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Economic Feasibility of the Induction Heating Method for Dismantling Structures: Analysis of Reinforcement Recovery Costs based on Required Demolition Equipment

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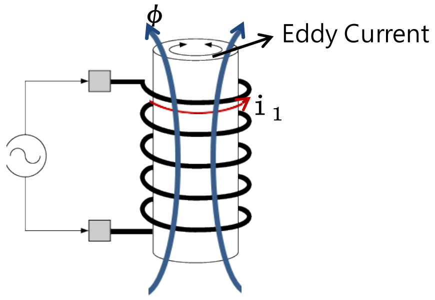
Abstract

The focus on the disassembly properties of materials to aid reduction, reuse and recycling is becoming an essential design element for building facilities. Structures built using construction systems that do not consider disassembly properties require high amounts of energy and effort to demolish. This study investigates a simple method for demolishing structures while conserving energy, devising a technique able to demolish RC components by heating steel reinforcement embedded in concrete without having to directly access the steel. This technique is then evaluated in terms of the comparative costs of steel recovery to verify its feasibility.

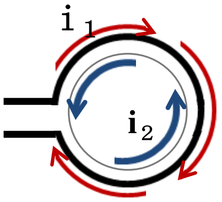
Keywords: reinforced concrete, demolition, recycling, induction heating, reinforcement

INTRODUCTION

When an alternating current passes through a wire, a magnetic field of changing magnitude is created around the wire. As shown in Fig. 1, if a conductive material, typically a metal, is placed nearby, an eddy current flows through the metal due to the changing magnetic field. As metals typically possess electrical resistance, when current flows through a metal, joule heat, defined as 「power=current^2×resistance」 is generated, heating up the metal. This is referred to as induction heating. Induction heating can only heat metals and therefore presents low risk of raising temperature in regions other than the target, preventing heat loss. Furthermore, cementitious materials experience internal dehydration at approximately 300 ℃, resulting in an increase in porosity and thermal contraction, and ultimately a reduction in strength. Therefore, the principle of induction hearing can be used at specific values to locally heat targeted steel reinforcement and to weaken the surrounding concrete of a member.



(a) Magnetic flux **φ** depending on alternating current **i**$_1$



(b) Induced current (Eddy Current **i**$_2$)

Figure 1: High-frequency induction heating mechanism

This study evaluates a demolition technique for RC components reliant on high-frequency induction heating by analyzing the economic feasibility of the system through the recovery rate of steel reinforcement using a simulated demolition process. The recovery rates and costs of reinforcing steel using the proposed system are compared to those when using a more conventional system. The induction heating mechanism used in this research is of a type currently applied to processing metals. It is hoped that applying a system of this type to building components will help develop demolition techniques allowing steel and concrete to be completely separated using small quantities of energy, increasing the quantity of recovered materials and ultimately reducing demolition cost. Note that the impact of this method on the *quality* of materials for the purpose of reuse is not included in the current scope of work.

MATERIALS AND METHODS

Economic feasibility analysis

The use of the proposed high-frequency induction heating mechanism developed in this study on current construction may not allow the reuse of demolished materials as building components, but instead require them to be crushed, and this extra work prior to any re-use must be considered in the economic evaluation. Consequently, the economic feasibility of reinforcing steel recovery from RC components demolished with high-frequency induction heating is determined during the period right after the component is removed from the structure until the constituent materials are removed from the site.

Analysis subject

The economic analysis is conducted on a hypothetical subject structure three-stories tall with a total area of 495 m^2 (165 m^2 × 3 stories)

-Wall: (3 × 2.5 m unit): 52 pcs

-Slab: (3 × 2.5 m unit): 27 pcs

-Column: 12 pcs

-Eaves: 12 pcs

Total demolished volume

-Wall: (3 × 2.5 m unit): 58.5 m^3

-Slab: (3 × 2.5 m unit): 40.5 m^3

-Column: 2.7 m^3

-Eaves: 6.24 m^3

Analysis Scope

The working conditions of the proposed system and the variables considered in the analysis are as follows. The induction heating mechanism is assumed to be applied ubiquitously and used to separate steel from concrete. For RC components, each targeted area is heated for 3 minutes per cycle regardless of the area of the component to be demolished. It is assumed that it takes an average of 5 minutes of crushing to separate steel from concrete, based on the preliminary experiment results of Lim et al. [1].

The current analysis assumes the induction heating apparatus consists of either a bifilar coil with a diameter of 120 mm, a rectangular coil of 480 mm× 480 mm for slabs, 600 mm × 380 mm for the columns, or 400 mm× 580 mm for the eaves. All coils were assumed to operate at a 10-kW output. The results of the analysis using these different components were compared with results using a crusher and a large breaker. The work time required by the different coils used is shown in Table 1 and Table 2.

Table 1: Work time for each demolished component using an induction heating method with a 120-mm bifilar coil

Component	Size (m) (W×D×H)	Quantity	Number of heating cycles	Component work time (min)	Total work time (h)	Required resources for unit time		
						Water Used (L)	Power	Number of Persons
Wall	3.0×2.5×0.15	52	83	664	575.5	1080	3 phase 00 V×18 min	2
Column	0.3×0.3×2.5	12	68	544	108.8	72	3 phase 00 V×12 min	2
Beam	0.2×0.2×13	12	40	320	64.0	108	3 phase 00 V×18 min	2
Slab	3.0×2.5×0.2	27	83	664	298.8	1080	3 phase 00 V×18 min	2

Table 2: Work time for each demolished component in target structure using induction heating method with rectangular coils.

Component	Size (m) (W×D×H)	Quantity	Number of heating cycles	Component work time (min)	Total work time (h)	Required resources for unit time		
						Water Used (L)	Power	Number of Persons
Wall	3×2.5×0.15	52	6	48	41.6	1080	3 phase 00 V×18 min	2
Column	0.3×0.3×2.5	12	16	128	25.6	72	3 phase 00 V×12 min	2
Beam	0.2×0.2×13	12	64	512	102.4	108	3 phase 00 V×18 min	2
Slab	3×2.5×0.2	27	6	48	21.6	1080	3 phase 00 V×18 min	2

RESULTS

Demolition cost for a conventional crusher

Costs for separating RC components using a crusher were calculated using a standard estimation system as shown in Table 3.

Table 3: Demolition cost using a conventional crusher

Calculation Basis	Material Cost	Labor Cost	Expense	Total
1. Machine Crushing				
Excavator (1.00 ㎥): 82,959/3.50 ㎥/h = 23,702.5	10,791	6,274	6,638	23,703
Crusher (pulveriser, 1.00 ㎥): 15,025/3.50 ㎥/h = 4,292.8			4,293	4,293
2. Labor Cost				
Regular worker : 74,008 × 0.08 persons = 5,920.6		5,921		5,921
Other materials cost (3 % of labor cost): 8,222.4×3/100 = 246.6	247			247
3. Total Transportation Cost (handcart D = 20 m) V = 2500 m/h, T = 450 min, D = 20 m, t1 = 5 min, rt = 2400 kg/m^3 N = (2,500 m/h × 450 min) / (120 × 20 m + 2,500 m/h × 5 min) = 75.503 times/person				
q2 = 75.503 times/person × 250 kg = 18,875.75 kg/person				
Q = 18,875.75 kg/person / 2,400 kg/㎥ = 7.865 ㎥/person				
∴ regular worker : 74,008 × 2 persons / 7.865 ㎥/person = 18,819.5		18,820		18,820
◈ Cost of demolition using concrete crusher, per ㎥	**11,038**	**31,465**	**10,931**	**53,434**

Demolition cost for a conventional large breaker

Costs for separating RC components using a large breaker were calculated using a standard estimation system as shown in Table 4.

Table 4: Demolition cost using a conventional large breaker

Calculation Basis	Material Cost	Labor Cost	Expense	Total
1. Machine Crushing (Work Capacity Q = (1.40 ㎥ +2.70 ㎥) / 2 = 2.05 ㎥/h)				
Excavator (0.7 ㎥)	10,420	10,711	9,249	30,381
Large Breaker (0.70 ㎥)			4,381	4,381
Wear and Tear Allowance	1,229			1,229
2. Labor Cost				
Work assistance (regular worker) : 74,008 ×v0.08 person ÷ 8 h ÷ 2.05 ㎥/h = 4,512.6		4,513		4,513

3. Total Transportation Cost (handcart D = 20 m) V = 2500 m/h, T = 450 min, D = 20 m, t1 = 5 min, rt = 2400 ㎏/㎥ N = (2,500 m/h × 450 min) / (120 × 20 m + 2,500 m/h × 5 min) = 75.503 times/person q2 = 75.503 times/person × 250 ㎏ = 18,875.75 ㎏/person Q = 18,875.75 ㎏/person / 2,400 ㎏/㎥ = 7.865 ㎥/person ∴ regular worker : 74,008 × 2 persons / 7.865 ㎥/person = 18,819.5		18,820		18,820
◈ Cost of demolition using large breaker, per ㎥	**11,649**	**34,044**	**13,630**	**59,323**

Demolition cost for induction heating with a 120 mm bifilar coil

Costs for separating RC components using induction heating were calculated using a standard estimation system as shown in Table 5.

Table 5: Demolition cost using induction heating with a 120-mm bifilar coil

Calculation Basis	Material Cost	Labor Cost	Expense	Total
1. Equipment Expenses - purchasing cost : 5,000,000 × 14.564 \ = 72,820,000 - depreciation cost : 1,125 / 107 = 0.0001125 - repair cost : 563 / 10107 = 0.0000563 - maintenance cost : 606 / 10107 = 0.0000606 - hourly equipment cost : 16,705/h → 72,820,000 × (0.0001125 + 0.0000563 + 0.0000606)			16,705	16,705
2. Electricity Cost - hourly consumption rate : 9.6 kW - hourly electricity cost : 79 × 9.6 kW = 758.4/h			758	758
3. Water Cost - water tank (5,500 L): 44,484/h	19,193	17,468	7,823	44,484
4. Labor Cost - regular machine worker: 75,660/day/person ÷ 8 h = 9,458/h - regular worker: 74,008/day/person ÷ 8 h × 5 persons = 46,255/h - hourly labor cost: 55,713/h		37,211		37,211
◈ Structure demolition cost using induction heating (\/ h)	19,193	54,679	25,648	99,158
◈ hourly cost → cost per unit volume (㎥) **1047 h/108 ㎥ = 9.694 h/㎥**	**186,065**	**530,083**	**245,134**	**961,282**

Demolition Cost for induction heating with rectangular coils.

Costs for separating RC components using induction heating with rectangular coils (480 mm× 480 mm for slabs, 600 mm × 380 mm for the columns, or 400 mm× 580 mm for the eaves) are shown in Table 6.

Table 6: Demolition cost using induction heating with rectangular coils

Calculation Basis	Material Cost	Labor Cost	Expense	Total
1. Equipment Expenses - purchasing cost：5,000,000 × 14.564 \ = 72,820,000 - depreciation cost：1,125 / 107 = 0.0001125 - repair cost：563 / 10107 = 0.0000563 - maintenance cost: 606 / 10107 = 0.0000606 - hourly equipment cost：16,705/h → 72,820,000 × (0.0001125 + 0.0000563 + 0.0000606)			16,705	16,705
2. Electricity Cost - hourly consumption rate：9.6 kW - hourly electricity cost：79 × 9.6 kW = 758.4/h			758	758
3. Water Cost - water tank (5,500 L): 44,484/h	19,193	17,468	7,823	44,484
4. Labor Cost - regular machine worker: 75,660/day/person ÷ 8 h = 9,458/h - regular worker: 74,008/day/person ÷ 8 h × 5 persons = 46,255/h - hourly labor cost: 55,713/h		37,211		37,211
◈ Structure demolition cost using induction heating (\/h)	19,193	54,679	25,648	99,158
◈ hourly cost → cost per unit volume (㎥) **1047 h/108 ㎥ = 9.694 h/㎥**	**33,979**	**96,802**	**44,766**	**175,546**

Demolition Cost Comparison

Table 7 compares the costs calculated to separate the RC components of the subject structure using the different types of equipment considered. Table 8 compares the required time periods to separate the RC components using the various methods in units of days.

Table 7: Comparison of RC separation costs (based on direct construction cost)

Equipment Cost	Induction Heater (120 mm coil)	Induction Heater (rectangular coil)	**Crusher**	Large Breaker
Prime cost per unit volume (㎥)	961,282	175,546	**53,434**	59,323
Total Cost	**103,818,456**	**18,958,968**	**5,770,872**	**6,406,884**
Comparison with Induction Heater	100 %	18.262 %	**5.559 %**	6.171 %

Table 8: Comparison of time period required to separate RC components*

Equipment / Cost	Induction Heater (120 mm coil)	Induction Heater (rectangular coil)	**Crusher**	Large Breaker
Prime cost per unit volume (㎥)	0.103 m^3/h	0.565 m^3/h	**4.2928 m^3/h**	2.05 m^3/h
Total Cost	1047 h	191.2 h	**25.144 h**	52.653 h
Comparison with Induction Heater	43.67 day	7.96 day	**1.05 day**	2.19 day

*Values shown for a total demolished volume of 10.94 m^3

CONCLUSIONS

This study evaluated the economic feasibility of demolishing RC components using high-frequency induction heating. A previous analysis of the demolition costs of a simulated structure demonstrated that the proposed induction heating method offered better economic performance than existing structural demolition techniques. However, these projected results were obtained under the assumption that the results from specimen tests in the laboratory environment would be applicable when analyzed for the demolition of a real, life-size structure. There is a possibility that this assumption could result in a distorted economic feasibility analysis. The application of this method to real structures has the very real possibility of yielding different results than those in this study, and may conclude that the proposed method is not actually economically feasible.

As there is currently there is no system to regulate the reuse of full structural components, when demolishing any concrete structure or component, the separation of reinforcing steel and concrete is required before anything can be reused. An economic feasibility analysis was done to determine the costs associated with separating reinforcing steel from concrete on site using the proposed induction heating method. The results indicated that the proposed method was over 90 % less efficient than more conventional methods, such as using a crusher or a large breaker.

Moreover, the comparative analysis between different shapes and configurations of 10 kW output coils demonstrated that rectangular coils adapted to their target member were approximately 80 % more economical than using a standard circular bifilar coil. Although the rectangular coil was still approximately 12 % less economical than using a crusher or a large breaker, the reduction in dust and pollutants could be considered to counterbalance, to a certain extent, such an increase in cost. However, in terms of time, a critical consideration in construction, the induction heating method for extracting reinforcing steel required approximately 5 days more than a crusher or a large breaker. Thus, it would be more economical to use conventional methods alone or simultaneously with high-frequency induction heating to separate reinforcing steel and concrete in demolished material. Again, it should be noted that this economic feasibility analysis relies upon results from the current theoretical study and lab-scale specimen tests, and thus cannot guarantee reliability of the results. Because of this need to improve reliability, a prototype induction heating demolition system must be developed to evaluate the real-world applicability of the system to structures, with the aim of defining the practical and economic usage of the proposed system. Once the prototype is in use and generating data from demolishing real-world structures, an economic feasibility analysis must be conducted once again in order improve the reliability of the results.

It is important to note that demolition using induction heating is conducted in multiple stages, unlike techniques using conventional crushers to demolish an entire structure in a single pass within a short period. As a result, the comparison of the proposed induction heating technique with any single conventional technique can create discrepancies in construction periods. Still, while some projects can rely on crushers to minimize the construction periods, or to take advantage of large areas for equipment to demolish everything uniformly, induction heating can be applied to sites without access for heavy equipment, sites undergoing partial maintenance and strengthening work, or sites that require reduced pollutant factors such as dust. If these advantages are considered when evaluating the applicability of induction heating demolition to a given site, the benefits of the system can be optimized.

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REFERENCES

[1] Myungkwan Lim, Heesup Choi, Hyeonggil Choi, Ryoma Kitagaki & Takahumi Noguchi, 2014, Development of Eco-friendly Deconstruction Technologies for Recycling Construction Waste,

Journal of Environmental Protection, v. 5, No. 7, Doi: 10.4236/jep.2014.57066

[2] Roberto Boccauthor, Arthur Hanna, The Global Energy Architecture Performance Index Report. World Economic Forum, 2014.

[3] Robert, W. and Messler, J.R., oining of Materials and Structures: From Pragmatic Process to Enabling Technology. Elsevier Inc., Amsterdam, 2004

[4] Gatta, D., Generation and Management of Construction and Demolition Waste in Greece: An Existing Challenge. Resources, Conservation and Recycling, 2003; Volume 40, pp. 81-91. http://dx.doi.org/10.1016/S0921-3449(03)00035-1

[5] Mizutani, R. and Yoshikai, S., A New Demolition Method for Tall Building. Kajima Cut & Take down Method. CTBUH Journal, Volume 5, 2011

[6] Sealey, B.J., Phillips, P.S. and Hill, G.J., Waste Management Issues for the UK Ready-Mixed Concrete Industry. Resources. Conservation and Recycling, 2011, Volume 32, pp. 321-324. http://dx.doi.org/10.1016/S0921-3449(01)00069-6

[7] Uttam, K. and Balfors, B., 9-Green Public Procurement (GPP) of Construction and Building Materials. Eco-Efficient Construction and Building Materials, Life Cycle Assessment (LCA), Eco-

[8] Labelling and Case Studies, 2014; pp. 166-195. http://dx.doi.org/10.1533/9780857097729.1.166

[9] Sthiannopkao, S. and Wong, M.H., Handling E-Waste in Developed and Developing Countries: Initiatives, Practices, and Consequences. Science of The Total Environment, 2013; Volume 463-

[10] 464, pp. 1147-1153. http://dx.doi.org/10.1016/j.scitotenv.2012.06.088

[11] Myungkwan Lim, Development of Eco-Friendly Deconstruction Technologies for Recycling Construction Waste, Journal of Environmental Protection, 2014; Volume 5, No.7, pp. 647-661 http://dx.doi.org/10.4236/jep.2014.57066

[12] Schneider, U., Properties of Materials at High Temperatures-Concrete,2nd edn, RILEM Report, Gesamthochschule Kassel, Germany, 1986

[13] Eurocode 2 : Design of concrete structures-Part 1-2:General rules-Structural fire design, BSI, 2004, pp. 26~29

[14] T. Z. Harmathy, Fire Safety Design and Concrete, Longman Scientific & Technical, 1993

[15] Sun-Jin Han, Degradation of flexural strength in reinforced concrete members caused by steel corrosion, 2014; Volume. 54, pp. 572–583

[16] ASTM C 234, Standard Test Method for Comparing Concrete on the basis of the bond Developed with Reinforced Steel, ASTM. 1991