Articles

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Application of Crushing Method to the Demolition of High-strength and Ultra-high Strength Concrete Structure

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Abstract

High-strength concrete buildings with a design strength greater than $60N/mm^2$ have been constructed since the 1990's, and the ultra-high-strength concrete with that of $200N/mm^2$ has now been covering the practical range. The demolition technology capable of demolishing such structures built with high-strength and the ultra-high-strength concrete is needed in the near future.

This study examines the effects of loading method on the demolition load of high-strength and the ultra-high-strength concrete structure by the laboratory and full-scale crushing experiments using mock-up beam specimens. It was found that the current breaking demolition method is advantageous even for the ultra-high-strength concrete members on the basis of the tensile mechanism because the increase ratio of tensile strength is smaller than that of compressive strength.

Keywords: Demolition, High Strength Concrete, Ultra-high Strength Concrete, Crushing Method

1. Introduction

In June 2014, the business categories in construction Industry Act was revised for the first time in 43 years, and the "demolition industry" was established as a one the of business categories in Japan[1)].

Around 1960, Japan entered the period of high economic growth and many buildings were built. However, the number of cases of demolition work for the buildings around that time has increased in recent years due to deterioration and aesthetic obsolescence. Because of its economic efficiency[1)-9)], the crushing method has been adopted in many cases. Buildings using high-strength concrete with a design strength over $60N/mm^2$ have been built since the 1990s, but now ultra-high-strength concrete with a design strength of over $200N/mm^2$ has been put into practical use[10)]. It is likely that the demolition of the structures using high-strength and ultra-high-strength concrete is needed[11)12)].

However, until now, the emphasis has been placed on research on the "construction" of buildings, so there is little research on "demolition". There are few papers on the crushing method even at the general strength level, and the demolition technology for high-strength/ultra-high-strength concrete structure has not yet been established[10)].

The purpose of this research is to study the demolition load aiming at developing demolition technology for the high-strength/ultra-high strength concrete structures mainly using the crushing method[13)]. First, the influences of the loading method on the breaking load were clarified by the unreinforced concrete specimens, and then the laboratory and actual crushing experiments were conducted by the mock-up beam member.

2. Experiments on the effects of loading method on the breaking load

2.1 Outline of the experiment

(1) Used materials, mix proportion and molding

Based on the mix proportions as shown in **Table 1**, concretes with water-cement ratio (W/C) of 60%, 40%, 20%, 16%, and 13% were prepared. When the W/C was 40% or

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Table 1 Mix proportion and properties of concrete for the laboratory experiments

＊100% diluted

Water-cement Ratio (%)	Aggregate	Unit water (kg/m³)	Unit mass (kg/m³)			No.70 (g)	SP-8N (g)	SSP-104 (g)	No.303A* (g)	Slump (cm)	Flow (cm)	Air content (%)	Mixing temp. (°C)	Compressive strength (N/mm²)	Tensile strength (N/mm²)
			Cement	Fine aggregate	Coarse aggregate										
60	OOI	185	308	836	939	771			1993	18.5		4.5	22.0	31.4	2.98
40	OOI	185	463	671	977		1852		3239	23.0		5.1	22.0	34.9	3.12
20	OOI	155	775	647	801			6200			58.0×56.2	8.0	20.0	103	5.46
	IIBUCHI	155	775	650	798			6200			46.6×46.0	9.5	22.0	113	5.86
16	OOI	155	969	573	708			2960			70.0×68.0	7.5	21.0	138	4.90
	IIBUCHI	155	969	575	708			2960			69.0×67.5	5.8	20.5	151	3.74
13	OOI	155	1192	603	603			35770			67.5×67.0	5.0	21.0	188	5.12
	IIBUCHI	155	1192	601	601			35770			59.0×58.0	3.8	21.0	211	4.37

more, the ordinary Portland cement (company M), river sand of the Ooi river system (surface dry density 2.63g/cm^3), river gravel of the Ooi river system (surface dry density 2.64g/cm^3) were used, while silica fume premix cement (Company M), Iibuchi crushed stone (surface dry density 2.62g/cm^3), and Iibuchi crushed sand (surface dry density 2.65g/cm^3) were used when W/C was 20% or less. As shown in Table 1, the chemical admixture of No. 70/SP-8N/303A by the company B and SSP-104 by the company T were used. The mixing water was Narashino City tap water. Concretes were molded both in a 150×150×150mm cubic specimen steel form and a ϕ 100×200mm cylindrical specimen form.

(2) Curing conditions

Three days after placing, specimens were removed from the mold, and then sealed and cured in a high temperature chamber at 60°C.

(3) Compressive strength test

A compressive strength test was conducted at the material age of 28-day according to JIS A 1108 “Compression test method for concrete”. As shown in **Fig. 1**, the 150×150×150mm cubic specimen was subjected to flat head loading and four-point hemispherical head loading, while flat head loading, single-point flat loading and hemispherical loading, as shown in **Fig. 2**, were applied for the ϕ 100×200mm cylindrical specimen.

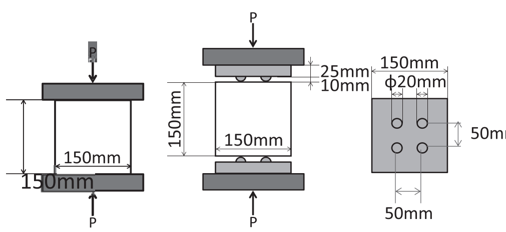

Fig. 1 Loading method for the cubic specimen (flat head loading and four-point hemispherical head loading)

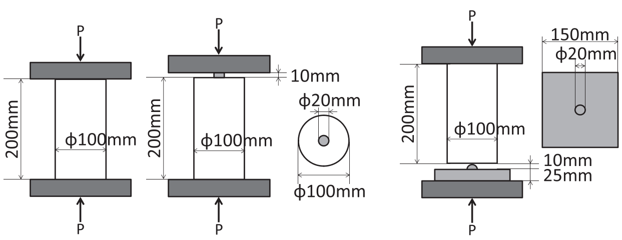

Fig. 2 Loading method for the cylindrical specimen (flat head loading, single-point flat and single-point hemispherical head loading)

(4) Splitting tensile strength test

Splitting tensile strength test was performed at 28-day after placing according to JIS A 1113 “Test method for splitting tensile strength of concrete”.

2.2 Results and discussion

(1) Relationship between loading method and compression load

Fig. 3 shows compressive load applied to the 150×150×150mm cubic specimen using the flat head loading and four-point hemispherical head loading, and that applied to the ϕ 100×200mm cylindrical specimen using the flat head loading, single-point flat head loading and one-point hemisphere head loading. **Fig. 4** shows compressive strength and splitting tensile strength. Compared to the flat head loading, single-point loading was able to break specimens with a smaller load.

In the case of the 150×150×150mm cubic specimen subjected to the four-point hemispherical head loading, the fracture load increased as the W/C decreased, but the dependency was not significant.

In the case of ϕ 100×200mm cylindrical specimen subjected to the single-point hemispherical head loading having a small loading area, the fracture load was the lowest, and the compressive fracture load was 100kN or less even when the W/C was13%.

The splitting tensile strength did not increase much even when the W/C was low, and the splitting tensile strength was 10N/mm^2 or less.

(2) Relationship between loading method and compressive load ratio

Fig. 5 shows the compressive load ratio of four-point

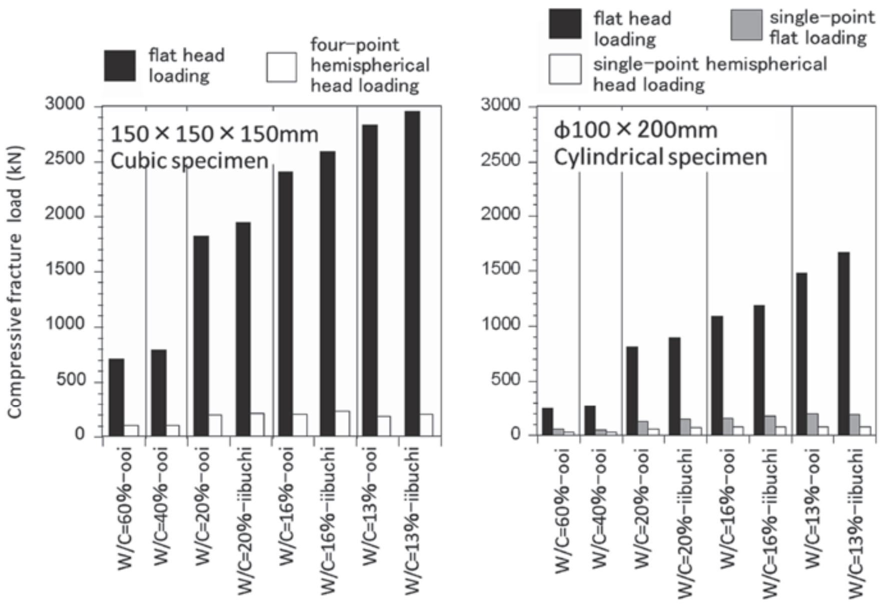

Fig. 3 Compressive fracture load.

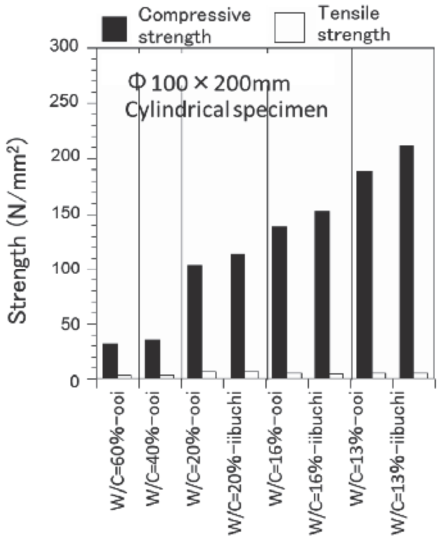

Fig. 4 Compressive strength and tensile strength

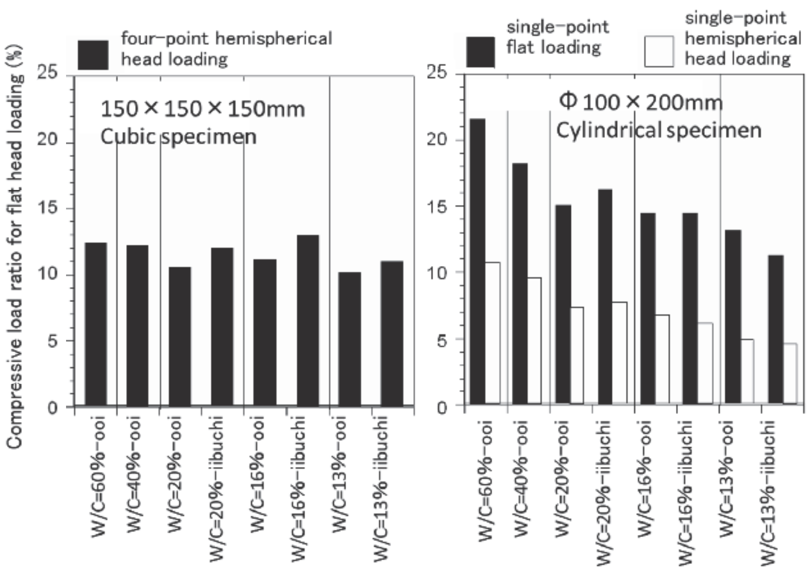

Fig. 5 Compressive load ratio for the flat head loading

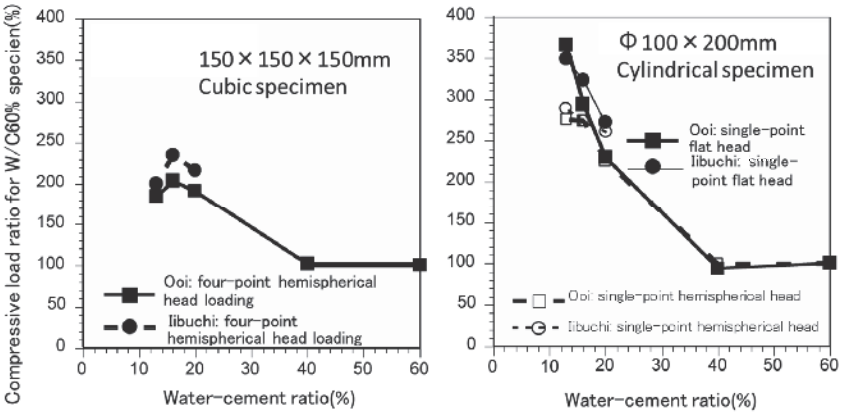

Fig. 6 Relationship between water-cement ratio and compressive load as compared with the control specimen of W/C 60%

hemispherical head loading, the single-point flat head loading, and the single-point hemispherical head loading normalized with the flat head loading applied to the 150×150×150mm cubic specimen and ϕ100×200mm cylindrical specimen. In the case of 150×150×150mm cubic specimens, the four-point hemispherical head loading did not show much difference by the W/C, and it always broke at a load of 10 to 15% of the flat head loading. In the case of ϕ100×200mm cylindrical specimens, the compressive fracture load ratio decreased as the W/C decreased both in the single-point hemisphere loading and the single-point flat loading.

(3) Normalization by the specimen with a W/C of 60%

Fig. 6 shows normalized compressive load of specimens subjected to the loading with four-point hemispherical head, single-point flat head and single-point hemispherical head with respect to the specimen with a W/C of 60%.

In the case of 150×150×150mm cubic specimen with a W/C less than 20% as shown left in **Fig.6**, compressive strength obtained with a four-point hemisphere head loading was 2.5 to 4.5 times as much as that with W/C of 60%, while fracture load was about twice.

In the case of ϕ100×200mm cylindrical specimen with a W/C less than 20% as shown right in **Fig.6**, compressive strength obtained with the single-point flat head loading and the single-point hemispherical head loading are 3.5～7.0 times as much as with the W/C of 60%, while fracture load was 2.3 to 3.7 times.

3. Crushing experiment using mock-up beam specimens

3.1 Preparation of the specimen

The specimen was an mock-up beam member (300×300×900mm). A steel mold was used and 8 main bars (D19) and 20 stirrup (D10) were used as the reinforcing bars. The bar arrangement is shown in **Fig. 7**.

The W/C of the concrete were 60%, 20%, 16% and 13% and the mix proportions are shown in **Table 2**. Materials used are

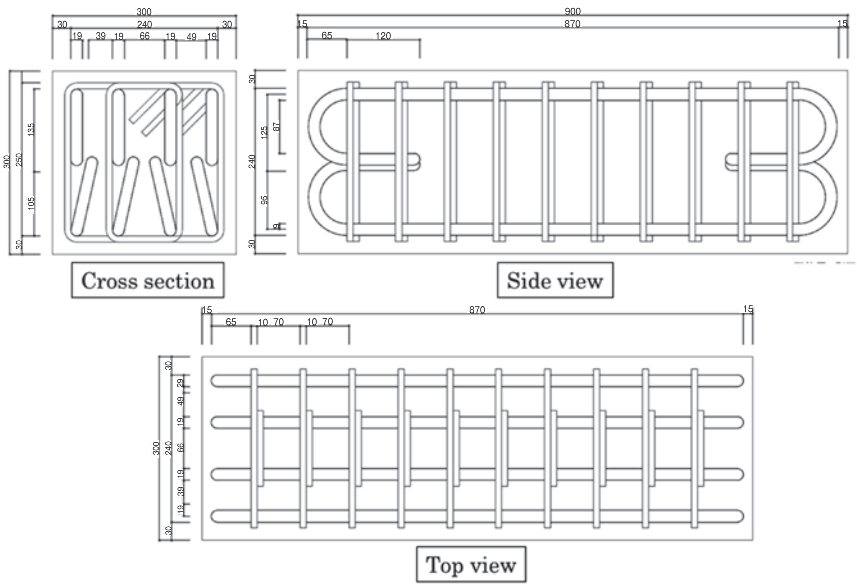

Fig. 7 Reinforcing bar arrangement

Table 2 Mix proportion and properties of concrete for the mock-up beam experiments

																＊100% diluted
Water-cement ratio (%)	Unit water (kg/m³)	Unit mass (kg/m³)					Chemical admixture (g/m³)			Slump Flow (cm)	Air content (%)	Mixing temp. (° C)	Compressive strength (N/mm²)		Tensile strength (N/mm²)	
		Cement	Silica fume	Silica fume premix cement	Fine aggregate	Coarse aggregate	No.70 (g)	SSP-104 (g)	No.303A* (g)				28-day	161-day (at demolition)	28-day	161-day (at demolition)
60	185	308			765	1011	770		2009	19.7(Slump)	4.8	20.5	31.5	34.4	2.7	2.9
20	157	659	116		630	780		11070	833	72.2×71.4	8.1	19.5	127	129	4.8	4.8
16	164			969	578	701		29063		88.0×86.4	7.4	18.5	114	141	3.7	5.0
13	166			1192	491	596		35769		75.8×72.5	5.9	19.0	142	177	3.8	4.8

Table 3 Relative strength at the age of demolition. (161-day)

W/C (%)	Compressive strength ratio to control (W/C=60%)	Tensile strength /compressive strength (%)	Tensile strength ratio to control (W/C=60%)
60	1.0	8.5	1.0
20	3.7	3.8	1.7
16	4.1	3.6	1.7
13	5.1	2.7	1.6

described in the section 2.1(1), except for the Portland cement manufactured by company M and silica fume manufactured by company E used for the specimen with a W/C of 20%.

The results of the compressive and tensile strength tests at the material age of 28-day and at the time of crushing experiment (161-day) are also shown in Table 2.

With respect to the control concrete with a W/C=60%, the compressive strength ratio of each concrete, tensile strength and the tensile strength/compressive strength (%) of the same concrete, are shown in **Table 3**.

Compared to the development of compressive strength associated with a decrease in W/C, the development of tensile strength was small. When the development of compressive strength became 5.1 times, the tensile strength developed only about 1.6 times. It is therefore advantageous for the demolition of ultra-high-strength concrete to apply tensile load with ingenuity.

3.2 Crushing loading test (laboratory experiment)

(1) Outline of experiment

The crushing test was performed with a load device having the maximum load of 4000kN. **Fig. 8** shows the installation of a specimen in the load device. The crushing blade manufactured by company S[13] (**Fig. 9**) was attached to the

Fig. 8 Specimen of the laboratory test

Fig. 9 The crushing blade for loading

Table 4 Crushing load

W/C (%)	Maximum crushing load (kN)	Maximum crushing load ratio to control (W/C=60%)
60	1706	1.0
20	2395	1.4
16	2280	1.3
13	2452	1.4

loading side (upper side in the Figure) of the load device, and the lower side was fixed and supported the entire specimen. The crushing blade was applied to the specimen, with a total length of 900mm, at the center of a part corresponding to the side surface of the beam 300mm from the end.

(2) Experimental results

Table 4 shows the maximum crushing load of each specimen. Although the maximum crushing load of ultra-high-strength concrete was larger than that of normal strength concrete, it did not change much in the range of W/C=20% to 13%, and the maximum observed with W/C=13% ultra-high-strength concrete members. The crushing load was only about 1.4 times of the maximum crushing load of the ordinary concrete members (W/C=60%).

3.3 Crushing experiment with a breaking machine

(1) Outline of experiment

A hydraulic shovel with a maximum hydraulic pressure of 30MPa was used. A crusher produced by company S (SDS250-SRC) was used as an attachment (**Fig. 10**), where the blade was not a new one, but has been used in the normal conditions. When a hydraulic pressure of 30MPa was applied, the blade was subjected to a load of approximately 800kN.

The specimens used in the laboratory crushing experiment were reused and subjected to a bite with both sides of the beam with the attachment to the center part at the horizontal position of 300mm opposite to the side crushed in the laboratory experiment. (**Fig. 11**).

(2) Experimental results

When a crushing load was applied through the attachment, the blade immediately entered the beam specimen of the ordinary strength concrete (W/C=60%), and it was easy to crush and break it. However, in the ultra-high-strength beam specimen as shown **Fig. 12**, firstly because the compressive strength of concrete was so high and secondarily repeated crushing of the same part after the bounce of the blade and scatter of fine concrete pieces were present (**Fig. 13**), it seemed to be in lack of the force due to insufficient hydraulic pressure, which was more remarkable when the W/C was lower and the strength level was higher.

Nevertheless, when operating attachments as normally

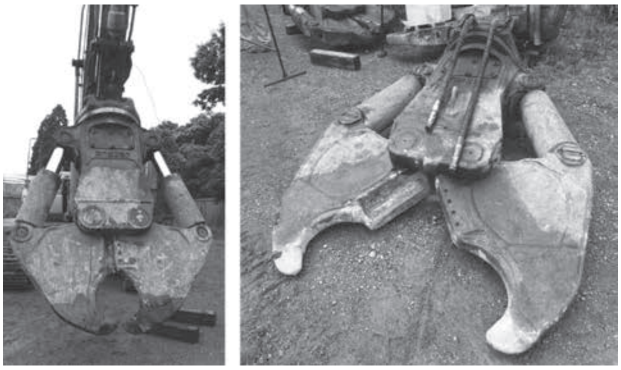

Fig. 10 Hydraulic shovel attachment

Fig. 11 A specimen held with the attachment

Fig. 12 Scatter of concrete pieces during crushing

Fig. 13 A beam specimen of W/C=13% after repeated crushing loads showing the shortage of the crushing power

Table 5 Maximum crushing load of shovel crusher.

W/C (%)	Maximum hydraulic pressure (MPa)	Maximum load at the head (kN)	Maximum load ratio to control (W/C=60%)
60	30.0	780	1.00
20	30.0	780	1.00
16	29.0	754	0.97
13	29.5	767	0.98

performed in the crushing and demolition process and changing of the biting position and applying the blade to the position of the reinforcing bar, it was possible for concrete by being pushed out from the reinforcing bar all at once due to the occurrence of cracks in the concrete. The crushed concrete pieces were sharply angled.

Table 5 shows the maximum hydraulic pressure and maximum crushing load in this experiment. It was obvious that the capacity of the hydraulic shovel was used to the maximum, including in the case of the ordinary concrete.

3.4 Overall look at the crushing demolition of ultra-high-strength concrete members

(1) Breaking load ratio of ultra-high-strength concrete specimen (member) to the ordinary concrete specimen (member)

Fig. 14 shows the strength and maximum load ratios of ultra-high-strength concrete against those of the ordinary concrete with a W/C=60% at the time of demolition (age of 161-day). It includes compressive strength and tensile strength with a cylindrical specimen of ϕ 100×200mm and maximum crushing loads of mock-up beam members both in laboratory and the actual machine tests.

Looking at the strength ratio of W/C=13% concrete, the

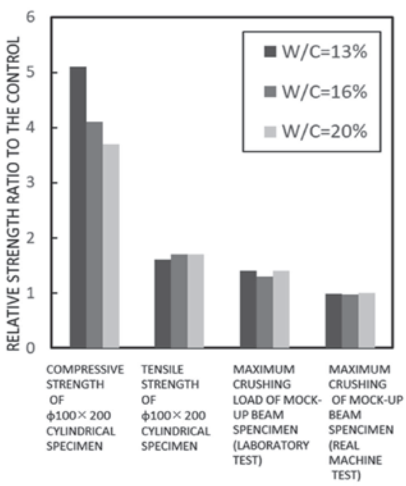

Fig. 14 Strengths of ultra-high-strength concrete normalized with the control with a W/C=60%

compressive strength was 5.1 times, but the tensile strength was 1.6 times, and the crushing load in the laboratory experiment was 1.4 times and almost no differences was found in the actual machine experiments. It was found that the current crushing demolition method can be applied to ultra-high-strength concrete members, and that the demolition method by crushing was advantageous as a breaking mechanism for the ultra-high-strength concrete members.

(2) Noise and particle scattering during crushing

In the crushing of the ultra-high-strength concrete members, it is not easy for the blade to enter the concrete, and the blade sometimes bounced with explosion noises of high frequency range unlike the level of the ordinary concrete.

Similar to the compressive strength test of the ϕ 100×200mm specimen, crushing during demolition accumulated force and broke members at once, so the broken pieces were sharper and had a greater scattering force than that of the ordinary concrete pieces.

4. Conclusions

From the experiment that examined the loading method for the demolition load of high-strength and ultra-high-strength concrete structures, the followings are obtained.

(1) Compared to the flat head compression loading, the single-point concentrated loading was able to break specimens at a smaller load.

(2) When the shape of the single-point head was hemispherical, the fracture load was smaller than loading with a single-point flat head.

(3) The compressive strength of ultra-high-strength concrete (W/C=20% or less) was 6 to 7 times that of the ordinary concrete (W/C=60%), while the ratio of fracture loads when using point loading was about twice.

(4) It was confirmed that the tensile strength of ultra-high-strength concrete did not increase unlike the increase in compressive strength level.

From the crushing experiment,

(5) In the range of water to cement ration of 20% to 13%, it was confirmed that the maximum breaking load in the

laboratory experiment did not become so large even if the strength level increased and that the biting amount of the blade at the breaking load was smaller in ultra-high-strength concrete than in ordinary concrete.

(6) It was confirmed that breaking of ultra-high-strength concrete members caused explosion noise of high frequency range associated with vigorous scattering of sharp concrete fragments.

(7) The ultra-high-strength concrete members with a water to cement ratio of 13% level can be demolished using the current actual equipment and the breaking demolition method when the bite position could be changed within the working range of the currently available attachments, while the force may be insufficient in terms of compression load if the same position may always be bitten.

(8) Demolition of ultra-high-strength concrete members on the basis of the tensile mechanism is advantageous because the increase ratio of tensile strength is smaller than that of compressive strength, and the use of current breaking demolition method makes sense in this respect.

Disclosure

This paper is an extended version of published without examination in Japanese[14)15)].

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高強度・超高強度コンクリート構造物の解体負荷に関する研究

湯浅　昇

概　要

1990 年代から設計強度 60N/mm^2 以上の高強度コンクリート造建物が建設され、現在では 200N/mm^2 以上の超高強度コンクリートが実際に使われている時代となった。近い将来、高強度コンクリートや超高強度コンクリートで造られたこのような構造物の解体が現実化するが、現在、このような高強度コンクリート・超高強度コンクリート構造物を解体できる技術は確立していない。

本研究では、高強度コンクリート・超高強度コンクリートを用いた試験体および模造梁試験片を用いて、実験室実験、解体機を用いた破砕実験を行い、高強度および超高強度コンクリート構造物の解体荷重に及ぼす荷重方法の影響を調べた。引張強度の増加率が圧縮強度の増加率よりも小さいため、圧砕工法は、超高強度コンクリート部材においても有利に解体できる工法であることを確認した。

Biographical Sketches of Author

Dr. Noboru Yuasa is a professor of College of Industrial Technology, Nihon University. He earned his B.Eng. in 1988 from Hokkaido University and M. Eng. in 1990 from Tokyo Institute of Technology.

After finishing master course in Tokyo Institute of Technology, he moved to Nihon University as a research associate. He promoted to a lecturer in 1998, an associate professor in 2003 and a professor in 2011. He received the degree of Dr. Eng. for “A Fundamental Study on the Quality of Surface Layer Concrete” in 1998 from Nihon University.

He has been studied “The surface layer concrete” in the point of view from moisture content and porosity as life work. And he received The Prize of AIJ 2019 (Research Theses Division) from Architectural Institute of Japan for “A SERIES OF STUDY ON SURFACE LAYER CONCRETE QUALITY” in 2019.

His current research topics include durability of concrete structures and finishing materials, non-destructive testing method, demolition of structures, earthquake resistance improvement for building of developing country and investigation of historical buildings.

He has been participated in several international research projects for Santuario di Vicoforte and L’Hangar per dirigibili di Augusta; 2002-03 and 2006-08, Sant’Agostino, San Silvestro e Torre Civica in L’Aquila; 2010-2014, Italy, Spain, Portugal; 2016-2021. And, he also participates in “Bhutan Project” by the JST/JICA SATREPS (Science and Technology Research Partnership for Sustainable Development).

During he was a lecturer of Nihon University, he was visiting researcher for one year at University of Dundee, Scotland in 2011.

He is a chairman, secretary or research leader of a lot of committees in Architectural Institute of Japan, Japan Concrete Institute, Japan cement association, Japan Society for Finishing Technology and Japanese Society of Non-Destructive Inspection.