- Technical Paper -

ESTIMATING THE COMPRESSIVE STRENGTH OF DRILLED CONCRETE CORES BY POINT LOAD TESTING

Achfas ZACOEB[1], Koji ISHIBASHI[2] and Yukihiro ITO[3]

ABSTRACT

Influence to existing structure soundness assessment, it is relatively difficult to gather a large sized core, and a pit place will be limited by main members. On this situation, a core of a narrow path from a concrete structure body gathered in this study and tried an application of the point loading test which is a simple test of rock. This study is conducted by a difference of diameter and length of core and examined concrete compressive strength from 20 to 50MPa levels. Compressive strengths were classified into general categories, conversion factors were determined, and scattering characteristics were also investigated.

Keywords: structure soundness assessment, drilled concrete core, standard specimen, point load strength index, compressive strength

1. INTRODUCTION

Generally, for measuring a compressive strength of concrete structure, a method by core collection, the surface hardness method, the ultrasonic pulse velocity method, and composition method are applied. A method by core collection is high in precision, but collection from a main structure member such as column or beam is difficult so that a deficit section becomes big, and there is a weak point that a pit place is limited to a wall or a slab. On this situation, a core of narrow path from a concrete structure body is gathered and the point loading test which is a simple test of rock is applied [1]. By making a smaller core can reduce influence for makeup, and easier [2].

It is established in JIS A1107 [3] that a core test diameter of 100mm from a concrete structure member should be taken for performing strength evaluation. To minimize the damage for giving a concrete makeup, and the method that can estimate compressive strength with high precision is examined now. There is the purpose of considering whether this study is effective indirect method for using the point loading test to estimate the compressive strength from 20 to 50MPa levels of drilled concrete core by a difference of diameter and length.

2. BASIC THEORY

Broch & Franklin [4] started with a simple formula taking an idealized failure plane of diametric core sample into account (Figure 1):

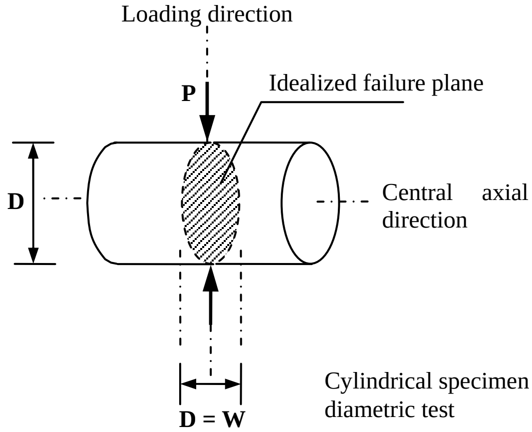

Figure 1 Specimen dimensions for a diametric point load test on cores

From Figure 1 can be used as conceptual model for derivation on Equation (1):

$$I_S = \frac{P}{D^2} \quad (1)$$

where,

1) Student, Graduate School of Sciences & Engineering, Saga University, JCI Member
2) Prof., Dept. of Civil Engineering, Saga University, D.Eng., JCI Member
3) Associate Prof., Dept. of Civil Engineering, Saga University, D.Eng., JCI Member

I_S : Point load strength index (MPa)
P : Load (N)
D : Core diameter (mm)

Because of this formula varied little, even though physical basis for it has been forwarded. By taking the circular area of the core into account, an argument can be made that Equation (1) should be written as:

$$I_S = \frac{4P}{\pi D^2} \qquad (2)$$

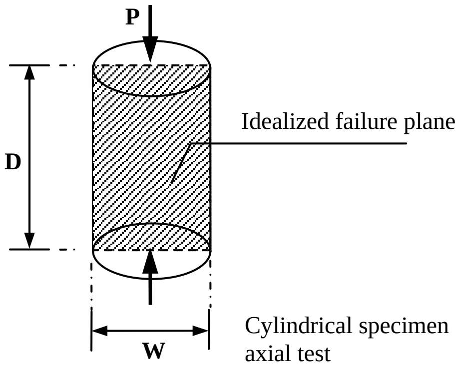

Figure 2 Specimen dimensions for an axial point load test on cores

From Figure 2 can be used as geometry model for derivation on Equation (3). Thuro & Plinninger [5] users of this test soon noticed, that the results of a diametric test (Figure 1) were about 30% higher than those for an axial test using the same specimen dimensions. It seems that Brooch & Franklin [4] and also the ISRM [6] suggestions acknowledge this difference by applying a size correction and introducing the "equivalent core diameter".

$$I_S = \frac{P}{D_e^2} = \frac{4P}{\pi WD} \qquad (3)$$

where,

I_S : Point load strength index (MPa)
P : Load (N)
D_e : Equivalent core diameter (mm)
W : Width of specimen (mm)
D : Thickness of specimen (mm)

Considerable variations of I_S with specimen size and shape lead Broch & Franklin [4] to introduce a reference index $I_{S(50)}$ which corresponds to the I_S of a diametrically loaded rock core of 50mm diameter. Accordingly, initial I_S values are reduced to $I_{S(50)}$ by size correction factors determined from empirical curves as a function of D. It is indicated that the considerably larger shape effect should be avoided by testing specimens with specified geometries. ISRM [6] proposed a new correction function which accounts for both size and shape effects by utilizing the concept of "equivalent core diameter" (D_e). This function (known as geometric correction factor) is given by:

$$I_{S(50)} = FI_S \qquad (4)$$

where,

F : the geometric correction factor

$$= \left(\frac{D_e}{50}\right)^{0.45} \qquad (5)$$

I_S varies with D_e, so that a size correction must be applied to obtain a unique point load strength index for the specimen. The size-corrected point load strength index $I_{S(50)}$ of a specimen is defined as the value of I_S that would have been measured on a specimen with D_e = 50mm. When testing specimens of D_e other than 50mm, size correction may be accomplished by using of Equation (5).

3. EXAMINATION SUMMARY

3.1 Concrete Block Specimens

The specified concrete strengths of 16, 21, 24, 36, and 50MPa, coarse aggregate size maximum of 20mm, and slump value of 12cm were used to make concrete block specimens. Compressive strengths each mix proportion at 91 days were 15.3, 31.4, 33.3, 45.7, and 54.6MPa, respectively.

All concrete block specimens were sized of 300x300x600mm, and made from each mix proportion. For curing, all specimens were covered with wet clothes and humidity taken care of itself for about 1 week. The dimension of concrete block specimen is shown in Figure 3.

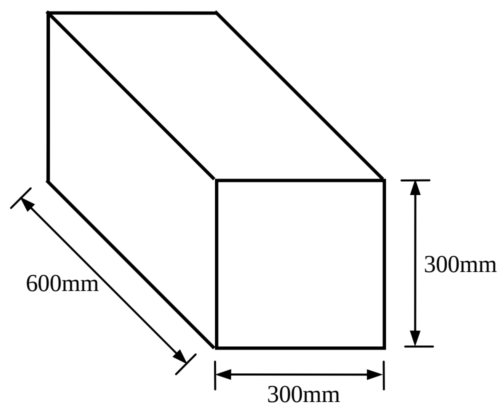

Figure 3 Dimension of block specimen

3.2 Point Loading Test

In the point loading test, a piece of specimen is taken from the concrete block and loaded between two hardened steel points of the point load tester. The system consists of a small hydraulic pump, a hydraulic jack, a pressure gauge and interchangeable testing frame of very high transverse stiffness. The two steel points are of standard dimension.

In the test, the core specimen is slowly loaded by activating the hand pump until failure of the sample. Failure load was taken from the digital indicator. The point load strength index I_S was calculated by using Equation (1) and for core specimen diameter 35mm also corrected to the standard core diameter as 50mm by using Equation (4).

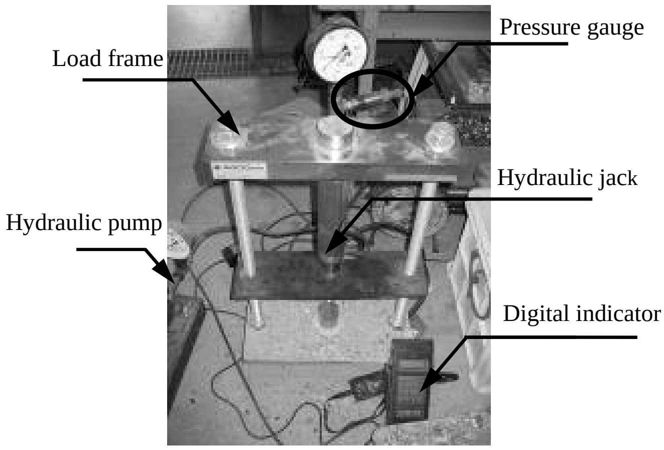

Figure 4 Point loading test devices

The examination used oil pressure cylinder type point loading test machine with maximum load capacity is 98kN. Oil pressure is attached with a pressure gauge all over the hydraulic line and measured it by a digital indicator measuring instrument. For the examination devices and situation of point loading test are shown in Figure 4 and Figure 5, respectively.

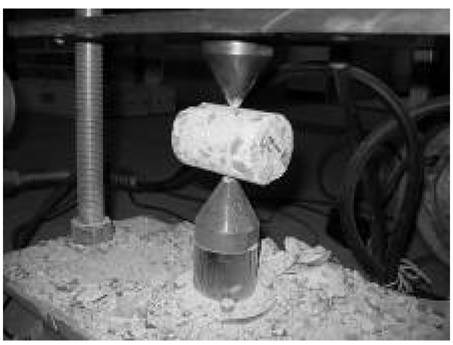

Figure 5 Point loading test situation

3.3 Core Cylinder Extraction

Three types of core cylinder diameter, ϕ 35mm, ϕ 50mm, and ϕ 100mm for axial compressive strength test were extracted from each concrete block in a plane. The extraction speed was about 4cm/min in the wet process that used water for. In addition, an extraction direction of a core considered work in a true makeup and did it with a ramming down direction of concrete and a perpendicular direction. The assumption of core cylinder collection number is 24 of ϕ 35mm, 20 of ϕ 50mm, and 3 of ϕ 100mm from each concrete block specimen. The position and example of core cylinder extraction is shown in Figure 6.

Figure 6 Core cylinder extractions

3.4 Test Specimens

The core cylinder extraction which pulled out cut both ends with a concrete cutter to become fixed height (H). Height diameter ratio (H/D) were limited to H/D=1.5 and 2.0. The appearance of ϕ 35mm and ϕ 50mm core specimens are shown in Figure 7, while for total number collection of each specimen is shown in Table 1.

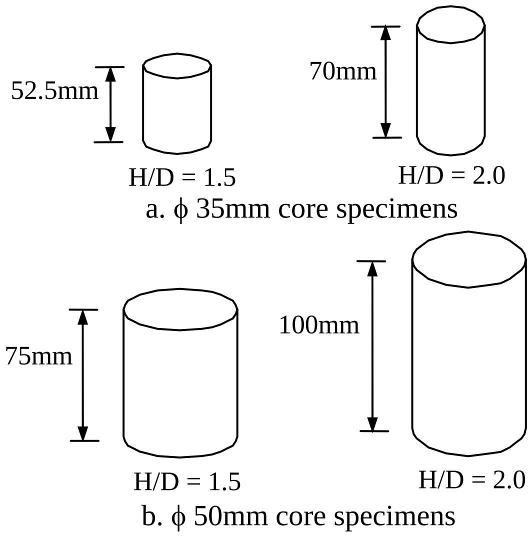

Figure 7 Core cylinder specimens

Table 1 Quantity of core specimens

Compressive Strength Level	Core Diameter	H/D	Total (unit)
16MPa	ϕ 35mm	1.5	135
		2.0	135
	ϕ 50mm	1.5	105
		2.0	99
	ϕ 100mm	2.0	12
21MPa	ϕ 35mm	1.5	90
		2.0	90
	ϕ 50mm	1.5	60
		2.0	60
	ϕ 100mm	2.0	5
24MPa	ϕ 35mm	1.5	66
		2.0	66
	ϕ 50mm	1.5	59
		2.0	58
	ϕ 100mm	2.0	6
36MPa	ϕ 35mm	1.5	123
		2.0	126
	ϕ 50mm	1.5	111
		2.0	108
	ϕ 100mm	2.0	12
50MPa	ϕ 35mm	1.5	67
		2.0	66
	ϕ 50mm	1.5	73
		2.0	72
	ϕ 100mm	2.0	5

4. RESULTS AND DISCUSSION

4.1 Compressive Strength of Normal Block Specimens

Be in conformity with concrete block specimen making, a normal specimen cylinder of ϕ 100x200mm were made with the same materials and examined by axial compressive strength testing on 28 and 91 days in each compressive strength level. The average compressive strength for normal block specimen is shown in Table 2.

The qualities of concrete to be compressive strength of materials were determined from the test result on 28 days. From Table 2, for concrete strength level of 16MPa giving a not satisfy result, less than standard. This cause might from differences of concrete mixed material and process in this study were not fulfilled the requirements. For this reason, scattering characteristics were investigated.

Table 2 Compressive strength average of normal block specimens

Compressive Strength Level	Age (Days)	Compressive Strength Average (MPa)
16MPa	28	14.0
	91	15.3
21MPa	28	31.1
	91	35.9
24MPa	28	27.7
	91	33.3
36MPa	28	40.1
	91	45.7
50MPa	28	47.6
	91	54.6

4.2 Compressive Strength of Core Specimens based on JIS A1107

Based on JIS A1107 [1] from a concrete block specimen and gathered a core cylinder of ϕ 100mm, cut both ends of the core with a concrete cutter and polished an end face and processed it to become H/D = 2.0 and examined compressive strength. The compressive strength average of core cylinder is shown in Table 3, and assumed this compressive strength as reference compressive strength in this study.

Table 3 Compressive strength average of core cylinder based on JIS A1107

Compressive Strength Level	Age (Days)	Compressive Strength Average (MPa)
16MPa	161	15.6
21MPa	337	35.4
24MPa	73	31.5
36MPa	177	42.9
50MPa	78	51.5

4.3 Point Load Strength Index

The average of results from point loading test were computed for both the diameter types (Table 4). The relationship between compressive strength ($f'c$) and point load strength index (I_S) for both the core specimens, core diameter of ϕ 35mm and ϕ 50mm are shown graphically in Figure 8 and Figure 9, respectively.

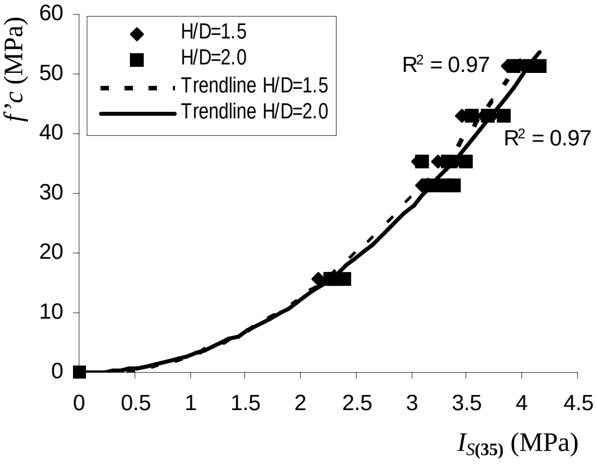

Figure 8 Relationship between *f'c* and $I_{S(35)}$

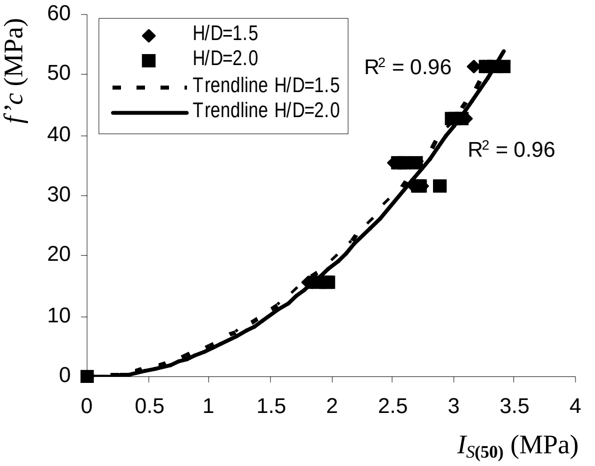

Figure 9 Relationship between *f'c* and $I_{S(50)}$

It is clearly evident from Figure 8 and Figure 9 that there are a curve line correlation between compressive strength and point load strength index. Table 4 shows complete information regarding the average of point load strength index each specimens.

Scattering characteristics were also investigated by mentioning of CV (coefficient of variation). The CV is the degree to which a set of data points varies. When assessing precision, the lower the CV percentage, the better the precision between replicates.

The level of CV for this test is shown in Table 4, which is almost same or less than that on actuality of ready-mixed concrete (from 10 to 15%). It can be stated that the test results are satisfy enough. Even the point's load position can be in three possibilities, as mortar-mortar, mortar-aggregate, and aggregate- aggregate. All failure patterns were in mortar-mortar, which means there were no influences from the point's loading position.

Table 4 Point load strength index average

Compressive Strength Level	Core Diameter	H/D	Point Load Strength Index Average (MPa)	CV (%)
16MPa	ϕ 35mm	1.5	2.27	11.4
		2.0	2.32	13.3
	ϕ 50mm	1.5	1.87	10.7
		2.0	1.93	10.8
21MPa	ϕ 35mm	1.5	3.24	11.4
		2.0	3.31	12.4
	ϕ 50mm	1.5	2.57	9.7
		2.0	2.61	11.1
24MPa	ϕ 35mm	1.5	3.21	12.4
		2.0	3.28	13.1
	ϕ 50mm	1.5	2.71	8.1
		2.0	2.77	9.3
36MPa	ϕ 35mm	1.5	3.61	11.9
		2.0	3.69	13.5
	ϕ 50mm	1.5	3.06	10.4
		2.0	3.02	10.9
50MPa	ϕ 35mm	1.5	3.95	8.1
		2.0	4.05	9.6
	ϕ 50mm	1.5	3.27	8.2
		2.0	3.34	8.9

From Table 4 shows that level of CV for H/D = 1.5 is smaller than H/D = 2.0. It can be stated that H/D = 1.5 is better than H/D = 2.0 for making a specimens. While for core diameter is better using ϕ50mm than ϕ35mm, because the level of CV is also smaller. Beside this reason, it is also fulfilled with the standard core diameter requirements.

4.4 Correlation between Point Load Strength Index and Compressive Strength

When point loading strength index $I_{S(50)}$ of ϕ 50mm core test body is assumed as standard value, point loading strength index of different core diameter and correlation with $I_{S(50)}$ are defined in Equation (4) and Equation (5), and normalize calculated point loading strength with revision point loading strength. Revision point load strength index of $I_{S(35)}$ is shown in Table 5.

Table 5 Revision point load strength index

Compressive Strength Level	Core Diameter	H/D	Point Load Strength Index Average (MPa)
16MPa	ϕ35mm	1.5	1.93
		2.0	1.98
21MPa	ϕ35mm	1.5	2.76
		2.0	2.82
24MPa	ϕ35mm	1.5	2.73
		2.0	2.79
36MPa	ϕ35mm	1.5	3.07
		2.0	3.14
50MPa	ϕ35mm	1.5	3.36
		2.0	3.45

The contradiction of approximation curve line such as in Figure 8 and Figure 9 is performed to arrange compressive strength and relations of point load strength index for standard core specimen. It is shown that square value of correlation coefficient in Figure 10 which judges the effectiveness of an approximation curve for H/D = 1.5 is thought to be similar for H/D = 2.0.

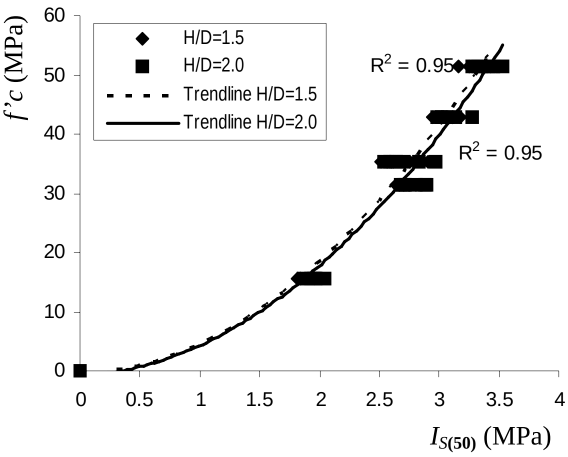

Figure 10 Relationship between $f'c$ and $I_{S(50)}$

A strong correlation is accepted in an approximation curve and standard compressive strength than Figure 10. Moreover, compressive strength level from 20 to 50MPa is really a frequent range used for a concrete structure makeup. In this range, an approximation curve has a similarity to an approximation straight line as shown in Figure 11.

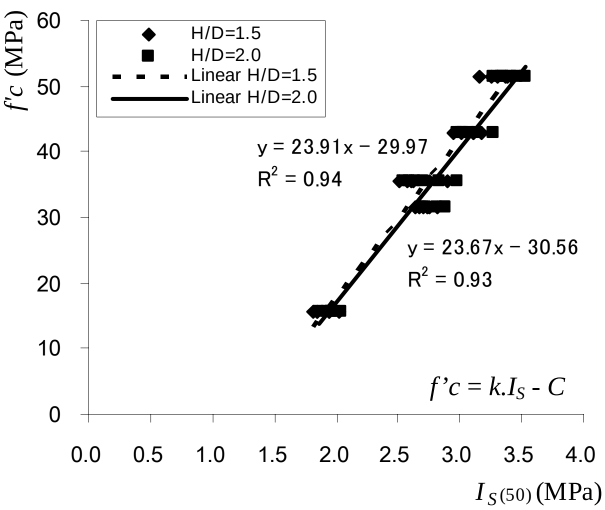

Figure 11 Correlation graph for point load strength index to compressive strength

Relation with the standard compressive strength that used as approximation straight line for index-to-strength conversion factor k is shown in Figure 11. The k value is calculated by divided the compressive strength ($f'c$) with point load index (I_S). While C is constant depend on the linear regression equation.

5. CONCLUSIONS

Based on this study, it can be concluded that an approximation curve showed a strong correlation between point load strength index (I_S) and compressive strength ($f'c$) for core diameter of ϕ35mm and ϕ50mm with H/D = 1.5 and 2.0. In addition for reference index $I_{S(50)}$, it can really deal with an approximation curve as an approximation straight line in a range of frequent compressive strength level used from 20 to 50MPa. To estimate a concrete compressive strength from a point load strength index can be calculated with proposed equation as $f'c = k.I_S - C$.

There is a prospect that point loading test can be applied as indirect method to estimate a compressive strength of structure concrete body. But, decision of specimens total number which is necessary based on statistical technique and examination of coarse aggregate size influence are important problems in the future.

REFERENCES

[1] V.S. Vutukuri & K.Katsuyama: Introduction to Rock Mechanics, Industrial Publishing & Consulting, Inc., 1994, pp.39-42.

[2] K. Liu Ruijie: The diameter-compression test for small diameter cores, Journal of Materials and Structures, Vol. 29, No. 1, 1996, pp. 56-59.

[3] JIS A1107 (1993): Method of sampling and testing for compressive strength of drilled cores of concrete.

[4] E. Broch & J.A. Franklin: The Point Load Strength Test, International Journal of Rock Mechanics and Mineral Sciences, Vol. 9, 1972, pp. 669-697.

[5] K. Thuro & R.J. Plinninger: Scale Effect in Rock Strength Properties, Part 2: Point Load Test and Point Load Strength Index, Proc. ISRM Regional Symposium Eurock 2001, Finland, 2001, pp. 175-180.

[6] ISRM Commission on Testing Methods: Suggested Method for Determining Point Load Strength, International Journal of Rock Mechanics, Mineral Sciences, & Geo-mechanics, Abstract 22, 1985, pp. 51-60.