Journal of Advanced Concrete Technology

Materials, Structures and Environment

Concrete Demolition and Surface Scraping using High Voltage Pulse Discharge

Kazuo Murakami, Yasuhiro Dosho, Kensuke Uemura and Hiroshi Kimura
Journal of Advanced Concrete Technology, volume 16 (2018), pp. 358-367

Related Papers [Click to Download full PDF!](#)

Review of the Current State of Knowledge on the Effects of Radiation on Concrete

Thomas M. Rosseel, Ippei Maruyama, Yann Le Pape, Osamu Kontani, Alain B. Giorla, Igor Remec, James J. Wall, Madhumita Sircar, Carmen Andrade, Manuel Ordonez
Journal of Advanced Concrete Technology, volume 14 (2016), pp. 368-383

Carbon Dioxide Uptake in Demolished and Crushed Concrete

Toshifumi Kikuchi, Yasuhiro Kuroda
Journal of Advanced Concrete Technology, volume 9 (2011), pp. 115-124

[Click to Submit your Papers](#)

Japan Concrete Institute - <http://www.j-act.org>

Technical report

Concrete Demolition and Surface Scraping using High Voltage Pulse Discharge

Kazuo Murakami^{1*}, Yasuhiro Dosho², Kensuke Uemura³ and Hiroshi Kimura⁴

Received 21 January 2018, accepted 9 August 2018

doi:10.3151/jact.16.358

Abstract

The demand for safe reuse of material from aged concrete structures is increasing. This report describes a technology for concrete demolition and surface concrete scraping for reuse of the material based on high voltage pulse discharge (HVPD) while immersed in water. The technological advantages of the new method compared with conventional methods are explained. The principle of concrete demolition using HVPD, experimental results on actual concrete structures (with and without steel reinforcement), and the influences of the immersion water are reported. A method of immersing a vertical surface (concrete wall) in water is described. Finally, the concept of mass reduction of radioactive concrete waste is discussed.

1. Introduction

Demand for the demolition destruction of concrete structures and reuse of scraped surface mortar is increasing. From an environmental perspective this type of work must minimize dust generation, CO₂ emissions, and danger.

This paper begins by explaining the principle of using high voltage pulse discharge (HVPD) technology to break up (demolish) an insulating, electrically non-conductive material (i.e. concrete). A newly developed HVPD setup named EG350 is compared with the classic Marx Generator. Experimental results on concrete demolition and surface material (mortar) scraping are reported including the influence of steel reinforcement and immersion in water, as well as how long scraping can continue before the alkaline pH of the immersion reduces discharge efficiency. Demolition efficiency is found to have a linear relation to accumulated number of discharge pulses and pH increase. The process is also evaluated for environmental effects, safety and anticipated CO₂ emissions. A method for scraping concrete walls (i.e. vertical structures) is presented in which the pulse discharge zone is kept immersed in water by at-

taching a steel holding structure.

Finally, the concept of using a HVPD setup to reduce highly radioactive waste concrete blocks with steel reinforcements is discussed along with anticipated barriers to realization of such system.

2. The principle of concrete demolition with HVPD

As the HVPD pulse duration is reduced (usually < 300 ns), the breakdown voltage of the insulating materials (concrete) falls below that of the immersion water. A discharge takes place between anodes and cathodes causing an electrical (or plasma) path in material. This leads to breaking up of the concrete surface (Kimura *et al.* 2005). This correlation can be seen in Fig. 1, where short pulse duration above point A in the figure, results in breakdown of the insulating material/ concrete. A typical arrangement of anode (energy source) and cathode (energy sink) for demolition work is shown in Fig. 2. The insulating material (concrete in this case) to be demolished or surface scraped is immersed in water (or sometimes in insulating oil) and the anode and cathode touch the surface of the material. Various mechanisms have

¹Deputy Director, Nuclear Projects Division, Shimizu Corporation, 2-16-1 Kyobashi, Chuo-ku, Tokyo 104, Japan. *Corresponding author,

E-mail: kazuo.murakami@shimz.co.jp

²Professor, Department of Environmental Science and Technology, Meijo University, 1-501 Shiogamaguchi, Tenpaku-ku, Nagoya City, Aichi Prefecture 468-0073, Japan.

³Professor, Fellow of ShinMaywa Industries, Ltd., 1-1 Shinmeiwacho, Takarazuka, Hyogo Prefecture 665-0052 Japan.

⁴Director, Nuclear Projects Division, Shimizu Corporation, 2-16-1 Kyobashi, Chuo-ku, Tokyo 104, Japan.

Fig. 1 Electrical breakdown characteristics of water and concrete.

been proposed for the scraping process that results from repeated electrical discharges between the electrodes: (1) concrete expansion as the plasma channel heats up; (2) entrained air bubbles in the concrete exploding upon heating; and (3) other effects related to shock waves generated in the immersion water (Zinovyev and Uemura 2002). Based on the principle, we developed the reasonably compact and light EG350 discharge system to generate discharges more rapidly than the classic Marx Generator (Kimura *et al.* 2010).

HVPD technology originated with the invention of the Marx Generator by Erwin (1924). This device generates high-voltage pulses from a low-voltage DC supply. The

technology spread worldwide and saw many dramatic modifications and alterations as it found application in high-energy physics experiments and simulating the effects of lightning on power-line and aviation equipment.

The Marx Generator circuit develops a high-voltage pulse by charging a number of capacitors in parallel, then connecting them in series to produce the discharge. The circuit is shown in parallel and series configurations in **Fig. 3** (which is taken from a general explanation of the Marx Generator). First, n capacitors (C) are charged in parallel to voltage V_C by a high-voltage DC power supply through resistors (R_C). The spark gaps used as switches each have voltage V_C across them, but the gaps have a breakdown voltage greater than V_C , so they all behave as open circuits while the capacitors charge. The last spark gap isolates the output of the generator from the load. To create the output pulse, the first spark gap is caused to break down (triggered). The breakdown shorts the gap, placing the first two capacitors in series and applying a voltage of about $2V_C$ across the second spark gap. Consequently, the second gap breaks down to add the third capacitor to the "stack", and the process continues to sequentially break down all of the gaps. The last gap connects the output of the series stack of capacitors to the load. Ideally, the output voltage will be $n \times V_C$. This principle of multiplying voltage by charging capacitors

Fig. 2 Principle of HVPD demolition method.

Fig. 3 Principle of the Marx Generator circuit in parallel and series configurations.

Table 1 Main characteristics of EG350.

Max. Discharge voltage	320 kV
Nominal electrode gap	27 mm
Discharge rate	5 Hz
Electrode scanning	Manual; 1.2 - 2.1 mm/sec

in parallel and discharging them in series is also used in the voltage multiplier circuit, used to produce high voltages. The Marx Generator produces a pulse.

Application of the classic Marx Generator to concrete demolition faced the fatal disadvantage of the huge scale of the generator as well as the long charging time. To reduce the scale and weight of the classic Marx Generator and speed up the discharge cycle, the HVPD setup shown in Fig. 4 and named the EG350 has been developed by ShinMaywa Industries, Ltd. (of Takarazuka, Japan) and Tomsk Polytechnic University (of Tomsk, Russia). The main circuit of the EG350 is shown in Fig. 5. The EG350 differs from the Marx Generator in having fewer capacitors which are replaced with high-power transformer and spark switches instead of the spark gaps. With these modifications, the weight of the HVPD equipment is reduced to 200 kg and the rate of discharge repetition is improved. A cross section of the high voltage section of the EG350 is shown in Fig. 6 and its major characteristics are given in Table 1. In Fig. 4, it is shown in experimental arrangement with a concrete slab in a portable water immersion tank. The HVPD module stands under its own weight on the concrete surface, pressing the electrodes onto the surface. It is scanned

Fig. 4 The EG350 HVPD equipment in experimental configuration, with electrodes held to concrete surface under its own weight in a portable water immersion tank.

manually over the concrete surface to carry out surface scraping.

3. Application of HVPD EG350 to concrete demolition

HVPD was applied historically (around half century ago) to reduce the volume of concrete. Figure 7 (a) shows the straight alignment of electrodes used to demolish concrete in block form. The alternative arrangement in Fig. 7 (b) shows the steel reinforcement being used as the ground (cathode) to demolish a steel reinforced concrete slab. In the case of Fig. 7 (a), repetition of the pulse discharges causes the concrete block to break down into pieces as shown in Figs. 8 (a), (b) and (c). Experiments were carried out to further break down the concrete with more pulse repetitions. As shown in Fig. 9, depending on the number of pulses, the concrete can be reduced to

Fig. 6 Cross-section of the high voltage pulse discharge of EG350.

Fig. 5 Main circuit diagram of EG350.

rubble finer than 40 - 70 mm (a) to 2 - 5 mm (e) and finer by sorting with a sieve. In every case, the concrete slab had the standard designed specific strength of 21 N/mm².

To determine further details of concrete breakdown phenomena when using the EG350, the parameters and conditions were varied as following.

(1) Discharge voltage

The results for varying the discharge voltage are shown in **Fig. 10**. Though small cracks were observed in the case of a 200 kV discharge, the concrete was not chipped totally with 150 mm electrode spacing. It was determined that if the electrode spacing is 150 mm, the discharge voltage should be set 400 kV or more.

Fig. 7 Electrode alignment.

Fig. 8 Results of discharge onto a concrete block.

Fig. 9 Size reduction of concrete by repeated discharge.

(2) Anode and cathode electrode gap and water immersion depth

To assure discharge, the electrode gap was shortened to 100 mm as compared with (1) 150 mm, in the above case, and the minimum water immersion depth was just above the concrete surface. The results are shown in **Fig. 11**, which indicates that the critical water depth L from the concrete top surface is $2 \times D$ (D : electrode spacing). When L was less than $2 \times D$, the discharge was insufficient and concrete chipping did not occur. On the other hand, when L was greater than $2 \times D$, the concrete was chipped well. This has been cited in Japan Patent Application 347577 (Urano *et al.* 2005).

(3) Embedded steel reinforcement

The demolition and scraping effects in the case of concrete with embedded steel reinforcement were measured with electrodes immediately above the reinforcement and also further apart. **Figure 12** compares the cases. These results electrical discharge path was through the steel, but this is a minor issue when considering that real on-site operation would involve the scanning of multiple -electrodes, (over the concrete surface).

(4) Scraping

After obtaining results for cases (1) to (3) above, it was determined that scraping was able to achieve;

Scraping depth : 10 mm

Output : 2 - 3 m²/Hr.

Fig. 10 Discharge voltage and chipping of Concrete Surface. (Distance between electrodes: 150 mm, water depth: 150 mm)

Fig. 11 Scraping occurrence (shaded domain) by water depth and electrode spacing.

Table 2 Environmental impact evaluation.

Chipping device	Hand breaker	Scraping with high voltage pulse discharge EG350
Status of operation
CO ₂ emissions	3.1 kg C/Hr.	2.5 kg C/Hr.
Noise	85 - 90 dB	85 - 90 dB
Dust	7%	0%

These values are equal to or better than conventional scraping using hand breakers (Oguri *et al.* 2004). Moreover they are achieved without dust generation in the air.

4. Environment and safety evaluation of EG350

4.1 CO₂ emissions

These were determined using the numerical calculation below for the case of common concrete with strength of 21 N/mm².

(1) Principle: CO₂ emissions/hour = Basic unit CO₂ for fuel^{*(a)*(b)} used x fuel consumption /hour

* (a) ; 2.58 kg C/l (AIJ 2013)

* (a) ; Light oil for hand breakers, and Electric Power

* (b) : 0.505 kg C/kWh (the data for Tokyo Electric Power Company Holdings (Ministry of the Environment 2015))

(2) Fuel Consumption

Hand Breaker : 3 l/ hour

EG350 : 10 kW/ hour

The output of these two devices is the same at 2.5 m²/hour.

CO₂ emissions to scrape 1m² concrete:

Hand Breaker : $2.58 \times 3 / 2.5 = 3.1$ kg C/ hour

EG350 : $0.505 \times 10 / 2.5 = 2.5$ kg C/ hour

Thus EG350 has 20% lower CO₂ emissions.

4.2 Noise and dust generation

The CO₂ emissions, noise and dust generated by a hand breaker and the EG350 are summarized in **Table 2**.

4.3 Safety

No safety data has been collected in real operations, so the safety factor was estimated in reference to Ministry of Health, Labor and Welfare Status of Occurrence of Industrial Accidents statistics data (Ministry of Health, Labor and Welfare 2015).

(a) Discharge directly above the reinforcement

(b) Discharge apart from the reinforcement

Fig. 12 Scraping with discharge (a) directly above the reinforcement and (b) apart from the reinforcement.

1795 persons/year; falls
1568 persons/year; cuts and abrasion
59 persons/year ; electric shock

Therefore, scraping with the EG350 is estimated to offer less risk of accident than the use of hand breakers.

5. Increase in alkalinity of immersion water with continued concrete scraping

Concrete blocks were prepared with dimension 300 x 300 x 50 mm in the market without steel reinforcement and with strength of 21 N/mm². A block was placed at the bottom of a water pool as shown in Fig. 4. The EG350 electrodes were held against the concrete blocks under the self-weight of the equipment and the equipment was manually scanned over the block surface at rates of 50 mm / 4 min and 50 mm / 7 min. The scraped of the blocks is shown in Figs. 13 and 14. There is no visible difference in scraped depth and scraped material depending on scanned rate.

The pH increased as the water became more alkaline with cumulative pulse discharge cycles, as shown in Fig. 15. When the block was initially placed in the portable water, it indicated pH 7.8 and this increased to pH 9.3 (after ≥ 1400 discharge cycles). This was approximately 200 seconds after the start in continuous mode. The scraped concrete and the scraped surface observed at certain pH levels and cumulative pulse cycles are shown in Fig. 16. There is no visible difference in the scraped surface between pH 8.0 (cumulative pulse cycle = 300)

and pH 9.3 (1 - 350 cycles) but the immersion water lost its clarity and became so muddy/-dark that the block surface could not be seen. This is scraping performance was not reduced but it seems some kind of water circulation with filters or replacement of the immersion water is required. In Fig. 1, it was seen that the water breakdown characteristic decreases with increasing discharge duration. The concrete breakdown characteristic also decreases with discharge duration, but once the discharge duration exceeds the crossing point between these two characteristics, no further discharge into the concrete occurs. The discharge then occurs through the immersion water.

As the immersion water alkalinity (pH) increases with continued scraping of the concrete surface, its electrical conductivity rises. To avoid this, we set as criteria for stopping scraping the concrete block becoming obscured by the suspended dust and mud. At that point, the immersion water was replaced with fresh water before scraping continued.

6. Demolition and scraping of concrete wall

It was thought that, if the electrodes (anode and cathode) could be kept submerged while held against a concrete wall, pulse discharges would pass through the concrete, allowing the wall to be demolished scraped. There is clear demand for demolition scraping of concrete walls, so we attempted to trap water against a wall (Kimura *et al.* 2008). The electrode arrangement and the critical device

(a) Scraped concrete surface

Speed	50 mm/7min
	1.2 mm/sec
N: total pulses	2100
Vs: efficiency m ² / Hr.	1.7
n : m ² / pulse	9.5×10^{-5}
h : depth mm	4.5 - 15
electrode gap mm	27
Hz	5

(c) Scraping condition

	(5)	(4)	(3)	(2)	(1)
4	7.5	6.5	12.5	8.5	8.5
3	6.5	4.5	13.5	6.5	8.5
2	11.5	8.5	13.5	8.5	14.5
1	10.5	8.5	14.5	13.5	15.5

(b) Scraped depth h (mm) in position

(d) Scraped position with scanning

(e) Scraped cross section

Fig. 13 Concrete surface scraping and results. (Scanning rate: 0.07 m/sec.)

that traps water against the wall are shown in **Figs. 17 (a), (b) and (c)**. In **Fig. 17 (a)**, numeral 4 points to the electrodes and 5 is the cylinder that seals the water against the wall. Numeral 6 and the letter F in **Fig. 17** indicate the seal and cushion, respectively. The seal was made of poly vinyl alcohol resin.

The device was suspended from a backhoe and held against a vertical concrete wall. Although some water leaked as the device was scanned over the wall, demoli-

tion and scraping of the wall were confirmed. **Figure 18** shows the proto-type device and the results obtained. The influence of water penetration depth into the wall on discharge performance was not determined in detail due to the small number of experiments. However, wall demolition scraping was observed in on-site experiments using the device.

Fig. 14 Concrete surface scraping and results. (Scanning rate: 0.125 m/sec.)

Fig. 15 Cumulative discharge pulse count and pH increase of immersion water.

Fig. 16 Scraping at each pH value. (a) pH 8.0 (cumulative pulse count 300) (b) pH 9.0 (1000) (c) pH 9.3 (1350) .

Fig. 18 Prototype demolition/scraping of concrete wall.

1. Concrete Wall 2. Water tube 3. Water tank 4. Electrodes
5. Cylinder to keep the Water 6. Seal 7. Cushion (F)

Fig. 17 Arrangement for submerging electrodes against concrete wall. (Kimura *et al.* 2008)

7. Concept of radioactive waste concrete volume reduction

The concept was to apply HVPD to reduce the volume of radioactive concrete blocks waste based on two assumptions: (1) radioactivity is at about level of 400 mSv and (2) the steel-reinforced blocks are about the size of human head. A patent has been applied for, although actual realization has not taken place (Uemura and Murakami 2013). Following the experiments described in the sections above, the barriers to realization were considered to be maintaining a reasonable pH and keeping the operators safe from radiation. The conceptual system for volume reduction is shown in **Fig. 19**. The pulse discharge method and electrode arrangement are similar to those illustrated in **Fig. 7 (a)**. It is a batch system and the

Table 3 Main parameters of the planned system.

Characteristic	Value
Input power	400 V
Discharge Voltage	500 kV
Stored Energy	10000 J
Pulse Duration	1 μ s
Pulse Repetition	2 Hz

steel rods are collected with a magnet system for re-smelting in a furnace for reuse.

The plan is for the immersion water to be recycled through the filters. However, treatment of the radio-activate waste water remains an unsolved issue. The resulting crushed concrete and pebbles would be placed into thick-walled concrete coffins until the radio activity has fallen considerably. The main parameters of the planned system are listed in **Table 3**.

8. Conclusion and discussion

The application of high voltage pulse discharges (HVPD) to concrete demolition-surface scraping was examined, using a modified device based on the classic Marx Generator (and designated the EG350). This is a reasonably compact setup (weighting less than 200 kg) and is suitable for use on site. Suitable working conditions for the EG350 were determined in terms of the parameters of the discharge voltage, anode-cathode gap and water immersion depth. It was shown that the EG350 performs better than conventional hand breakers. Further, in terms of environmental impact, the EG350 performs better in terms of power consumption and CO₂ emissions than conventional tools. Noise output is about the same level as with hand breakers, but there is a dramatic difference

with respect to dust generation. This is an epoch making technology for concrete scraping in general and is of particular interest for the concrete structure of old nuclear plants where care is needed to avoid scattering of fine radioactive concrete dust. Safety of on-site work was compared between conventional tools and the EG350 based on government statistical data; this clarified several advantages of the new device.

Also investigated were realistic operational limits for use of the system as the immersion water becomes more alkaline. Once the pH exceeds 9.4, (and the also the immersion water comes), operation becomes problematic unless the water is filtered and recirculated. Use of the system is to demolish and scrape vertical walls was also tested, using a modified system that keeps the area of wall around the electrodes.

One potential use of the system is to reduce the volume of highly radio-active waste concrete containing reinforcing steel. A system such as that shown in Fig. 19 is expected to protect the environment from scattered fine radioactive dust.

Recirculation of the immersion water is the next target of efforts to realize a useful system.

— In the experiments, concrete with a strength of 21 N/mm² was used.

— Referring to Japan Patent Application IPC E21C37/18 (Nishizawa *et al.* 1998), a similar system has also been applied to granite. Also experiments to demolish nuclear facilities are referred to in papers by Hitachi-GE Nuclear Energy Ltd. (2013) and Adam *et al.* (1998), citing the demolition of “solid insulator materials

including at least one of rock, permafrost, and artificial solids including concrete, ceramics, and plastics”. Based on these results, it can be predicted that an HVPD system will be able to demolish high strength concrete up to 36 N/mm². Till now, we have been unable to extend the concrete demolition and scraping experiments with HVPD to consider differences in gravity, absorption rate and porosity of the concrete. However, it is estimated that hard concrete with strength of 36 N/mm² would be easier to handle than concrete with a strength 21 N/mm² according to the mentioned references.

Acknowledgements

The author owes gratitude to recently deceased Professor V. Lopatin of the High Voltage Research Institute at National Science Tomsk Polytechnic University, Russia and also expresses thanks to Industrial Machinery Systems Division of ShinMaywa Industries, Ltd. The help of scientists and engineers at Tomsk Polytechnic University, Shimizu Corporation, ITAC Ltd and ShinMaywa Industries in Japan for their help with the experiments is much appreciated.

References

- Adam, A., Vajov, V., Vorb'en, G., Levchenko, B., Siomkin, B. and Chapikov, A., (1998). “*Method of solid insulator.*” US Patent 5845854A.
- AIJ, (2013). “*Guidelines for life cycle assessment of buildings.*” Architectural Institute of Japan. (in Japanese)
- Erwin, M., (1924). “Versuche über die Prüfung von

Fig. 19 Volume reduction of radioactive waste concrete. (Uemura *et al.* 2013)

- Isolatoren mit Spannungsstößen.” *Elektrotechnische Zeitschrift*, 25, 652-654.
- Hitachi-GE Nuclear Energy, Ltd., (2013). “*Compilation of technical information and measurement of properties evaluating the application of high voltage pulse discharge to debris size reduction.*” Project Report, 1-61.
- Kimura, H., Murakami, K., Omata, K. and Uemura, K., (2010). “Development of concrete surface chipping technique using high voltage pulse discharge.” *Proceedings of the Japan Concrete Institute*, 32(1), 1343-1348. (in Japanese)
- Kimura, H., Uemura, K. and Omata, K., (2008). “*High voltage pulse discharge to scrap the concrete wall.*” Japan Patent Application 2008-5593. (in Japanese)
- Kimura, K., Kimura, H., Urano, S., Tazo, T., Murakami, K., Akiyama, H. and Namihira, T., (2005). “*Concrete scraping setup.*” Japan Patent Application 2005-347578, Japan Patent registration 4674335. (in Japanese)
- Ministry of the Environment, (2015). “*Emission factors of electric power suppliers : For calculation of greenhouse gas emissions of specified emitters.*” Government of Japan, Retrieved from https://ghg-santeikohyo.env.go.jp/files/calc/h28_coefficient_rev2.pdf. (in Japanese)
- Ministry of Health, Labor and Welfare, (2015). “*Analysis of industrial accident occurrence situation in 2015.*” Government of Japan, Retrieved from https://www.mhlw.go.jp/file/04-Houdouhappyou-11302000-Roudoukijunkyokuanzeniseibu-Anzenka/H27rousaikakutei_sankou2.pdf. (in Japanese)
- Nishizawa, I., Kiyama, H. and Igor, L., (1998). “*Method of electric demolition and its setup.*” IPC E21C 37/18 Japan Patent Application 1998-38808. (in Japanese)
- Oguri, D., Torii, K. and Tsukahara, Y., (2004). “Development of decontamination technologies for contaminated concrete.” *Decommissioning Gihou (Journal of the Randec)*, Radwaste and Decommissioning Center, 30, 42-52.
- Uemura, K. and Murakami, K., (2013). “*Radioactive waste concrete with steel reinforcement volume reduction.*” Japan Patent Application 2013-142618. (in Japanese)
- Urano, S., Tazo, T., Kimura, K., Kimura, H., Murakami, K., Akiyama, H. and Namihira, T., (2005). “*Method to scrape the concrete surface.*” Japan Patent Application 2005-347577. (in Japanese)
- Zinovyev, N. T. and UEMURA, K., (2002). “*Electric impulse technology of utilizing used reinforced concrete.*” Tomsk Polytechnic University, High Voltage Institute technical report.