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VARIATION OF CONCRETE COMPRESSIVE STRENGTH DATA OBTAINED BY USING SMALL DIAMETER CORE

D. Yamamoto [1] H. Hamada [1] Y. Sagawa [1]

[1] Kyushu University, Fukuoka, Japan

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**Corresponding Author,*
Email address: yamamoto@doc.kyushu-u.ac.jp

ABSTRACT:

It is widely known that the smaller the diameter of the concrete core specimen, the larger the variation of the compressive strength test value, and the loading method also affects the variation of the compressive strength test value, too.

In this research, a compressive strength test using small diameter core (φ25mm and φ33mm) with h/d=2.0 is focused on the purpose for obtaining compressive strength test value with less deviation. To reduce the deviation of compressive strength test value of small diameter cores, arranging the obtained test value by using the statistical method and testing method should be based on the viewpoint of the friction influence on the end edge surface of the specimen and the loading plate was experimentally considered. The end face of the core specimens was polished, and compressive strength tests conducted under both with friction (without Teflon sheet) and without friction (two overlapped Teflon sheets with a thickness of 0.1 mm as an antifriction material on both end faces inserted between the end faces and the loading plate)

As a result, it is clarified that the deviation of compressive strength becomes small in the condition of loading without friction on φ33mm diameter small cores. In addition, when the allowable error range of the compressive strength of the small diameter core is 5.0 N/mm^2, the required number of specimen to satisfy this condition is from 4 to 10, and the obtained test value of small core is found around from 80 to 90% compared to the φ100mm core strength.

Furthermore, applicability trial test of compressive strength test by using small core specimen collected from demolished T-girder of PC Bridge is conducted. The obtained result indicates that it is possible to obtain a test value of about 90% compared to φ100mm strength in case of the condition of φ33mm small core without friction loading. Then, it is clarified that its deviation use can control small diameter core strength for practical.

KEYWORDS: small diameter core, compressive strength, suppression of compressive strength variation.

1. Introduction

In Japan, many concrete structures were constructed as infrastructure during the period of high economic growth (1970's ~ 1980's). From the viewpoint of long term safety use of existing structures, it is often predicted that huge amount of structures which built during the period of high economic growth will require being repaired and maintenance in the near future. However, difficult situations often arise in many structures such as to obtain basic information like concrete mix proportion due to loss of design books. For this reason, it is sometimes difficult to obtain information on the strength of the concrete, which is essential for the restoration design. Compressive strength is one of the important engineering parameters, which is a major clue to diagnose the condition of the structure. In such case, it may be necessary to confirm the compressive strength based on core dollied sample from the existing concrete structure.

According to JIS A 1107, when the maximum size of coarse aggregate of concrete is 20 to 25 mm, the core diameter of the core sample is usually selected as 100 mm (hereinafter referred to as φ 100 mm) in order to satisfy the diameter more than three times of the maximum size of coarse aggregate. However, often it is difficult to collect the core sample due to inducing large damage to the existing structure by coring φ 100 mm specimen or due to restriction the available coring point because of high density reinforcing bars. In such a case, sometimes compressive strength test value by obtained small diameter core less than φ 50 mm (hereinafter referred to as a small-diameter core) is used. Currently, the method for compressive strength test by using small diameter core is proposed as a micro-fracture test to examine the strength of concrete by the Ministry of Land, Infrastructure, and Transport of Japan [1]. Generally, the smaller the core diameter concerning the coarse aggregate size, the larger the variation of the compressive strength test value (hereinafter referred to as the test value) which makes difficult to hand the test value of the small diameter core.

There are two opposite opinions in previous researches. The first; some researchers mentioned that strength test value of small diameter core is considered to be larger as compared to the test value obtained by φ100 mm diameter core [2] The second; some researchers mentioned that to be almost same as φ100 mm [3]. There are contradictory reports exist in the result of the test value of small diameter core strength value, and those differences might be caused to occur by influence on the different testing method. In addition, how to organize the test values is already reported in reference [4]. In the previous study results of the authors [5], the test value that was obtained by the small diameter core was lower than the test value obtained by the φ100 mm core. Also, the loading method using the Teflon sheet after polishing the end face results in higher accuracy than capping method result.

In this research, from the view point of improving the accuracy of the compressive strength test value obtained by small diameter core specimen, an experimental study was performed concerning the diameter of the core and the loading method. As a result, a suppression method of the test value variation of small diameter core using a statistical approach is proposed.

2. Factor analysis of small diameter core compressive strength value deviation

2.1 Experimental outline

In order to investigate the influence of loading method difference (with friction, without friction), and the impact of the specimen diameter size of strength test value regarding the fluctuation of the small diameter core test value under several concrete mix proportion condition, experimental analysis was carried out. In this research, small diameter core specimens such as φ100mm, φ33mm, and φ25mm were used. Here, core specimens were collected from three different types of concrete or mortar prism specimens (mix proportion I, II, III). The ratio of height and diameter (h/d) of all samples is 2.0.

For mix proportion I, core samples were collected from concrete blocks with W/C = 50%. In mix proportion II, the effect of coarse aggregate on the small core on test values was examined. The mix proportion I was obtained by neglection of gravel in the wet-screening process. Re-calculation and adjustment of water, cement, and sand from the result of mix proportion I was casted to be mortar of the mix proportion II. Ordinary Portland cement (density = 3.16 g/cm^3) as binder, sea sand (SSD density = 2.58 g/cm^3, water absorption rate = 1.59%) as fine aggregate, crushed stone (SSD density = 2.91 g/cm^3, water absorption rate = 0.81%), and AE water reducing agent (lignosulfonic acid type) were used as material of mix proportion I and II. Cubic specimens with the dimension of 300×300×500 mm were prepared under the conditions of mix proportion I and cubic test specimens of 300×300×100 mm were also prepared under the conditions of mix proportion II. Each prism specimen was demolded one day after casting. It was cured under water immersed condition up to 28 days of age and switched to air curing at a temperature of 20 °C.

Table 1: Mix proportion of concrete and mortar

Mix proportion	W/C (%)	Maximum size of coarse aggregate (mm)	s/a (%)	Unit Weight(kg/m^3)				AE water reducing agent (g/m^3)	AE agent (ml/m^3)
				W	C	S	G		
I	50.0	20	43.3	165	330	749	1150	1031	12
II ※	50.0	-	-	273	546	1239	-	1705	20
III	42.0	20	44.0	166	395	753	1023	3560	-

※Mix proportion II is a mortar obtained by wet screening concrete of Mix proportion I

Core sampling was performed after 12 months of age. Core dolling was done in the direction perpendicular to the casting direction in mix proportion I, and in the same direction as casting direction in mix proportion II. Table 1 shows the formulation of concrete and mortar from mix proportion I to mix proportion III.

In loading test preparation, the end surface of the core specimen was polished. Compressive strength tests were conducted under both top and bottom surface with and without friction. The case of with friction, Teflon sheet was not used. Two overlapped Teflon sheets with a thickness of 0.1 mm as an antifriction material on both end faces of the core specimen were inserted between the end faces and the loading plate to provide no friction during the test. It was used to confirm the influence of the lubricant on the test value. Two wire strain gauges were attached in the axial direction on both top and a bottom surface of the core specimen, and the average value was taken as longitudinal strain. 60 mm of wire strain gauge for the diameter of φ 100 mm, and 30 mm of wire strain gauge length for φ50mm, φ33mm, and φ25mm were used, respectively. Since φ33mm and φ25mm core specimens were small in dimensions, therefore the spherical seat mounted on the load testing machine was too large. Due to this reason, loading test was conducted using a small spherical seat for compressive strength test. Photo 1 shows the compressive testing situation of φ25mm core. Here, reject adoption was performed under assuming that the distribution of compressive test values follows the normal distribution, regardless of whether there is friction or not, excluding which test values deviate from (the average value of test values) ± 3 × (standard deviation).

Table 2 shows the core specimen factors of each mix proportion after reject adoption applied in this method. The indicated data is based on the average value obtained by the number after rejection.

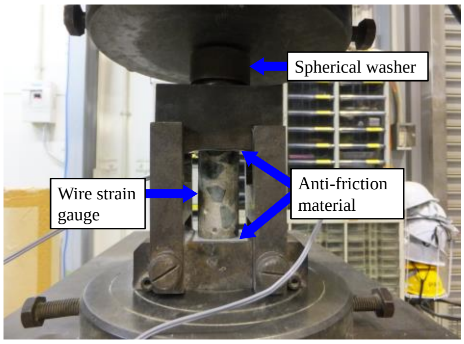

Photo 1 Loading test situation (φ25 mm)

Table 2 Factor of core specimen

Mix proportion	Core diameter（mm）	Loading method	Number of specimens	Number of specimens after rejection	Remarks
I	φ100	With friction	3	3	Concrete specimen W/C=50% Maximum size of coarse aggregate=20mm s/a=43.3%
	φ50	With friction	3	3	
	φ25	With friction	25	25	
		Without friction	25	25	
	φ33	With friction	50	49	
		Without friction	50	50	
II	φ100	With friction	3	3	Mortar specimen W/C=50% mortar obtained by wet screening concrete of Mix proportion I
	φ50	With friction	5	4	
	φ25	With friction	25	25	
		Without friction	25	25	
	φ33	With friction	20	20	
		Without friction	20	20	
III	φ100	With friction	3	3	Concrete specimen W/C=42% Maximum size of coarse aggregate=20mm s/a=44.0%
	φ50	With friction	5	5	
	φ25	With friction	25	25	
		Without friction	25	25	
	φ33	With friction	25	25	
		Without friction	25	25	

2.2 Compressive strength test value and static elastic modulus test result

The average of the test values of each mix proportion is shown in Figure. 1, and the variation coefficient of the compressive strength is shown in Figure 2. According to Figure 1, in case of with friction, both mix proportion I and mix proportion II show smaller value than the reference compressive strength of φ100mm for both φ33mm and φ25mm, but mix proportion III is larger than the reference strength of φ100mm. In case of with friction, the small diameter core test values could be result larger or smaller than the φ100mm reference strength. In addition, the small diameter core of φ33mm and φ25mm without friction show lower test values than with friction. The average test value of the small diameter core of φ33mm and φ25mm without friction always show smaller than that of the φ100mm with friction.

The variation coefficient of compressive strength shown in Figure 2 indicates that the smallest variation coefficient is φ 50mm in mix proportion I and φ100mm in mix proportion II and III . Also, Figure 2 shows that there is almost no significant difference (less than 1 %) in coefficient of variation even if the presence or absence of friction of the small diameter core of φ33mm and φ25mm. However, φ33mm shows rather smaller variation coefficient of core with and without friction if the coefficient of variations is compared between φ33mm and φ25mm. From this test result, it can be said that it might be possible to obtain somewhat stable test value by using φ33mm small diameter core compared to φ25mm from the viewpoint of the coefficient of variation of compressive strength. The static modulus of elasticity values are shown in Figure 3 and its coefficients of variations are shown in Figure 4. The tendency of static modulus of elasticity values is similar to the test value of strength and the coefficient of variation of φ33mm is smaller than that of φ25mm. In addition, the static modulus of elasticity is less influenced by the presence or absence of friction, and the result obtained by φ33mm is smaller than that of φ100mm in the range from almost same to 5 kN/mm^2 smaller. From this figure also presents that the coefficient of variation of φ25mm in mix proportion III deviates to another value and no specific reason is identified from this test.

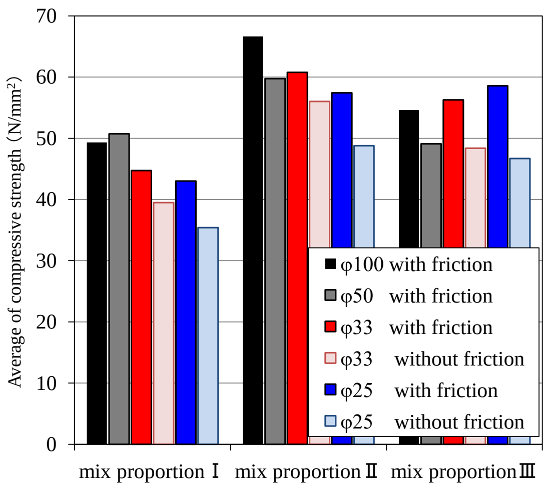

Figure 1 Average of compressive strength

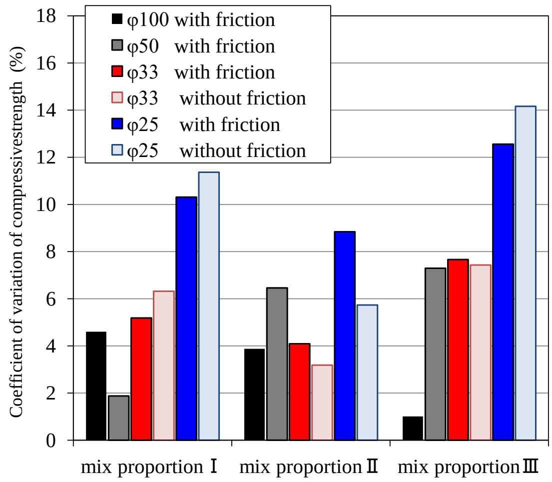

Figure 2 Coefficient of variation of compressive strength

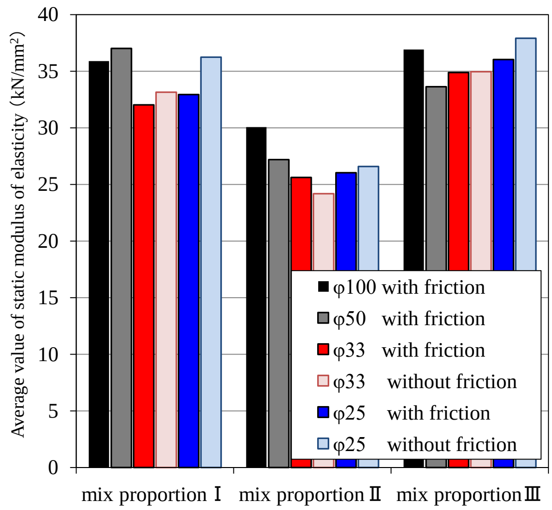

Figure 3 Average value of static modulus of elasticity

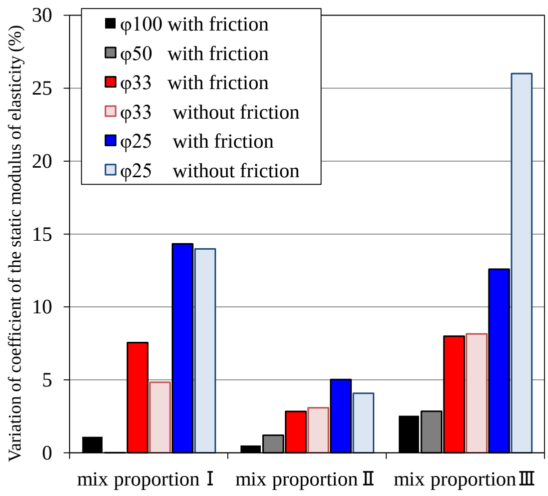

Figure 4 Variation of coefficient of the static modulus of elasticity

2.3 Influence of core diameter size on the situation of compressive fracture

Figure 5 shows the relationship between the compressive strength test value and the strain at maximum stress of mix proportion I of the φ100mm reference core, without friction of φ33mm and φ25mm. From this figure, it is clarified that a positive correlation is found between the strength test value and the strain at the maximum stress on each factor, and its positive correlation in φ33mm is much higher than φ25mm. This tendency is clearer in the case without friction than with friction. Furthermore, similar tendencies have been confirmed with other mix proportions.

As the diameter of the core decreases, the size of the coarse aggregate and the dimensions of the voids and defects in the concrete become relatively large which greatly affects the fluctuation of the test value of the small core [6]. If compared to φ25mm and φ33mm test results, the coefficient of variation of φ33mm is lower, which is presumably because the above effect is reduced in this study also.

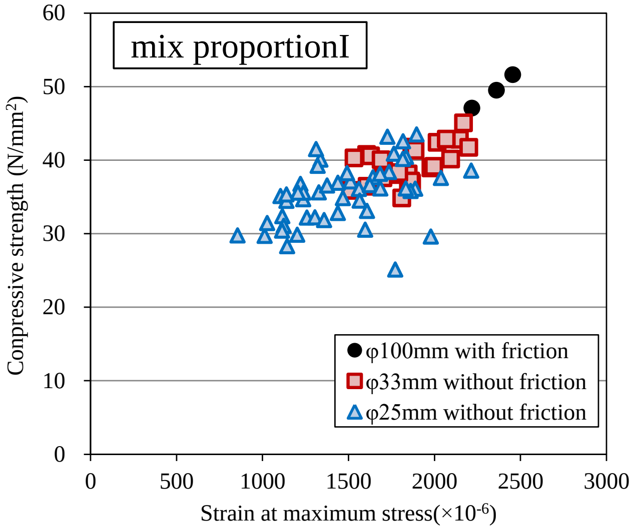

Figure 5 Relationship between compressive strength test value and strain at maximum stress (mix proportion I)

2.4 Influence of friction of end surface on situation of compressive fracture

Figure 6 and Figure 7 show the relationship between the strength test value and the strain at maximum stress of φ33mm small diameter core with friction and without friction. From these figures, it can be said that the correlation evaluated by the deviation value between the strength test value and the strain at the maximum stress is higher in the absence of friction than with friction. This is because the coarse aggregate size in the small diameter core is relatively larger compared to the coarse aggregate size in φ100mm reference core specimen, so the stress distribution in the small core specimen during compression loading might tend to be non-uniform. It is clear from previous studies that reduction of friction between the end face of the core specimen and the loading plate contributes to equalization of compressive stress distribution in the core specimen.

Based on the data obtained in this study, it is confirmed that the correlation between the compressive strength test value and the stress at maximum stress become higher when without friction in the compressive strength test of concrete with a small diameter core. It might due to the improvement effect of the non-uniformity of stress distribution in the specimen contributed to reducing eccentricity in such a small core specimen.

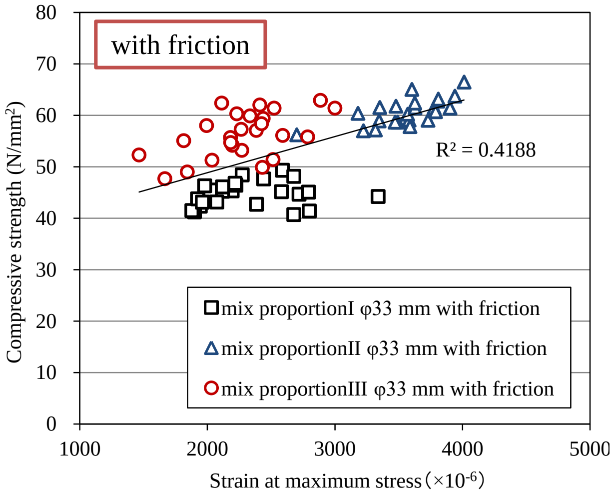

Figure 6 Relationship between compressive strength and strain at maximum stress (with friction)

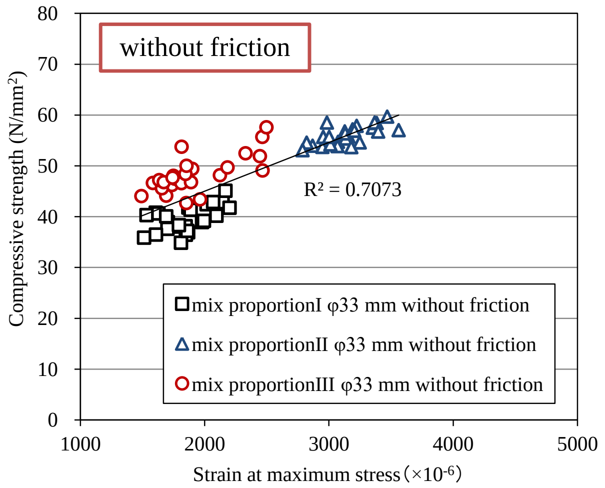

Figure 7 Relationship between compressive strength and strain at maximum stress (without friction)

2.4 The change of the standard deviation of the compressive strength by random sampling and discussion on the required number of small core samples

In the general compressive strength test method by φ100mm core specimen, it is usually assumed that fluctuation of 3 samples average value is within the 95% confidence interval. On the other hand, the test values with small diameter cores such as φ25mm and φ33mm revealed that the smaller the size of the core specimen, the higher the influence of coarse aggregate and internal defects, and also the larger the variation of the test value.

Therefore, it is necessary to reexamine the number of the required core samples to satisfy the confidence interval of 95% with the test method using a small diameter core. Here, using the test data obtained by this research, based on the change in the standard deviation of small diameter core test value by random sampling, the required specimen number to satisfy the confidence interval of 95% is discussed.

(1) Calculation method to obtain the required number of core specimens

The method of this calculation is shown below. Small diameter core test values obtained with φ25mm and φ33mm is randomly extracted from all test data (parameters) for each mix proportion using random numbers, respectively. The numbers of samples to be extracted are set 1 to 20, and then the average values based on extracted samples are calculated. Random sampling is tried 1000 times for each extraction number, and the average value of the test value of the extracted data and its standard deviation is obtained for each number of extracts. Here, the allowable error at the confidence level 95% by the φ100mm reference core is 5.0 N/mm^2 in this experiment.

Therefore, the allowable error range of the test value of the small diameter core is also set to 5.0 N/mm^2. That is, within the range of ± 2.5 N/mm^2 from the average value of the test value in order to set the same level of confidence level as the φ100mm core. Here, when the mean value is μ and the standard deviation is σ, to satisfy the confidence interval with the significance level of 5%, $\mu \pm 2\sigma$ should be less than 5.0 N/mm^2. That is, when σ = 1.25 N/mm^2, to satisfy the allowable error at the confidence level probability of 95%, a variation value should be within ± 2.5 N/mm^2 from the average value of the test value. The number of core specimens required to satisfy the standard deviation σ = 1.25 N/mm^2 can be obtained from the calculation result of the number of extracted samples and the standard deviation variation.

(2) Calculation results of the required number of core specimens

The relationship between the extracted number and the standard deviation calculated by the above calculation method is shown in Figure 8 for mix proportion I, in Figure 9 for mix proportion II, and in Figure 10 for mix proportion III. Here, from those calculation results of Figures 8 to 10, the number of required core specimens in without friction tends to be less than with friction, and the required specimen number is also less for φ33mm than φ25mm. In other words, the required number of core specimens is the lowest amount on the condition of φ33mm and without friction within the scope of this research.

Figure 5 indicates strong relationship observed in φ33mm rather than φ25mm, and Figure 6, and Figure 7 indicate stronger correlation observed in without friction condition. The tendency agrees that the larger size of the core specimen and without friction condition deliver the stronger correlation between the strength test value and the strain at the maximum stress. On the other hand, the calculation result of the required number of core specimens is different even if same condition as case of φ33mm without friction, such as 4 for mix proportion I, and 7 for mix proportion III. This is consistent with the fact that the larger variation coefficient of compressive strength requires the larger number of core specimens as shown in Figure 2.

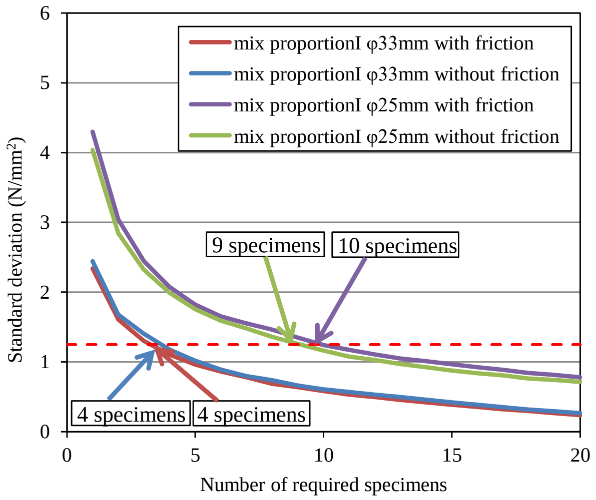

Figure 8 Relationship between standard deviation and number of required specimens (mix proportion I)

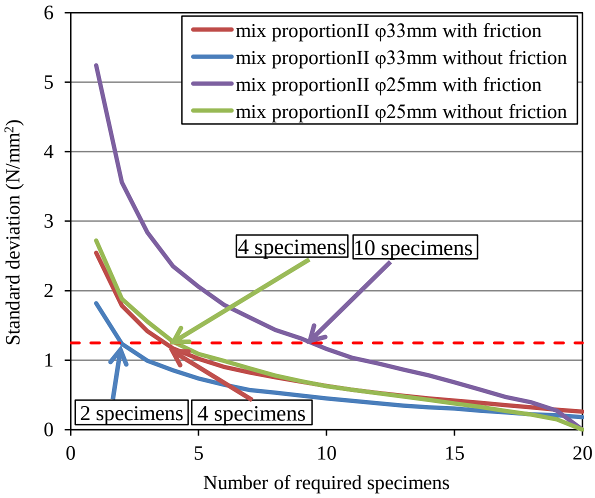

Figure 9 Relationship between standard deviation and number of required specimens (mix proportion II)

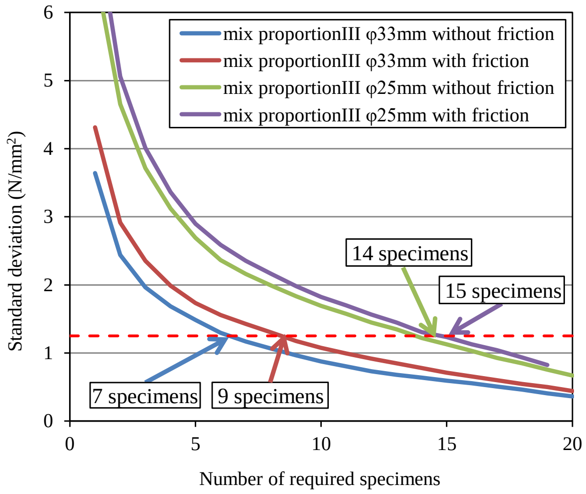

Figure 10 Relationship between standard deviation and number of required specimens (mix proportion III)

Table 3 shows the strength value obtained by a small diameter core of φ33mm without friction on condition of the required number and the strength value of φ100mm strength as a reference. Also, the intensity ratio of the small diameter core test value to φ100mm reference strength is shown in the same table. In the scope of this research, the test value of the small diameter core is about 80% to 90% compared to the φ100 mm reference strength. Also, the coefficient of variation of the compressive strength of the mortar specimens of mix proportion II is smallest of those other mix proportion I and mix proportion III (Figure 4). This stability might be caused due to no influence by the coarse aggregate. But the strength ratio of mix proportion II to φ100mm reference strength is in the range of 80% to 90% as well as the concrete mix proportion.

Table 3 φ100mm reference strength and small core compression strength test value

	The reference strength φ100mm with friction (N/mm^2)	φ33mm without friction compressive strength ±2.5 (N/mm^2)	The ratio of the compressive strength to the reference strength(%)
Mix proportionI	49.3	39.5±2.5	80.1
Mix proportionII	66.7	56.0±2.5	84.0
Mix proportionIII	54.6	48.4±2.5	88.6

(3) Proposal of Compressive Strength Test Method with Using Small Diameter Core

In the small core compressive strength test in this experiment, the test value obtained in the case of φ33mm without friction is the most stable. Also, it is inferred that it is difficult to control the deviation in compressive strength of φ25mm small core because the size of the φ25mm diameter is too small under the condition of the coarse aggregate maximum size of 20mm. Furthermore, when the allowable error range of the small diameter core strength value is set to 5.0 N/mm2, the number of core specimens required to satisfy this varies depending on the coefficient of variation of the compressive strength of the small diameter core was calculated to be 4 to 7 in case of φ33mm concrete core specimens.

However, even under the above conditions, it is presumed that the mechanism of compression fracture of the φ100 mm core and compression fracture without the friction of the small diameter core is different as can be seen from Figure 5. Therefore, the obtained test values are not the same. However, if it is difficult to collect φ100mm core from the target structure, within the scope of this research, and if the proposed the small diameter core method to the compressive strength test is applied, it is possible to obtain a strength value from 80% to 90% accuracy with respect to the reference strength of φ100mm.

3. Applicability of Compressive Strength Test by using Small Diameter Core Collected from Actual Structure

Applicability trial test of compressive strength test by using small core specimen collected from demolished T-girder of PC Bridge which had been used in Kyushu Island in Japan for 32 years from 1974 is conducted. Photo 2 shows the appearance of the disassembled T-girder. No noticeable deterioration is confirmed on the cross section of the T-girder. The maximum size of the coarse aggregate is 20 mm. The factors of the specimen and the experimental results are shown in Table 4. As the same tendency in mix proportion III, the test value of φ33mm small diameter core in the case of with friction is larger than the reference

Table 4: Specimen factors of PC Bridge T-girder and experimental results

factor name	Core diameter (mm)	Loading method	Number of specimens	Number of specimens after rejection	Average of Compressive strength (N/mm^2)	Coefficient of compressive strength variatio (%)	Number of core specimens satisfying 95% confidence limits	The ratio of the compressive strength to the reference strength (%)
PC Bridge T-girder	φ100	With friction	3	2	55.8	4.3	-	-
	φ33	With friction	25	25	58.4±2.5	11.6	14	104.7
		Without friction	25	25	51.0±2.5	9.5	10	91.4

strength, on the other hand, the strength value is 91.4% concerning the reference strength in the case of without friction. In addition, the number of core specimens satisfying the 95% confidence limit is 10 in the case of without friction of φ33mm, which is because the variation coefficient of compressive strength without φ33mm friction is as large as 9.5%.

From the above results, it can be said that it is possible to obtain a test value of about 90% compared to the reference strength by the method proposed in this research, even when using φ33mm small diameter core specimen collected from the actual structure.

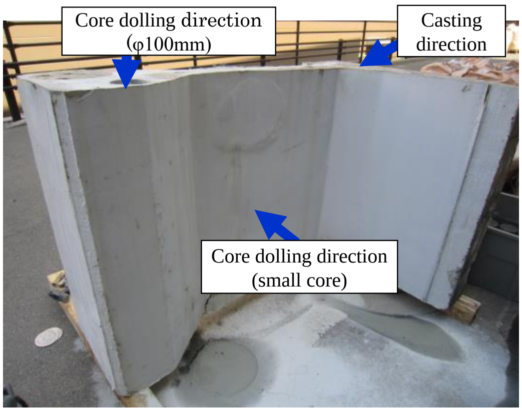

Photo 2 Appearance of demolished T-girder of PC Bridge

4. Conclusion

In this paper, it is examined the factors of fluctuation in compressive strength test focusing on the influence of core specimen size and edge friction as a parameter and also examined how to suppress the fluctuation of compressive strength of small core based on these factors. According to the findings obtained in this research, in order to achieve the accuracy of the compressive strength test value of 95% or more in the confidence interval, after polishing both end faces of the core specimen, 4 to 10 pieces are required. The test value obtained by the small diameter core obtained in this way is 80 to 90% as compared to the test value by the φ100 mm core. However, the fracture mechanism on compressive strength test is not the same between φ100mm core and small diameter core, so the test values obtained are not same. Therefore, if it is possible to collect a φ100 mm core, conducting a compressive strength test by φ100mm is preferable. The findings obtained in this paper are shown below.

1. In the small diameter core compressive strength test, the test value obtained without friction loading method is more stable compared to with friction. For this reason, without friction loading method is desirable for the small core compressive strength test.

2. In the small diameter core compressive strength test, the correlation between the compressive strength value and the strain at the maximum stress is the highest in the case of φ33mm without friction. Also, the number of required core samples to satisfy the strength value of the allowable error at the confidence level 95% is also smallest when φ33mm without friction. In the case of φ33 mm without friction, the number of core specimens to satisfy the test value of the allowable error at the confidence level 95% is 4 to 10.

3. It is difficult in principle to obtain test data substantially equal to the core reference compressive strength of φ100mm using a small diameter core. Within the scope of this research, the small diameter core test value concerning the reference strength of φ100mm is about 80 to 90% with φ33mm and without friction, as a result of the most appropriate small diameter core compressive strength test.

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