A STUDY ON THE LIFE-CYCLE FOR SELECTING A GRATING

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ABSTRACT: A gutter-shaped U grating is a facility that is installed at the sides of a road to provide pedestrians with a rainwater-free road. The previous studies on this facility focused mainly on the progress of the efforts that are being made to improve its performance and interception efficiency so as to prevent damages in regional areas due to the heavy rains caused by climate change. The studies on its maintenance, however, are still inadequate. Therefore, this study was conducted to analyze and compare the life cycle costs and performance evaluations of the steel and magic gratings, which are installed in apartments. The results of the study show that the replacement period and rate of gratings differ depending on where they are installed. The initial capital investment cost of a magic grating installed at a road where many vehicles pass is quite high, but in terms of its maintenance and entire-life-cycle costs, its total expenses are lower than those of a steel grating. The results of this study are expected to serve as preliminary data for the selection of an adequate grating that is suitable for particular places in the design phase of construction projects.

Keywords: Life-Cycle Cost, Grating, Economic Evaluation

1. INTRODUCTION

1.1 Research Background and Purpose

Domestic construction in Korea has shown fast growth due to the Five-Year Plan for Economic Development and the Five-year Plan for New Economic Development, among others. In the construction projects being undertaken nationwide, ground surfaces are replaced with concrete or asphalt, which are nonpermeable materials. The increase in the number of nonpermeable areas on ground surfaces also increases the frequency of the occurrence of floods when there are heavy rains, not to mention the temperature within the city.

As the direct and indirect damages from rainwater have been increasing, studies on rainwater drainage facilities have also been continuously undertaken. The past studies focused on the performance of rainwater inlets, their interception efficiency, and their efficiency according to their shape and constructability. Studies involving cost analysis, however, are still inadequate.

Therefore, this study was conducted to measure the economic efficiency of the grating of rainwater inlets, among the various rainwater drainage facilities, using life cycle cost (LCC) analysis.

1.2 Research Methodology and Procedures

Theoretical research was conducted to select the grating used in the gutter, and its economic efficiency was analyzed based on the collected data.

To execute the economic-efficiency analysis, the basic assumptions needed to calculate the LCC were determined. The LCC was calculated through the LCC techniques, based on the data collected after the implementation of the cost breakdown structure (CBS). Considering the basic assumptions and the variability and uncertainty of the cost data, sensitivity analysis was carried out through Monte Carlo simulation (MCS).

The present value (PV) was applied to all the costs required for the economic-efficiency analysis. Fig. 1 shows the diagrammatic flow of this research.

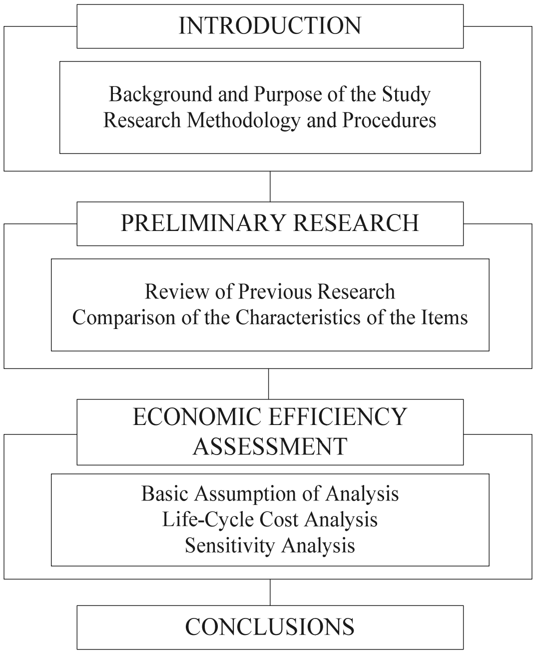

Fig. 1 Process Flow Diagram

2. PRELIMINARY RESEARCH

2.1 Rainwater Inlet in a Rainwater Drainage

A rainwater inlet is a facility that collects and lets the rainwater on public roads flow into the public sewage system constructed beneath the roads. The inlet is manufactured in round or quadrilateral shapes, with concrete or reinforced concrete, and its top consists of a grating. The grating plays the role of a cover for the water collection and drainage courses around buildings and roads. It is manufactured and constructed in customized sizes according to the height of the ground surface and the size of the rainwater inlet, to make the movement of people and vehicles smooth. It also refers to a constructed facility in a construction or an industrial site, and a facility that can be used as the footstep of the workers [2].

The inner width of a rainwater inlet is about 300-500 mm, and it is 800-1,000 mm deep. If it is too large, it will obstruct the traffic, and if it is too small, its maintenance, such as the removal of the soil, sand, and solids suspended from it, will become inconvenient.

2.2 Review of Previous Researches

A domestic study on gratings was performed only for rainwater inlets on roads. Due to the environmental changes, heavy rains frequently occur; as such, researches on rainwater treatment are in progress. They mostly focus, however, on the design of the rainwater inlets that will allow them to most effectively treat rainwater. The ideal size, shape, and intervals of the rainwater inlet were proposed in [4], based on the results of the experiment that was conducted on the changes in the width, vertical-section inclination, and cross-section inclination of roads.

The scale of inlets' rainwater drainage ability was analyzed in [3] by changing the shape of the entrance and the amount of the flow of the gutter in the rainwater inlets. The construction intervals of the rainwater inlets according to the road conditions were studied in [1] by measuring the interception efficiency according to the changes in the intervals of the rainwater inlets, through a rainwater experiment. The constructability of rainwater inlets, among various rainwater drainage facilities, and the characteristics of their maintenance according to their shapes, were analyzed in [2].

Such previous studies focused only on the rainwater drainage efficiency of rainwater inlets and not on the economic efficiency of inlets in consideration of their LCCs.

2.3 Comparison of the Characteristics of the Gratings for Rainwater Inlets

Table 1 compares and analyzes the performance of the two gratings needed for rainwater inlets, among the current rainwater drainage facilities [7]. Simply summarized, the existing grating facilities do not consider the weights of the vehicles that will pass over them, which results in a high probability that the grating will be damaged by the passage of vehicles over them. In constructing the grating, the convenience of pedestrians should be considered, as well as its role of draining rainwater. General steel gratings are satisfactory rainwater drainage facilities, but they make it difficult for children, the aged, and wheeled instruments to pass over them as their lattice gap is too wide. They thus expose people to the risk of injury. Magic gratings make up for the shortcomings of the existing general gratings. They also have smaller lattice gaps, making it easier for children or small-wheeled instruments to step on them. Moreover, as they are stronger due to the modified structure and shape of their lattice, they resist damage from the passage of heavy vehicles over them.

Table 1 Grating Performance Comparison

Classification	Magic Grating	Steel Grating
Safety	☐ As an innovative triangular structure, it is not slippery but is safe for people to walk on. ☐ The patent for the structure has been registered. ☐ Children, the aged, and vehicles with small wheels can safely pass over it as it is like a flat ground. ☐ It can carry heavier weights due to its triangular structure (realization of a highly durable grating).	☐ Its general rectangular structure may cause children or the aged to slip or be hurt while walking on it. ☐ It poses the danger of injury as the wheel of a vehicle or the foot of a child or an old person may fall into it. ☐ Vehicles can be easily damaged when they pass over it.
Major construction areas	☐ As it meets the safety standards of the Housing Performance Grade Indication System (21-1 of the Housing Act), it ensures safety if it is established at the entrance of apartments or schools.	☐ It is constructed in playgrounds and on streets in residential areas. As it is the early form of grating, it has been constructed in many sites.
Sewage	☐ It has improved sewage-processing ability as it clearly prevents the inflow of wastes, such as falling leaves. ☐ Its drainage ability is fair even during heavy rains.	☐ It has an inferior sewage-processing ability during heavy rains due to its weak ability to prevent wastes from flowing into it.
Cost	☐ It is relatively expensive. ☐ As it is very durable due to its triangular structure, its replacement cost is lower.	☐ It has a low initial construction cost. ☐ It has a higher replacement cost due to its frequent breakage owing to the passage of vehicles over it.
Relevant laws and compensation	☐ It is manufactured in compliance with the PL (Product Liability) Act. ☐ It complies with the regulations in the Traffic Minority Movement Convenience Improvement Act.	☐ It does not meet the PL Act standards. ☐ It does not comply with the regulations in the Traffic Minority Movement Convenience Improvement Act.

3. ECONOMIC EFFICIENCY ASSESSMENT

3.1 Research Methodology and Procedures

1) Selection of the Subject

The economic efficiency of the grating that is used for the U-shaped gutters within apartment complexes was measured in this study. The selected material was the magic grating with a triangular structure, which addresses the problems of the general lattice-type steel grating and the existing grating, which are the most common gratings in apartment complexes.

2) Basic Assumption for the Analysis

In the LCC analysis, all the costs that were incurred during the life cycle of the facilities, and the initial construction costs, were considered. In such costs, the maintenance costs, the replacement costs, the salvage value, etc. were included. Furthermore, the following basic assumptions were made, and the monetary value of the costs was standardized.

(1) Realistic Discount Rate

The realistic discount rate was used to convert the costs that were incurred at different points into the value of the costs that were incurred at a certain point, so that the values of the costs could be objectively compared in the cost analysis. The return on investment, market interest rate, inflation rate, etc. were considered factors that influence the realistic discount rate.

The realistic discount rate was calculated using the nominal interest rate and the inflation rate, as shown in Eq. 1. The nominal interest rate was computed using the average value of the monthly corporate loan interests (bank interest rate) of the Bank of Korea for the last nine years. Moreover, the inflation rate was set using the average consumer price index of the Korea National Statistical Office for the last eight years. The realistic discount rate was computed as shown in Eq. 1 [6] and was determined to be 3.65%. Table 2 shows the values that were applied to the computation of the realistic discount rate.

Table 2 Estimate of Realistic Discount Rate

Years	Nominal interest Rate (%)	Inflation Rate (%)
2000	8.18	2.24
2001	7.49	3.85
2002	6.50	2.75
2003	6.17	3.30
2004	5.92	3.49
2005	5.65	2.70
2006	6.08	2.15
2007	6.60	2.48
2008	7.04	-
Means	6.62	2.87
Realistic Discount Rate		3.65

$$i = \frac{(1+i_n)}{(1+f)} - 1 \quad \cdots\cdots\cdots\cdots\cdots \quad \text{Eq. 1}$$

Where i is discount rate, i_n nominal rate, and f inflation.

(2) Analysis Period

The analysis period in LCC analysis is very important. In particular, if the break-even point occurred within the analysis period, it could be an important factor for decision making.

To set the analysis period in this study, the LCC was assumed to have been 40 years, with reference to the standard life cycle and the life cycle of buildings in the "Enforcement Regulations of Corporate Law [Appendix 5] (August 16, 2006)." The starting date of the analysis was set to be May 2008. The results of the analysis are summarized in Table 3.

Table 3 Table of Ranges of Durable Years

Enforcement Regulations of Corporate Law [Appendix 5] (August 16, 2006).

Classification	Standard Life Cycle (Lowest Life Cycle / Highest Life Cycle)	Structures and Assets
1	5 years (4-6 years)	Cars and vehicles, tools, instruments and other equipment
2	12 years (9-15 years)	Vessels and aircraft
3	20 years (15-25 years)	Bricks, blocks, concrete, soil, soil wall, wooden, wooden-frame-mortar, and all other buildings
4	40 years (30-50 years)	All iron-skeleton, reinforced-concrete, and stone brick buildings

3) Implementation of the Cost Breakdown Structure (CBS)

The costs that were incurred during the life cycle of the facilities were largely classified into initial construction costs, maintenance costs, and dismantling and disposal costs [5]. Based on the factors that directly influenced the LCC of the grating, the CBS was established as shown in Table 4.

Table 4 Implementation of the CBS

Classification	Principal Classification	Detailed Classification	Applica-tion	Note
CBS of the grating	Initial construction costs	Material costs	○	Based on the performance description
		Labor costs	○	
		Other costs expenditures	○	
	Maintenance costs	Repair and replacement costs	○	Periodic partial replacement cost
	Dismantling and disposal costs	Removal costs	×	Included in the replacement costs
		Salvage value	○	Price of the scrap iron after dismantling

Regarding the computation of the LCC, the planning and designing costs were excluded as they were equally applied to both materials. As the initial construction costs are the costs incurred during the initial construction of the grating, they were classified into materials costs and labor costs. In the maintenance costs, only the replacement cost due to the partial damages and deterioration of the materials was included, and it was computed by multiplying the initial construction costs by the replacement rates. The dismantling and disposal costs were classified into the removal costs and the salvage value.

4) Computation of the LCC

(1) Computation of the Investment Costs by Item

In the computation of the LCC, the initial construction costs were computed by adding the materials costs, the labor costs, and the other expenditures based on the performance description. Since the removal costs were included in the labor costs in the replacement costs, they were excluded from the LCC. The salvage value was computed by applying the average value of the scrap irons by region, as proposed by the Korea Environment & Resources Corporation in May 2008, to the weight of the removed grating.

For the maintenance costs, the results of the interviews with and of the questionnaire surveys among the engineering experts and their staff in the facilities' management offices revealed that there was a large difference between the replacement period and the replacement rates according to the manufactured parts. Therefore, the analysis was performed by classifying the maintenance costs into those of the gratings that were installed in places where the traffic is usually heavy (at the entrance of the parking lots in apartments, etc.) and those of the gratings were the traffic is usually light.

Table 5 Investment Costs by Item

Classification	Item	Steel Grating	Magic Grating	Note
Initial construction costs	Material costs	39,240 won/set	115,800 won/set	Performance unit price
	Labor costs	15,610 won/set	15,610 won/set	
	Other expenditures	548 won/set	548 won/set	
Replacement costs	Replacement period	4 years	10 years	Interview with experts
	Replacement rate	70%	30%	
	Replacement costs per time	38,779 won/set	39,587 won/set	Initial construction costs × Replacement rates
Dismantling and disposal costs	Salvage value (1 time)	-6,216 won/set	-3,083 won/set	Scrap iron prices

According to the opinions of the experts and the relevant personnel in the grating manufacturing companies, in places where there is usually almost no vehicular traffic, gratings are replaced mainly when their materials have deteriorated or when they have problems in terms of their exterior appearance due to the fading of their color, etc. Through the related research, such problems were identified as directly related to the thickness of the coating of the grating itself, and it was found that the coating thickness of both selected materials are almost the same. Therefore, the life cycles of both materials were predicted to be 20-25 years.

With only the aforementioned analysis results, economic-efficiency analysis for the place without vehicular traffic was possible, and the steel grating with lower initial construction costs was found to be more economical.

Besides, in the place with heavy traffic, the LCC was computed by applying the construction costs to the performance description, the replacement period, and the replacement rates provided by the experts and the relevant manufacturers. The costs of such items are shown in Table 5.

(2) Computation of the LCC

The LCC was computed by applying the present-value method based on the basic assumptions and the CBS that were established earlier. Table 6 shows the LCC per grating set (size: 495*995*38*4.5 T) in the place with heavy traffic in two-year units.

5) Economic Efficiency Analysis

The LCC was checked via the replacement points from the analysis results shown in Table 6, and the break-even point was found and the costs were compared based on each point. The occurrence of the break-even point within the analysis period was an important factor in the selection of materials. Fig. 2 shows the occurrence of the break-even point based on Table 6.

When the cost increases were checked from the break-even point graph, they were found only in the year when the corresponding grating replacement was made. Therefore, the break-even point occurred between the 23rd and the 24th years, and the magic grating was found to be economically superior to the steel grating until the 40th and final year of their life cycle.

Fig. 3 shows the total costs that were incurred during the life cycle by investment item.

The relationship between the initial construction costs, the maintenance costs, and the total LCC proposed in Fig. 3 explains well why the economic efficiency was measured by considering the LCC. That is, it is a typical LCC analysis case in which the total LCC is low when the initial construction cost is high, but the maintenance cost is low.

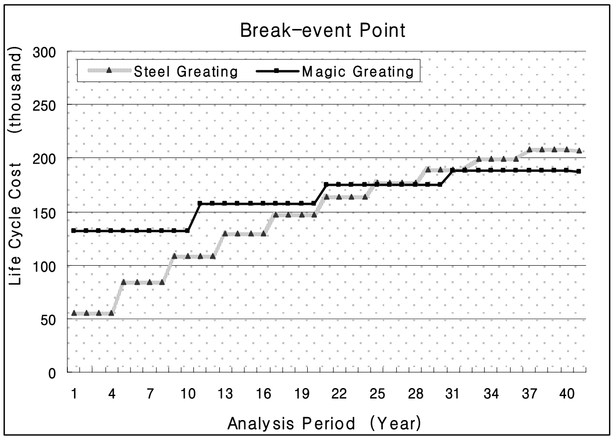

Fig. 2 Break-even Point Graph

Table 6 Comparison Table of the LCC by Time

(Unit: won/set)

Useful Life of the Gutter	Life Cycle Cost		Useful Life of the Gutter	Life Cycle Cost	
	Steel Grating	Magic Grating		Steel Grating	Magic Grating
Initial construction cost	55,398	131,958	22 years	163,532	175,314
2 years	55,398	131,958	**24 years**	**177,321**	**175,314**
4 years	83,616	131,958	26 years	177,321	175,314
6 years	83,616	131,958	28 years	189,270	175,314
8 years	108,068	131,958	30 years	189,270	187,783
10 years	108,068	157,476	32 years	199,624	187,783
12 years	129,258	157,476	34 years	199,624	187,783
14 years	129,258	157,476	36 years	208,597	187,783
16 years	147,620	157,476	38 years	208,597	187,783
18 years	147,620	157,476	40 years	207,113	187,047
20 years	163,532	175,314			

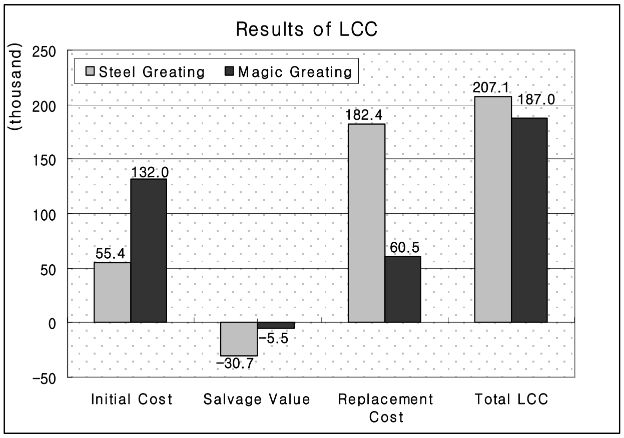

Fig. 3 Result of the Collection of Costs by Investment Item

Table 7. Variables Range in the Sensitivity Analysis

Cost Items	Distribution Form	Fluctuation
Initial construction cost	Beta	-10% ~ + 10%
Nominal interest rate	Custom	Based on the monthly data from January 2000 to April 2008
Inflation	Custom	
Replacement rate	Triangular	Steel: 60-80%, magic: 25-35%
Scrap iron price	Triangular	₩410-₩480

3.2 Sensitivity Analysis

Sensitivity analysis was performed using the Monte Carlo simulation (MCS) technique to determine the change in the analysis results according to the basic assumptions needed for the computation of the LCC and for determining the degree of variability and uncertainty of the cost data. Table 7 shows the distribution form and fluctuation range of the applied values considering the characteristics of the cost items.

When the simulations had been performed 5,000 times based on the aforementioned set values, the cost ranges were calculated as shown in Fig. 4.

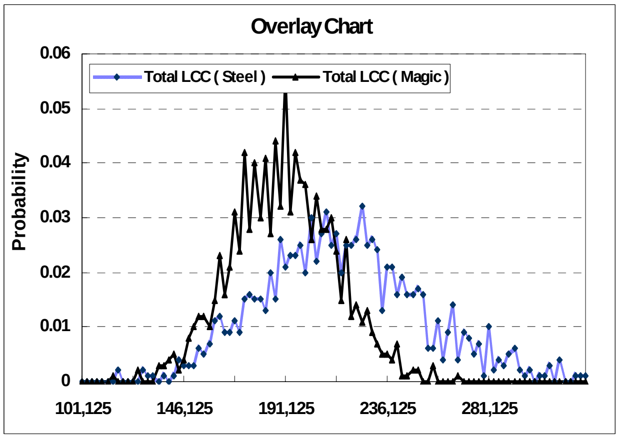

Fig. 4 Cost Distribution Diagram of the Sensitivity Analysis

Regarding the results of the sensitivity analysis shown in Fig. 4, it was confirmed that the LCC of the steel grating was slightly higher than that of the magic grating. Moreover, the LCC fluctuation range of the steel grating was relatively wider. This can be seen as the result of the larger influence of each variable on the steel grating.

The results of the observation of the influence of the variables used in the sensitivity analysis on the values in the results are shown in Fig. 5 and 6. The initial construction cost had the greatest influence on both materials, followed by the nominal interest rates, inflation, replacement rates, and scrap iron price, in that order.

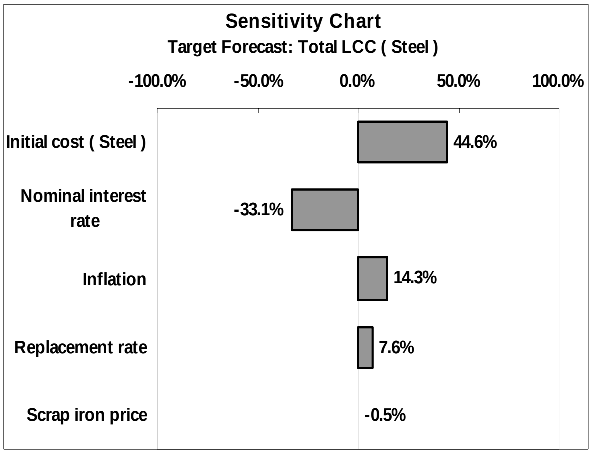

Fig. 5 Sensitivity of the Variables in the Steel Grating

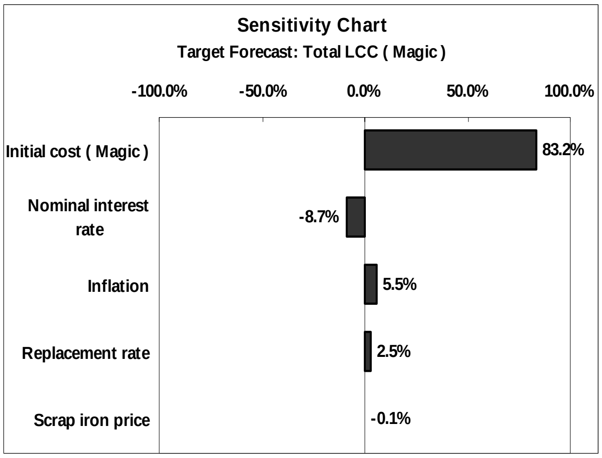

Fig. 6 Sensitivity of the Variables in the Magic Grating

5. CONCLUSIONS

An economic-efficiency analysis of the 40-year-old life cycle of gratings used in apartment complexes was conducted for the rational selection of materials.

To examine the change in the analysis results due to the cost data used in the economic-efficiency analysis and the uncertainty of the assumptions, sensitivity analysis was also performed, using MCS.

The results of the study are as follows:

- The replacement period and rates differed significantly according to the places where the gratings were used.
- The magic grating was more economical from the 24th year in the places with heavy vehicular traffic.
- Also factoring in the experts' opinions, the steel grating can be said to be more economical from the initial point in the places without heavy vehicular traffic. Furthermore, Table 6 explains the LCC by point for places with heavy vehicular traffic.

Regarding the computation of the LCC, as the performance data for the replacement period and the replacement rates, which significantly influenced the replacement costs, were inadequate, the LCC was computed based on the data that were secured through the interviews with experts. Furthermore, the failure to consider the costs that were incurred at uncertain points was a limitation of this study. For a more accurate analysis, the use of the actual performance data with respect to the replacement period and rates is required in the future.

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