2. Estimation and Recycling Management of Concrete Demolition in Urban Areas

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Abstract: This research aims to develop a systematic method for estimating the amount of demolished concrete in urban areas, and to evaluate and compare several recycling scenarios. First, the amount of demolished concrete from buildings and urban infrastructure is estimated based on statistical data and using a geographical information system. Then, through a case study, the economical efficiency of recycling demolished concrete in road subgrades or as new concrete aggregates is evaluated, as well as the case of dumping the demolished concrete in landfill.

1. Introduction

Recently, several problems related to the environmental impact of concrete structures during their lifecycle have been studied such as exhaustion of limestone and aggregates resources, CO₂ emission from the cement industry, and pollution resulting from the uncontrolled dumping of concrete demolition wastes. Especially, the necessity of recycling concrete waste resulting from the demolition of concrete structures has been emphasized.)1).

For the successful recycling of concrete aggregates resulting from the demolition of concrete structures, the management of this concrete is a prerequisite. In the case of public projects in Japan, a government official supervises the recycling or disposal of the concrete waste. However, in the case of the demolition of private buildings, the amount of resulting concrete waste and its processing method are not controlled at present.

In order to optimize the recycling plan of concrete waste, it is necessary to know the total future amount of demolished concrete. The estimation of this amount is possible based on the information of available concrete structures. In this paper, a method for estimating the amount of concrete waste expected to appear in near future in Nagoya City from private buildings and roads based on the information of the present buildings and roads, as the main source of concrete from public structures, is suggested. Then, a method for comparing the costs of different short-term recycling methods and the disposal of the concrete is discussed based on a case study in Nagoya City, Japan. In addition, a GIS prototype system is developed to exploit the spatial analysis capabilities of GIS in the estimation of concrete demolition weight and the evaluation of recycling plans. This system is useful for both short-term and long-term concrete recycling planning as shown in Fig. 1.

2. Estimating the Amount of Concrete Demolition Wastes

In order to estimate the amount of concrete demolition waste, a waste generation model has been developed and a database of the concrete structures has been built. Previous approaches to estimate the amount of concrete demolition used the service life concept in a simple deterministic manner to calculate the total amount of concrete waste on the national level(3,6), estimating for example all concrete structures built 30 years ago will be demolished this year. In this paper, the amount of concrete per floor area(3,4,5), and the service life of the building(5) are estimated according to the usage and type of the building. Weibull probability distribution density function is used to calculate the probability of generating concrete waste from demolished buildings that attend the end of service life of the building.
The weight of concrete waste $W_{ps}(t)$ from buildings of usage type $p$ and structure type $s$ at year $t$ is estimated using Eq. (1):

$$W_{ps}(t) = \sum_{i} C_{ps}(t-i) \cdot f_{ps}(i)$$  \hspace{1cm} (1)

where $C_{ps}(t-i)$ is the weight of concrete resulting from demolishing buildings constructed at year $(t-i)$ of usage type $p$ and structure type $s$, and $f_{ps}(i)$ is the probability that the buildings will be demolished after $i$ years of its construction. This probability is assumed to follow the Weibull distribution density function. Then, the total weight of concrete waste at year $t$ can be calculated by Eq. (2):

$$W(t) = \sum_{p} \sum_{s} W_{ps}(t)$$  \hspace{1cm} (2)

The estimation method explained above requires a large volume of data about the buildings in an urban area. GIS is used in this research to maintain these data in its spatial database and to perform network analysis and other spatial analyses as will be explained later. The data of Nagoya City are used including the landuse data, administrative areas' borders of districts, and the number of buildings of a specific type within each district. As for the landuse data, the data of the Japanese Geographical Survey Institute\(^8\) is used. Fig. 2 shows a part of the landuse data of Nagoya City. This data is 10m mesh raster data of landuse classified as forest, mountain area, housing, landuse are further classified into more detailed types. The GIS software used in this research is ARC/INFO\(^9\).

Fig. 3 shows the polygons representing the administrative boundaries of Chikusa Ward in Nagoya City as displayed using ARC/INFO. For each administrative area, the number of buildings of each combination of structure type, construction period, number of floors, and usage is added as attributes of that area. The structure types considered here are timber, light steel, steel, RC and SRC structures. Construction period is classified into four periods corresponding to major changes in design specifications: before 1964, 1965-1970, 1971-1981, and after 1982. The number of floors is classified into three ranges: 1-2 floors, 3-6 floors, and 7 or more floors. Finally, the usage of the building can be private housing, public housing, housing combined with work place, shopping, hospital, hotel, factory, store, office, theatre, movie theatre, and others.

Problems encountered in manipulating the GIS data used in this research can be summarized as follows: (1) Data from different sources are difficult to relate to each other. Especially when the coordinate system and projection method are not clearly defined; (2) In some cases, the borders of administrative areas are not consistent in different sets of data, e.g. the border of an administrative area may change over time. Fig. 4 shows the result of estimation of concrete waste.
weight based on the previous data of Chikusa Ward. The reason of the decrease in the estimated weight of concrete waste after 2006 is that there is no reliable data of the concrete used after 1992 and that the number of buildings in Chikusa Ward did not increase after 1980.

3. Estimation of Concrete Waste from Civil Infrastructures

Since, as shown in Fig. 5, the major part of the concrete used in urban infrastructures is that used in roads, roads with concrete pavement are considered in this research as representative of the concrete civil infrastructures. Generally speaking, road pavement can be classified into asphalt pavement with service life of 7-8 years, and concrete pavement with service life of 20-30 years. Although the concrete pavement is 3 to 5 times more expensive than asphalt pavement, it has been increasingly used in roads with high traffic volume in Nagoya City especially when building a common ditch under the road.

The Public Works Department of Nagoya City has in its road register\(^{12}\) the plan and cross sections of the roads including the width of the

\(^{a}\) Distribution at 1977
\(^{b}\) Distribution at 1992
Fig. 2 Example of Detailed Landuse 10m Mesh Data: Distribution of High-Rise Housing

\(^{a}\) Buildings Constructed before 1964
\(^{b}\) Buildings Constructed after 1982
Fig. 3 Number of Buildings at Each District of Chikusa Ward, Nagoya City
Estimation and Recycling Management of Concrete Demolition in Urban Areas

(a) Total Estimated Weight of Concrete Waste for Chikusa Ward
(b) Estimated Weight of Concrete Waste for Each Discrete at 1997

Fig. 4 Estimated Weight of Concrete

Fig. 5 Concrete Demand by Sector

Fig. 6 Example of Road Register Data

Fig. 7 Type of Pavement for Each Segment of the Designated National Road of Nagoya City Represented as GIS Data
Fig. 8 Recycling Flow of Concrete Waste

road and the type of the pavement, etc., as shown in Fig. 6. These data are not available yet in digital format. Therefore, in this research, the digital data of part of the designated national road in Nagoya City has been experimentally input to the GIS based on the detailed landuse data and the road register figures. Then, the weight of concrete waste \( W(t) \) at year \( t \) resulting from concrete pavement is estimated using the following equation

\[ W(t) = \sum_{i} V(t-i) \cdot f(i) \]  

where \( V(t-i) \) is the weight of concrete pavement constructed at year \( t-i \), and \( f(i) \) is the probability that the concrete pavement will be replaced after \( i \) years. This probability is assumed to follow the Weibull distribution density function. The parameters of this function are 25 years as the average service life and 5 years as the standard deviation\(^{13} \).

As in the case of buildings, it is desirable to have similar classification of the amount of concrete pavement according to the construction year, etc., within each administrative area so that costs of recycling methods can be compared considering the cost of shipping. However, since such detailed data of construction years are not available, the estimation of generated concrete waste was carried out for the whole area of Nagoya City.

The result of the estimation shows large difference of the amount of concrete waste generated every year. This is due to that only the concrete pavement of designated national roads is considered in this research. In fact, the area of this pavement is only 5% of the total concrete pavement in Nagoya City including the prefecture and local roads. It is expected that having more road pavement data in the GIS database will improve the quality of the estimation.

4. Evaluation of Concrete Recycling Methods

Four methods of processing concrete waste are considered in this research: (1) Roughly crushed, then dumped in landfill; (2) Finely crushed in intermediate processing facilities, then recycled as road subgrades etc.; (3) Finely crushed on site, then recycled as road subgrades; and (4) Finely crushed in intermediate processing facilities extracting only the aggregates that are then recycled.

Using the estimation methods discussed in sections 2 and 3, a GIS-based prototype system for estimating and evaluating the cost of each of the four processing methods of concrete waste is developed. Such a system should help in the following tasks: (1) Plans for new concrete waste processing facilities since it forecasts the future amount of concrete waste; (2) Selection of optimal recycling methods of available and future concrete structures; (3) Plans for new construction projects considering the possibility of using recycled concrete waste, and the associated costs; and (4) Optimal routing of the concrete waste from the demolition sites to the recycling sites or final disposal, and the optimal selection of the intermediate processing facilities. Having all the related data in the GIS database in addition to the network analysis capabilities of ARC/INFO facilitates this kind of optimization.

4.1 Cost of Recycling Methods

Fig. 8 shows the recycling flow of concrete wastes. The unit costs for each processing method are given in Eqs. (4)-(7) given below. Table 1 shows the meaning of each unit cost and its average value\(^{14,15} \).
1) Roughly crushed, then dumped in landfill.
   \[ C_1 = C_{c1} + C_{cf} + C_{tr} \]  

2) Finely crushed in intermediate processing facilities, then recycled as road subgrades.
   \[ C_2 = C_{c1} + C_{ip} + C_{rb} - C_{rb} + C_{tr} \]  

3) Finely crushed on site, then recycled as road subgrades.
   \[ C_3 = C_{c2} + C_{rb} - C_{ag} + C_{tr} \]  

4) Finely crushed in intermediate processing facilities, then recycled as aggregates.
   \[ C_4 = C_{c1} + C_{ip} + C_{ag} - C_{ag} + C_{tr} \]  

### 4.2 Case Study

The equations of unit costs introduced in the previous subsection are used to compare the costs of several recycling plans in a real case study. Fig. 9 shows the location of the concrete public housing buildings to be demolished, in addition to the routes extracted from the GIS based on the national road network and the locations of the concrete buildings to be demolished, the locations of seven recycling centers within Nagoya City, and a few final disposal sites in the suburb of the city. Although the road network data do not include local roads, it is considered that the data are enough to carry out the case study and to demonstrate the usefulness of the prototype system.

The recycled concrete can be used in two ways: as subgrades of the roadbed above a common ditch project, or as aggregates for low quality concrete. The recycling costs are calculated as shown in Eqs. (4)-(7) and according to the following conditions: (1) Concrete waste origin is a public housing complex of five floors RC buildings in Meito Ward east of Nagoya City with total floor area of 330 m²; (2) The weight of the concrete waste is 1.3 t/m² x 330 m² x 5 floors = 2145 t; (3) Recycled subgrades and aggregates destination is a construction project of common ditch in Kita Ward; (4) Intermediate processing facilities are available in Tenpaku Ward south of Nagoya; and (5) Final disposal site is in Seto City, northeast of Nagoya. Other secondary conditions are: (1) The capacity of the dump truck for shipping the concrete waste is 10 t; (2) The shipping shortest path is found on the designated national and general road network of Nagoya City using GIS as shown in Fig. 9; and (3) 46% of the weight of concrete waste can be recycled as aggregates.

Table 2 shows the results of unit cost calculations for each processing method. According to the calculated costs, among the four processing methods, the cost of the first processing method, disposing the concrete waste without recycling, is 60% cheaper than the other methods from the point of view of contractors. The cost of the other methods is almost the same, though the cost of recycling as aggregates is a little higher than that of recycling as subgrades. In addition, processing the subgrades on site is cheaper than at an intermediate facility due to the shipping cost. However, these costs are the direct costs that the contracting company will pay, and
other indirect costs and externalities such as the maintenance cost of the dumping site and the environmental impacts are not included in the calculations. Therefore, from the point of view of the social benefit, disposing the concrete waste without recycling is expected to be far from being an optimal solution. The case study showed clearly that the shipping distance largely influences recycling cost. Therefore, the need to select the optimal route for shipping the concrete waste and to select the optimal location for intermediate processing facilities was demonstrated.

One major step to encourage recycling and discourage landfill dumping is to use economic instruments such as imposing environmental taxes on dumping and on using virgin aggregates, or giving subsidies to construction projects that use recycled concrete. For example, in Denmark, the tax for dumping industrial solid wastes is about 2600 Yen/\text{t}^{16)} by applying this value in the previous case study, the cost of dumping becomes 9.56 million Yen, or about 1.5 times the average cost of recycling.

### 4.3 Other Issues Related to Concrete Recycling

The following issues are to be considered in future research:

1) Environmental tax: As explained earlier, introducing an environmental tax is expected to greatly effect the processing methods of concrete waste. However, before such tax can be established, there is a need for a detailed research regarding the reaction of the companies involved in concrete recycling, the environmental impact of concrete wastes, and the cost-benefit analysis of recycling.

2) Technical improvement and cost reduction of recycling methods: As shown in Table 2, intermediate processing of concrete waste costs about 90% of the total cost of recycling. Therefore, technical improvement and cost reduction of the intermediate processing

<table>
<thead>
<tr>
<th>Processing Scenarios</th>
<th>Processing Cost</th>
<th>Shipping Cost</th>
<th>Material Cost</th>
<th>Dumping Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Roughly crushed, then dumped in landfill</td>
<td>367</td>
<td>23</td>
<td>---</td>
<td>2</td>
<td>392</td>
</tr>
<tr>
<td>(2) Finely crushed in intermediate processing facilities, then recycled as road subgrades</td>
<td>667</td>
<td>40</td>
<td>-54</td>
<td>---</td>
<td>653</td>
</tr>
<tr>
<td>(3) Finely crushed on site, then recycled as road subgrades</td>
<td>689</td>
<td>17</td>
<td>-54</td>
<td>---</td>
<td>652</td>
</tr>
<tr>
<td>(4) Finely crushed in intermediate processing facilities, then recycled as aggregates</td>
<td>667</td>
<td>27</td>
<td>-37</td>
<td>---</td>
<td>657</td>
</tr>
</tbody>
</table>

### Table 1(a) Unit Cost of Each Recycling Process

<table>
<thead>
<tr>
<th>Cost</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Plate</td>
<td>Yen/100m³</td>
</tr>
<tr>
<td>Concrete Foundation</td>
<td>Yen/100m³</td>
</tr>
<tr>
<td>Rough Crushing Cost (C_{\text{r}})</td>
<td>7,500</td>
</tr>
<tr>
<td>Fine Crushing Cost (C_{\text{f}})</td>
<td>1,500</td>
</tr>
<tr>
<td>Intermediate Processing Cost (C_{\text{i}})</td>
<td>1,400</td>
</tr>
<tr>
<td>Shipping Cost (C_{\text{s}})</td>
<td>See Table 1(b)</td>
</tr>
<tr>
<td>Recycled Subgrades Cost (C_{\text{r}})</td>
<td>1,040</td>
</tr>
<tr>
<td>Virgin Subgrades Cost (C_{\text{v}})</td>
<td>1,290</td>
</tr>
<tr>
<td>Recycled Aggregates Cost (C_{\text{r}})</td>
<td>1,130</td>
</tr>
<tr>
<td>Virgin Aggregates Cost (C_{\text{v}})</td>
<td>1,500</td>
</tr>
<tr>
<td>Final Dumping Cost (C_{\text{d}})</td>
<td>600</td>
</tr>
</tbody>
</table>

### Table 1(b) Unit Shipping Cost

<table>
<thead>
<tr>
<th>Distance</th>
<th>Yen/10t\text{-km}</th>
</tr>
</thead>
<tbody>
<tr>
<td>10km</td>
<td>7,920</td>
</tr>
<tr>
<td>20km</td>
<td>10,420</td>
</tr>
<tr>
<td>30km</td>
<td>13,330</td>
</tr>
<tr>
<td>40km</td>
<td>15,830</td>
</tr>
<tr>
<td>50km</td>
<td>18,330</td>
</tr>
</tbody>
</table>

### Table 2 Cost Calculation for the Four Processing Scenarios (10,000 Yen)

<table>
<thead>
<tr>
<th>Processing Scenarios</th>
<th>Processing Cost</th>
<th>Shipping Cost</th>
<th>Material Cost</th>
<th>Dumping Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Roughly crushed, then dumped in landfill</td>
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<td>657</td>
</tr>
</tbody>
</table>

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methods are necessary in order to increase the competitiveness of recycled concrete.

3) Controlling the amount of concrete waste from the private sector: Considering that most of the concrete waste is generated from private buildings, the development of an optimal concrete waste recycling system without including the amount of concrete waste from the private sector is impossible. By controlling concrete waste from these buildings, optimally locating the intermediate processing facilities and reducing the cost of recycling are expected to become more feasible.

4) Developing an information system for concrete waste recycling management: This system can help in selecting the recycling method of concrete waste, the location of intermediate processing facilities, the sites where recycled concrete will be used, etc. Developing such a system will not only reduce the cost of recycling, but also wide spreading the recycling of concrete waste. In addition, such a system will help in the long-term estimation of concrete waste amount and recycling plans, including the economic impact evaluation of different policies such as imposing an environmental tax on concrete waste dumping.

5. Conclusions

The following conclusions can be stated:

1) A method for estimating the amount of future concrete waste based on the data of urban structures was established.

2) A simple approach for calculating the costs of concrete waste recycling methods was proposed based on the unit costs. This approach is used to compare recycling methods in a case study.

3) The case study showed clearly that recycling cost is largely influenced by the shipping distance. Therefore, the need to select the optimal route for shipping the concrete waste and to select the optimal location for intermediate processing facilities was demonstrated.

4) The necessity and benefits of developing an information system for concrete waste recycling management were discussed, and a prototype system was developed that proved the usefulness of such a system.

Acknowledgment

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References