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An experimental study on the development and verification of NCC(new concrete cutting) system

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Abstract. This paper introduces the development process of NCC(New Concrete Cutting) system and analyzes first verification test. Based on the first verification test results, some problems of NCC system have been newly modified. We carry out the second verification test. We tried to verify cutting performance and dust control efficiency of NCC system through the cutting test of concrete bridge piers. In particular, this verification test strives to solve the problem of concrete dust, which is the biggest problem of dry cutting method. The remaining dust problems in cutting section tried to solve through this verification test. This verification test of the NCC system shows that the dust problem of dry cutting method is closely controlled and solved. In conclusion, the proposed NCC method is superior to the dry cutting method in all aspects, including cutting performance, dust vacuum efficiency and cooling effect. The proposed NCC system is believed to be able to provide eco-friendly cutting technology to various industries, such as the removal of the SOC structures and the dismantling of nuclear plants, which have recently become a hot issue in the field of concrete cutting.

Keywords: concrete cutting; NCC method; water-cooled cutting; dry cutting; dust vacuum efficiency; temperature

1. Introduction

The demolition industry is often considered a main culprit to blame for environmental pollution due to its production of noise, dust scattering, and sludge (Han 2006, Korean Institute of Construction and Transporting Technology Evaluation and Planning 2005). In the field of concrete cutting, the existing water-cooled concrete cutting method (WCCM) shows relatively superior cutting performance to the other diamond wire saw (DWS) cutting systems. But it also produces serious environmental issues like soil or water pollution due to concrete slurry. Accordingly, many researchers and companies have developed alternative methods to the water-cooled concrete cutting method, including the dry cutting method or the liquid nitrogen cutting method (Rule *et al*. 2003). Meanwhile, the dry cutting method from Japan had been introduced and had been used in our country as an alternative technology to the water-cooled cutting method (Husqvarna 2010). This dry cutting method solved the concrete sludge problems of WCCM. But, for this method, concrete dust leave out on the cutting section due to its limited dust collection capacity, and such remaining dust is scattered into the atmosphere, or falls in the river. It is causing the secondary environmental pollution. Furthermore, the remaining dust makes it difficult to handle in cutting process, which results in degrading its cutting performance. Therefore, there has been consistent demand on developing an eco-friendly cutting technology in a worldwide that completely substitutes for the water-cooled concrete cutting method, and at the same time, solves the issues of the dry concrete cutting method. Toward this end, this article introduces the development process of the New Concrete Cutting Method (NCC method), which solves both the environmental pollution issues caused by concrete sludge waste from WCCM and the remaining dust on cutting sections from the dry concrete cutting method. The first verification test of NCC method was carried out and showed some problems. We resolve these problems and then perform the second verification test. The experimental comparison study is conducted by a concrete bridge pier model test. Through the second verification test, we tried to verify cutting performance and dust control efficiency of the modified NCC system. Especially, we tried to solve the remaining concrete dust problem on cutting section.

2. Problems of existing technologies and alternatives

2.1 Problem analysis of the existing technologies

As noted in Park and Lim (2017), the existing water-cooled concrete cutting method uses about 2,000 liters of cooling water per hour to lower the temperature generated by the DWS. As the cooling water mixes with concrete dust, this method produced the large quantity of concrete sludge waste, which causes serious environmental pollution to soil or water. Fig. 1 is an example of such environmental

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Fig. 1 Problem of water-cooled concrete cutting method

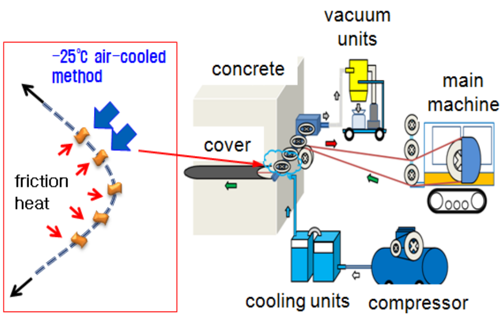


Fig. 2 Schematic of dry cutting method (Japan)

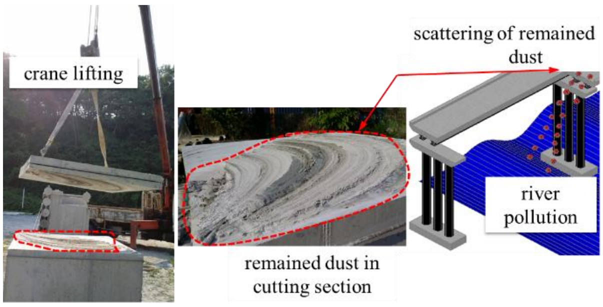


Fig. 3 Problem of dry cutting method

pollution from a demolition project using the existing water-cooled concrete cutting method. To solve this issue, the dry concrete cutting method was developed in Japan. As shown in Fig. 2, instead of using cooling water, this dry cutting method uses forced cooling air at –25 degree Celsius to cool the friction heat produced as the DWS cuts concrete structure. Not using water, this dry cutting method can solve the environmental pollution from the WCCM. The dry cutting method uses a dust vacuum device to collect generated dust. However, because of its limitation of dust vacuum capacity, concrete dust remained on the cutting sections, and as discussed above, such remaining concrete dust is causing the secondary environmental pollution. (Fig. 3) To solve these problems, a new concrete cutting technology has been developed. The development background of this technology was referred to in reference 7.

2.2 Development process of the NCC method

As shown in Fig. 4, the study first considered a new

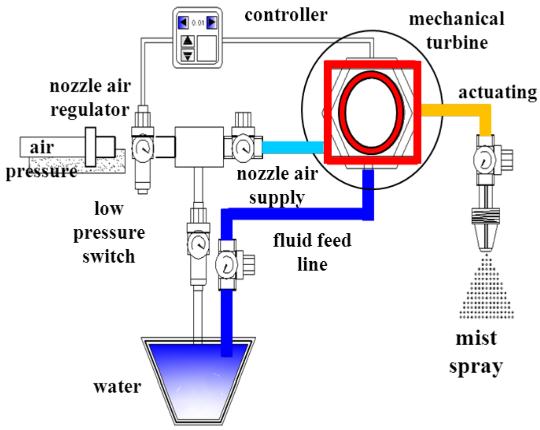


Fig. 4 Schematic of "water + air" mist spray method for first idea

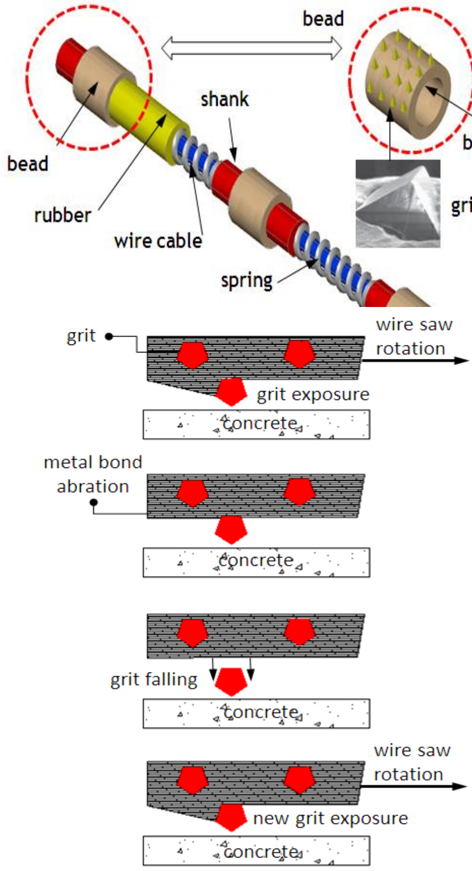


Fig. 5 Diamond wire saw cutting mechanism

"air+water" mist spray-based cooling method to develop a new DWS concrete cutting technology. In the proposed "water+air" spray method, water is used to cool and to lubricate the contact surface of diamond wire saw, and air is used to clean the cutting section and to remove the remaining dust. In case of the WCCM, water flows sufficiently into the cut contact surface in order to cool and lubricate it. This mist spray method uses only a small amount of water (3-20 liters per hour). It mixes air with water to cool and lubricate the surface. Moreover, the air used by mist spray method to blast out the remaining dust

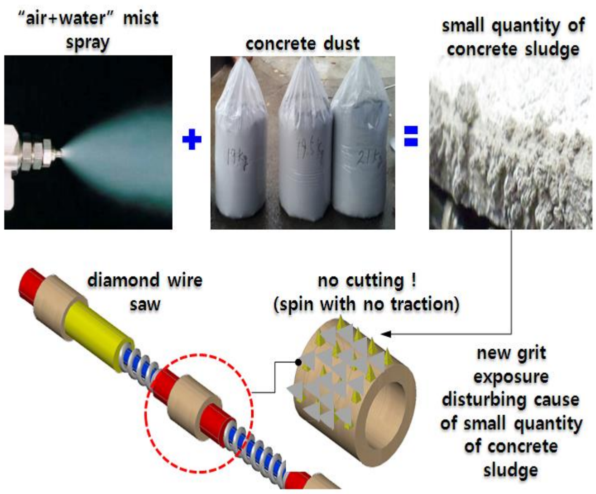


Fig. 6 Problem of mist spray method

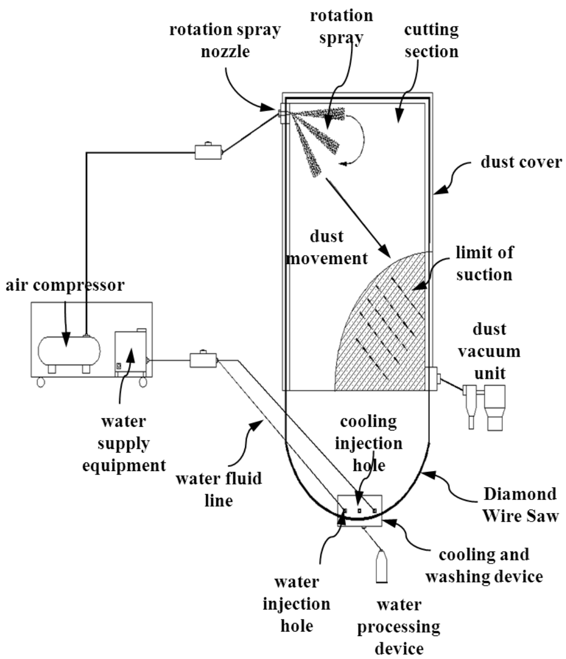


Fig. 7 Concept of new diamond wire saw concrete cutting system

on the cutting section, which is a problem of the dry concrete cutting method. As a part of the development process of NCC method, the DWS's cutting mechanism of concrete structures analyzed, as in Fig. 5. This figure shows that the DWS consists of beads, wire cables, lubber coating, a shank, and springs, and the beads consist of abrasive diamond grains, which play the crucial role in cutting concrete, and bonds.

As shown in Fig. 5, the exposed abrasive diamond grains in the first phase of the DWS's cutting mechanism are worn out as the bonds make contact with the concrete in the second phase, and in the third phase, as the old abrasive grains come off, new abrasive grains are exposed to continue the cutting mechanism (Filgueira *et al*. 2003).

However, as indicated in Fig. 6, if misty air is sprayed on the section, it mixes with concrete dust, causing concrete

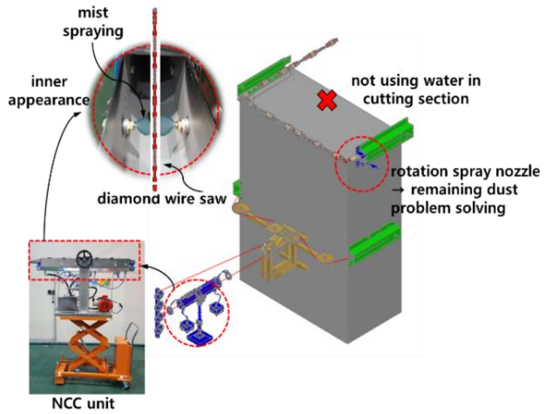


Fig. 8 Schematic of new diamond wire saw concrete cutting system

dust to become sticky. The analysis result shows that the sticky concrete dust then may fill in the gaps between the abrasive diamond grains, preventing smooth exposure of the abrasive grains in the DWS's cutting mechanism, as shown in Fig. 5, and potentially degrading the DWS's cutting performance. Accordingly, the study considered other cutting methods and concluded, based on the comprehensive analysis on the test results, that no water in any type, including mist spray, should be sprayed on sections.

Consequently, as shown in Fig. 7, the study has been developed a new concrete cutting method, which first implements a rotating air spray nozzle device that removes concrete dust inside the section with blasting air, and then a washing and cooling device located outside the section that cools the overheated DWS during the cutting process of concrete, and cleans a small amount of concrete dust left on the DWS. The core of this technology is the notion that no water should be used on the cutting section. In order to cool the friction heat of the DWS, this technology is intended to treat the cooling problem as put cooling device in out of cutting section. In addition, to solve the residual dust problem of the dry cutting method, rotation spray nozzle blow out the remaining dust into dust vacuum unit, as seen in Fig. 7.

Fig. 8 shows these concepts. Cooling device is installed on the outside of the cutting section. The mist spray is sprayed within the development unit and can be expected to cool the DWS. This method is differentiated from existing technologies by installing cooling and washing unit outside the cutting section. The rotation spray nozzle solves the problem of dry cutting method, whereas the washing and cooling device attempts to solve the problem of water-cooled method.

3. Experimental verification of the proposed NCC method

3.1 First test problem, modification and second test plan

The first experimental verification test aimed to verify

Table 1 Mock up specimen properties

Gmax (mm)	Slump (mm)	W/B (%)	S/a (%)	Unit quantity(kg/m^3)					
				W	C	Fine Aggregate	Coarse Aggregate	Fly Ash	Additive
25	120	47	46.6	122	238	414	954	70	2.6

Fig. 9 Mock up specimen manufacturing

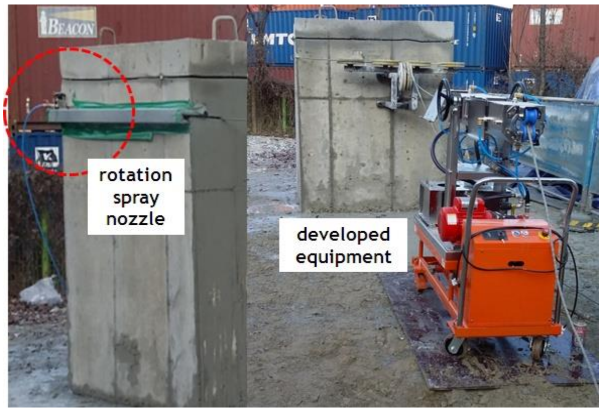


Fig. 10 First test scene of concrete pier specimen

the technical superiority of proposed NCC method over the water-cooled concrete cutting method and the dry concrete cutting method by using a pier specimen that had been widely used in cutting demolition projects. The test was conducted to evaluate the cutting time, the most important performance parameter in DWS cutting, and the generated heat temperature to compare the cooling effect of the proposed method and the existing methods. The fabrication of a specimen was modeled after an actual pier cutting situation, and by considering its rectangular shape of a pier, the test produced a life-size specimen in 1.5 m×1.5 m in cross section and 2 m in height. The axial steel used for the specimen was D25-40EA, and the concrete strength was 24 MPa. Table 1 shows the properties of the specimen, and Fig. 9 shows the fabrication process of the specimen. The curing took 28 days. Fig. 10 shows the developed cooling device for the cut section, an installation of the device on actual specimen, and an installation of rotating air spray nozzle that effectively removes remaining concrete dust on the section surface. While a model cutting test could consider several variables, the test is carried out to verify concrete cutting performance, dust vacuum efficiency, which is the most important variable in the test, and the generated maximum temperature, which is linked to cooling effect.

We find two problems from the first verification test. As shown in Fig. 11, the first problem is that a large quantity of

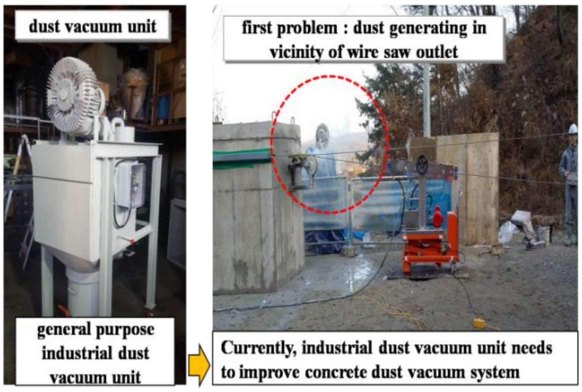


Fig. 11 The first problem of first verification test

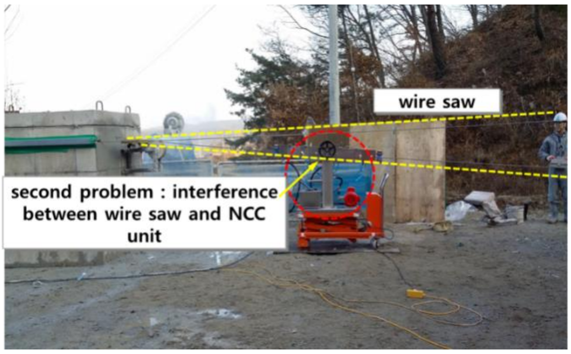


Fig. 12 The second problem of first verification test

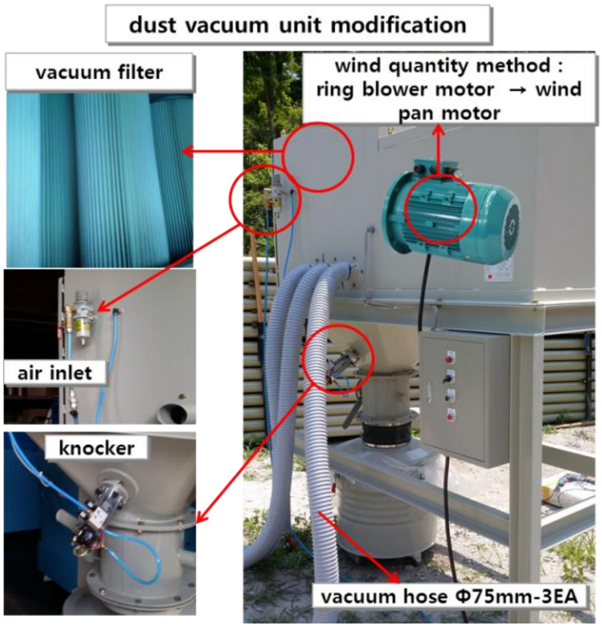


Fig. 13 Modification of dust vacuum unit

dust scattered in the vicinity of wire saw outlet. This causing is that a general-purpose dust vacuum unit can't get rid of the concrete dust enough. As shown in Fig. 12, the second problem is that the developed NCC unit interfered with the rotation of wire saw during the cutting process of concrete. To solve the first problem, dust vacuum system has been modified from wind pressure method to wind volume method, as seen in the Fig. 13. Furthermore, the dust total volume occurring in the cutting section occurred

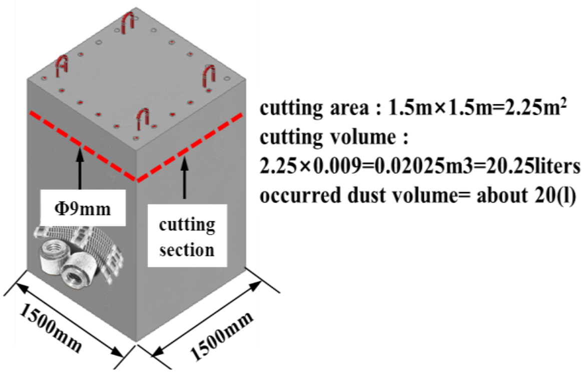


Fig. 14 Generating total dust volume in cutting section

Table 2 Modification content of dust vacuum unit

Division	Vacuum method	Vacuum hose diameter
general purpose vacuum unit	wind pressure method (ring blower motor)	50mm-1EA
modified concrete vacuum unit	wind quantity method (wind pan motor)	75mm-3EA

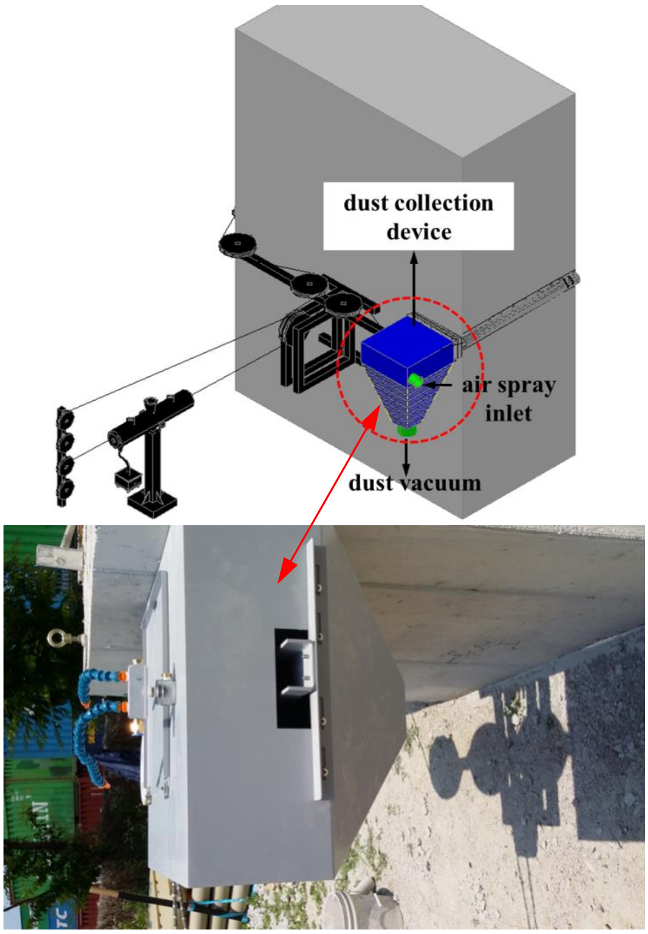


Fig. 15 Dust collection device

about 20 liters, as seen in Fig. 14. The conventional wind pressure method failed to process the total dust volume generated during the cutting process of concrete. For this reason, the wind pressure method is changed to the wind volume method, as shown in Table 2. In addition, the dust hose diameter, as seen in Fig. 13, is changed from 50-1EA mm to 75 mm-3EA. Furthermore, as shown in Fig. 13,

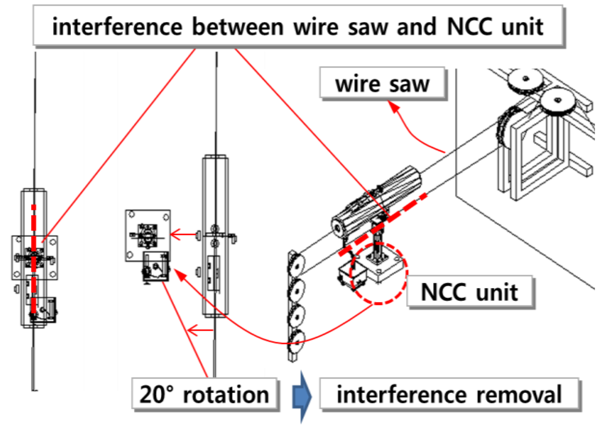


Fig. 16 Modification of NCC unit

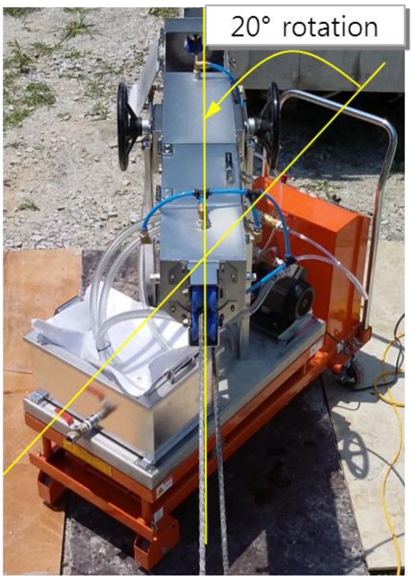


Fig. 17 Modification of NCC unit

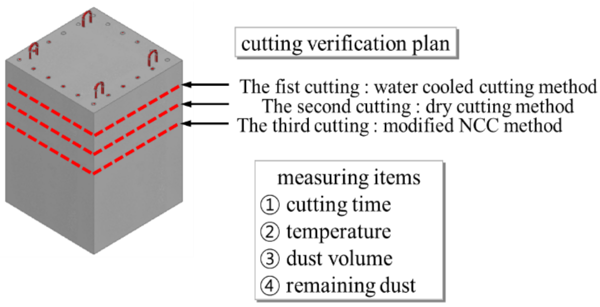


Fig. 18 Cutting verification plan

knocker is a shooting device intended to remove dust inside the dust unit.

A dust collection device is developed to clean up the dust particles that flow into the NCC unit, as seen in Fig. 15. This unit is developed to remove the fine amount of dust from the diamond wire saw, as air is sprayed into this dust collection device. As shown in Fig. 11, there was a lot of dust in the vicinity of outlet of the diamond wire saw. The dust collection device is also intended to process such dust

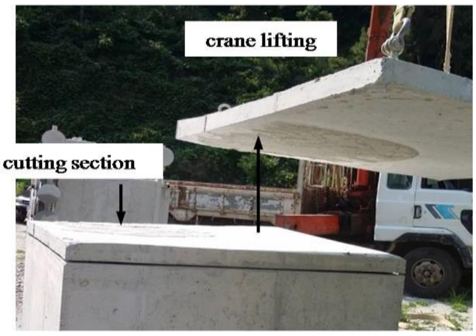


Fig. 19 Scene of cutting section lifting

Fig. 20 Scene of second verification test

Table 3 Cutting performance test results

Division	Cutting time (minute)	Cutting performance (min/m^2)
water-cooled cutting method(WCCM)	25	11.1
dry cutting method	32	14.2
NCC method	27	12.0

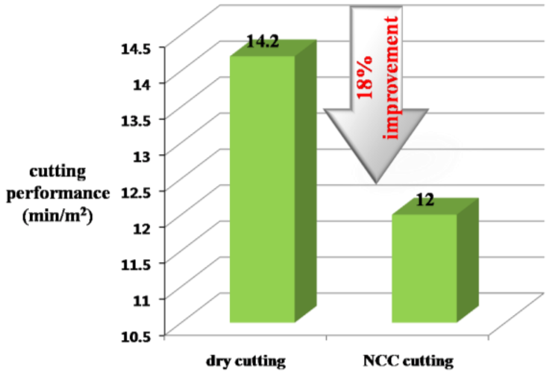


Fig. 21 Comparison of cutting performance

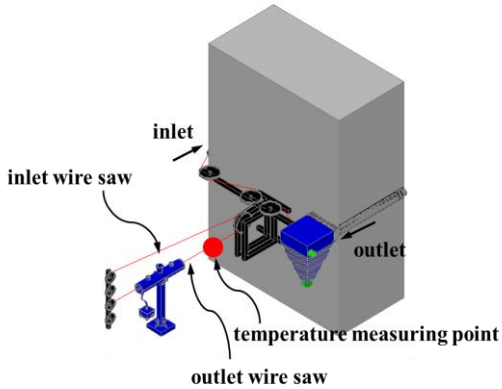


Fig. 22 Temperature measuring point

efficiently. In order to solve the second problem of the interference between wire saw and the NCC unit, the unit was rotated by 20 degrees as seen in Figs. 16 and 17. The verification test was performed to measure the cutting time, occurrence maximum temperature, and dust volume generating in the cutting section. The main purpose of this verification test is to efficiently collect concrete dust particles from the concrete cutting test. In this experiment, the improved dust collection technology is intended to verify the efficiency of dust collection system, and also to verify the efficiency of the rotation air spray nozzle. As shown in Fig. 18, the verification test is conducted for each method of improved NCC method, conventional water cooled cutting method, and dry cutting method.

To evaluate the concrete cutting performance, the same drive cutting speed and wire saw tension were applied to the same bridge pier model. The cutting time was measured by the difference between the start time and the end time of the each method, and was measured the temperature of the diamond wire saw at the same location every 10 minutes. To verify dust vacuum efficiency, the remaining dust particles on the cutting section were measured. For this purpose, the upper section of the concrete cutting plane was lifted using a set of anchor and crane, as seen in Fig. 19. Fig. 20 shows second verification test scene.

3.2 Test results

3.2.1 Cutting performance

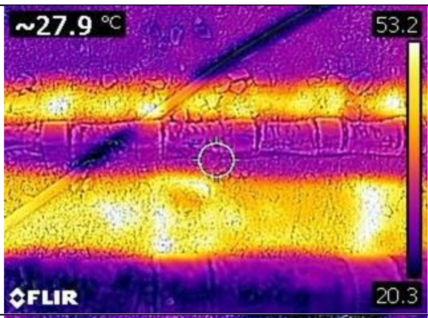
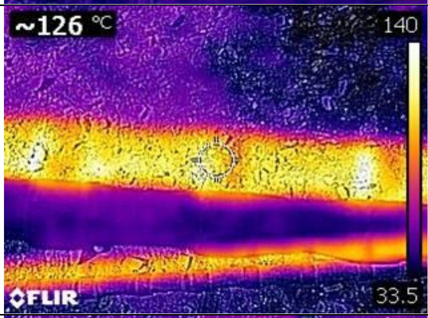
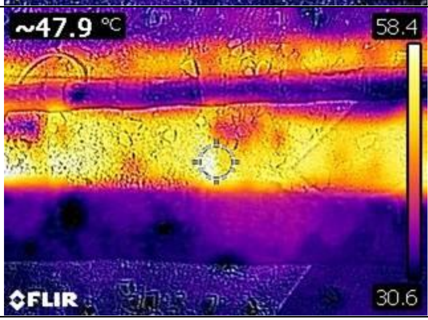
As the result of the cutting time, the water cooled method took 25 minutes for cutting the same concrete section, and the dry cutting method took 32 minutes, and the modified NCC method took 27 minutes.

To evaluate the cutting time, this study applied identical running speed and wire saw tension to the identical pier model specimen and conducted the cutting test. The results are shown in Table 3 and Fig. 21. The cutting performance divided by the 1.5 m×1.5 m area of the each cutting time is shown in Table 3. The cutting performance required to cut the same unit square meter took 11.1 min/m^2 with the water-cooled concrete cutting method, 14.2 min/m^2 with the dry concrete cutting method, and 12.0 min/m^2 with the NCC method, showing that there was no significant difference between the developed NCC method and the water-cooled concrete cutting method. However, it showed about 18% increase in cutting performance compared to the dry concrete cutting method. It is believed that this is because the sufficient concrete dust cleaning action by the rotating air spray has led to the smooth operation of the exposure of the abrasive diamond grains.

3.2.2 Temperature evaluation of the generated heat

The present study compared the temperature generated

Table 4 Temperature test results

Division	Max. Temperature
water-cooled method (Max. 53.2°C)	
dry cutting method (Max. 140°C)	
NCC method (Max. 58.4°C)	

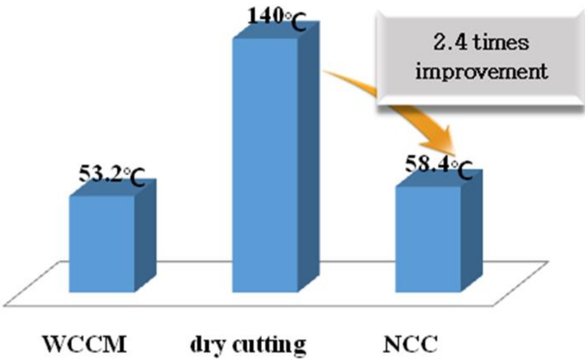
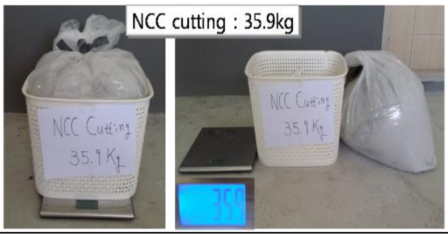


Fig. 23 Comparison of temperature

by the developed NCC method, the water-cooled concrete cutting method, and the dry concrete cutting method. Images for the heat generation analysis were taken by a thermos-graphic camera at the starting point, the mid-point, and the end point of the cutting process. The resolution of the camera used for measurement is 640×480 pixels, and the measurement ranges are -40°C-2000°C. As shown in the Fig. 22, temperature is measured in a constant position. This is because there is a greater heat in the vicinity of the wire saw outlet than the vicinity of the wire saw inlet.

Table 4 shows maximum temperatures of DWS during the test. The upper right bar in Table 4 shows a maximum

Table 5 Dust vacuum efficiency comparison

Division		Dust vacuum quantity
test scene		
dry cutting method	30.7 kg	
modified NCC method	35.9 kg	

temperature of DWS, whereas the lower right bar shows a surrounding temperature. The maximum temperature of DWS generated during the cutting process based on the developed NCC method, the water-cooled concrete cutting method, and the dry concrete cutting method was 58.4 degrees Celsius, 53.2 degrees Celsius, and 140 degrees Celsius, respectively. The result shows that both water-cooled concrete cutting method and proposed NCC method had a similar temperature increase, whereas dry concrete cutting method resulted in a considerable increase in temperature.

As shown in Fig. 23, compared to dry concrete cutting method, NCC method improved temperature by about 2.4 times. Both water-cooled concrete cutting method and proposed NCC method generated the heat below 100 degrees Celsius, which is considerably lower than 800 degrees Celsius, the melting point of abrasive diamond grains. On the other hand, dry cutting method is close to 120 degrees Celsius, the melting point of lubber, which covers the gap between beads on the DWS, and it is expected that lubber will become deteriorated by heat, resulting in reducing the durability life of DWS. Although this test cut the specimen only one time and measured the result, it is determined that further research would be required to evaluate the durability life of DWS in more detail by cutting several sections.

3.2.3 Dust vacuum efficiency

In order to increase the cutting efficiency the dust generated from the cutting section shall be released smoothly from the inside of the cutting section to outside. If dust does not flow smoothly from the inside of the cutting section to dust vacuum system, it causes the dust to jam between the wire saw and the cutting section, resulting in an

Fig. 24 Remaining dust comparison between NCC method and dry cutting method

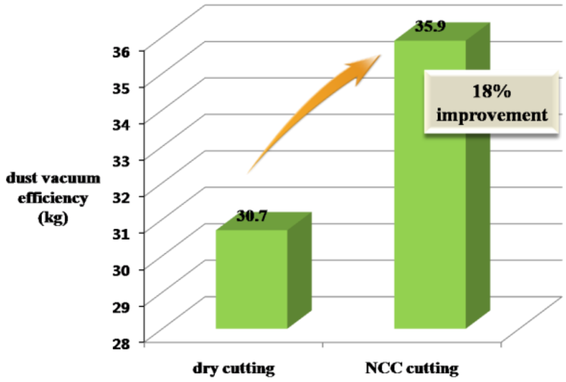


Fig. 25 Dust vacuum efficiency comparison between NCC method and dry cutting method

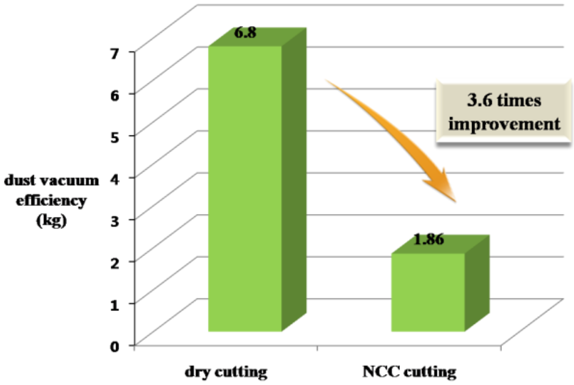


Fig. 26 Remaining dust efficiency comparison between NCC method and dry cutting method

obstruction to the cutting effect. Therefore, the generated dust volume during concrete cutting was measured in relation to the enhancement of cutting performance. When conducting the verification, the dust was completely sealed using a dust cover to prevent dust from dissipating into the air. The amount of dust generated by cutting a concrete structure of 1.5 m×1.5 m cross section by 9 mm wire saw is about 20 liter, as shown in Fig. 14. As the test result, dust emitted by conventional dry cutting techniques is estimated to be 30.7 kg, while the dust emitted by the modified NCC

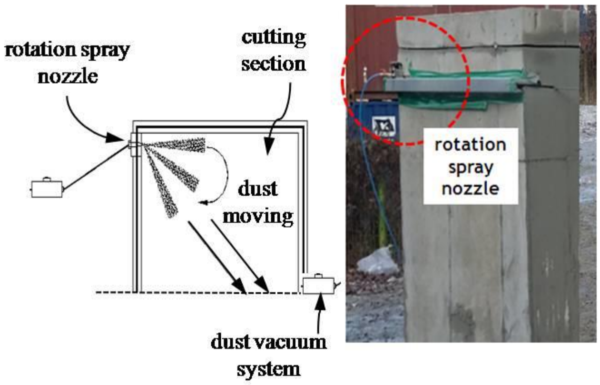


Fig. 27 Cause of remaining dust efficiency enhancement

Fig. 28 Comparison between NCC method and water cooled cutting method

Table 6 Test results summarization

Division	Cutting time (minute)	Cutting time (min/m^2)	Max. Temperature	Dust vacuum efficiency (remained dust quantity)
water-cooled cutting method (WCCM)	25	11.1	53.2°C	-
dry cutting method	32	14.2	140°C	30.7 kg (6.8 kg)
NCC method	27	12.0	58.4°C	35.9 kg (1.86 kg)

Fig. 29 New and wonderful alternative in concrete cutting technologies

techniques is estimated to be 35.9 kg. It's an average of 18% more dust emitted than existing dry cut techniques as shown in Table 5 and Fig. 25. In cutting section, the remaining dust by conventional dry cutting techniques is estimated to be 6.8 kg, while the remaining dust by the modified NCC techniques is estimated to be 1.86 kg with an average of 3.6 times the dust emitted by existing dry cut techniques as shown Figs. 24 and 26.

These results are attributed to the use of rotation air spray nozzle to blow dust out of the dust vacuum system as shown in Fig. 27. It is also assumed that the improved dust vacuum unit effectively handles the dust generation.

4. Conclusions

This experimental study shows that the dust problem of dry cutting method is closely controlled and solved. The proposed NCC method is superior to the dry cutting method in all aspects, including cutting performance, dust vacuum efficiency and cooling effect. The conclusions of this study are as follows.

1) It is known that the water-cooled concrete cutting method uses about 2,000 liters of water per hour, and a process of six hours would then use as much as 16,000 liters of water. Once mixed with remaining concrete dust on concrete cutting sections, it produces significant amount of concrete sludge waste. Not using cooling water on cutting sections, the NCC method produces no concrete sludge waste as shown in the Fig. 28.

2) Table 6 is the results of performance evaluation among the NCC method, the water-cooled concrete cutting method, and the dry concrete cutting method.

3) As shown in Table 6, cutting performance is the highest with water-cooled concrete cutting method, and compared to dry concrete cutting method, NCC method shows an about 18% increase in cutting performance. The generated temperature is also shown to be the lowest with water-cooled concrete cutting method, and compared to dry concrete cutting method, NCC method improves the temperature characteristics about 2.4 times.

4) Dust emitted by conventional dry cutting techniques is estimated to be 30.7 kg, while the dust emitted by the modified NCC techniques is estimated to be 35.9 kg, with an average of 18% more dust emitted by existing dry cut techniques. From these results, we confirm that the rotation nozzle and dust vacuum unit is very efficient.

5) According to the test results, the water-cooled concrete cutting method is shown to be superior to the other two methods in terms of cutting performance. However, considering 2,000 liters of concrete sludge waste per hour it will generate and the resulting environmental damage, it is determined that NCC method will be a new and effective alternative in concrete structure cutting technologies using DWS, as shown in Fig. 29; and finally.

6) It is believed that further research would be required to evaluate the durability life of DWS in more detail by cutting several sections.

Acknowledgments

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