Journal of Social Research

E-ISSN: 2828-335x
Vol. 5, No. 11, October 2026, pp. 5833-5845
DOI : 10.55324/josr.v5i11.3513
Journal of Social Research

Shear Capacity Analysis of Reinforced Concrete Beams with Glass Fibers: Experimental Study and Validation of SAP2000

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Keywords:
Reinforced concrete; Shear capacity; Glass fiber; SAP2000; (SNI 2847, 2019).

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International Journal Labs

Abstract

Reinforced concrete is the main material in construction in Indonesia, but it has weaknesses in tensile strength and susceptibility to shear failure. This study aims to evaluate the effect of the addition of glass fiber with doses of 0.5%, 1.0%, and 1.5% on the compressive strength, shear capacity, and crack pattern of reinforced concrete blocks. The research method was carried out through laboratory tests on cylindrical and beam test objects, as well as numerical modeling using SAP2000 compared with the provisions of SNI 1726:2019 and SNI 2847:2019. The results showed that the fiber dose of 1.0% provided optimal performance with an increase in compressive strength of 22.4% and a shear capacity of 22.3% compared to normal concrete. In addition, the damage pattern changed from brittle to more ductal with an increase in deflection of up to 18.7%. Modeling validation showed a difference of less than 5% to the experimental data, confirming the reliability of the model used. These findings prove that glass fibers can be an effective alternative to improving structural safety without significant changes to cross-sectional dimensions.

INTRODUCTION

The growth of development in Indonesia demands structural systems that are not only strong, but also able to respond reliably to environmental loads (Pratama & Wibowo, 2024; Alguhi & Tomlinson, 2023). Reinforced concrete is still the main material due to its abundant availability, relatively economical cost, and ease of implementation. However, concrete's weak properties to tensile forces make it vulnerable to shear failure, especially in beam elements (Embunsari, 2021; (Almusallam et al., 2012).

Shear failure is different from bending failure. If bending failure is characterized by an increase in deflection before collapse, shear failure occurs suddenly without sufficient warning. Post-earthquake reports show that beam collapse due to insufficient shear capacity is one of the main causes of building damage (Darmawan, 2022). This condition confirms the need for innovation to increase the shear capacity of reinforced concrete (Chou Wu et al., 2022).

The addition of fibers is one of the widely studied approaches to improve the mechanical properties of concrete (Ahmad et al., 2022a; (Sutanto, 2023). Glass fiber was chosen because it has high tensile strength, corrosion resistance, and is more affordable than other fibers. A number of previous studies have shown that fibers can increase the ductility of concrete and slow down the development of cracks (Zhang et al., 2022). However, studies on the influence of glass fibers on the sliding behavior of reinforced concrete blocks accompanied by computational validation using structural analysis software are still limited (Ahmad et al., 2022b).

This research offers novelty in three ways. First, it provides a comprehensive evaluation of the effect of glass fiber dose variations (0.5%, 1.0%, and 1.5%) on both compressive strength and shear capacity, which has not been done in prior studies. Second, it validates the experimental results through numerical modeling using SAP2000, providing a bridge between experimental research and practical structural analysis. Third, it compares the experimental results with the provisions of SNI 1726:2019 and SNI 2847:2019, providing direct evidence of whether glass fiber addition can help concrete meet or exceed code requirements. By addressing these gaps, this research contributes to both the theoretical understanding of fiber-reinforced concrete behavior and the practical knowledge needed to improve structural safety in earthquake-prone regions (Almusallam, 2021; Xu & Li, 2019).

Therefore, this study was conducted to analyze the effect of variations in glass fiber dosage (0.5%, 1.0%, and 1.5%) on compressive strength, shear capacity, and crack patterns of reinforced concrete blocks. The results of the experiment were then validated by numerical modeling using SAP2000, and compared with the provisions of SNI 1726:2019 and SNI 2847:2019. This research is expected to provide a scientific basis for the use of glass fiber as an alternative to improving structural safety without significant changes in cross-sectional dimensions (Suryadi, 2022).

METHOD

Research Design

This study uses a laboratory experimental approach combined with numerical modeling. The aim is to analyze the effect of glass fiber dose variations on the compressive strength and shear capacity of reinforced concrete blocks, as well as validate the results of the experiment by simulation using SAP2000 software.

Materials and Equipment

The materials used include Portland Type I cement, river sand, broken gravel with a maximum size of 20 mm, clean water, and type E glass fiber with a length of 12 mm. The equipment used includes mixing machines, cylinder and block molds, pressure testing machines, deflection measuring instruments, and SAP2000 version 22 software.

Mixed Plans

The planned concrete quality is fc' = 25 MPa with a cement water factor of 0.55. The variations in the addition of glass fibers to the cement weight are: 0% as a control, 0.5%, 1.0%, and 1.5%. Each variation is made as many as three test specimens to ensure the accuracy of the data.

Testing Procedure

- **Compressive strength tests** were performed at the age of 7, 14, and 28 days according to (SNI 1974, 2011).
- **The shear capacity test** was performed on beams measuring 15 × 25 × 120 cm with an effective span of 100 cm. Loading was applied gradually at two points until the beam collapsed. The parameters recorded included initial crack load, maximum load, crack pattern, and maximum deflection.

Computational Modeling

Modeling is carried out by incorporating the dimensions of the elements, the material properties of the laboratory test results, and the configuration of the reinforcement into the SAP2000. The conditions of the support and the way of loading are made exactly the same as the real test conditions so that the comparison of results can be carried out directly.

Data Analysis

The experimental results data were compared with the results of the numerical simulation. Validation was carried out by calculating the relative difference between the maximum load of the experiment and the SAP2000 results. Next, the results were analyzed against the conditions and to assess the conformity with the planning standards (SNI 1726, 2019; SNI 2847, 2019).

RESULTS AND DISCUSSION

Physical Characteristics of Materials

The results of the inspection show that all materials used meet the applicable technical requirements. The specific gravity of sand and gravel is within reasonable limits, so it does not interfere with the quality of the planned concrete mixture.

Compressive Strength Analysis

Table 1. Average Yield of Compressive Strength of Concrete

Variations	Fiber Dosage (%)	Age 7 Days	Age 14 Days	Age 28 Days	Increase (%)
K0	0	18,2	22,1	25,4	-
K1	0	20,5	24,3	27,8	9,45
K2	1,0	23,8	28,6	31,1	22,44
K3	1,5	22,1	26,4	29,7	16,93

The results of the compressive strength test showed that the addition of glass fiber increased the strength of the concrete in all variations compared to normal concrete. The highest increase occurred at the dose of 1.0% with an increase of 22.44% at 28 days of age. This showed that the glass fiber functioned optimally as a micro-crack binder at that dose. Conversely, at the 1.5% dose there was a decrease in performance due to uneven distribution of the fibers and the formation of air cavities. These findings are in line with the study that stated that the optimal fiber dose was at 1.0% (Chou Wu et al., 2022).

Shear Capacity Evaluation

Table 2. Shear Behavior of Concrete Beams

Variations	Initial Cracking Load (kN)	Maximum Load (kN)	Capacity Increase (%)	Max deflection (mm)
K0	32,5	42,6	-	3,2
K1	38,8	48,9	14,8	3,7
K2	45,2	52,1	22,3	4,1
K3	41,0	49,5	16,2	3,8

The fiberless beam (K0) initially cracked at a load of 32.5 kN and collapsed at 42.6 kN. The addition of fibers increased the shear capacity, with the best results at a dose of 1.0% (K2)

reaching 52.1 kN, an increase of 22.3% compared to control. In addition, the maximum deflection increased to 4.1 mm, signaling a change in material properties from brittle to more ductile. These results are consistent with those reported that glass fibers are able to improve the ductility of concrete (Tarek H Breakfast et al., 2012).

Validation of Modeling Results

Table 3. Comparison of Experimental and Computational Results

Variations	Experimental Max Load (kN)	Max Load SAP2000 (kN)	Difference (%)
K0	42,6	41,8	1,9
K2	52,1	50,7	2,7

Comparison of the results of the experiment and SAP2000 simulation showed a difference of less than 5%, i.e. 1.9% for K0 and 2.7% for K2. This proves that the numerical model used is quite accurate in representing the behavior of the structure. These findings support research that emphasizes the reliability of SAP2000 in the analysis of reinforced concrete blocks (I Gede Andika Tycoon et al., 2024).

Compliance with Planning Standards

Referring to SNI, the permissible shear capacity for concrete quality fc' = 25 MPa is 46.8 kN. Normal concrete (K0) only reaches 42.6 kN, so it does not meet the standard. However, blocks with 1.0% glass fiber (K2) are able to withstand loads of up to 52.1 kN, exceeding the standard provisions. This suggests that the addition of glass fiber provides an important additional safety reserve in the face of unexpected loads, such as earthquakes (PUPR ministry, 2025; SNI 2847, 2019).

Example of concrete mix calculation;

(referring to SNI 03 2834 – 2000 and ACI 211.1-91)

A . Mix of normal concrete design (SNI 03 2834 – 2000)

Planning compressive strength of concrete (f'c) with a certain lifespan, max = 28 days. f'c = 25 MPa.

B . Calculation of the planning of the mormal concrete mixture

1 . Added Value (M)

This value taken from Table .6.2 is M = 7 MPa. Because f 'c = 20 MPa.

(diambil yang terbesar) :

$M = 1{,}34\ S$

atau

$M = 2{,}33\ S - 3{,}5$

$$S = \sqrt{\frac{\Sigma(\ fc - fcr\ )^2}{N - 1}}$$

Table 4. Average Compressive Strength Required If Data Are Not Available to Determine Standard Deviation

Required Compressive Strength fc' (MPa)	Value Added (MPa)
< 21	7,0
21–35	8,5

Required Compressive Strength fc' (MPa)	Value Added (MPa)
> 35	10,0

Keterangan pada gambar:
Pada pengujian ini dipakai M =
Rumus kuat tekan beton rata-rata:
fcr = fc' + m

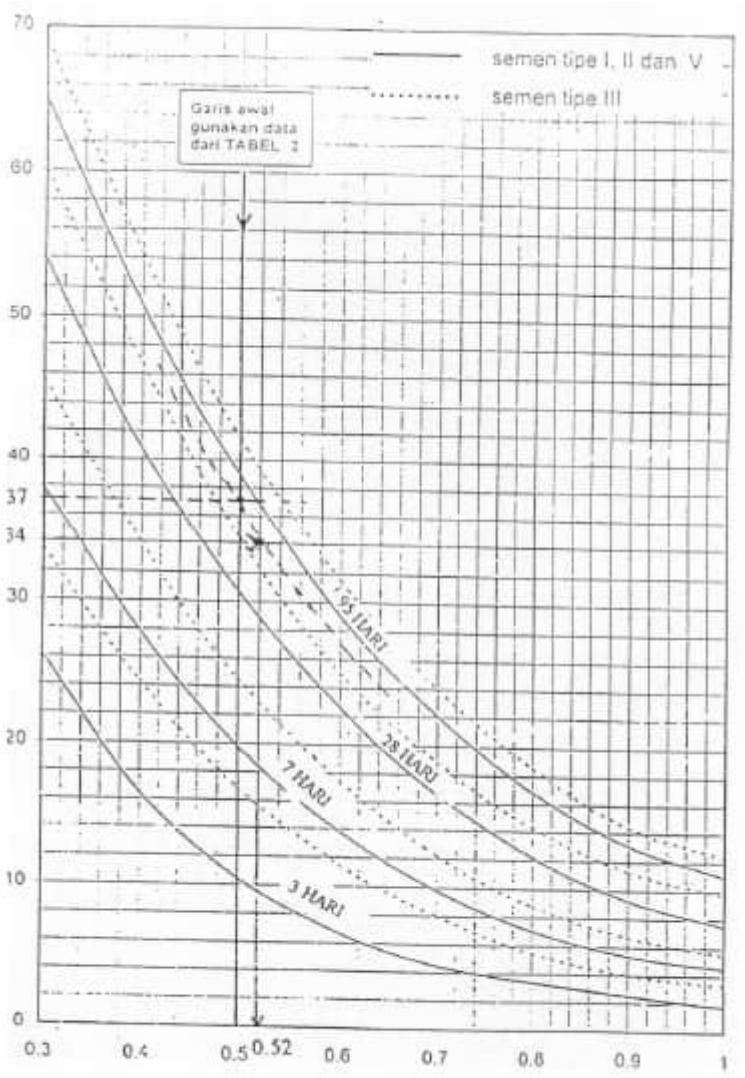
Table 5. Modification Factor for Standard Deviation if the Number of Tests is Less than 30 Samples

Number of Tests	Modification Factor for Standard Deviation
Less than 15 samples	Use Table 5
15 samples	1.16
20 samples	1.08
25 samples	1.03
30 samples or more	1.00

Sumber: SNI 03-2834-2000

Data not available to set
2 . Calculate Average Compressive Strength of Concrete (Fcr):
Fcr = f' c + M
= 20 + 7
= 27 MPa = 27 N/mm2 = 27 x 100/9.81 = 275.23 kg/cm2
3 . Determining Cement: Used Type 1 cement
4 . Determining the types of coarse aggregates and fine aggregates
a . Coarse Aggregate: Broken Stone / Split (Artificial).
b . Fine aggregate: Natural sand
5 . Cement water factor (Fas) for cylindrical test pieces 150 x 300 mm.
Where Y-axis = Compressive strength (Kg/Cm2)

AxisX=AirFactorCement



Grafik 1
Hubungan antara kuat tekan dan daktor air semen
(benda uji berbentuk silinder diameter 150 mm, tinggi 300 mm)

Dibisa can be seen in the graph the compressive strength of the concrete f 'c average = 26 kg/cm2 and Fas = 0.60

6 . Determining the Maximum Cement Water Factor (Fas Max): see Table 4

Table 6. Minimum Cement Quantity Requirements and Maximum Water-Cement Factors for Various Types of Concreting in Special Environments

Location	Minimum Cement Amount per m³ of Concrete (kg)	Maximum Water-Cement Factor
Concrete inside a building:		
a. Non-corrosive surrounding conditions	275	0.60

Location	Minimum Cement Amount per m³ of Concrete (kg)	Maximum Water-Cement Factor
b. Corrosive surrounding conditions caused by condensation or corrosive vapors	325	0.52
Concrete outside a building:		
a. Not protected from rain and direct sunlight	325	0.60
b. Protected from rain and direct sunlight	275	0.60
Concrete infiltrated into the ground:		
a. Experiences alternating wet and dry conditions	325	0.55
b. Is exposed to sulfates and alkalis from the soil	—	See Table 5
Concrete in continuous contact with:		
a. Fresh water	—	See Table 5
b. Sea water	—	See Table 6

Catatan: Tanda **—** saya gunakan karena pada gambar tidak terlihat angka jumlah semen minimum pada bagian tersebut.

Taken Fas Max = 0.60 for outdoor concrete locations of buildings / for outdoor construction.

7 . Determining the Slump Value: Here by looking at Table 6.4, we determine the use of concrete for what type of structure? We plan for slabs, beams, columns, walls then

Slump values are in the range of max 15 cm and Min 7.5 cm.

Table 7. Determining the Slump Value

Concrete Uses (based on the type of structure being constructed)	Maks. (cm)	Min. (cm)
Walls, foundation slabs, and reinforced footings	12,5	5,0
Unreinforced footings, caissons, and underground structures	9,0	2,5
Slabs, beams, columns, and walls	15,0	7,5
Road paving	7,5	5,0
Mass concreting (mass concrete)	7,5	2,5

Sumber: SNI 03-2834-2000

8. Determining the Maximum Aggregate: Maximum Aggregate Size = 20 mm

9. Determine the free water content (W water) = 0.67 Ah + 0.33 Ak = ... liter /m3

= 0.67 (195) + 0.33 (225) = 204.90 litres/m3

Where Ah = for fine Aggregate

Ak = for coarse aggregates (see Table 6.5) visible Slump in the range of 60 Maximum aggregate grain size = 20 mm Then the value Ah = 195, Ak = 225

Table 8. Estimated Free Water Content (kg/m³)

Maximum Aggregate Grain Size	Aggregate Type	Slump 0–10 mm	Slump 10–30 mm	Slump 30–60 mm	Slump 60–180 mm
10 mm	Uncrushed stone	150	180	205	225
10 mm	Crushed stone	180	205	230	250

Maximum Aggregate Grain Size	Aggregate Type	Slump 0–10 mm	Slump 10–30 mm	Slump 30–60 mm	Slump 60–180 mm
20 mm	Uncrushed stone	135	160	180	195
20 mm	Crushed stone	170	190	210	225
40 mm	Uncrushed stone	115	140	160	175
40 mm	Crushed stone	155	175	190	205

Sumber: SNI 03-2834-2000

10 . Determining the Amount of Cement (W cement) = W water / Fas Kg/m3
= 204.90 / 0.60
= 341.50 kg/m3 > 325 kg/m2 Ok

11 . Determining the Minimum Cement: See Table 9.
Concrete outdoors Cement Min = 325 kg/m2

Table 9. Minimum Cement Quantity Requirements and Maximum Water-Cement Factors for Various Types of Concreting in Special Environments

Location	Minimum Cement Amount per m³ of Concrete (kg)	Maximum Water-Cement Factor
Concrete inside a building:		
a. Non-corrosive surrounding conditions	275	0.60
b. Corrosive surrounding conditions caused by condensation or corrosive vapors	325	0.52
Concrete outside a building:		
a. Not protected from rain and direct sunlight	325	0.60
b. Protected from rain and direct sunlight	275	0.60
Concrete infiltrated into the ground:		
a. Experiences alternating wet and dry conditions	325	0.55
b. Is exposed to sulfates and alkalis from the soil	—	See Table 5
Concrete in continuous contact with:		
a. Fresh water	—	See Table 5
b. Sea water	—	See Table 6

Catatan: Tanda **—** digunakan karena pada gambar tidak tercantum angka jumlah semen minimum untuk baris tersebut.

12. Determining the Fine Aggregate Gradation Arrangement: See Table 6.6, where our aggregate area is in areas 2 and 3 (zones 2 and 3) where our aggregate size is 20 mm then see Appendix 2

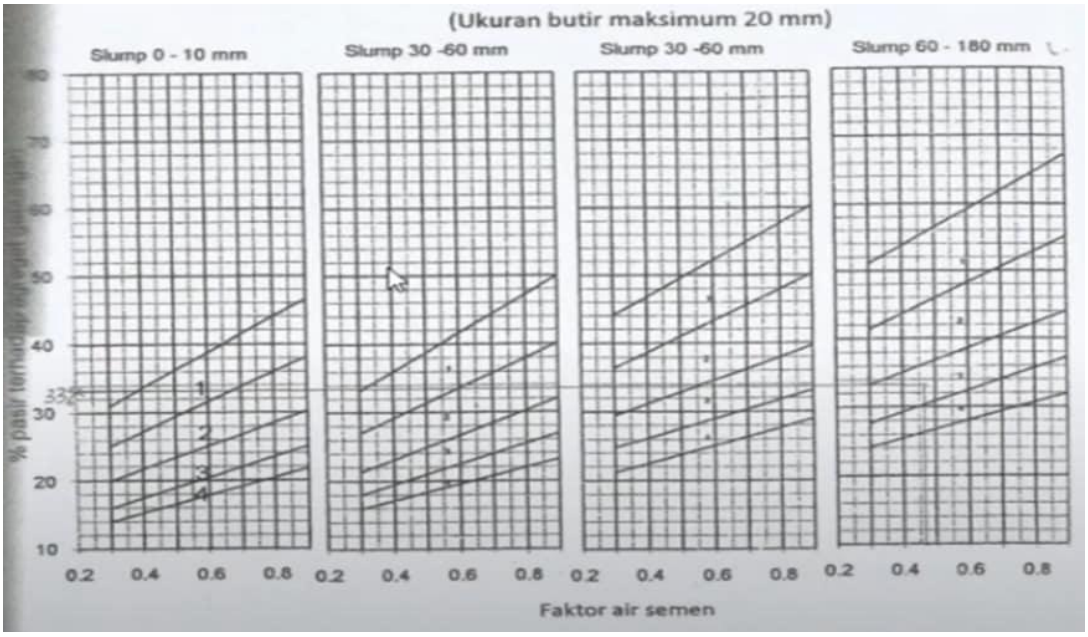
Table 10. Sand Coarseness Gradation

Lubang (mm)	Daerah 1	Daerah 2	Daerah 3	Daerah 4
10	100	100	100	100

Lubang (mm)	Daerah 1	Daerah 2	Daerah 3	Daerah 4
4,8	90–100	90–100	90–100	95–100
2,4	60–95	75–100	85–100	95–100
1,2	30–70	55–90	75–100	90–100
0,6	15–34	35–59	60–79	80–100
0,3	5–20	8–30	12–40	15–50
0,15	0–10	0–10	0–10	0–15

Note: The values in columns 1–4 represent the percentage of grains passing through the sieve by weight.

Source: Ir. Kardiyono Tjokrodimuljo, M.E., Concrete Technology, 2007.



So for the x axis = factor of cement water = 0.60 and Percent of Sand (Fine Aggregate) = 44%, Thus Percent of Gross Aggregate = 100% - 44% = 56%

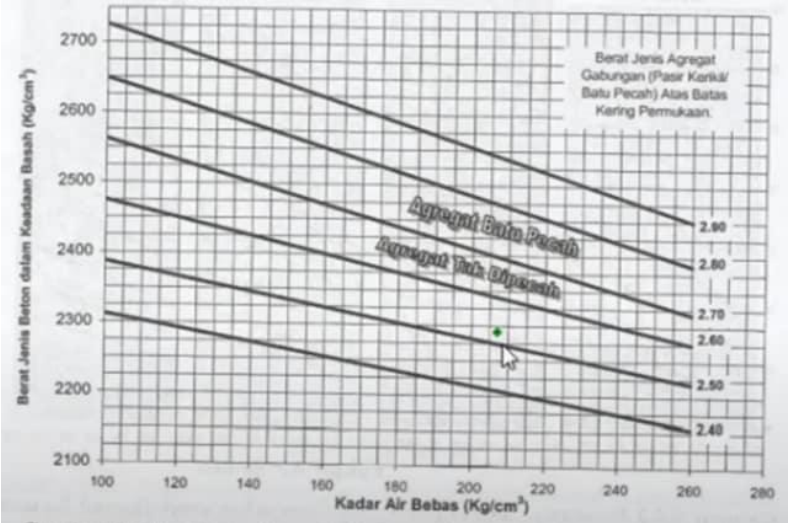
13 . Determining the Specific Gravity of the Aggregate (Relative): where the specific gravity of the aggregate sample in the laboratory is based on (SDD) Fine Aggregate (P) = 2.5225 and Coarse Aggregate (K) = 2.5527.

Then Mixed Specific Gravity = P/100 x Bj Ah + K/100 x Bj Ak

= 44/100 x 2.2525 + 56/100 x 2.5527

= 0.9911 + 1.4295 = 2.4206 kg/m3

14. Specific Gravity of Wet Concrete: See Appendix 3, where we see that on the X axis is the free moisture content (W of water) = 204.90 kg/cm2 and the Y axis is the specific gravity of concrete in wet conditions is = 2,238 kg/m3.



Gambar 8.6 *Perkiraan Berat Jenis Beton Basah yang Dimampatkan Secara Penuh*

15. Determining BJ Aggregate Mixture:

Specific Gravity of Mixed Aggregate = Bj Wet concrete – W Cement – W water

= 2,238 - 341.50 - 204.90

= 1,691.60 kg/m3

16. Determining Fine Aggregate = P/100 x BJ Mixed Aggregate

= 44/100 x 1691.60 kg/ m3

= 744.3040 kg/m3.

17. Determining Gross Agrgate = K/100 x BJ Mixed Aggregate

= 56/100 x 1691.60 kg/m3

= 947.2960 kg/m3.

Check Gross Aggregate = 1691.60 – 744.3040 = 947.2960 kg/m3 ..... OK

18. Material conclusions for 1 m3 of mixture are as follows:

a . Water Requirement ..... = 204.90 liters/m3

b . Cement ..... requirement = 341.50 kg/m3

c . Requirement Fine aggregate (sand) ..... = 744.30 kg/m3

d. Gross Aggregate Requirement (Split) ..... = 947.30 kg/m3

19. Material Requirements for one concrete test piece.

a . Check the volume of the cylindrical test specimen measuring 150 x 300 mm, then the results are as follows:

Cylinder Volume = 1/4 x 3.17 x R 2 x T = 1/4 x 3.17 x 0.152 x 0.30 = 0.0053 m3

Plus safety factor 10% = 10% x 0.0053 = 0.00053

Cylinder volume = 0.0053 + 0.00053 = 0.00583 m3

20. The proportion of concrete forming materials for one cylinder test piece is as follows:

a . Water Requirement = W water x Cylinder Volume

= 204.90 x 0.00583

= 1,195 liters.

b . Cement Type I Requirement = W cement x Cylinder Volume

= 341.50 x 0.00583

= 1.991 kg

c . Requirements for fine aggregate (sand) as follows:

= P/100 x Bj Mixed Aggregate x Cylinder Volume
= 744.30 x 0.00583
= 4.3393 kg

d . Crude Aggregate Integrity (Split) as follows:

=K/100 x Bj Mixed Aggregate x Cylinder Volume
= 947.30 x 0.00583
= 5.5228 kg

CONCLUSION

Based on the results of the experimental study and computational validation, it can be concluded that the addition of glass fiber has a significant effect on the improvement of the mechanical properties of concrete, with an optimal dose of **1.0% of the cement weight**. The shear capacity of the beams increases to **22.3%** at the optimal dose, accompanied by a change in the damage pattern from brittle to more ducttail. Modeling using **SAP2000** shows a high degree of conformity with the experimental results, with a difference of less than 5%. Concrete with 1.0% glass fiber is able to exceed the shear capacity requirements set in **SNI 2847:2019**, thus providing an additional safety reserve against unexpected loads (Wu et al., 2022;Susanto, 2023).

FUNDING

The author states that no financial support has been received for the implementation of this research and/or the publication of this article.

CONFLICT OF INTEREST

The author states that this research was conducted without any commercial or financial relationship that can be interpreted as a potential conflict of interest.

AUTHOR CONTRIBUTIONS

Bambang Triguno: Conceptualization, methodology, data collection, data preprocessing, system development, data analysis, visualization, and writing the original draft.

Bambang Triguno: Supervision, methodology validation, critical review, interpretation of results, and manuscript revision.

Gunawan Wibisono: Software development, implementation of the classification model, data analysis, evaluation, and manuscript revision.

All authors contributed to reviewing and approving the final version of the manuscript.

GENERATIVE AI STATEMENT

The author states that generative artificial intelligence (AI) was used in the preparation of this manuscript. The author acknowledges the use of generative AI to help improve language clarity and improve the grammatical structure of the manuscript. The use is done in compliance with the applicable ethical guidelines regarding the use and disclosure of generative AI in

scientific research. Each author has made a substantial intellectual contribution to this work. The entire content of the manuscript has been carefully reviewed to ensure its accuracy, and the author is solely responsible for the integrity and final content of the manuscript.

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