Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Size effect on shear stress of concrete beam without coarse aggregate

To cite this article: Daniel Christianto *et al* 2020 *J. Phys.: Conf. Ser.* **1477** 052043

Size effect on shear stress of concrete beam without coarse aggregate

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Abstract. In this paper, an experimental of size effect on shear stress of concrete beam without coarse aggregate is described, where concrete beams without using transverse reinforcement and using longitudinal reinforcement with a maximum ratio. The study explains the size effect of shear stress that can be bears by concrete beams with shear arm ratio a/d 2.744. The test object in this research is cylinder with diameter 100 mm and height 200 mm and beam with variations of height 60 mm, 90 mm, 120 mm, 150 mm, and 180 mm with width 60 mm and length 1100 mm. From the test results of the compressive strength test, compressive strength of concrete between 58.51 MPa to 99.8 MPa. Based on shear strength test, diagonal tension failure and shear tension failure occurred on the beam. The test results show that the shear stress is size dependent. The shear stress will decrease with rising height of the beam. The pattern of changes in shear stress value due to changes in beam height resembles the results of previous studies by Kani (1967).

1. Introduction

Concrete is one of the important materials that are widely used in the manufacture of various infrastructures amid the rapid development of construction. The characteristics of concrete are having high compressive stress and low tensile stress [1]. Along with the times, construction requires high-quality concrete, where high-quality construction materials are also high-performance materials. The structural design of reinforced concrete buildings also undergoes more innovative changes. The quality of concrete has led to ultra-high concrete. High quality concrete is concrete that has a minimum compressive strength of 6000 psi (40 MPa) to support all loads with a fairly slim structural component dimension. To meet the high demand for concrete, the latest innovation research on this construction material has begun. However, at this level of strength, coarse aggregate becomes the weakest point in concrete. So to increase the strength of the concrete press further, the only way is to remove coarse aggregates [2].

Factors that influence the behavior and shear strength of the beam are very complex, such as tensile strength of concrete, longitudinal reinforcement ratio, size of beam cross section, aggregate, shear arm ratio (a/d). The shear strength on the beam is influenced by the effective height factor of the matrix (size effect). The size effect can be explained by considering a structure of different sizes but the same geometric shape, for example a beam with the same steel ratio and the same span ratio (a/d). One of the researchers who conducted research on this size effect on normal concrete was Kani [3]. Kani concluded that the shear stress will decrease as the depth of the concrete increases.

Journal of Physics: Conference Series **1477** (2020) 052043 doi:10.1088/1742-6596/1477/5/052043

Based on the research done by Kani to normal concrete, this study will discuss the size effect, namely the variation in the ratio h/b on the beam to the shear stress of the concrete without coarse aggregate. This is done to evaluate the pattern of changes in shear stress to variations in changes in beam height. We also can check the compatibility how size effect works between normal concrete and concrete without coarse aggregate.

Below as shown in Figure 1, the graph of the Derivation of Design Equation is taken from ACI-ASCE 326 [4] and it's used for normal concrete beam. From the data obtained and equation given from ACI-ASCE, we also can plot the Derivation of Design Equation graph for beam without coarse aggregate.

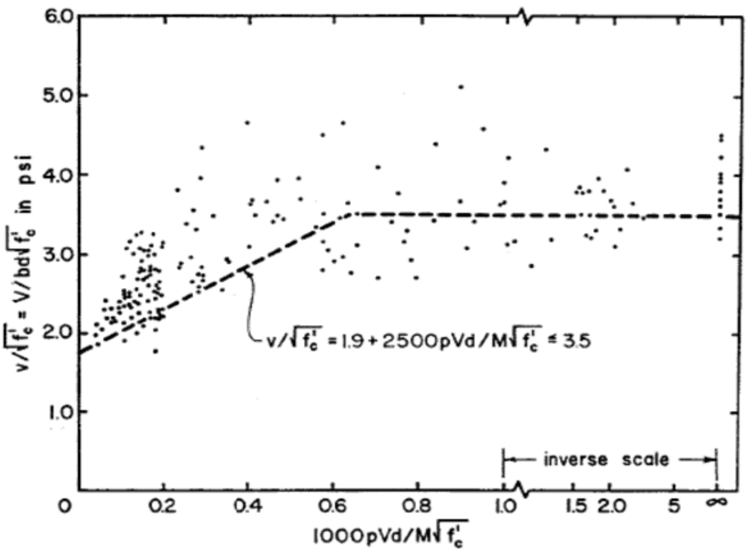

Figure 1. Derivation of design equation

The equation used to calculate concrete shear strength is [5]:

$$V_c = \mathbf{0.17}\sqrt{f'_c}\,.\,b_w.d \tag{1}$$

1.1. Shear Stress

Concrete beams are structural elements that support their own and heavy loads, which give a bending moment (M) and shear force (V). All beam structural elements, both concrete and steel structures are inseparable from shear force problems. Published experiments show that the nature of collapse due to shear forces on a reinforced concrete structural element is brittle, not ductile, and its sudden collapse without warning. Therefore, concrete can be cracked if the load borne creates a tensile stress that exceeds the tensile strength [6]. The shear stress on the cracked part of the beam begins with the initial stage of the crack which starts with a vertical direction crack.

Based on the formula, the shear stress in the crack section of the beam is obtained with the equation:

$$v = \frac{V}{b_w.d} \tag{2}$$

In the ACI Building Code [7], the shear stress formula has the effect of a/d ratio and concrete compressive strength:

$$V_c = 1.9\sqrt{f'_c} + 2500\,\rho\,\frac{V.d}{M} \tag{3}$$

1.2. Size Effect

When a structure is considered similar, any deviation from the structure property of the structure is called size effect and it will affect the shear strength. Kani [3] conducted research at the University of Toronto, comparing four shear-less beams with 6, 12, 24, and 48 inch heights (153, 305, 610 and 1220 mm). The beam has a compressive strength (f'c) = 3800 psi (26.2 MPa), the longitudinal reinforcement ratio ρ = 2.8%, and the ratio of a/d varies from 1 to 10. Kani found that the transition point is a / d = 2.5 - 3 where the beam is critical of shear (the lowest bending moment when a failure occurs). For a ratio below that limit, the beam will be able to withstand a greater shear force due to the arch action. However, if the a/d ratio is above the critical point, then the concrete failure occurs together with the sliding crack that occurs.

Kani also concluded that the shear stress will decrease as the depth of the concrete increase, if the other parameters are constant it will show the size-effect clearly as shown in Figure 2.

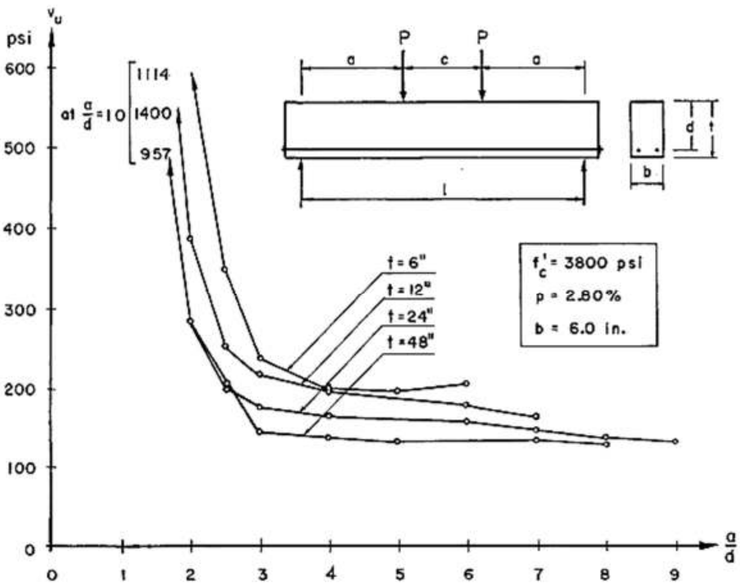

Figure 2. Graph of shear stress and a/d ratio with variable depth

1.3. Diagonal Shear Failure

This can occur because the increasing of the shear force can widen and spread the initial crack and so on until the beam collapse. The diagonal shear failure exhibits a strong size effect of fracture mechanics type, due to differences in the stored energy that can be released to drive the failure propagation [8]. The larger the structure, the grater the energy release [9]. Therefore, for this type of failure, it's appropriate to consider the size effect which theoretically results from a dimensional analysis of the energy release rate [10]

2. Experimental

In this study, the test specimens is a cylinder with a diameter of 100 mm with a height of 200 mm and a beam with a variation of the ratio h/b = 1; 1.5; 2; 2.5 and 3. Kani discovered at the same time that the width of the concrete beam did not have a very important effect on the beam's shear strength [3]. So in this experiment we keep the width constant. Shear strength testing was carried out on beam samples with a/d = 2.744 (expected to be the lowest shear strength based on Kani [3] and adjusted with the condition of the test machine). Beam is using maximum longitudinal reinforcement ratio to avoid bending failure first before the shear failure. This research was carried out in stages at the Laboratory of

Construction Materials Technology at the Tarumanagara University Civil Engineering Department. Model specimens can be seen in Figure 3.

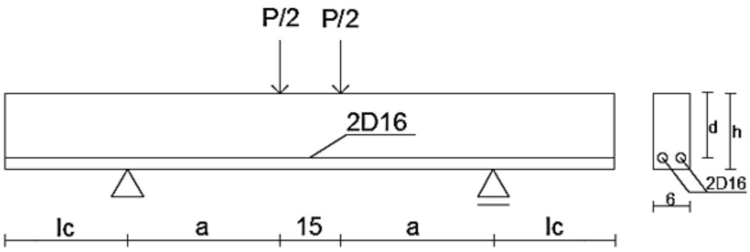

Figure 3. Modeling test beam object

3. Results

3.1. Compressive Strength and Shear Strength Test Results

Table 1. shows the results of cylinder compressive strength and shear force. The shear failure pattern can be seen in Figure 4.

Table 1. Test results of compressive strength and shear force

The Size of The Test Object	Cylinder Test Objects (Ø10 cm x 20 cm)		Beam Test Object	
	Force (kN)	f'c (N/mm^2)	Force (kN)	Type of Failure
Beam 1 B (60 x 60 x 1100 mm^3)	752,5	95,82	37,02	Shear
	707,6	90,1	37,62	Shear
	Average	92,96	37,32	
Beam 1,5 B (60 x 90 x 1100 mm^3)	783,8	99,8	37,02	Shear
	727,1	92,57	37,78	Shear
	Average	96,185	37,4	
Beam 2 B (60 x 120 x 1100 mm^3)	459,6	58,51	35,03	Shear
	541,2	68,91	52,76	Shear
	Average	63,71	43,895	
Beam 2,5 B (60 x 150 x 1100 mm^3)	723,7	92,15	49,26	Shear
	708,7	90,24	45,86	Shear
	Average	91,195	47,56	
Beam 3 B (60 x 180 x 1100 mm^3)	466,8	59,44	31,74	Shear
	612,1	77,94	48,61	Shear
	Average	68,69	40,175	

Figure 4. Shear failure pattern on beam

From the calculation results, it can be made a recapitulation of beam shear strength analysis and how the effect of the increase in concrete quality on beam shear strength as seen in each of the following Table 2.

Table 2. Recapitulation analysis of shear strength

No.	Beam Height (m)	f'c (N/mm^2)	P (kN)	V_c (kN)	V_u (kN)	M_n (kNm)	M_u (kNm)
1	0,06	92,96	37,32	4,2423	18,6769	3,27	2,2485
2	0,09	96,185	37,4	10,8862	18,736	8,6633	3,7974
3	0,12	63,71	43,895	8,3011	22,0098	12,747	6,2714
4	0,15	91,195	47,56	12,3524	23,8756	18,7724	8,7615
5	0,18	68,69	40,175	13,5922	20,2236	22,6861	9,057

3.2. *Shear Stress Analysis*

Based on data above, we can plot the result to obtain the graph of Derivation Design Equation for beam without coarse aggregate as mentioned before. The graph can be seen on Figure 5 below. The pattern of the graph below is similar with the graph given in ACI-ASCE for normal concrete.

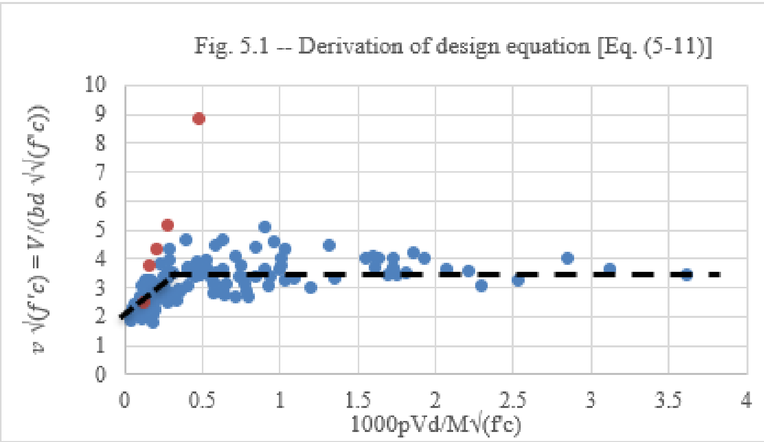

Figure 5. Derivation of design equation

The test results graph below (blue line) is compared with the shear stress based on the ACI formula with and without the influence of moment as can be seen in Figure 6.

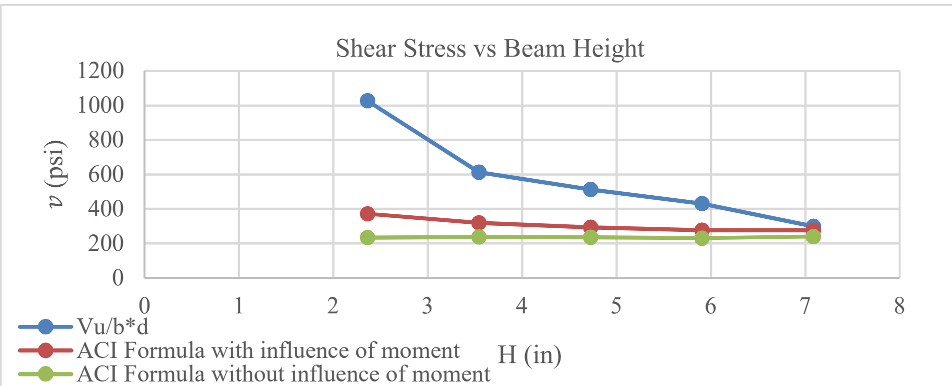

Figure 6. Shear stress vs beam height

The shear stress of the test results looks larger than the shear stress based on the ACI formula and ACI formula that ignores the influence of moment. So, it’s quite safe if we want to use the ACI formula (which for normal concrete) to calculate the shear stress for the concrete without coarse aggregate.

4. Conclusions

- There is size effect of the concrete beam without coarse aggregate. It can be seen based Figure 6. The higher the beam, the shear stress will decrease. The pattern of changes in the shear stress (v) due to changes in beam height (H) resembles the results of previous studies conducted by Kani.
- There is 70.95 % shear stress reduction of the beam which has a height of 3 times the width of the beam (3 B) to has a height equal to the width (1 B).
- It can be seen in the results of the experiment with the value of a/d = 2.744, in the condition of the beam having a height equal to the width (1 B) to the beam which is 1.5 times higher than the width (1.5 B), the shear stress is very drastically decrease compared to other beam conditions.
- Based on Figure 6, it can be seen that the higher the beam, the shear stress ratio will be decrease.
- Based on the *Derivation of Design Equation* graph, it can be seen that the calculation results is above the minimum limit of $\frac{V}{b \times d \times \sqrt{f'c}} > 2$ and the concrete beam does not have flexure cracks and only shear cracks, it can be seen from the results of calculations, where $M_u < M_n$. Shear failure on the beam is a diagonal tension failure and shear tension failure.

Acknowledgements

I would like to express my deep gratitude for all the experts that have mentored me in building this project from the very beginning for the thorough guiding, patience, and support. Special thanks are also given to all parties who have contributed their time and energy in perfecting this experimental research work; to PT INDOCEMENT TUNGGAL PRAKARSA, Tbk for providing the cement and to BASF for providing silica fume. I would also like to extend my thanks to the lab technicians who helped a lot so that the experiment can run smoothly.

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