCE)0899-1561(1992)4:4(415).
[18] FANTILLI, A. P. - VALLINI, P. - FERRETTI, D. - IORI, I.: Behaviour of R/C Elements in Bending and Tension: The Problem of Minimum Reinforcement Ratio, in Minimum Reinforcement in Concrete Members. A. B. T.-E. S. I. S. Carpinteri, Ed. Elsevier, Vol. 24, 1999, pp. 99–125.
[19] TAYLOR, M. - LYDON, F. D. - BARR, B. I. G.: Toughness measurements on steel fibre-reinforced high strength concrete. Cem. Concr. Compos., Vol. 19, No. 4, 1997, pp. 329–340.
[20] J. D. R. Joseph, J. Prabakar, and P. Alagusundaramoorth: Flexural Behavior of Precast Concrete Sandwich Panels Under Different Loading Conditions such as Punching and Bending. Alexandria Eng. J., vol. Vol. 57, pp. 309–320, 2018. http://dx.doi.org/10.1016/j.aej.2016.11.016.
[21] ACI 318R-14.: Building code requirements for structural concrete : ACI Committee 318, 2014.
[22] BIRKLE, G. - DILGER, W.: Influence of slab thickness on punching shear strength. ACI Struct. J., Vol. 105, 2008, pp. 180–188.
[23] URBAN, T. - GOŁDYN, M. - KRAKOWSKI, J. - KRAWCZYK, Ł.: Experimental Investigation on Punching Behavior of Thick Reinforced Concrete Slabs. Arch. Civ. Eng., Vol. 59, No. 2, 2013, pp. 157–174. doi: https://doi.org/10.2478/ace-2013-0008.
[24] SNI 03-2847-2013, Persyaratan Beton Struktural untuk gedung. (in English: Structural Concrete Requirement for Building) Jakarta: Badan Standarisasi Nasional (BSN), 2013.
[25] JOMAA'H, M. - KHAZAAL, A. - AHMED, S.: Effect of replacing the main reinforcement by steel fibers on flexural behavior of one-way concrete slabs. MATEC Web Conf., Vol. 162, Jan. 2018, pp. 1-9. doi: 10.1051/matecconf/201816204010.

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