Environmental Impact Evaluation of Concrete

*Kenji Kawai**

1. Introduction

The Committee on Concrete in Japan Society of Civil Engineers (JSCE) has been dealing with sustainability since 1997. Since the land of Japan is small and has few natural resources, the Subcommittee on Effective Utilization of Resources to Concrete which was chaired by Prof. Tazawa at Hiroshima University was organized to develop concrete technology considering the environment and to promote its use in terms of energy saving and natural resources saving. In this subcommittee, an evaluation system of materials for effective utilization of resources and an evaluation method for environmental impact of concrete structures were discussed and investigated. As for the latter topic, a performance value considering environmental impact in the life cycle of concrete was proposed[1) but only conceptual discussions were conducted within a limited active period of two years.

After this subcommittee, focusing on environmental impact of concrete, the Research Subcommittee on Environmental Impact Assessment of Concrete was organized from 1999 to 2004. This subcommittee was chaired by the author and the aim of this subcommittee was to prepare a method for evaluating environmental impact of concrete as a performance of concrete. To achieve the aim, inventory data related to concrete and concrete structures were comprehensively collected and investigated, and an evaluation method for environmental impact of concrete was proposed[2, 3)]. Eventually inventory data were prepared regarding 120 detailed items in total which include 13 items for energy, 16 items for transportation, 19 items for constituent materials of concrete, 46 items for production and execution of concrete, 18 items for demolition work, and 8 items for disposal and recycling of concrete. Although the publications from this subcommittee activities are written in Japanese, to spread these results, an evaluation method for environmental impact of concrete, inventory data related to concrete and concrete structures, and case studies were summarized in English[4, 5)].

The Subcommittee on Standard Specifications for Concrete Structures organized the Task Force on Environmental Aspects which was chaired by Prof. Sakai at Kagawa University, in 2004 to discuss the introduction of environmental aspects to the Standard Specifications for Concrete Structures. As a result of this task force, “Recommendation on Environmental Performance Verification for Concrete Structures (Draft)” was published in 2005[6)] and the body text and commentary were translated into English the next year[7)]. In this publication, the activity results of the Research Subcommittee on Environmental Impact Assessment of Concrete which include inventory data related to concrete and concrete structures and a concept of environmental performance of concrete

* Professor, Dept. of Civil and Environmental Engineering, Hiroshima University, Japan
kkawai@hiroshima-u.ac.jp

were thoroughly introduced.

In this publication, an evaluation method for environmental impact of concrete and inventory data preparation related to concrete and concrete structures are briefly described.

2. Evaluation method for environmental impact of concrete

Environmental impact of concrete can be evaluated basically based on the LCA(Life Cycle Assessment) method which is specified in ISO 14000s. However, inventory data related to concrete and concrete structures are not sufficiently prepared. Inventory data mean basic units for constituent materials, execution, demolition, disposal and recycling of concrete in terms of energy consumption, natural resources consumption, CO_2 emission, SOx emission, NOx emission, particulate matter emission etc. In that sense, a limited range of environmental impact factors for concrete can be evaluated at this time.

In the above-mentioned "Recommendation on Environmental Performance Verification for Concrete Structures (Draft)", environmental impact of concrete is considered to be one of the performances of concrete such as safety, serviceability and durability. And the influence of construction activities on the environment is named 'environmentality'. This 'environmentality' is verified in this Recommendation (Draft). The verification is carried out with a performance-based design method which is the same method for verifying the mechanical and durability performances of concrete in the Standard Specifications for Concrete Structures in Japan.

The flow of process of the environmental design in this Recommendation (Draft) is shown in <Fig. 1>.

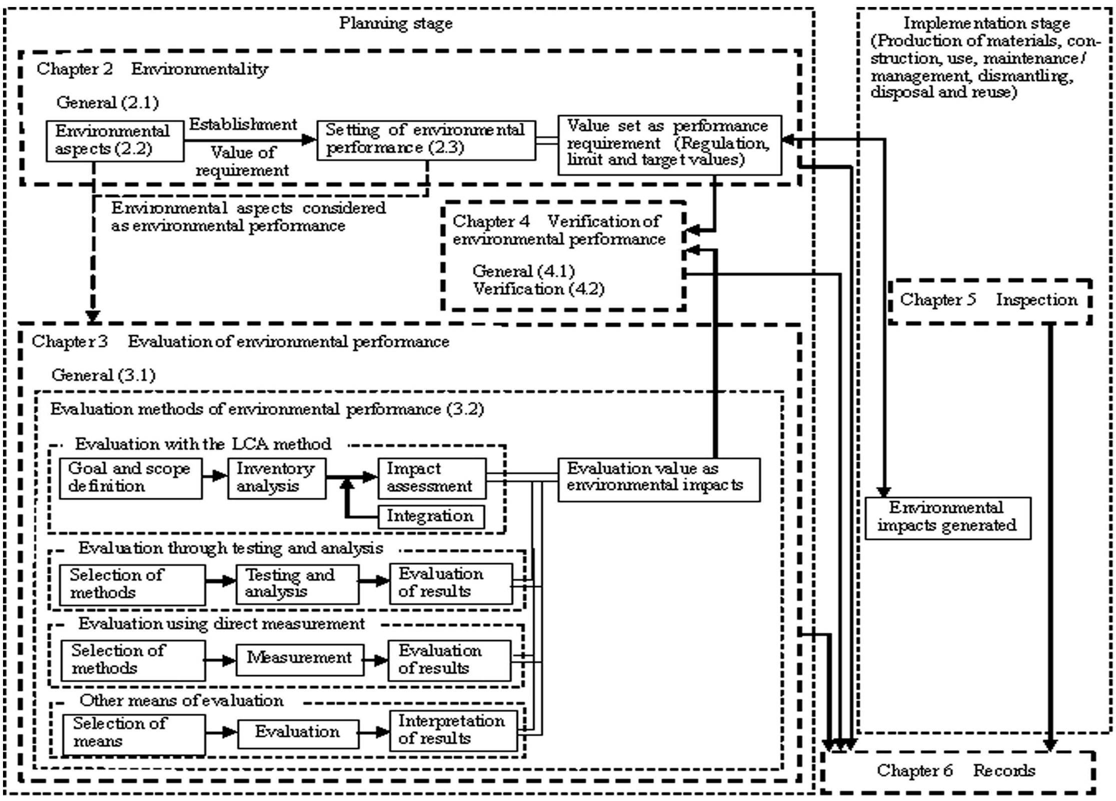

Fig 1. Flow of process of considering environmentality

(The number in the figure indicates the section number in the Recommendation(draft))

At first, environmental performance requirements are set up in Chapter 2. They are determined by owners and/or by laws and regulations. They may be given at relative values such as 20% reduction of CO_2 emission compared with a conventional construction method, and absolute values such as 5t reduction of CO_2 emission. The environmental performance of concrete and concrete structures is evaluated in Chapter 3. This performance is calculated based on constituent materials used in concrete, execution methods, transportation methods, etc. Normally the performance is assumed to be evaluated with the LCA method, but in some cases it may be evaluated with some testing, analysis or measurement. After that, the performance requirements and the evaluated results are compared in Chapter 4. This action is verification. If the evaluated results satisfies the performance requirements, the process moves from the planning stage to the implementation stage which includes production of constituent materials, execution, use, maintenance, demolition, disposal and recycling. In this implementation stage, whether or not the performance requirements are actually satisfied in each process is inspected, which corresponds to Chapter 5. And finally, the performance requirements, the evaluated results, evaluation methods and the verification results are recorded in addition to the inspection methods and results in Chapter 6. This concept was also adopted in the activities of *fib*, the International Federation for Structural Concrete which is the unique international organization of concrete, and an environmental design method was proposed[8].

As a matter of course the other performance requirements of safety, serviceability and durability have to be satisfied together with those of environmentality in concrete and concrete structures. Therefore a design harmonizing all performances will be needed.

3. Inventory data preparation

To perform the above-mentioned environmental design, the environmental performance of concrete and concrete structures has to be quantitatively calculated. From this calculation, it can be known how much energy is consumed and how much CO_2, SOx, NOx, particulate matters, etc. are emitted in the manufacturing process of constituent materials of concrete, in the execution process of concrete structures, etc. For this calculation, however, inventory data have to be prepared. As mentioned above, inventory data are basic units for energy, materials, machines, etc. and are multiplied by the amounts of energy, the amounts of materials, the operation periods of machines, etc. to obtain the total emissions. As an example, inventory data for energy and inventory data for constituent materials of concrete are shown in <Table 1> and <Table 2>, respectively.

In general, inventory data are collected with an input-output analysis or a process analysis. In the input-output analysis, input-output tables showing the trading amounts of all of goods and services produced and consumed in a year in a country by section with a common unit (normally with a monetary unit) are used, and direct and indirect input energy and environmental impact are calculated using investigated inventories between industries with a top-down processing. In this analysis, the direct and indirect inventory of a product can be theoretically calculated, but it is not suitable to an analysis of various products and technologies since the classification of section is rough and the evaluation is limited to the average of goods in a section. On the other hand, the process analysis is carried out with a bottom-up processing and the life cycle of a product is investigated in detail. In this analysis, the preparation basis of inventories is clear, while the coverage of processes which can be investigated is limited.

The Research Subcommittee on Environmental Impact Assessment of Concrete and the author have investigated and collected inventory data with the process analysis[2, 3, 5, 10, 11] through literature survey

Table 1. Example of inventory data for energy

Type of energy		Unit (*)	CO_2 emission (kg-CO_2/*)	SOx emission (g-SOx/*)	NOx emission (g-NOx/*)	PM emission (g-PM/*)	Ref.
Coal (imported)		kg	2.36	(-)	(-)	(-)	1)
LPG for fuel		kg	3.03	#	#	#	1), 2)
Gasoline		L	2.31	0.59	#	#	1), 2)
Kerosene		L	2.50	(-)	(-)	(-)	1), 2)
Light oil		L	2.64	2.04	19.77 *1 39.61 *2	1.66 *1 2.01 *2	1), 2)
Heavy oil (Type A)		L	2.77	13.00	# *1 2.38 *2	# *1 3.00 *2	1), 2)
Heavy oil (Type C)		L	2.97	56.40	# *1 (-) *2	# *1 (-) *2	1)
Petroleum coke		kg	3.31	(-)	(-)	(-)	1)
Natural gas (domestic)		Nm^3	2.79	(-)	(-)	(-)	1)
LNG (imported)		Kg	2.79	(-)	(-)	(-)	1), 2)
Electricity	(Average)	kWh	0.407	0.13	0.16	0.03	1), 2)
	A Company	kWh	0.479	0.56	0.43	(-)	3)
	B Company	kWh	0.441	0.23	0.32	(-)	3)
	C Company	kWh	0.339	0.05	0.08	(-)	3)
	D Company	kWh	0.481	0.05	0.09	(-)	3)
	E Company	kWh	0.457	0.34	0.25	(-)	3)
	F Company	kWh	0.338	0.014	0.039	(-)	3)
	G Company	kWh	0.67	0.21	0.31	(-)	3)
	H Company	kWh	0.368	0.4	0.5	(-)	3)
	I Company	kWh	0.375	0.25	0.21	(-)	3)
	J Company	kWh	0.932	1.0	0.39	(-)	3)
Acetylene gas		m^3	3.38	(-)	(-)	(-)	1), 2)

PM: Particulate matter
Note: Each entry does not include mining and subsequenttransport of corresponding energy source.
Note: '*' in the unit of each emission is substituted with the unit of each type of energy. For instance, the units of CO_2 emission for coal (imported) and gasoline are kg-CO_2/kg and kg-CO_2/L, respectively.
#: Refer to the literature by Nanzai *et al*, (2002)[9].
*1: Fuel consumption by driving a truck and other related vehicleson public road, which is considered a part of construction.
*2: Fuel consumption by operating machinery and equipement.
(-) indicates either no data available or additional survey needed for each particular case.
Reference No.: 1) JSCE (2004)[3], 2) Kawai et al. (2005)[5], 3) Homepage of each electric power company in Japan

and hearing to institutes concerned.

These inventory data will vary in different countries, different regions, and even in different companies because production processes and methods which affect the values of inventory data are different. For example, in <Table 1>, several emission inventory data for electricity are shown. There are 10 independent regional electric power companies in Japan, and major power generation sources which include hydroelectric power, thermal power, and nuclear power are different in each company. Also in the thermal power generation, coal, oil, and LNG are used as fuel. The difference of the power generation sources directly affects the difference of emission inventory data. As a result, the emission inventory data for each electric power company are largely varied. Inventory data may be more accurate if they are calculated from as small a unit as possible, although it is very difficult to get such data. Usually inventory data will be prepared in each country or region, which means that the inventory data are average values within that country or region.

In <Table 2>, eco-cement is cement developed in Japan in terms of measures for reduction of environmental impact. This cement consists of the same main mineral components as normal portland cement[12], but about 50% of its raw materials are wastes including municipal incinerator ash. That is why the amount of material recycling for normal eco-cement is very high compared with that for normal portland cement. However, the CO_2 emission for normal eco-cement is larger than that for normal portland cement because the scale of an eco-cement plant is not so large. As shown here, the selection of a material is dependent on an important environmental impact factor. That is to say, if emphasis on material

Table 2. Example of inventory data for constituent materials of concrete

Item	Material	Type of energy *1 (main use)	Input energy *2 (GJ/t)	Oil conver (kg)	Coal conver (kg)	Purchased power (kWh)	Non-metal mineral (kg)	Iron resource (kg)	Material recycling (wet-kg)	Waste emission (wet-kg)	CO_2 emission (kg-CO_2/t)	SOx emission (kg-SOx/t)	NOx emission (kg-NOx/t)	Particulate matter emission (kg-PM/t)
Cement	Normal portland cement	C, Oc, Hc, E	3.40	16.24	93.84	31.2	1,236	-	148	-	766.6	0.122	1.55	0.0358
	Blast furnace slag cement (Type B)	C, Oc, Hc, E	2.28	13.13	56.80	30.1	715	-	85	-	458.7	0.0809	0.919	0.0218
	Fly ash cement (Type B)	C, Oc, Hc, E	3.02	18.25	75.71	34.0	998	-	120	-	624.0	0.0984	1.25	0.0289
	Normal eco-cement	Ha, E	6.40	108.67	-	250.9	829	-	765	-	784.0	0.152	0.319	0.00652
Aggregate	Coarse aggregate (Natural, Crashed)	L, E	0.05	0.37	-	4.3	1,000	-	0	-	2.9	0.00607	0.00415	0.00141
	Fine aggregate (Natural, Crashed)	L, E	0.07	0.37	-	6.2	1,000	-	0	-	3.7	0.00860	0.00586	0.00199
	Limestone aggregate	L, E	0.05	0.37	-	4.3	1,000	-	0	-	2.9	0.00607	0.00415	0.00141
	Waste aggregate (Melted using fuel)	K, E	29.71	721.86	-	240.0	-	-	1,238	141	2,293.6	0.0309	0.0376	0.00624
	Waste aggregate (Melted electronically)	E	9.13	13.09	-	959.3	-	-	1,238	141	430.3	0.123	0.150	0.0249
	Recycled aggregate (Type III)	E	0.06	0.21	-	5.9	-	-	1,000	No Data	3.1	0.00127	0.0108	0.000655
	Recycled aggregate (Type I)	E	0.38	0.49	-	39.8	-	-	1,000	No Data	17.7	0.00628	0.0289	0.00218
Mineral	Blast furnace slag	E	0.58	-	-	65.0	-	-	0	No Data	26.5	0.00836	0.0102	0.00169
Admixture	Fly ash	E	0.43	-	-	48.2	-	-	0	No Data	19.6	0.00620	0.00754	0.00125
	Limestone powder	L, E	0.35	0.37	-	36.8	1,000	-	0	No Data	16.1	0.0112	0.0103	0.00244
	Coal ash	-	-	-	-	-	-	-	1,000	-	-	-	-	-
Steel	Electric furnace steel	E	4.24	3.60	71.79	337.7	33	93	No Data	7	767.4	0.134	0.124	0.0101
	Basic oxygen furnace steel (Shapes)	Cc, C, E	18.54	7.29	728.45	260.5	65	1,028	No Data	7	1,256.0	1.18	1.80	0.00781
	Basic oxygen furnace steel (Bars)	Cc, C, E	18.40	7.29	728.45	253.2	65	1,028	No Data	7	1,213.0	1.18	1.80	0.00759
	Basic oxygen furnace steel (Wire rods)	Cc, C, E	18.98	7.29	728.45	299.4	65	1,028	No Data	7	1,321.8	1.18	1.81	0.00898

Note : The values written in italics include only emissions derived from electric power. because of no data, The emissions derived from manufacturing processes are not considered.
*1 : Type of energy : C=Coal, Cc = Coke, Oc = Oil coke, Hc = Heavy oil type C, Ha = Heavy oil type A, L = Light oil, K = Kerosene, E = Electricity.
*2 : Conversion into calorific value.

recycling is put, eco-cement may be selected as cement, while blast furnace slag cement or fly ash cement will be selected if CO_2 emission reduction is considered to be important.

In the same manner, by preparing inventory data for production and execution of concrete, it is possible to know which process largely contributes to environmental impact. This will enable developments of environmental impact reduction technologies.

4. Concluding remarks

Many activities considering the environment have been done in the concrete industry as represented by the utilization of industrial byproducts and wastes for fuel and raw materials of cement, the utilization of blast furnace slag, fly ash, rice husk ash, and silica fume for mineral admixtures, and the recycling of concrete. However, these actions were not quantitatively evaluated. Today the contribution to the reduction of environmental impact is to be represented in a quantitative manner and the concrete industry should also follow the demand. To promote quantitative evaluation of environmental impact of concrete, organizational actions are essential since the concrete industry relates to many other industries.

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담당 편집위원 :
권기주(한국전력공사) *kyeunkjoo@kepco.co.kr*