A case study on environmental impact assessment of precast concrete products with a revegetation function

K. Kawai
Department of Civil and Environmental Engineering, Hiroshima University, Higashi-Hiroshima, Hiroshima, Japan

A. Fujiki
Research & Development Laboratory, Landes Co. Ltd., Maniwa, Okayama, Japan

ABSTRACT: In this paper, a case study on environmental impact assessment of precast concrete products with a revegetation function was performed, and appropriate evaluation of the effect of revegetation on environmental impact reduction was discussed. The precast concrete structure studied here was a retaining wall. Environmental impacts in the material manufacturing and construction stages of a retaining wall using precast concrete with a revegetation function and a retaining wall placed in situ with ready-mixed concrete were compared. The retaining wall using precast concrete was constructed by piling hollow precast concrete boxes of which hollows were filled with soils emitted in the construction site. These boxes were planted. As a result, integrated environmental damage of the retaining wall using precast concrete was 35% smaller than that of the retaining wall using ready-mixed concrete. Especially the environmental damage regarding land use was largely different between two types of retaining walls. This is because of reuse of soils emitted in the site. But this is not a direct effect of revegetation. Based on this calculation result, a quantitative evaluation method for the revegetation function was discussed.

1 INTRODUCTION

To reduce environmental impact of a concrete structure, several countermeasures are conducted in each stage of manufacturing of materials, transportation, construction, maintenance, demolition, disposal and reuse after demolition. The effects of these actions on environmental impact reduction can be evaluated with some methods. As a typical method, the LCA method is used. LIME (Lifecycle Impact Assessment Method based on Endpoint Modeling) is an LCA method developed in Japan that can characterize and integrate different inventories such as CO_2, NO_x, SO_x and waste emissions (Yamaguchi 2003, JEMAI 2004). Although many kinds of inventories are considered with the characterization/integration method like LIME, even some factors cannot be dealt with. One of these factors is a revegetation function by constructing a structure. Indirect effects of revegetation on environmental impact could be evaluated with a current integration method, but not direct effects.

In this paper, a case study on environmental impact assessment of precast concrete products with a revegetation function was performed using LIME, and appropriate evaluation of the effect of revegetation on environmental impact reduction was discussed. There are many kinds of precast concrete products which have been designed based on environmental conservation thinking in the market. However, in practice, the performances of those products have not been assessed because of a lack of both background data and valuable assessment methods (JSCE 2004). The precast concrete structure studied here was a leaning-type retaining wall. Environmental impacts in the material manufacturing and construction stages of a retaining wall using precast concrete with a revegetation function and a retaining wall placed in situ with ready-mixed concrete were compared. The retaining wall using precast concrete was constructed by piling hollow precast concrete boxes of which hollows were filled with soils emitted in the construction site. These boxes were planted. Based on this calculation result, a quantitative evaluation method for the revegetation function was discussed.

2 OUTLINE OF THE LEANING-TYPE RETAINING WALL

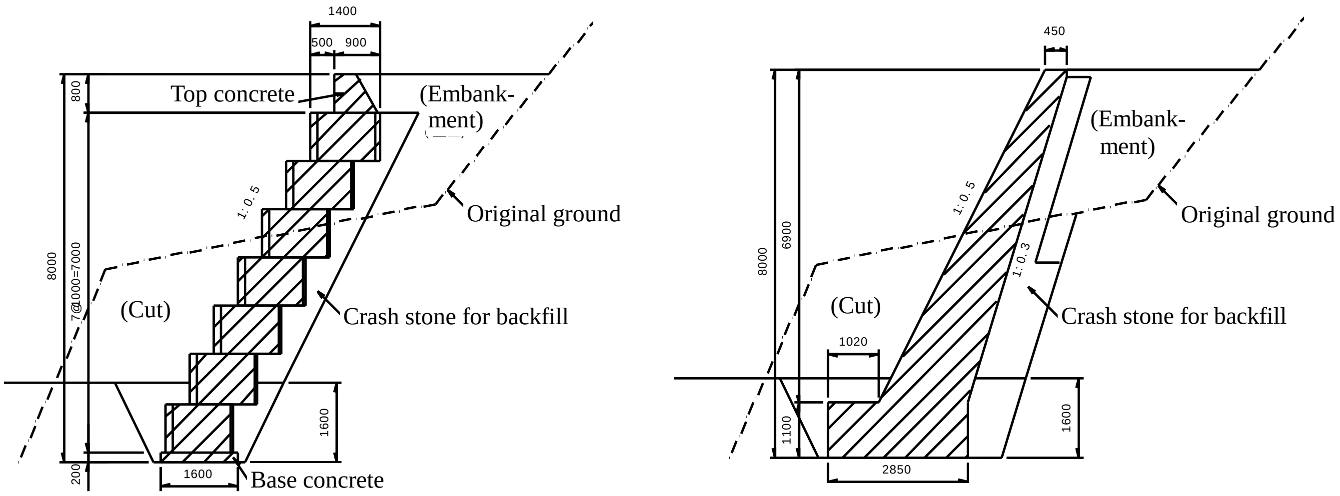
In this paper, leaning-type retaining wall works accompanying road construction on the slope of a mountain was studied (Kawai et al. 2005a). The following two cases of the construction of a retaining wall (height: 8.0 m, slope: 1:0.5, length: 120 m) were considered.

Case-1: a leaning-type retaining wall using precast concrete products (hollow blocks)

Case-2: a leaning-type retaining wall constructed with ready-mixed concrete in situ

For the leaning-type retaining wall of Case-1, hollow blocks (width: 1.5 m, length: 1.6 m, height: 1.0 m) are piled up before connecting them with ready-mixed concrete and steel bars. Surplus soil emitted during the construction is treated in the site by being filled into the hollow blocks. Together with transportation of concrete products resulting in little concrete placing in situ, reduction of construction term and secure concrete quality can be expected.

Figure 1. Revegetation area by leaning-type retaining walls (7 years after construction).



Case-1: Retaining wall using hollow blocks

Case-2: Retaining wall constructed in situ

Figure 2. Schematic view of the leaning-type retaining walls studied.

Table 1. Total amounts for construction works in each case.

Materials and works	Unit	Case-1	Case-2
Soil excavation	m^3	1704	1799
Excavation for foundation	m^3	538	904
Backfill of foundation	m^3	241	420
Placing of hollow block	m^3	690	---
Embankment	m^3	698	974
Crushed stone for backfill	m^3 (t)	444 (910)	542 (1111)
Hollow block	Number (t)	560 (753)	---
Steel bar	t	3.3	---
Ready-mixed concrete	m^3	264	1320
Wood form	m^2 (t)	278 (1.7)	2054 (12.3)
Scaffold work	m^2	---	1326
Surplus soil	m^3 (t)	517 (646)	1385 (1731)
Revegetation	m^2	360	---

Furthermore, it is possible to revegetate the construction site by planting the hollow blocks as shown in Figure 1. The schematic view of the retaining walls is shown in Figure 2. Total amounts for construction works in each case are listed in Table 1.

3 METHOD OF THE ENVIRONMENTAL IMPACT ASSESSMENT

An environmental impact assessment was performed using LIME whose evaluations are based on Japanese weather and the country's geographical conditions. The LIME method sets forth four objects of protection consisting of human health, public assets, biodiversity and primary production capacity, which have unique indexes consisting of DALY (Disability-Adjusted Life Year, unit: year), YEN (Japanese monetary unit, unit: yen), EINES (Expected Increase Numbers of Extinct Species, unit: species) and NPP (Net Primary Productivity, unit: t/ha/year), respectively (Kawai et al. 2005a). The degree of environmental impact can be evaluated with these four indexes and furthermore with a single index that is an integrated index of these four indexes.

In this case study, the manufacturing of materials, transportation of materials, construction, waste treatment, material recycling and change of land use were estimated. As environmental impact, the uses of oil, coal, natural gas, purchased electricity, non-metallic minerals and iron and the emissions of CO_2, SO_X, NO_X and particulate matter were estimated.

To evaluate the revegetation on the hollow blocks in Case-1, the followings are assumed based on categories of land use in LIME shown in Tables 2 & 3: 1200 m^2 of "forest" were changed to 360 m^2 of "other groves" and 840 m^2 of "road," and the land uses were maintained for 50 years. Regarding the construction works, the road construction work was adopted as the EINES damage factors of works shown in Table 4, in this case study.

4 INVENTORY ANALYSIS

Total amounts used for calculation of each case are listed in Table 5 and emission inventory data in Tables 6-8 (Kawai et al. 2005b). The inventory analysis was performed using the amounts of each emission per unit, and the output data are shown in Tables 9-17.

Table 2. NPP damage factors for maintenance of land use.

Land use	Damage factor (t/ha/yr)
Rice field	3
Field	2
Fruit farm	4
Other grove	3
Forest	1
Rough	2
Building	14
Road	13
Others	7

Table 4. EINES damage factors for works.

Kind of works	Damage factor (EINES/ha)
Road construction	3.64×10^{-6}
Mining of soil and stone	9.83×10^{-7}
Construction of final disposal grounds	4.75×10^{-6}
Others	1.18×10^{-6}

Table 3. NPP damage factors for change of land use.

After / Before	Rice field	Field	Fruit farm	Other grove	Forest	Rough	Build-ing	Road	Others
Rice field	0	-18	13	9	-42	-20	975	963	67
Field	18	0	32	27	-23	-1	993	981	85
Fruit farm	-13	-32	0	-4	-55	-33	961	949	53
Other grove	-9	-27	4	0	-51	-29	966	954	58
Forest	42	23	55	51	0	22	1017	1005	109
Rough	20	1	33	29	-22	0	995	983	87
Building	-975	-993	-961	-966	-1017	-995	0	-12	-908
Road	-963	-981	-949	-954	-1005	-983	12	0	-896
Others	-67	-85	-53	-58	-109	-87	908	896	0

Unit of damage factors: t/ha

Table 5. Total amounts used for calculation in each case.

				Unit	Case-1	Case-2
Manufacture of materials	Hollow block	Material	Blast furnace slag cement (Type B)	t	110	---
			Fine aggregate	t	242	---
			Coarse aggregate	t	366	---
			Steel bar	t	13	---
		Production	Process in plant	t	773	---
			Form vibrator	h	93	---
			Steam curing	m^3	326	---
	Ready-mixed concrete	Material	Blast furnace slag cement (Type B)	t	68	338
			Fine aggregate	t	217	1085
			Coarse aggregate	t	295	1474
		Production	Process in plant	t	621	3103
	Steel bar			t	3	---
	Crushed stone for backfill			t	910	1111
Transportation of materials	Ready-mixed concrete	Agitator truck (4.5 m^3)		km.m^3	10560	52,800
	Crushed stone for backfill	Truck (10t)		km.t	91000	111100
	Hollow block	Truck (10t)		km.t	75300	---
	Steel bar	Truck (10t)		km.t	330	---
	Wood form	Truck (10t)		km.t	170	1230
Construction	Soil excavation	Excavator (0.6 m^3)		h	46	49
	Excavation for foundation	Excavator (0.6 m^3)		h	14	25
	Placing of hollow block	Truck crane (15-16t)		h	90	---
	Backfill of foundation	Excavator (0.6 m^3)		h	10	17
		Tamper (60-100kg)		h	43	76
	Crushed stone for backfill	Excavator (0.6 m^3)		h	70	86
	Embankment	Excavator (0.6 m^3)		h	28	39
		Tamper (60-100kg)		h	125	175
	Compaction in hollow	Excavator (0.6 m^3)		h	28	---
		Tamper (60-100kg)		h	124	---
	Scaffold work	Wheel crane (25t)		h	---	64
	Placing of ready-mixed concrete	Agitator truck (4.5m^3)		h	60	294
		Truck crane (15-16t)		h	36	60
Waste treatment	Surplus soil			t	646	1731

Table 6. Emission inventory data (manufacture of materials).

		Manufacture of materials					
		Blast furnace slag cement (Type B)	Fine aggregate (Natural, crushed)	Coarse aggregate (Natural, crushed)	Electric furnace steel	Concrete plant	Form vibrator (0.1kW)
Unit		t	t	t	t	t	h
Input energy (GJ)		2.281	0.077	0.053	4.239	0.115	0.000
Consumption	Oil (kg)	13.1	0.4	0.4	3.6	2.1	0.0
	Coal (kg)	56.8	0.0	0.0	71.8	0.0	0.0
	Natural gas (kg)	0.00	0.00	0.00	0.00	0.32	0.00
	Purchased power (kWh)	30.06	6.19	4.32	337.70	0.64	0.05
	Non-metal mineral (kg)	715.0	1000.0	1000.0	33.4	0.0	0.0
	Iron (kg)	0.0	0.0	0.0	93.2	0.0	0.0
Material recycling (wet-kg)		85.1	0.0	0.0	0.0	0.0	0.0
Emission	Waste (wet-kg)	0.0	0.0	0.0	6.6	0.0	0.0
	CO_2 (kg)	457.65	3.50	2.75	755.29	7.68	0.02
	SOx (kg)	0.0808649	0.0042445	0.0060692	0.1339010	0.0034197	0.0000070
	NOx (kg)	0.91871	0.00749	0.00415	0.12403	0.06505	0.00001
	Particulate matter (kg)	0.0217816	0.0019910	0.0014131	0.0101310	0.0033092	0.0000016

Table 7. Emission inventory data (manufacture of materials, transportation of materials and construction).

		Manuf. of materials	Transportation of materials		Construction		
		Steam curing	Truck (10t)	Agitator truck (4.5m^3)	Agitator truck (4.5m^3)	Excavator (0.6m^3)	Truck crane (15-16t)
Unit		m^3	km.t	km.m^3	h	h	h
Input energy (GJ)		0.593	0.002	0.004	0.488	0.747	0.239
Consumption	Oil (kg)	9.9	0.0	0.1	11.0	16.8	5.4
	Coal (kg)	0.0	0.0	0.0	0.0	0.0	0.0
	Natural gas (kg)	0.00	0.00	0.00	0.00	0.00	0.00
	Purchased power (kWh)	10.35	0.00	0.00	0.00	0.00	0.00
	Non-metal mineral (kg)	0.0	0.0	0.0	0.0	0.0	0.0
	Iron (kg)	0.0	0.0	0.0	0.0	0.0	0.0
Material recycling (wet-kg)		0.0	0.0	0.0	0.0	0.0	0.0
Emission	Waste (wet-kg)	0.0	0.0	0.0	0.0	0.0	0.0
	CO_2 (kg)	38.48	0.12	0.25	33.78	51.69	16.52
	SOx (kg)	0.0241081	0.0000941	0.0001948	0.0260086	0.0397902	0.0127194
	NOx (kg)	0.03172	0.00091	0.00379	0.25262	0.77439	0.12354
	Particulate matter (kg)	0.0347691	0.0000768	0.0001922	0.0212267	0.0392549	0.0103808

Table 8. Emission inventory data (construction, waste treatment and purchased power).

		Construction		Waste treatment	Purchased power
		Wheel crane (25t)	Tamper (60-100kg)	Surplus soil	
Unit		h	h	t	kWh
Input energy (GJ)		0.774	0.032	0.024	0.009
Consumption	Oil (kg)	17.4	0.7	0.5	0.1
	Coal (kg)	0.0	0.0	0.0	0.1
	Natural gas (kg)	0.00	0.00	0.00	0.02
	Purchased power (kWh)	0.00	0.00	0.00	---
	Non-metal mineral (kg)	0.0	0.0	0.0	0.0
	Iron (kg)	0.0	0.0	0.0	0.0
Material recycling (wet-kg)		0.0	0.0	0.0	0.0
Emission	Waste (wet-kg)	0.0	0.0	1000.0	0.0
	CO_2 (kg)	53.57	2.15	1.64	0.37
	SOx (kg)	0.0412413	0.0000005	0.0012617	0.0001300
	NOx (kg)	0.80263	0.00001	0.02456	0.00016
	Particulate matter (kg)	0.0406864	0.0000005	0.0012447	0.0000300

Table 9. Inventory analysis for hollow blocks in Case-1 in terms of manufacture of materials.

			Material			Production			
			Blast furnace slag cement (Type B)	Fine aggregate	Coarse aggregate	Steel bar	Process in plant	Form vibrator	Steam curing
Unit			t	t	t	t	t	h	m^3
Input energy (GJ)			251	19	19	57	89	0	193
Consumption	Oil (kg)		1443	89	136	48	1645	0	3230
	Coal (kg)		6242	0	0	962	0	0	0
	Natural gas (kg)		0	0	0	0	247	0	0
	Purchased power (kWh)		3304	1498	1582	4525	495	5	3374
	Non-metal mineral (kg)		78582	241900	366400	448	0	0	0
	Iron (kg)		0	0	0	1249	0	0	0
Material recycling (wet-kg)			9355	0	0	0	0	0	0
Emission	Waste (wet-kg)		0	0	0	88	0	0	0
	CO_2 (kg)		50296	847	1008	10121	5935	2	12544
	SOx (kg)		9	1	2	2	3	0	8
	NOx (kg)	Stationary resource	101	2	2	2	50	0	10
		Moving resource	---	---	---	---	---	---	---
	Particulate matter (kg)	Stationary resource	2	0	1	0	3	0	11
		Moving resource	---	---	---	---	---	---	---

Table 10. Inventory analysis for materials and production in Case-1 in terms of manufacture of materials.

			Material					
			Blast furnace slag cement (Type B)	Fine aggregate	Coarse aggregate	Production process in plant	Steel bar	Crushed stone for backfill
Unit			t	t	t	t	t	t
Input energy (GJ)			251	19	19	89	14	48
Consumption	Oil (kg)		1443	89	136	1645	12	338
	Coal (kg)		6242	0	0	0	237	0
	Natural gas (kg)		0	0	0	247	0	0
	Purchased power (kWh)		3304	1498	1582	495	1114	3929
	Non-metal mineral (kg)		78582	241900	366400	0	110	910000
	Iron (kg)		0	0	0	0	308	0
Material recycling (wet-kg)			9355	0	0	0	0	0
Emission	Waste (wet-kg)		0	0	0	0	22	0
	CO_2 (kg)		50296	847	1008	5935	2492	2503
	SOx (kg)		9	1	2	3	0	6
	NOx (kg)	Stationary resource	101	2	2	50	0	4
		Moving resource	---	---	---	---	---	---
	Particulate matter (kg)	Stationary resource	2	0	1	3	0	1
		Moving resource	---	---	---	---	---	---

Table 11. Inventory analysis for materials and production in Case-2 in terms of manufacture of materials.

			Material					
			Blast furnace slag cement (Type B)	Fine aggregate	Coarse aggregate	Production process in plant	Steel bar	Crushed stone for backfill
Unit			t	t	t	t	t	t
Input energy (GJ)			---	---	---	---	---	59
Consumption	Oil (kg)		---	---	---	---	---	413
	Coal (kg)		---	---	---	---	---	0
	Natural gas (kg)		---	---	---	---	---	0
	Purchased power (kWh)		---	---	---	---	---	4797
	Non-metal mineral (kg)		---	---	---	---	---	1111000
	Iron (kg)		---	---	---	---	---	0
Material recycling (wet-kg)			---	---	---	---	---	0
Emission	Waste (wet-kg)		---	---	---	---	---	0
	CO_2 (kg)		---	---	---	---	---	3056
	SOx (kg)		---	---	---	---	---	7
	NOx (kg)	Stationary resource	---	---	---	---	---	5
		Moving resource	---	---	---	---	---	---
	Particulate matter (kg)	Stationary resource	---	---	---	---	---	2
		Moving resource	---	---	---	---	---	---

Table 12. Inventory analysis in Case-1 in terms of transportation of materials.

			Ready-mixed concrete / Agitator truck (4.5m^3)	Crushed stone for backfill / Truck (10t)	Hollow block / Truck (10t)	Steel bar / Truck (10t)	Wood form / Truck (10t)
Unit			km.m^3	km.t	km.t	km.t	km.t
Input energy (GJ)			39	161	133	1	0
Consumption	Oil (kg)		866	3607	2985	13	7
	Coal (kg)		0	0	0	0	0
	Natural gas (kg)		0	0	0	0	0
	Purchased power (kWh)		0	0	0	0	0
	Non-metal mineral (kg)		0	0	0	0	0
	Iron (kg)		0	0	0	0	0
Material recycling (wet-kg)			0	0	0	0	0
Emission	Waste (wet-kg)		0	0	0	0	0
	CO_2 (kg)		2672	11128	9208	40	21
	SOx (kg)		2	9	7	0	0
	NOx (kg)	Stationary resource	---	---	---	---	---
		Moving resource	40	83	69	0	0
	Particulate matter (kg)	Stationary resource	---	---	---	---	---
		Moving resource	2	7	6	0	0

Table 13. Inventory analysis in Case-2 in terms of transportation of materials.

			Ready-mixed concrete / Agitator truck (4.5m^3)	Crushed stone for backfill / Truck (10t)	Hollow block / Truck (10t)	Steel bar / Truck (10t)	Wood form / Truck (10t)
Unit			km.m^3	km.t	km.t	km.t	km.t
Input energy (GJ)			193	196	---	---	2
Consumption	Oil (kg)		4331	4404	---	---	49
	Coal (kg)		0	0	---	---	0
	Natural gas (kg)		0	0	---	---	0
	Purchased power (kWh)		0	0	---	---	0
	Non-metal mineral (kg)		0	0	---	---	0
	Iron (kg)		0	0	---	---	0
Material recycling (wet-kg)			0	0	---	---	0
Emission	Waste (wet-kg)		0	0	---	---	0
	CO_2 (kg)		13362	13586	---	---	150
	SOx (kg)		10	10	---	---	0
	NOx (kg)	Stationary resource	---	---	---	---	---
		Moving resource	200	102	---	---	1
	Particulate matter (kg)	Stationary resource	---	---	---	---	---
		Moving resource	10	9	---	---	0

Table 14. Inventory analysis in Case-1 in terms of construction.

			Soil excavation / Excavator (0.6m^3)	Excavation for foundation / Excavator (0.6m^3)	Placing of hollow block / Truck crane (15-16t)	Backfill of foundation / Excavator (0.6m^3)	Backfill of foundation / Tamper (60-100kg)	Crushed stone for backfill / Excavator (0.6m^3)	Embankment / Excavator (0.6m^3)
Unit			h	h	h	h	h	h	h
Input energy (GJ)			35	11	21	7	1	52	21
Consumption	Oil (kg)		774	241	482	161	31	1176	467
	Coal (kg)		0	0	0	0	0	0	0
	Natural gas (kg)		0	0	0	0	0	0	0
	Purchased power (kWh)		0	0	0	0	0	0	0
	Non-metal mineral (kg)		0	0	0	0	0	0	0
	Iron (kg)		0	0	0	0	0	0	0
Material recycling (wet-kg)			0	0	0	0	0	0	0
Emission	Waste (wet-kg)		0	0	0	0	0	0	0
	CO_2 (kg)		2388	744	1487	496	93	3628	1442
	SOx (kg)		2	1	1	0	0	3	1
	NOx (kg)	Stationary resource	36	11	11	7	0	54	22
		Moving resource	---	---	---	---	---	---	---
	Particulate matter (kg)	Stationary resource	2	1	1	0	0	3	1
		Moving resource	---	---	---	---	---	---	---

Table 15. Inventory analysis in Case-2 in terms of construction.

			Soil excavation / Excavator ($0.6m^3$)	Excavation for foundation / Excavator ($0.6m^3$)	Placing of hollow block / Truck crane (15-16t)	Backfill of foundation / Excavator ($0.6m^3$)	Backfill of foundation / Tamper (60-100kg)	Crushed stone for backfill / Excavator ($0.6m^3$)	Embankment / Excavator ($0.6m^3$)
Unit			h	h	h	h	h	h	h
Input energy (GJ)			37	18	---	13	2	64	29
Consumption	Oil (kg)		824	412	---	281	55	1438	653
Consumption	Coal (kg)		0	0	---	0	0	0	0
Consumption	Natural gas (kg)		0	0	---	0	0	0	0
Consumption	Purchased power (kWh)		0	0	---	0	0	0	0
Consumption	Non-metal mineral (kg)		0	0	---	0	0	0	0
Consumption	Iron (kg)		0	0	---	0	0	0	0
Material recycling (wet-kg)			0	0	---	0	0	0	0
	Waste (wet-kg)		0	0	---	0	0	0	0
Emission	CO_2 (kg)		2543	1271	---	868	162	4435	2016
Emission	SOx (kg)		2	1	---	1	0	3	2
Emission	NOx (kg)	Stationary resource	38	19	---	13	0	66	30
Emission	NOx (kg)	Moving resource	---	---	---	---	---	---	---
Emission	Particulate matter (kg)	Stationary resource	2	1	---	1	0	3	2
Emission	Particulate matter (kg)	Moving resource	---	---	---	---	---	---	---

Table 16. Inventory analysis in Case-1 in terms of construction and waste treatment.

			Embankment / Tamper (60-100kg)	Compaction in hollow / Excavator ($0.6m^3$)	Compaction in hollow / Tramper (60-100kg)	Scaffold work / Wheel crane (25t)	Placing of ready-mixed concrete / Agitator truck ($4.5m^3$)	Placing of ready-mixed concrete / Truck crane (15-16t)	Waste treatment for surplus soil
Unit			h	h	h	h	h	h	t
Input energy (GJ)			4	21	4	---	29	9	15
Consumption	Oil (kg)		91	462	90	---	657	193	341
Consumption	Coal (kg)		0	0	0	---	0	0	0
Consumption	Natural gas (kg)		0	0	0	---	0	0	0
Consumption	Purchased power (kWh)		0	0	0	---	0	0	0
Consumption	Non-metal mineral (kg)		0	0	0	---	0	0	0
Consumption	Iron (kg)		0	0	0	---	0	0	0
Material recycling (wet-kg)			0	0	0	---	0	0	0
	Waste (wet-kg)		0	0	0	---	0	0	646000
Emission	CO_2 (kg)		269	1427	266	---	2027	595	1059
Emission	SOx (kg)		0	1	0	---	2	0	1
Emission	NOx (kg)	Stationary resource	0	21	0	---	15	4	16
Emission	NOx (kg)	Moving resource	---	---	---	---	---	---	---
Emission	Particulate matter (kg)	Stationary resource	0	1	0	---	1	0	1
Emission	Particulate matter (kg)	Moving resource	---	---	---	---	---	---	---

Table 17. Inventory analysis in Case-2 in terms of construction and waste treatment.

			Embankment / Tamper (60-100kg)	Compaction in hollow / Excavator ($0.6m^3$)	Compaction in hollow / Tramper (60-100kg)	Scaffold work / Wheel crane (25t)	Placing of ready-mixed concrete / Agitator truck ($4.5m^3$)	Placing of ready-mixed concrete / Truck crane (15-16t)	Waste treatment for surplus soil
Unit			h	h	h	h	h	h	t
Input energy (GJ)			6	---	---	49	144	14	41
Consumption	Oil (kg)		126	---	---	1104	3220	321	915
Consumption	Coal (kg)		0	---	---	0	0	0	0
Consumption	Natural gas (kg)		0	---	---	0	0	0	0
Consumption	Purchased power (kWh)		0	---	---	0	0	0	0
Consumption	Non-metal mineral (kg)		0	---	---	0	0	0	0
Consumption	Iron (kg)		0	---	---	0	0	0	0
Material recycling (wet-kg)			0	---	---	0	0	0	0
Emission	Waste (wet-kg)		0	---	---	0	0	0	1731000
Emission	CO_2 (kg)		376	---	---	3407	9932	991	2837
Emission	SOx (kg)		0	---	---	3	8	1	2
Emission	NOx (kg)	Stationary resource	0	---	---	51	74	7	43
Emission	NOx (kg)	Moving resource	---	---	---	---	---	---	---
Emission	Particulate matter (kg)	Stationary resource	0	---	---	3	6	1	2
Emission	Particulate matter (kg)	Moving resource	---	---	---	---	---	---	---

Table 18. Inventory analysis (total amounts).

	Input energy (GJ)	Consumption				
		Oil (kg)	Coal (kg)	Natural gas (kg)	Non-metal mineral (kg)	Iron resource (kg)
Case-1	1,736	24972	13022	943	2157676	1557
Case-2	2,428	34144	21294	1594	3912009	0
C-1/C-2	71%	73%	61%	59%	55%	---

	Emission						
	Waste (wet-kg)	CO_2 (kg)	SO_X (kg)	NO_X (kg)		Particulate matter (kg)	
				Stationary	Moving	Stationary	Moving
Case-1	343	171218	73	478	193	35	15
Case-2	932	256429	105	878	303	44	19
C-1/C-2	37%	67%	70%	54%	64%	79%	79%

C-1/C-2 represents a ratio of the amount for Case-1 to the amount for Case-2.

Table 18 shows the total emission obtained from the inventory analysis for each case. Since the use of hollow blocks leads to reduction of concrete volume, every emission amount except for the use of iron resource became lower in Case-1 than in Case-2. Especially, the waste emission in Case-1 was 63% lower compared with Case-2.

5 DAMAGE AMOUNTS

Damage amounts were calculated using an inventory analysis method based on the data of resource consumptions, waste emissions, emissions of CO_2, NO_X, SO_X and particulate matter, areas of change of land use and maintenance periods of land use. Figures 3-6 show the damage amounts of four indexes, namely, human health, public assets, biodiversity and primary production capacity. Case-1 shows a lower damage amount than Case-2 in every category, such as 30% lower in human health, 32% in public assets, 14% in biodiversity and 34% in primary production capacity. Large reductions in damage amounts for human health and public assets were related to emissions of CO_2, NO_2 and PM10. Waste emission influenced the damage amounts for biodiversity and primary production capacity. In addition, the change and maintenance period of land use also largely influenced the results, especially for primary production capacity.

6 INTEGRATION RESULTS

Four indexes of damage amounts consisting of human health, public assets, biodiversity and primary production capacity were integrated using LIME vers. 1 to 3. LIME ver. 1 is an environmental assessment method based on a conjoint analysis, and has a monetary unit. It is usually used for cost benefit analysis, environmental accounting and full cost estimation. LIME ver. 2 is also based on a conjoint analysis, but has no such unit. LIME ver. 3 is calculated based on the analytic hierarchy process (AHP) and has no such unit. The integration results are shown in Figures 7-9. The environmental impacts for Case-1 calculated with LIME vers. 1 and 2 were 27% lower than those for Case-2, while the impact for Case-1 was 28% lower with LIME ver.3. This reduction was derived from the change of land use and its subsequent maintenance, waste emissions and emissions of CO_2, NO_X, SO_X and particulate matter.

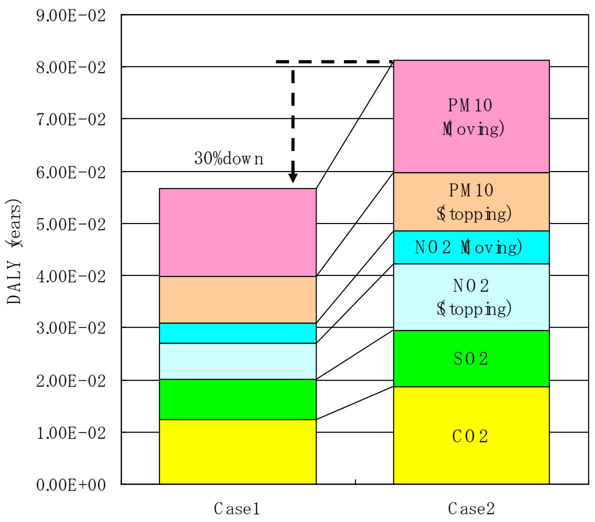


Figure 3. Damage amounts of human health.

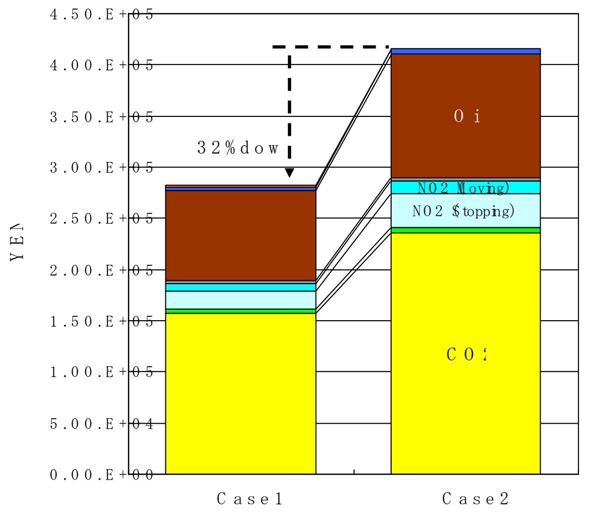


Figure 4. Damage amounts of public assets.

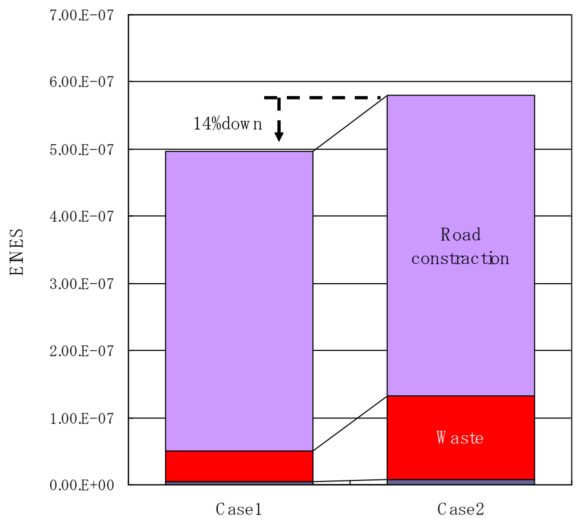


Figure 5. Damage amounts of biodiversity.

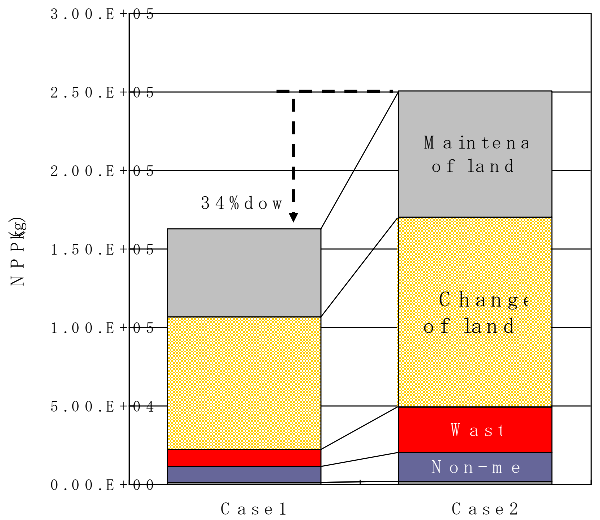


Figure 6. Damage amounts of primary production capacity.

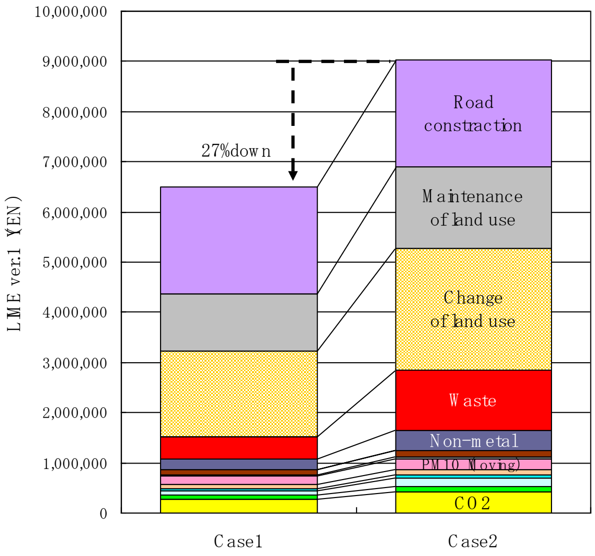


Figure 7. Integration results by LIME ver. 1.

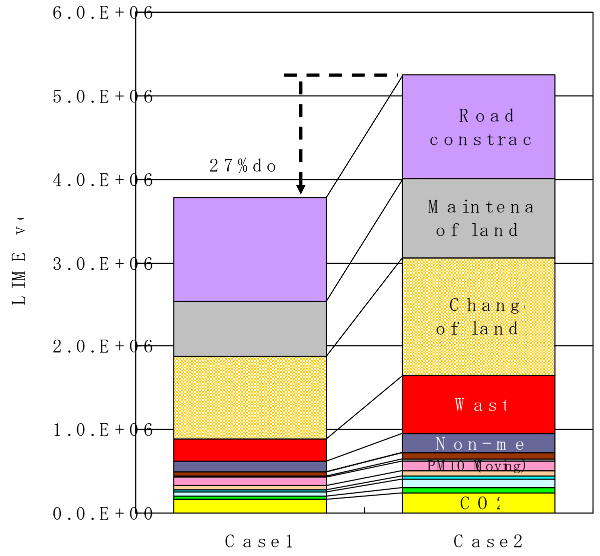


Figure 8. Integration results by LIME ver. 2.

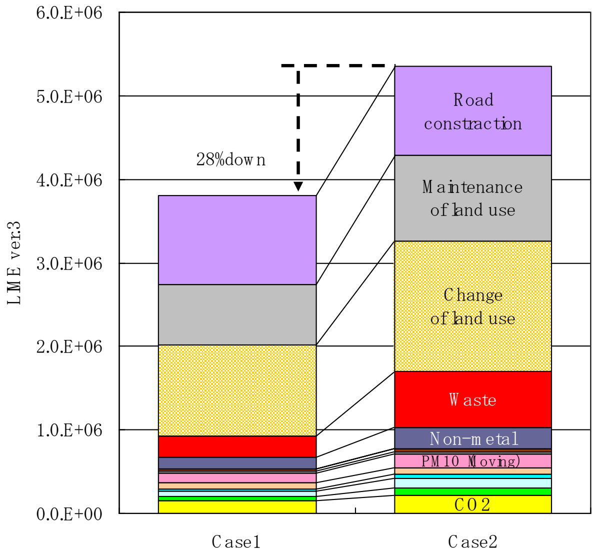


Figure 9. Integration results by LIME ver. 3.

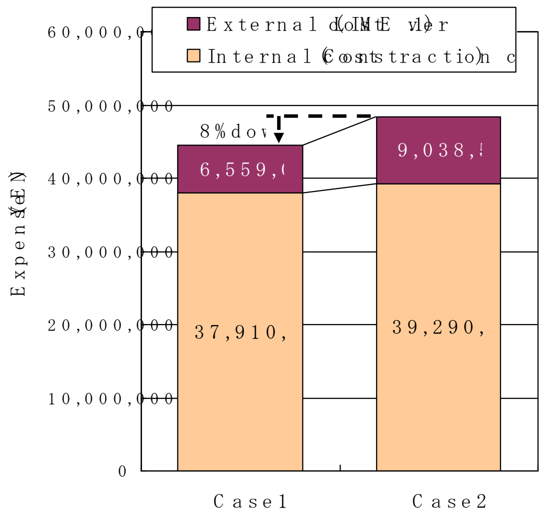


Figure 10. Estimation of internal and external costs.

Since LIME ver.1 has a monetary unit, cost analysis was also performed by considering the environmental impact as an external cost due to construction. From the cost result shown in Figure 10 using LIME ver.1, it is found that Case-1 gave a lower external cost than Case-2, as well as a lower internal cost.

7 EFFECTS OF REVEGETATION ON ENVIRONMENTAL IMPACT REDUCTION

In addition to the integration results of Case-1 and Case 2 by LIME ver. 1, the following two cases were estimated by LIME ver. 1.

Case1-A: The revegetation on the hollow blocks was considered as "forest" in the categories of land use in LIME shown in Tables 2 & 3, that means the categories did not changed before and after construction.

Case1-B: The revegetation on the hollow blocks was not performed.

The estimation results are shown in Figure 11 together with the integration results of Case-1 and Case-2. The environmental impacts for Case1-A and Case1-B were 35% and 15% lower than those for Case-2, respectively. The environmental impacts for Case-1 were 15% lower than those for Case1-B.

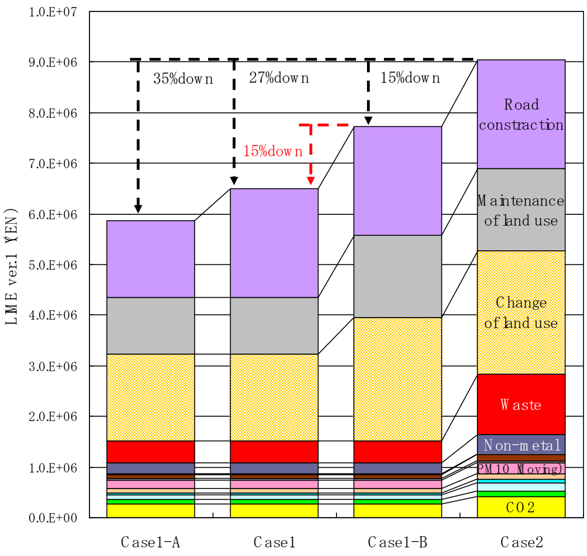


Figure 11. Effects of revegetation (Integration results are expressed by LIME ver. 1.).

Therefore it is estimated that revegetation can reduce environmental impact by 15%.

8 CONCLUSIONS

According to these two case studies, the environmental impact of Case-1 (a retaining wall using hollow blocks) could be reduced by approximately 30% compared with that of Case-2 (a retaining wall constructed in situ) because of the reduction of concrete by using the hollow blocks. The change of land use and its subsequent maintenance also largely related to this reduction. The revegetation function of the hollow blocks also greatly contributed to the reduction of environmental impact. Furthermore, the cost result shows that the external cost corresponded to 17% of the construction cost for Case-1 and 23% for Case-2. If this expense must be borne by a contractor or concrete product maker, they will have a serious problem.

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