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Economic Feasibility of the Induction Heating Method for Dismantling Structures: Analysis of Direct Construction Cost based on Required Demolition Equipment

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Abstract

Recently, an emphasis on reduction, reuse, and recycling has resulted in a consideration of the disassembly properties of various materials. The building industry is no exception, where disassembly properties have become an important structural design element. In this study, the use of an induction heating method as a reinforced concrete demolition technology is evaluated by an economic feasibility analysis of the demolition process cost when using the proposed induction heating method against the cost when using more conventional crushers or breakers. The results of the analysis indicate that the proposed method offers superior economic performance over existing structural demolition methods.

Keywords: reinforced concrete, demolition, induction heating, economic feasibility

INTRODUCTION

Recycling of construction waste has become a priority in many countries. In Japan, the construction recycling act was enacted in May 2000, and enforced from 2002. In Korea, a basic plan for building waste recycling was established with separating demolition mandated. However, the current “demolish first, separate later” approach only provides demolition efficiency when the subsequent issues related to recycling the various dismantled by-products are not considered. This “demolish first, separate later” approach effectively pushes many of the demolition costs further down the recycling process.

Because of this unbalanced cost, it is necessary to change the predominant demolition method used in the industry to a “separate first, demolish later” approach (hereafter referred to as “separation demolition”) that facilitates later recycling of the dismantled by-products. However, the use of separating demolition changes the cost of demolition significantly, thus there is a need for a comprehensive analysis of the economic feasibility of separation demolition methods.

One of the separation demolition methods currently under development for concrete structures utilizes induction heating of the reinforcement cast inside concrete member. In this paper, the economic feasibility of the induction heating method for separating demolition of concrete structures is analyzed and compared to more conventional methods for demolition.

MEANS AND METHODS

Overview of the economic feasibility analysis

In addition to the direct economic benefits of the proposed demolition method, such as cost savings and the reclamation of high-quality recycled aggregate, a reduction in social cost is expected from lower environmental impact. However, it is difficult to determine all the incurred economic and social expenses of proposed or exiting demolition methods this early in the research stage. In order to provide a preliminary evaluation of the proposed induction heating demolition method, an analysis was conducted identify only the potential direct economic characteristics of the proposed method, as the current research is limited to the outcome of small-scale, laboratory experiments.

The economic feasibility study in this paper was conducted by investigating and comparing the cost of demolition performed using existing demolition methods and using induction heating (assuming the proposed method is completely developed). However, cost reductions and improved economic value resulting from anticipated benefits of the proposed demolition method, such as higher quality recycled aggregates and lower environmental impact (such as dust and noise reduction) were not considered in the present analysis.

Target and scope of the economic feasibility analysis

The induction heating method can only be used to demolish reinforced concrete structures. As it would be difficult to conduct an economic feasibility analysis using all currently extant civil and building structures, the current analysis is performed using the assumed reinforced concrete building structure described in Section 3.1.

Target structure

The proposed target structure for analysis is a three-story building constructed of reinforced concrete with the geometric properties given below:

Total floor area of building: 495 ㎡ (165 ㎡ × 3 stories)

- Building area: 165 ㎡ (15 m × 11 m)
- Slab thickness: 200 mm
- Columns (four per floor): 0.3 m × 0.3 m × 2.5 m (main reinforcement: four D25 bars)
- Girders (four per floor): two at 0.2 m × 0.2 m × 15 m and two at 0.2 m × 0.2 m × 11 m (main reinforcement: four D25 bars)
- Story height: 2.5 m
- External wall area (per story): 130 ㎡ (thickness: 150 mm)

Analysis scope

The economic feasibility analysis in the present study was conducted by comparing the cost of demolition with the proposed induction heating method with the demolition costs of using crushers and breakers, which currently represent the typical demolition methods used in the “demolition first separation later” approach. Figure 1 shows examples of a crusher, a large breaker, and a high frequency induction heating device, the last of which is the target of the present research and development.

Assumptions and variables for economic feasibility analysis

The demolition of structures utilizing the induction heating method currently being developed is not yet applicable to full-size structures outside of the laboratory environment. As a result, it is necessary to assume an amount of required work, and therefore cost, to demolish an actual structure based on the current progress of the induction heating method development. Analysis of the economic feasibility of methods in the research stage cannot be conducted with cost data accumulated through the application of actual equipment, meaning that assumed cost values for each element, such as manufacturing cost, life expectancy, and the annual number of work days, must be assumed before they can be applied in the economic analysis.

Demolition work assumption when using the induction heating method

Structural demolition with induction heating is a technology for disassembling and removing concrete members from structures sequentially by applying induction heating to the surface of members and joints in a structure. The ultimate aim of the induction heating method is to cut out the rebar exposed by the effects of induction heating, enabling the removal of the member. However, tests in the current research stage have determined that the use of only induction heating rarely exposes the rebar sufficiently to be cut, requiring the inclusion of the additional labor cost to expose the rebar in the calculation.

The scope of work that can be performed in a single heating attempt is limited according to power and coil type of the induction heating device regardless of the work order. Therefore, unit work amounts for demolition in each area of the structure were established as presented in Table 1, allowing the subsequent calculation of a total work amount and time for the target structure demolition.

(a) Crusher (b) Large breaker (c) High frequency induction heating device

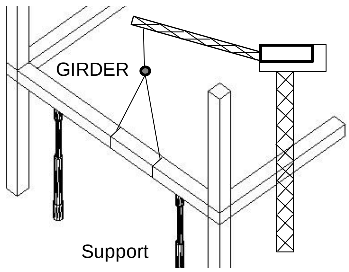
Figure 1: Demolition devices considered in economic feasibility analysis

Table 1: Unit task amount and total work amount for 3-story building demolition

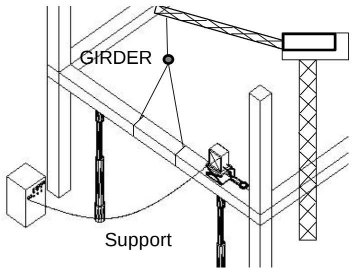
Demolition target	Total work	Unit task	Unit task time	Total no. of tasks	Total Work time	Required resource per unit time		
						Water	Power	Laborer
Wall	~390 ㎡	3m×2.5m	27 min.	52 times	Around 1,404 min.	1080 L	Three-phase 00V × 18 min.	Two
Column	12 pcs	1 pcs	17 min.	12 times	Around 204 min.	72 L	Three-phase 00V × 12 min.	Two
Girder	12 pcs	1 pcs	25 min.	12 times	Around 300 min.	108 L	Three-phase 00V × 18 min.	Two
Slab	~495 ㎡	3 ×2.5 m	27 min.	66 times	Around 1,782min.	1080 L	Three-phase 00V × 18 min.	Two

Demolition process using the induction heating method

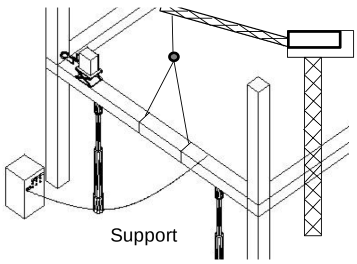
The process for reinforced concrete member demolition using the high frequency induction heating method is applied to a hypothetical site in Fig. 2. First, the lower portion of the member to be removed by induction heating is fixed using lifting equipment and supports (Fig. 2a). Then, the member to be separated is heated using a high frequency induction heating device (Figs. 2b and c) and the rebar is exposed by impacting the cracked area that develops (Fig. 2d). The exposed rebar is then cut (Fig. 2e) and the member is removed (Fig. 2f).



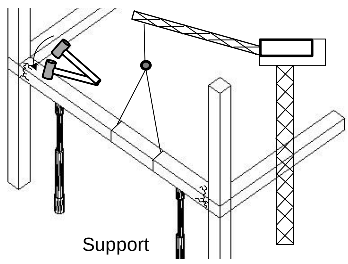
(a) Installation work



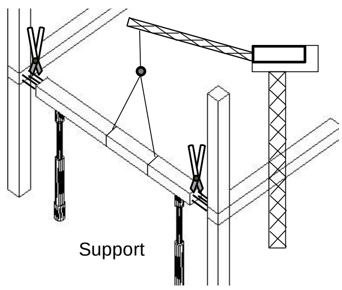
(b) High frequency induction heating device (1)



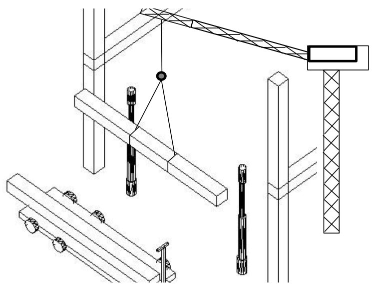
(c) High frequency induction heating device (2)



(d) Hitting and separating



(e) Rebar cut



(f) Member collection

Figure 2: Demolition process of a reinforced concrete member using the high-frequency induction heating method

Analysis variables

The manufacturing cost of the proposed equipment used in the present economic feasibility analysis was set to approximately KRW 70 million, based on the price of the equipment when used in other industries. The number of laborers required by the proposed method was calculated to be seven: one general machinery operator to operate the induction heating device, one assistant laborer, two concrete breakers to expose rebar (general laborers), one crane operator, and two lifting workers for handling the removed members. To calculate the working expense of the induction heating device, the working expense of an AC welding machine was used as it is similar. The other equipment required for the proposed demolition method consists of a 5,500 L water tank and a truck-mounted crane. The unit cost estimates for building construction as made by the Korea Institute of Construction Technology was employed as a basis of demolition work expenses.

RESULTS

Demolition cost using the existing crusher method

The cost of building structure removal using a crusher was calculated based on the unit cost estimation presented in Table 2.

Table 2: Demolition cost using a crusher (in KRW, based on the 2011unit cost estimation of building construction)

Calculation basis	Material cost	Labor cost	Expense	Sum
1. Machinery				
Excavator (1.00 ㎥) : 82,959/3.50 ㎥/hr = 23,702.5	10,791	6,274	6,638	23,703
Crusher (pulverizer, 1.00 ㎥) : 15,025/3.50 ㎥/hr = 4,292.8			4,293	4,293
2. Labor cost				
Welder: 115,090 × 0.02 persons = 2,301.8		2,302		2,302
General laborer: 74,008 × 0.08 persons = 5,920.6		5,921		5,921
Miscellaneous material cost (3% of labor cost): 8,222.4 × 3/100 = 246.6	247			247
3. Small freight cost (handcart D = 20m)				
V = 2500 m/hr, T = 450 min, D = 20 m, t1 = 5 min, rt = 2400 ㎏/㎥				
N = (2,500 m/hr ×450 min) / (120×20 m +2,500 m/hr × 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				
∴ General laborer: 74,008 × 2 person/7.865 ㎥/person = 18,819.5		18,820		18,820
◈ Total cost of demolition with concrete crusher, per ㎥	**11,038**	**33,317**	**10,931**	**55,286**

Demolition cost using the existing breaker method

The cost of building structure removal using a large breaker was calculated based on the unit cost estimation presented in Table 3.

Table 3: Demolition cost using a large breaker (in KRW, based on the 2011 unit cost estimation of building construction)

Calculation basis	Material cost	Labor cost	Expense	Sum
1. Machinery (work capacity Q = (1.40 m^3 +2.70 m^3) / 2 = 2.05 m^3 /hr)	10,420	10,711	9,249	30,381
Excavator (0.7 m^3)			4,381	4,381
Large breaker (0.70 m^3)	1,229			1,229
2. Labor cost Work assistant (General laborer): 74,008×0.08 person ÷ 8hr ÷ 2.05 m^3/hr = 4,512.6		4,513		4,513
3. Rebar cut and cutter work expense				
Acetylene: 10,000 × 0.23 kg = 2,300	2,300			2,300
Oxygen: 2.167 × 680 L = 1,473.5	1,474			1,474
Welder: 115,090 × 0.12 persons = 13,810.8		13,811		13,811
Equipment expense: 13,810.8 × 1/100 = 138.1	138			138
4. Small freight cost (handcart D = 20 m) V = 2500 m/hr T = 450 min, D = 20m, t1 = 5 min, rt = 2400 kg/m^3 N = (2,500 m/hr. × 450 min) / (120 × 20m + 2,500 m/hr. × 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/m^3 = 7.865 m^3/person ∴ General laborer: 74,008 × 2 person/7.865 m^3/person = 18,819.5		18,820		18,820
◈ Total cost of demolition with concrete breaker, per m^3	**15,561**	**47,855**	**13,630**	**77,046**

Demolition cost using induction heating

To determine the cost of structure demolition using induction heating, costs were calculated based on the unit tasks assumed in Table 1 to produce the costs shown in Table 4.

Table 4: Demolition cost using the high-frequency induction heating method
(in KRW, based on the 2011 unit cost estimation of building construction)

Calculation basis	Material cost	Labor cost	Expense	Sum
1. Machinery				
- Purchase price: 5,000,000 × 14.564 = 72,820,000				
- Redemption cost: 1,125 / 107 = 0.0001125				
- Maintenance cost: 563 / 10107 = 0.0000563				
- Management cost: 606 / 10107 = 0.0000606				
- Equipment cost per hour: 16,705/hr				
→ 72,820,000 × (0.0001125+0.0000563+0.0000606)			16,705	16,705
2. Electricity expense				
- Hourly usage: 9.6 kW				
- Electricity charge per hour: 79 × 9.6 kW = 758.4/hr			758	758
3. Water cost				
- Water tank (5,500 L) : 44,484/hr	19,193	17,468	7,823	44,484
4. Labor cost				
- General machinery operator: 75,660/day/person ÷ 8 hr = 9,458/hr		9,458		9,458
- General laborer: 74,008/day/person ÷ 8hr × 5 persons = 46,255/hr		46,255		46,255
5. Lifting cost				
- Hourly charge of truck-mounted crane (5 ton): 10,362/hr			10,362	10,362
- Fuel cost 5.1 L + miscellaneous material 1.02 L = 10,404/hr	10,404			10,404
- General machinery operator 9,458/hr		9,458		9,458
◈ Total cost of demolition using induction heating method (per hr)	29,597	82,639	35,648	147,884
◈ Hourly unit cost → converted to unit cost per unit volume (㎥)	**10,835**	**30,252**	**13,049**	**54,136**
61.5 hr / 168 ㎥ = 0.36607 hr/㎥				

The comparative economic feasibility of the high-frequency induction heating demolition of reinforced concrete members is presented in Table 5.

Table 5: Comparison of demolition cost (based on direct construction cost)

Method / Cost	**Induction heating**	Crusher	Large breaker	Notes
Cost per unit volume (㎥)	**54,136**	55,286	77,046	
Total expense (KRW)	**9,094,866**	**9,288,048**	**12,943,728**	For 168 ㎥ demolition
Compared to induction heating	**100 %**	102.12 %	142.32 %	

CONCLUSIONS

The economic feasibility analysis for the target structure demolition indicates that the proposed induction heating method is less costly than existing structure demolition methods. However, this result is merely an estimate based on the ideal application of the proposed demolition method as observed in current laboratory research. As such, these estimates may distort the economic analysis and resulting comparison. As the induction heating demolition method is developed and its associated costs are better quantified, the use of induction heating demolition could prove less feasible economically when compared to current methods.

Note that although the cost of using induction heating may at some point prove greater than that of using existing methods, the induction heating method has additional benefits, such as improvements in the quality of recycled aggregates and reductions in dust and noise, which may offset any increase in cost. This remains to be seen: the current analysis of the economic feasibility of induction heating demolition based on experimental results in the laboratory environment and theoretical study do not guarantee any final result at this time.

To produce more reliable economic cost data, it is necessary to develop a prototype induction heating demolition system. This prototype will assist researchers in determining the performance requirements and applicability limitations of this method on actual demolition sites prior to any attempt to commercialize the equipment and method. These prototype tests will also aid researchers in refining the understanding of the economic performance of the proposed induction heating demolition method when used on full-size structures.

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