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COMPARATIVE ANALYSIS OF NEW GEOMATERIALS AND EMBANKMENT CONSTRUCTION METHODS CONSIDERING RECYCLING

*Hideyuki Ito[1], Koichi Yamanaka[2], Hideo Noguchi[3], Takahiro Fujii[4] and Kunio Minegishi[5]

[1,2,4,5]College of Science and Technology, Nihon University, Japan;

[3]Tsuchiura City Hall, Japan

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ABSTRACT: The cutting and embankment construction method may cause grand subsidence or landside at a location with soft ground or risk of landsides. A construction method employing a new composite geomaterial using expanded polystyrene is effective for construction at such a location because of its light weight and workability. However, there is not much research reported on the use such new materials with examples of constructions using these materials. This study aimed to understand the problems associated with the use of the new geomaterials and determine how they can be improved by analyzing various environmental loads and life cycle costs that in various embankment construction methods in consideration of whether new geomaterials are used and waste materials are recycled. Four different methods were compared with respect to their environmental impact and cost. The research demonstrated the possibility of reducing environmental loads and life cycle costs by employing recycling in various embankment constructions methods.

Keywords: Life Cycle Assessment, Lightweight Geomaterial Mixed with Expanded Polystyrene Beads, Expanded Polystyrene Construction Method, Foamed Waste Glass Construction Method, Life Cycle Cost

1. INTRODUCTION

The conventional cut-and-fill method of embankment construction can cause ground subsidence and landslides at locations with soft ground and risk of landslides. To deal with this issue, we have developed a construction method that uses a new lightweight and workable composite geomaterial mixed with expanded polystyrene (EPS), which is believed to be effective for construction on soft ground and landslide-prone areas.

Using life cycle assessment (LCA) and life cycle cost (LCC), Ito et al. [1] have analyzed the environmental load and costs of embankment construction using the cut-and-fill and EPS construction methods. The results show potential for reducing the environmental load by recycling embankment materials. Ochiai and Omine [2] have summarized the added value and physical properties of various mixed geomaterials and have classified the constituent materials. They also used LCA to analyze embankment materials composed of recycled tires with respect to the manufacturing process for the materials alone. Inazumi et al. [3] have assessed the recycling of construction sludge generated from embankment works. Onizuka et al. [4] have described the engineering characteristics of foamed waste glass material and provided useful examples of its applications.

There have been a number of conventional studies examining the new geomaterials, but few have provided examples of their use in construction work or performed LCA analyses. Conventional comparative analyses of environmental load and costs from the LCA perspective include those performed by Ito et al. [1] and Ochiai and Omine [2], who introduced the possibility of using waste in mixed geomaterials, but there are few studies on the use of new geomaterials containing recycled embankment materials.

The present study aims to identify areas for improvement and the problems associated with the use of new geomaterials. Thus, in this research, we estimated emissions of CO_2 and air pollutants SO_x and NO_x and comparatively analyzed the LCCs of four construction methods throughout the life cycle of the materials, from raw material collection to construction, and from usage to disposal. For our analyses, we assumed an earth filling design for a mountainous area with the possibility of landslide. We analyzed four methods in the construction of embankments in mountainous areas, including the conventional cut-and-fill method, the EPS block method that uses blocks of the new EPS geomaterial, the lightweight EPS bead mixture method that uses EPS beads mixed with earth and sand, and the foamed waste glass method that uses embankment material with recycled foamed waste glass.

2. METHOD AND SYSTEM DETAILS

In this research, the Mineoka area located in the southern part of Chiba prefecture was selected as a study area as in the previous research [1] because landside control works are conducted in mountainous roads in this area (Fig. 1). For comparative LCA analysis, we used the four methods describe above for constructing mountainous roads.

Based on an embankment design for a mountainous area with the possibility of landslide, we focused on the weight savings and recycled embankment materials in our analyses of the four methods.

In the EPS block 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.

In the lightweight EPS bead mixture method, lighter earth is used, comprising EPS beads mixed with earth and sand. This method is effective for use in earth 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 earth and sand.

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.

We set a functional unit that provides a logical basis for comparing the environmental performance of alternatives for applying LCA to these four construction methods. We defined the target road condition (2 lanes, 7 m wide and 1m long) as a functional unit as shown in the Fig.2. In addition, we hypothesized that the inclined a the angle between the mountain and the road is 35° (Table 1).

Fig. 1 Location of the case study area.

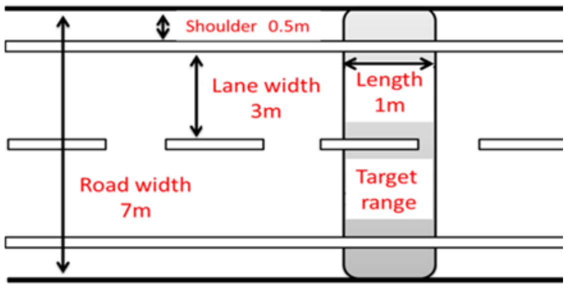
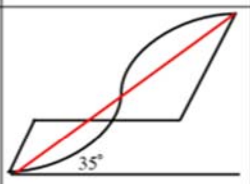
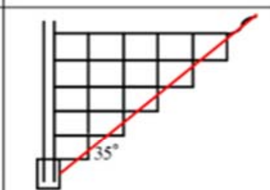
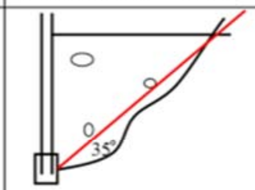
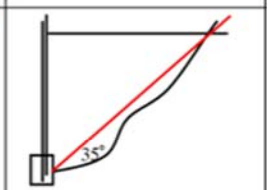


Fig. 2 Functional unit.

3. SYSTEM BOUNDARY AND RECYCLING METHODS

The system boundaries of the conventional cut-and-fill method, the EPS block method, and the lightweight EPS bead mixture method were set up in

Table 1 Parameters of the four construction methods.

Construction method	Cut-and-fill	EPS construction method	Lightweight embankment construction method	Foamed waste glass construction method
				
Fill	12.375m³	17.5m³	17.5m³	17.5m³
Cut	26.25m³	—	—	—
Weight per unit volume	14kN/m³	0.4kN/m³	7kN/m³	4kN/m³

the same condition as in previous research [1].

To consider the recycling impact, we performed four embankment tasks and assumed that the road would be reconstructed every 100 years after its initial construction for 400 years. For the EPS and waste glass cases, as used in the system boundaries of lightweight EPS bead mixture method, we calculated the CO_2 emission, air pollution, and LCCs for all life cycles with and without recycled materials. As recycling methods for most embankment materials are still in the research and development phases, we based our analyses on a method used in the industry for recycling embankment materials, as identified by results from a questionnaire and interviews with 10 business operators. Table 2 shows the recycle conditions of each construction method.

The system boundary of the foamed waste glass method using embankment material with recycled waste is shown in Fig. 3. Foamed waste glass is produced using recycled glass in the plant, and then it is leveled and compacted. In the waste phase, the used embankment materials will be recycled. We assumed that the method used recycled embankment material of foamed waste glass materials collected after demolishing the roads. We established distances based on the locations of factories located around the Mineoka mountain district in Chiba Prefecture, where embankment work is often conducted.

To calculate the total amount of air pollutants and CO_2 emitted by each method, we set the CO_2, SO_x, and NO_x units (Table 3) and the cost unit for each material (Table 4). These units were developed based on data from sources such as the LCA guidelines for building [5], IDEA (Inventory Database for Environmental analysis) [6], the LCA database developed by the Life Cycle Assessment Society of Japan [7], the database of the Express Highway Research Foundation of Japan [8], and the database of JEMAI-LCA PRO [9]. The cost unit for each material was estimated using the Input-Output Table of Japan's Ministry of Internal Affairs and Communications [10].

Table 2 Recycle conditions.

Construction method	Recycle method (first time)	Recycle method (after second time)
Cut-and-fill	Raw materials are used for cut-and-fill first	Banking material used for cut-and-fill are recycled by mixing cement
EPS construction method	Expanded polystyrene is not able to recycle, so the recycle is not considered	
Lightweight embankment construction method	Mixed breaking foamed styrol used once, soil and cement are used for lightweight embankment construction method	After removing beads from dismantled banking material, foamed styrol is recycled
Foamed waste glass construction method	Raw materials of glass are used for foamed waste glass construction method first	Dismantled banking material is recycled.

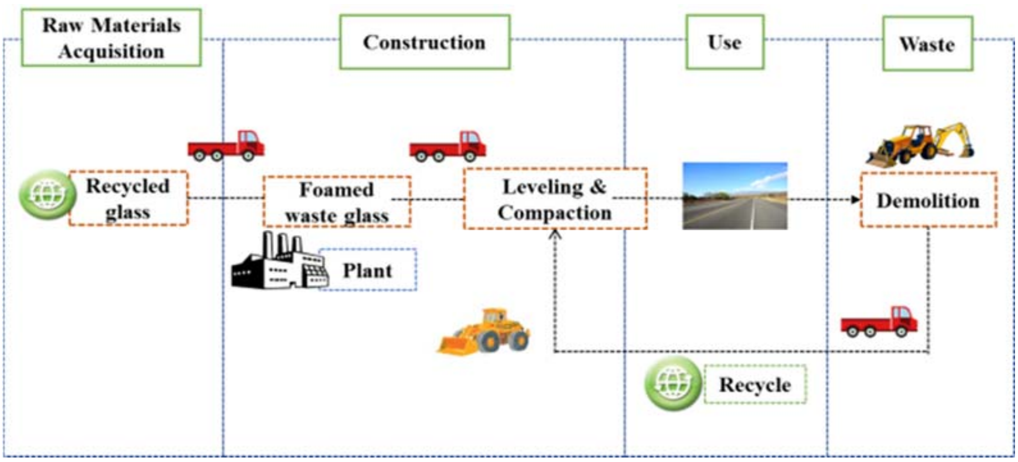


Fig. 3 System boundary of the foamed waste glass method.

Table 3 CO_2, SO_x, and NO_x units.

Life-cycle	Materials	CO_2 (kg-CO2)	SOx (g-SOx)	NOx (g-NOx)
Raw Materials Acquisition	Soil, Sand (kg)	0.0020	0.0034	0.0106
	Limestone (kg)	0.0047	0.0009	0.0015
	Foamed EPS (kg)	1.3123	0.2555	1.1651
	Aluminum (kg)	9.218	76.8	30
	Zinc (kg)	1.443	5.92	1.327
	Porous lightweight foam material	0.176	0.268	0.082
Construction	Leveling (m^2)	20.900	28.919	48.173
	Compaction (m^2)	12.100	16.742	27.890
Transport	20t Truck (Diesel) (km)	1.180	1.450	3.640
	15t Truck (Diesel) (km)	0.962	1.180	2.970
	10t Truck (Diesel) (km)	0.742	0.910	2.229
	4t Truck (Diesel) (km)	0.472	0.560	1.450
	2t Truck (Diesel) (km)	0.323	0.400	1.000
Waste	Dismantlement and recycle (kg)	0.00196	0.00341	0.01060
	EPS (kg)	2.64	0.544	1.22
	Metal (kg)	0.366	0.325	0.591
Energy	Diesel (L)	0.069	2.999	0.005
	Electricity (Thermal power plant) (kwh)	0.425	0.170	0.130

Table 4 Cost unit for each material.

Materials	Unit	Cost
Soil, Sand	JPY/kg	2.000
Polystyrene	JPY/kg	209.862
Limestone	JPY/kg	0.633
Aluminum	JPY/kg	76.539
Zinc	JPY/kg	186.132
Additive agent	JPY/m^3	1000.000
Diesel	JPY/L	78.000
Electricity	JPY/kwh	16.198
Leveling & Compaction	JPY/m^2	934.271

4. RESULTS

The estimated amount of emission of air pollutants and CO_2 for each construction method is shown in Fig. 4. The methods ranked according to CO_2 emission amounts, from the highest to the lowest, are as follows: the EPS block method, the lightweight EPS bead mixture method (without recycle and with recycle), the foamed waste glass method (without recycle and with recycle), and the cut-and-fill method. In the EPS block method, a large amount of CO_2 is emitted by the manufacturing and burning of EPS during its raw material collection and waste stages. In the lightweight EPS bead mixture method, most CO_2 is emitted during construction and disposal. This is due to the heavy equipment used in the work. When recycled materials are used, the CO_2 generated during raw material collection is reduced. The CO_2 emitted by the foamed waste glass method occurs mostly in the construction stage; hence, CO_2 reduction is achieved by using recycled materials rather than by collecting raw materials.

The methods ranked according to SO_x emission amounts, from the highest to the lowest, are as follows: the foamed waste glass method, the foamed waste glass method without recycle, the foamed waste glass method with recycle, the lightweight EPS bead mixture method without recycle, the lightweight bead mixture method with recycle, the cut-and-fill method, and the EPS block method. Large emission was observed in the raw material acquisition and construction stages in the foamed waste glass method, in the construction stage alone in the lightweight EPS bead mixture method and in the cut-and-fill method, and in the raw materials collection and disposal stages in the EPS block method. SO_x emission during raw material collection was reduced using recycled embankment materials in the lightweight EPS bead mixture method and in the foamed waste glass method.

The methods ranked according to NO_x emission amounts, from the highest to the lowest, are as follows: the lightweight EPS bead mixture method (without recycle and with recycle), the foamed waste glass method (without recycle and with recycle), the EPS block method, and the cut-and-fill method. Most emissions were observed during the construction stage in the lightweight EPS bead mixture method, the foamed waste glass method, and the cut-and-fill method. In the EPS block method, in contrast, most emissions were observed during the raw materials collection and disposal stages. However, NO_x emission during raw material collection was reduced, as with SO_x, by using recycled embankment materials in the lightweight EPS bead mixture method and in the foamed waste glass method.

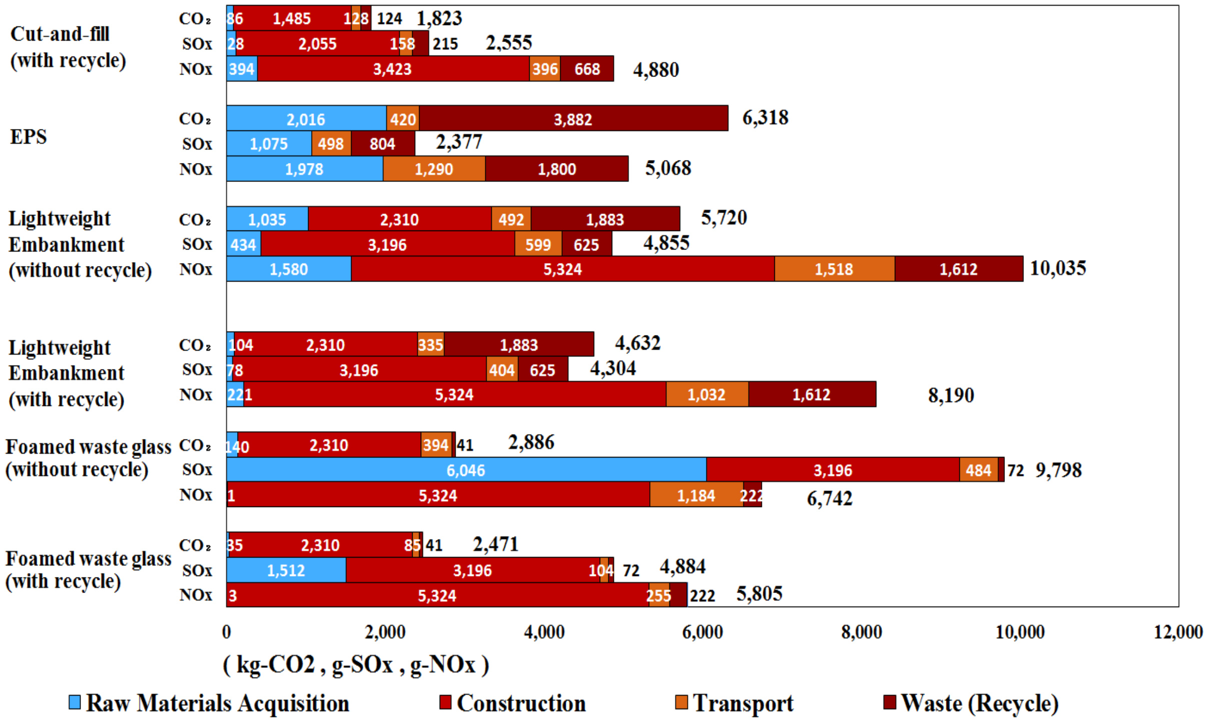


Fig. 4 Estimated amounts of air pollutants and CO_2 emitted by each construction method.

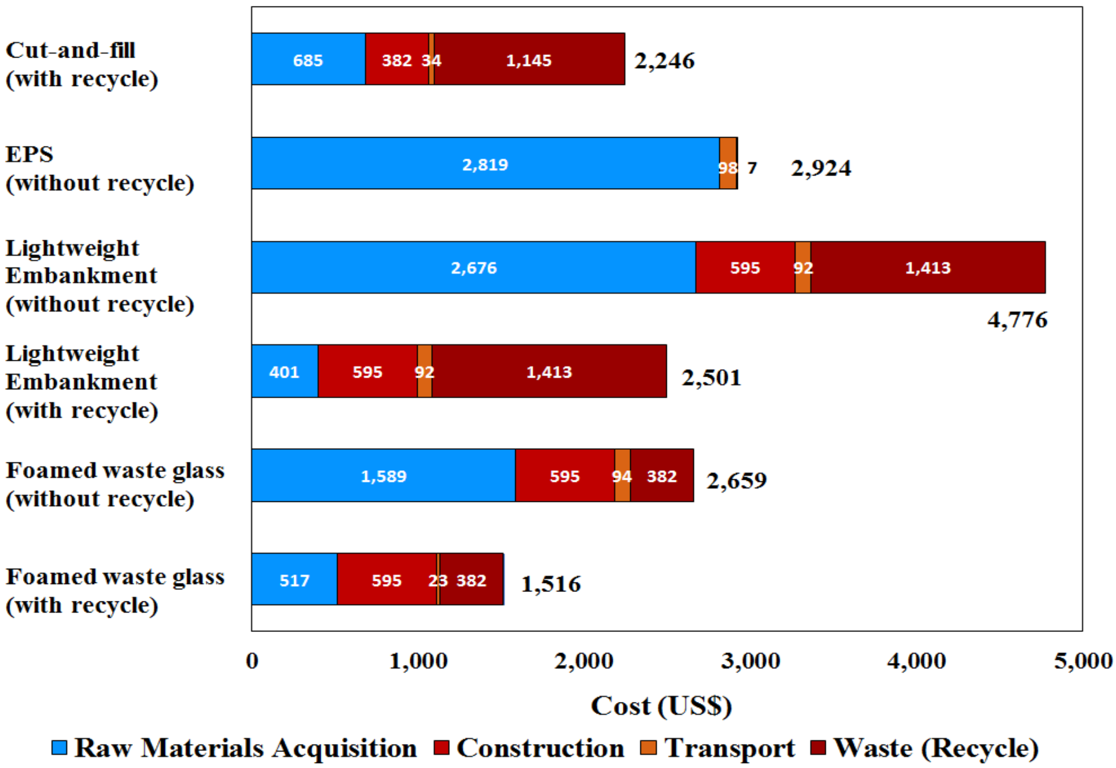


Fig. 5 Estimated total life-cycle cost of each construction method.

Fig. 5 shows the estimated total LCCs of each construction method. The methods are ranked in decreasing order of LCCs as follows: the lightweight EPS bead mixture method, the EPS block method, the foamed waste glass method, and the cut-and-fill method. The raw material collection and disposal stages were costlier in the lightweight EPS bead mixture method and in the cut-and-fill method. In the

EPS block method, more than 90% of the costs occurred during the raw material collection stage. However, in the lightweight EPS bead mixture method and the foamed waste glass method, the cost of raw material collection was reduced by recycling embankment materials.

5. DISCUSSION

In this research, it was shown that all construction methods need to recycle or reuse to lower the negative impacts because producing new materials has larger adverse impacts than recycling or reusing materials.

According to results on CO_2 and air pollutant emissions and LCC, the conventional cut-and-fill method has lower impact on the environment and has reasonable LCC compared with other methods. Regarding the lightweight EPS bead mixture method, it has a larger impact on environment and cost even when recycled materials are used because CO_2 and air pollutants are emitted in large amounts at the construction phase including the manufacturing process. Thus, it is necessary to improve the techniques to produce and recycle EPS beads such that they have a lower environmental impact.

The EPS block method emits the largest amount of CO_2 among all methods. We need to develop new techniques to recycle or reuse EPS after dismantlement because EPS blocks are just dumped currently because there are no methods to recycle and reuse the EPS blocks. The foamed waste glass method with recycle has the second lowest impact among all methods.

This research focused only on the emission of CO_2 and air pollutants and cost. We should select the appropriate construction method based on not only these results but also the environmental performance and regional characteristics of the construction site.

6. CONCLUSION

The present research confirmed the potential for reducing environmental load and LCC using recycled materials in various embankment construction methods.

For further research, the estimated LCC must include external costs and life cycle impact assessments must include considerations such as health impacts. In addition, it is necessary to perform comprehensive evaluation including the perspective of safety for a fair comparison through life cycle impact assessment.

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