

LIFE CYCLE IMPACT ASSESSMENT OF NEW GROUND MATERIAL AND EMBANKMENT CONSTRUCTION METHODS CONSIDERING RECYCLING

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ABSTRACT: In Japan, the conventional cut-and-fill method is often used in banking construction methods. However, this construction method is pointed out that it causes land subsidence and/or landslide in soft ground. For solving these problems, various new construction methods using the ground materials such as EPS (styrofoam), recycled foamed waste glass and expanded polystyrene beads have been developed as a new lightweight and workable composite geomaterials. These new construction methods are believed to be effective for construction on soft ground and landslide-prone areas. In existing researches of this field, they aimed to identify areas for improvement and the problems associated with the use of these new ground materials. However, there are few types of research that focused on negative impacts on land use, by exhausting air pollution and GHGs (Green House Gases) with recycling from the perspective of the environmental economics field. Thus, in this research, we compared conventional cut-and-fill method and some new ground materials such as the expanded polystyrol construction method using the new EPS geomaterial, the lightweight embankment construction method with EPS beads and the foamed waste glass construction method using embankment material with recycled waste by analyzing the negative impacts to land use considered ecosystem services and life cycle cost (LCC) including external cost by emissions of GHGs and air pollutants such as SOx and NOx using life cycle impact assessment analysis.

Keywords: Life Cycle Assessment, Life Cycle Impact Assessment, Life Cycle Cost, New Ground Material

1. INTRODUCTION

In Japan, social assets including roads that were constructed from the postwar period to the high-growth period are facing a renewal period. In this context, it will be important from now on for establishing a circulation-type society that includes the reuse of materials recycled from wastes and the selection of environmentally friendly construction methods. Currently, the conventional cut-and-fill method is most widely used among embankment construction methods. The conventional cut-and-fill method is considered to have a chance of causing ground sinking and/or landslide at soft grounds and the areas likely to experience landslide, construction methods that take advantage of new ground materials like expanded polystyrene (EPS) are believed to be effective for the construction on soft grounds and the areas likely to experience landslide because of their lightweight properties and construction properties, etc.

While there are previous researches such as a comparative analysis done by Ito et al. [1] on the influences and costs caused to environments by the various construction methods and a study performed by Ochiai et al. [2] in which the potential of mixed ground materials made from wastes is discussed.

However, no research has ever been conducted where the impacts made by new recycling-friendly ground materials on land use including air-pollution substances, global greenhouse gas (GHGs) and ecosystem services are comprehensively assessed as external costs.

Thus, the purpose of this research is to do a comparative analysis by life cycle impact assessment (LCIA) for each kind of embankment construction methods using new ground materials. Specifically, this research performs, while taking account of the presence or absence of the recycling of wastes, a comprehensive assessment of external costs converted to a currency for the respective embankment construction methods including the external costs attributable to the emission of air-pollution substances and GHGs and those resulting from the land use at every lifecycle stage.

2. LITERATURE REVIEW

In the previous researches about the lifecycle assessment (LCA) that pay attention to new ground materials and the presence or absence of the recycling of wastes, Ito et al. [1] revealed that environmental burdens and lifecycle costs could be reduced in each kind of embankment construction methods utilizing new ground materials (EPS) and

wastes (expanded beads and expanded waste glass) if recycling would be done while considering lifecycle stages. However, any external cost was not considered in this research.

Ochiai et al. [2] organized additional values, physical natures and the grouping of constitutional materials of various mixed ground materials in their previous researches regarding the materials constituting mixed ground materials, which reported more than one research result on mixed ground materials. In addition, they assessed environmental burdens and the recycling efficiency of mixed ground materials made from wastes. However, since these researches figured out environmental burdens only from the production process of embankment materials, environmental burdens were not analyzed through the entire lifecycle.

Amano et al. [3] visualized the potential of recycled materials in paving roads. More specifically, they revealed that environmental burdens could be reduced to a maximum by around 40% with the use of recycled materials at both the stages of construction and maintenance/repair, by totaling the environmental burdens and costs associated with the construction of paved roads and their maintenance/repair for respective stages of initial construction and maintenance/repair and by evaluating the lifecycle of paved roads from both the sides of environmental burdens and costs. Both of the environmental burdens and costs for asphaltic pavement at the stage of its maintenance/repair accounted for 40 to 50% of those at its entire stages. This research, however, didn't deal with an impact on road structures and surrounding environments in the entire lifecycle.

In their previous research that employed LCA and environmental economy assessment methods, Ito et al. [4] performed an LCIA of biodiversity and ecosystem services based on the extinction risk of living things while focusing on the construction of wooden residences and steel residences. Then, this research assessed an impact on biological ecosystems and ecosystem services that would disappear due to the alteration and occupation of land occurring in the entire lifecycle. However, this research only made an assessment of residential construction, not new ground materials.

Inazumi et al. [5] previously conducted assessment research of social and environmental efficiency regarding the recycling of construction polluted mud as a ground material. Specifically,

they discussed an evaluation method of social and environmental efficiency assessing the recycling of wastes from a social perspective by internalizing environmental burdens as an environmental cost, in addition to environmental assessments, LCAs using environmental accounting methods, social and environmental efficiency and cost calculation utilizing the Monte Carlo simulation. However, this research dealt with construction polluted mud and its impact assessment of land use was not enough.

Kamemura et al. [6] implemented research with regard to the lifecycle cost assessment of civil engineering structures with considering the risk. Specifically, it showed the size and characteristics of risks as well as the effects of objects by optimizing cost statistics regarding the construction costs for structures and their operation/maintenance costs while they are in use. However, this research only made an assessment of the lifecycle cost.

Omine et al. [7], after organizing the additional values, physical natures and the grouping of constitutional materials of various mixed ground materials, estimated the CO₂ emission at the production stage of cement stabilization soil, bubble mixed lightweight soil, fluidization disposal soil, clay mixed calcination fixation agent and tire chip mixed soil, although they didn't assess impacts resulting from polluted substances other than CO₂.

While Minegishi et al. [8] explained about the strength and impacts of repeated stress ratios made on the deformational characteristics of EPS mixed lightweight soil, Kagawa [9] analyzed the characteristics and physical strengths as earth fill of the EPS civil engineering method as well as the durability, weather resistance, environment in soil and drug resistance of EPS. Such previous research analyzed the strength, etc. of EPS but didn't make its lifecycle assessment.

Onitsuka et al. [10] demonstrated the potential of expanded waste glass materials as new materials by doing an experiment for improving the engineer characteristics of expanded waste glass materials and fundamental road bases, although they didn't implement an environmental assessment with the LCA method.

It is concluded from the above that no research has ever while focusing attention on respective construction methods using new ground materials, conducted a comprehensive assessment in terms of external costs resulting from the emission of air-pollution substances and GHGs as well as those due to the land use including ecosystem services.

3. METHODS AND SYSTEM DETAILS

In this research, the Mineoka area in mountainous roads located in the southern part of Chiba prefecture was selected as case study area as well as in the previous research [1], and then compared above 4 construction methods. The summary of each embankment construction method using new ground materials is shown in Table 1.

We also set the same functional unit that provides a logical basis for comparing the environmental performance of alternatives for applying LCA to these four construction methods based on the previous research [1]. We defined the target road condition (2 lanes, 7 m wide and 1m long) as a functional unit and then, it was hypothesized that the inclined a the angle between the mountain and the road is 35 degree.

3.1 Setting of Recycle Method in Each Construction Method

For the purpose of analyzing recycled embankment materials and environmental burdens, this research conducted a survey on how to recycle embankment materials by doing a questionnaire survey and an interview survey with ten construction companies and then set a recycling method based on the results of such surveys. In order to take account of recycling, this research based on the presumption established from the results of the research by Ito et al. [1] that roads would be reconstructed in 100 years from the start of their service, assumed that embankment construction work would be done four times in total as well as the system boundary.

In addition, since the interview survey had found that recycling was difficult in the EPS

construction method, it was assumed that roads would be reconstructed every 100 years with virgin materials. This research aims to identify future tasks and improvement plans through the calculation of the total environmental burdens and costs generated depending on the presence or absence of recycling.

3.2 Estimation Method for External Costs Attributable to Air Pollution and GHGs

The impacts made including on environments, human health and social assets by air-pollution substances and GHGs that are emitted in road construction throughout the overall lifecycle are integrated in terms of a currency. In this research, a LCIA was performed utilizing the values representing the emission amounts of air-pollution substances and GHGs estimated in the research by Ito et al. [1] External costs were estimated in a way to integrate them by multiplying the total amounts of air-pollution substances and GHGs that are emitted in all lifecycle stages by the original unit for external costs per unit emission amount in respective environmental impact fields used in the Life-cycle Impact assessment Method based on Endpoint modeling (LIME2) environmental impact integration software [11].

3.3 Estimation Method for External Costs Caused by Influences on Land Use

The impacts made on land use by the alteration and occupation of land in the entire lifecycle are substantial. In this respect, the impacts given on ecosystem services from the perspective of land use are assessed in term of a currency with classifying land use into four categories such as forests, tidelands, waters and desserts. Regarding the analysis method, the influenced area is calculated

Table 1 Summary of each embankment construction method using new ground materials

Expanded Polystyrol Construction Method	EPS blocks are stacked as embankment materials and are integrated by dedicated clamps. When stacked, these ultra-lightweight embankments have advantages of their compressive resistance, durability, and independent stack design.
Lightweight EPS Bead Mixture Method	Lighter soil is used, comprising EPS beads mixed with soil and sand. This method is effective for use in soil fills on soft ground and in landslide-prone areas due to its capability of reducing the applied load on the ground more effectively than ordinary soil and sand.
Foamed Waste Glass Method	Foamed waste glass is a porous embankment material manufactured by pulverizing, burning, and foaming recycled waste glass. The specific gravity and degree of water absorption can be controlled during manufacturing according to the requirements of specific applications. Hence, foamed waste glass is used in a wide range of applications including civil engineering, greening of slopes and rooftops, agriculture, water purification, and heat insulation. This material is lightweight, water permeable, water retentive, fire resistant, and a good thermal insulator.

by land use classification for respective construction methods and then the external costs resulting from the loss of ecosystem services are estimated.

First, the recycling methods and the utilization amounts of materials per unit area for respective construction methods that were set in the previous researches are shown in Table 2 and Table 3. Then, the setting of land use classification is illustrated in Table 4 and the conversion factors for calculating impacted area by fuel/energy consumption in each lifecycle based on JEMAI-LCA database [12], existing research [4] and the hearing survey to construction companies are shown in Table 5.

The estimated results of influenced land area per unit amount are obtained by figuring out the influenced area per functional unit based on the ultimate recoverable reserves of materials used in respective construction methods and such area. Table 6 shows the estimated/calculated results of the impacted area by land use classification for respective construction methods.

Table 2 Recycling methods

Construction method	Recycle (first time)	Recycle (from second time)
Cut & Fill (R)	Virgin material is used for first time	Used banking material mixed with cement is reused from second time
EPS (V)	No recycle because EPS block cannot be recycled	
Lightweight EPS bead mixture method (V)	Virgin material is used for first time	Used banking material mixed with cement is reused from second time
Lightweight EPS bead mixture method (R)	After used styrofoam was blasted, it is used by mixing soil and cement	EPS beads is removed from demolished banking material and then recycle the styrofoam
Foamed waste glass method (R)	Virgin material is used for first time	Demolished banking material is recycled

Table 3 Utilization amounts of materials per unit area for respective construction methods

	Soil	Cement	EPS Block	Aluminum	Zinc	EPS beads	Foamed waste glass	Clamping materials
Unit	kg/m ²	kg/m ²	m ³ /m ²	kg/m ²	kg/m ²	kg/m ²	kg/m ²	kg/m ²
Cut & Fill (R)	15,750	645	-	-	-	-	-	-
EPS (V)	-	-	367.08	2.15	1.70	-	-	734.17
Lightweight EPS bead mixture method (V)	19,250	1,790	-	-	-	161.22	-	-
Lightweight EPS bead mixture method (R)	19,250	1,790	-	-	-	161.22	-	-
Foamed waste glass method (V)	-	-	-	-	-	-	5,250	-
Foamed waste glass method (R)	-	-	-	-	-	-	5,250	-

Table 4 Land use classification of the impacted area

Energy	Crude Oil	Electricity	Natural Gas	Coal
Country	Saudi Arabia	Japan	Australia	Australia
Type of Land Use	Oil field Desert area	Tideland	Sea area	Mine
Impact	Impact by oil field development	Impact to tideland by reclamation for constructing thermal power station	Impact by developing natural gas field	Impact by coal mine development

Table 5 Conversion factors for calculating impacted area by fuel/energy consumption

Estimation Item		Conversion Factor	
Impacted area by obtaining construction materials	Impacted area by obtaining aggregate	4.00E-04	m ² /kg
	Impacted area by obtaining lime	1.10E-03	m ² /kg
	Impacted area by obtaining aluminum	6.88E-05	m ² /kg
	Impacted area by obtaining zinc	3.63E-03	m ² /kg
Impacted area at production phase	Impacted area by constructing and operating refinery	4.02E-03	m ² /kg
	Impacted area by constructing and operating zinc refinery	3.57E-02	m ² /kg
	Impacted area by constructing and operating cement works	7.90E-07	m ² /kg
	Impacted area by constructing and operating manufacturing plant of EPS block	2.92E-05	m ² /kg
	Impacted area by manufacturing clamping materials	4.0E-05	m ² /kg
	Impacted area by manufacturing expandable beads	2.92E-05	m ² /kg
Impacted area by recycle facility	Impacted area by constructing and operating recycling factory of waste glass	1.10E-02	m ² /kg
	Impacted area by constructing and operating recycling factory of styrofoam	1.54E-04	m ² /kg
	Impacted area by constructing and operating recycling factory of steel	6.20E-02	m ² /kg
	Impacted area by reclaiming waste material	1.39E-01	m ² /m ³
Impacted area by extracting energy	Impacted area by extracting crude oil	2.00E-04	m ² /kg
	Impacted area by generating electric power	2.60E-07	m ² /kWh
	Impacted area by extracting natural gas	4.70E-01	m ² /kg
	Impacted area by mining coal	7.50E-04	m ² /kg

4. RESULTS AND DISCUSSION

4.1 Estimated Results of External Costs Due to the Emission of Air-Pollution and GHGs

The estimated result of external costs attributable to the emission of polluted air substances and GHGs demonstrated that the external costs for the EPS construction method were the smallest as shown in Fig.1. Also, it was found that the emission of SO_x being a cause for air pollution would make substantial impacts on the increase in external costs, that the biggest external costs were those for the expanded waste glass materials construction method, and that the said external costs would be in the same range as those for the expanded beads lightweight soil construction method if taking account of recycling.

Table 6 Impacted area by land use classification for each construction method

Total Impacted Area of each Land Use for 300 Years									
Construction Method	Total Impacted Area(m ²)	Material	Impact to Land		Energy		Total		
		Forest	Forest	Tideland	Tideland	Sea area	Forest	Tideland	Sea area
Cut & Fill ①V②-④R		36.8	1.0	2189.3	3.8E-05	0	37.8	2189.3	0
EPS ①-④V		0	1.0	1.4	1.5E-04	0.4	1.0	1.4	0.4
Lightweight EPS bead mixture ①-④V		38.7	1.0	10703.1	1.8E-04	0	39.7	10703.1	0
Lightweight EPS bead mixture ①-④R		38.7	1.0	2675.9	1.1E-04	0	39.7	2675.9	0
Foamed waste glass ①-④V		0	1.0	3150.0	1.3E-03	178.1	1.0	3150.0	178.1
Foamed waste glass ①V②-④R		0	1.0	787.5	3.4E-04	44.5	1.0	787.5	44.5

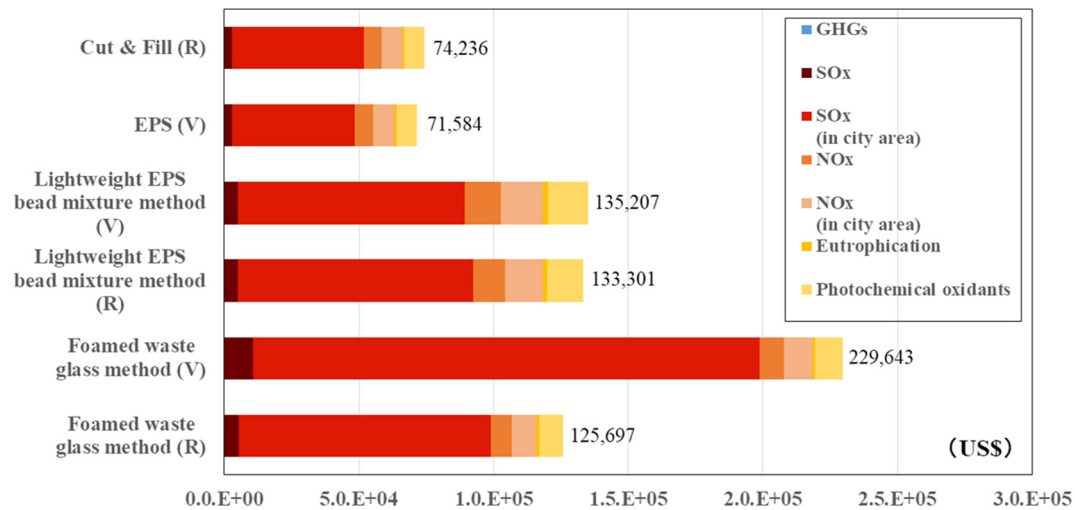


Fig.1 Estimated results of external costs of emission of air-pollution substances and GHGs

4.2 Estimated Results of External Costs Caused by Impacts on Land Use

The impacts made on land use by the alteration and occupation of land in the entire lifecycle are substantial and therefore there is a need to assess the impacts on ecological services from the perspectives of land use such as forests, tidelands and waters. In this context, the influenced area was calculated by land use classification for respective construction methods and then the external costs resulting from the loss of ecology services were estimated.

First, the total amounts of fuels and energies per functional unit were estimated according to the JLCA-LCA database [12] and also the interview survey and the total amounts of all raw materials to be used in the respective database were calculated. Then, the influenced area by each land use was figured out by multiplying such amounts by

respective influenced areas per estimated unit amount. Also, the areas influenced by the collection of construction materials and respective fuels/energies as well as by each land use such as the occupation of factories, etc. were calculated, then by summing up which influenced areas the influenced areas by land use classification for respective construction methods were figured out. Lastly, external costs were estimated by multiplying the estimated influenced areas by land use classification for respective construction methods by the economic value of ecological services per unit area which was estimated in the previous research. Consequently, the external costs for the EPS construction method were found to be the smallest as shown in Fig.2 because the estimation was made on the presumption that crude oil being the raw material for EPS blocks would be produced in the desert areas of Saudi Arabia and therefore its impact on ecological services was considered to be small. The external costs for the expanded waste

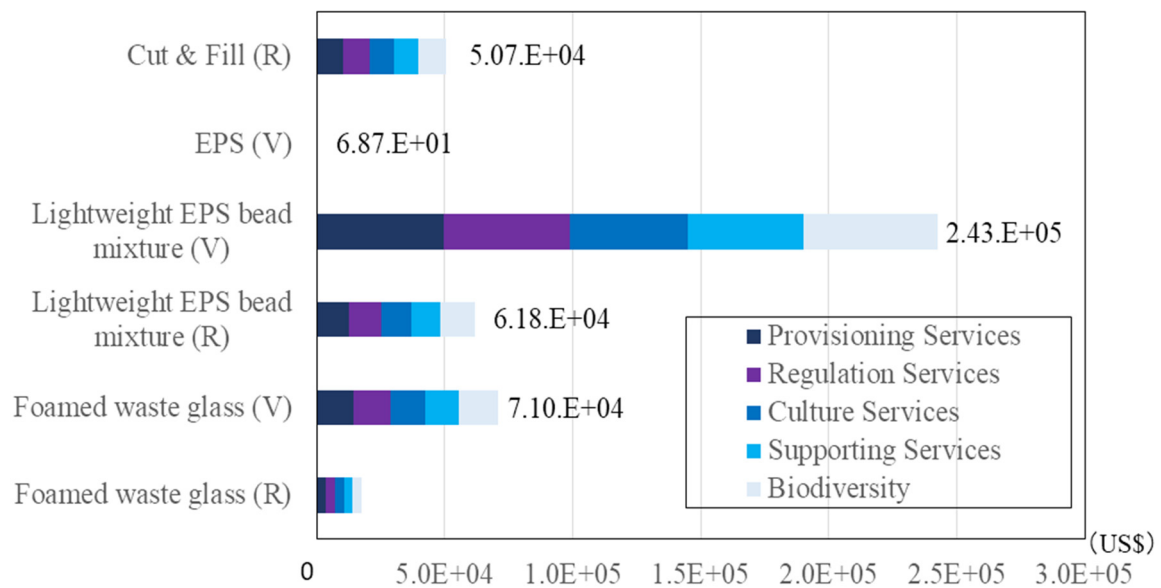


Fig.2 External costs caused by impacts on land use

glass materials construction method V which causes a considerable impact on tidelands by occupying the land were estimated to be the biggest. Further, it was shown that external costs would be substantially influenced depending on the presence or absence of recycling.

4.3 Estimated Results of Total External Costs

Fig.3 shows the total external costs by summing up the life cycle cost estimated by existing research [1] and all external costs by the emission of GHGs, air-pollution and impacts on land use.

As the result, the total external costs were increased in the order of EPS, cut & fill, foamed waste glass method (R), lightweight EPS bead mixture method (R), lightweight EPS bead mixture

method (V) and foamed waste glass method (V).

In addition, it was shown that total external costs would be substantially influenced depending on the presence or absence of recycling. In terms of foamed waste glass method (V), since the external cost of GHGs and air pollution at extraction of raw materials phase was very big, the technical improvement for reducing those emissions is necessary.

5. CONCLUSION

This research, while paying attention to the presence or absence of recycling, made a comprehensive LCIA including of external costs generated by land use as well as by air-pollution substances and GHGs in addition to market prices.

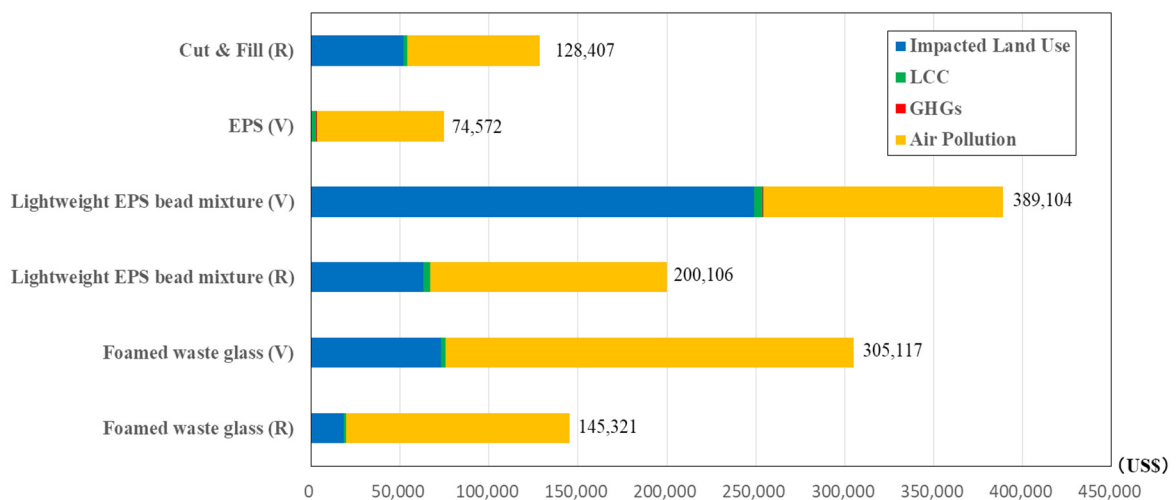


Fig.3 Total external costs of each construction method

External costs by life stage for respective construction methods were clarified through such effort and accordingly future tasks for reducing the external costs were presented.

From now on, there is a need to identify future tasks including the elaboration of original units for external costs by considering regional characteristics.

6. ACKNOWLEDGMENTS

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