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Preparation of Inventory Data for Environmental Performance Evaluation of Concrete and Concrete Structures

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ABSTRACT

To promote the reduction of environmental loads and effective utilization of resources related to concrete and concrete structures, environmental impact assessment will be essential. To apply the LCA method to the environmental impact assessment of concrete and concrete structures, a set of inventory data related to concrete and concrete structures has to be prepared and it has to be reliable. However, these inventory data will vary in different countries, regions, and even in different companies because production processes and methods which affect the values of inventory data are different. 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 this paper, some inventory data related to concrete and concrete structures which have been prepared in Japan are introduced, and the methodology of preparation of inventory data and the regionality of the data are discussed.

INTRODUCTION

To promote the reduction of environmental loads and effective utilization of resources related to concrete and concrete structures, environmental impact assessment of concrete and concrete structures will be essential. As well as other goods and services, environmental impact assessment of concrete and concrete structures can be performed in general with the LCA method. To apply the LCA method to the environmental impact assessment of concrete and concrete structures, however, a set of inventory data related to concrete and concrete structures has to be prepared and it has to be reliable.

Through literature survey and hearing to institutes concerned, the authors have intensively and comprehensively collected necessary data and prepared inventory data related to concrete and concrete structures, so far [Kawai et al. 2005a, 2005b]. As a result, environmental impact of concrete and concrete structures can be estimated to a considerable extent in their whole life cycle and in each stage of constituent material manufacturing, transportation, execution, maintenance, demolition, disposal and recycling.

On the other hand, these inventory data will vary in different countries and regions, and even in different companies because production processes and methods which affect the values of inventory data are different. 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 this paper, some inventory data related to concrete and concrete structures which have been prepared in Japan are introduced, and the methodology of preparation of inventory data and the regionality of the data are discussed.

INVENTORY DATA COLLECTION

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 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.

Authors previously collected inventory data related to concrete and concrete structures with the process analysis [JSCE 2004; Kawai et al. 2005b], and these data are basically referred to in this paper. Also some of these data were renewed in this paper and new inventory data were collected also with the process analysis.

When inventory data are collected with the process analysis, the resources of the data must be clear and reliable. Usually the data will be collected through literature survey and hearing to engineers or workers concerned. In most cases, inventory data may not be able to be collected directly, but be obtained from some calculations. For instance, in the case of machinery for construction, fuel efficiency of a machine can be firstly investigated. This efficiency must be multiplied by a unit-based emission for the fuel to obtain the inventory data for the machine.

The kinds of inventory data are categorized into energy used for operation, transportation, constituent materials, construction, demolition, and disposal and recycling in this study. The methodologies of inventory data collection for each category are described below although the fundamental methodologies of inventory data collection are quite same as shown in the previous study [Kawai et al. 2005b].

Energy

As for fuel, data for mining in a production company, transportation to Japan, refinement, and transportation to a final demand place were cited from Petroleum Energy Center, Japan [PEC 2002] and Plastic Waste Management Institute, Japan [PWMI 2001]. The value of CO_2 emission by combustion of fuels were based on the emission coefficients for 1999 published by the study group on the calculation methodology of the emissions of green house gases, Ministry of the Environment, Japan [MOE 2000]. Regarding the use of light oil, sources were divided into moving emission sources such as trucks and stationary emission sources such as construction machines. The emissions of NOx and particulate matter generated by the consumption of light oil in each source were obtained from the literature by Nanzai et al. [2002]. As for purchased power, the amount of CO_2 emission which is an average of the total amount of CO_2 emitted from all of the electric power companies in Japan in 2002 was obtained from the report of the Federation of Electric Power Companies of Japan [FEPC 2004a]. The average amounts of SOx and NOx emission are calculated by the amount of each emission per unit of electricity generated by thermal power and the ratio of thermal power relative to total electric power generation which were reported by the Federation of Electric Power Companies of Japan [FEPC 2004b]. The emission amount of particulate matter was based on the paper reported by Matsuno et al. [1998]. In addition to the average emission inventory data, the inventory data for each electric power company were collected from the home page of each company.

Transportation

Fuel consumption of each was calculated from multiplying engine power by specific fuel consumption and being divided by maximum capacity and by average speed. Average speed was assumed to be 30km/h, and engine power and specific fuel consumption were obtained from the Equipment Cost Calculation Chart [JCMA 2001, 2008]. The amounts of CO_2, SOx, NOx, and particulate mater emissions to the air in motion were calculated by fuel consumption and the inventory data for energy.

Materials

Emission inventory data for portland cement, blast furnace slag cement, and fly ash cement are the sum of the inventory data as of 2003 reported by Japan Cement Association and corresponding emission data derived from the transportation of raw materials and the use of purchased power. The data of the uses of fuels, purchased power, resources, and wastes and CO_2 emission for ecocement were referred to the previous studies [JSCE 2002]. The emissions of SOx, NOx, and particulate matter for ecocement are the sum of these data supplied by its manufacturing company and other emission data derived from the use of purchased power. Ecocement was developed in Japan in terms of measures for reduction of environmental impact. About 50% of its raw materials are wastes including incinerator ash. This cement consists of the same main mineral components as normal portland cement [Shimoda and Yokoyama 1999]. The amount of energy consumption during grinding process for manufacturing natural aggregate and lime stone aggregate was calculated by the Bond method [JCMA 1975]. In addition, related energy at the collection of lime stone for the ceramics whose data is available from Japan Cement Association was added. Then the total energy for these aggregates was calculated by further adding the energy related to electricity for sieving and to transportation within a production site. The amount of energy consumption for melting slag aggregate using municipal waste was calculated on the basis of a calculation software [HOK 1998]. Its calculation domain ranges from generation of sintered ash of municipal waste to manufacture of melting slag aggregate. Among emission inventory data for aggregates and mineral admixtures, the emissions of SOx, NOx, and particulate matter derived from their manufactures could not be collected and the emissions derived from electric power only were considered. Accordingly these emission inventory data should have been estimated very small. Waste aggregates are produced using incinerated ashes of municipal wastes as a primary raw material like the ecocement. The emission inventory data of SOx, NOx, and particulate matter for these waste aggregates of both melted using fuel type and electrical type were estimated small because the emission data regarding to environmental impact during the manufacturing processes are not included in this estimation. Mineral admixtures such as blast furnace slag and fly ash are manufactured products and hence traded as valuables. However since mineral admixtures are byproducts, the emission inventory data for these materials are generally estimated using only consumption of energy necessary for their processing. For example, the process of blast furnace slag requires energy as electric power to crush. Other environmental impacts during the manufacturing stage for these byproducts are not taken into account. The amount of energy during grinding for manufacturing blast furnace slag with a specific surface area of 4400 cm^2/g by blain was calculated using reported inventory data on electricity for its grinding [Uchida 1991]. The amount of electricity consumed during grinding process of fly ash was collected from reported data [Tamashige et al. 1992]. For lime stone powder, energy used for the collection was added to energy used for coarse and fine grindings using reported calculation method [Sano et al. 2000]. The amounts of CO_2, SOx, and NOx emissions during steel manufacturing processes were investigated using a reference [Ishikawa et al. 1999]. Emission inventory data for steel materials were estimated using the amount of these emitted gases and the necessary amount of electric power consumption for the manufactures. Estimation of the emission of particulate matter of each steel was based on only the source of electric power consumption because of no information.

Construction

Emission inventory data for manufacturing concrete in a concrete plant was calculated with the amount of electric power consumption for mixing concrete except for SOx, NOx, and particulate matter emissions which were obtained from emission inventory data for stationary emission sources of construction machines and the amount of light oil consumption. Energy needed by autoclave curing was empirically assumed to 1.2 times than that needed by steam curing. Regarding steam curing, a Japanese precast concrete production company recently investigated the consumption of light oil for steam curing by its plant [Landes 2009] and its internal data were provided for the estimation of CO_2, SOx, NOx, and particulate matter emissions. In the calculation for construction machines, engine power of each machine [JCMA 2001] and light oil consumption per power were used. For NOx emission of construction machines, the adoption of Japan's exhaust emission measures was considered. Based on the trend of Japan's regulation values concerning measures to reduce automobile exhaust gas [MOE 2003], the emission of a machine adopting the measures was estimated to be 70 % of the emission of a machine without measures. Emissions of CO_2, SOx, NOx, and particulate matter were estimated according to inventory data for energy depending on the kinds of energy and their amount consumed as well as the magnitude of construction methods concerned.

Demolition

Emission inventory data of demolition works were estimated on the basis of the amount of fuel consumption by machinery used and classified for kinds of concrete structures to be demolished. Light oil and acetylene gas are normally used for the running of machinery such as breaker, welding machine, and crawler crane. Then the amount of these fuels consumed resulted in taking responsibility for the estimation of the emission inventory data of demolition work. In addition, according to the magnitude of concrete members and structures to be demolished, the amount of fuel consumption necessary for the corresponding demolition works will be varied. Therefore the emission inventory data were prepared depending on the magnitude and kinds of concrete structures under consideration. Types of machinery and the magnitude of concrete members and structures that can be commonly employed and represented in a demolition work were assumed using the data issued by Construction Research Institute [CRI 1998]. Emissions of CO_2, SOx, NOx, and particulate matter were estimated according to inventory data for energy depending on the kinds of energy and the magnitude of demolition work concerned.

Disposal and recycling

Emission inventory data of disposal and recycling were estimated on the basis of the amount of consumed energy such as electric power, light oil, heavy oil, and kerosene, which were normally used to run a correspond machinery and instruments for these operations. Emissions of CO_2, SOx, NOx, and particulate matter were estimated according to inventory data for energy depending on the kinds of energy concerned.

Operation of the disposal of concrete pieces, metals, and others involved can be classified in leachate-controlled type and not-leachate-controlled type within a landfill site for industrial waste. The landfill operation and its management were assumed to be conducted similar to the case of general waste materials. Then the amounts of electric power, light oil, heavy oil, and kerosene consumed for the landfill operation were cited from the Hokkaido University report [HOK 1998].

Emission inventory data of recycling are expressed as per 1 ton of concrete waste that is treated for recycled aggregates. With a self-mobile recycling machine used on site, Type III recycled coarse aggregate and equivalent Type II recycled fine aggregate are produced. These recycled aggregates are mostly employed as roadbed materials and filling materials. Data regarding kinds of energy and necessary amount of running the recycling machine were collected by a hearing from engineers concerned. The amount of light oil used up for the recycling includes the amount of light oil for running heavy machines to transport and throw concrete pieces into the recycling machine within site. Recycled aggregates which are treated outside site include Type I recycled coarse aggregates and Type I intensely recycled fine and coarse aggregates that are highly treated with heating and rubbing methods. Kinds of energy and its amount for both Type I recycled aggregates were obtained through literature survey [CRR 1997; Shima et al. 2001; Mitsubishi Materials 2001].

INVENTORY DATA

Emission inventory data for energy used for operation, transportation, constituent materials, construction, demolition, and disposal and recycling which were collected with the above-mentioned methods are shown in Tables 1, 2, 3, 4, 5, and 6, respectively.

Regarding emission inventory data for energy, it can be seen that the values of emission amounts for electricity are largely different in companies. There are 10 independent regional electric power companies in Japan, and major power generation sources are different in each company. The difference of the power generation sources directly affects the difference of emission inventory data. It is shown that inventory data of electricity for the company from which electricity is going to be purchased should be prepared to estimate accurate environmental impacts.

As for inventory data for transportation and construction, some of the data prepared in the previous studies [JSCE 2004; Kawai et al. 2005b] were renewed and new data were added. Regarding steam curing, inventory data for different plants was able to be collected. These data were obtained from a precast concrete production company. It is found that the values of the data are largely varied even in the same curing method and with the same fuel. This seems to be because an efficiency of curing differs in each plant since different precast concrete products are produced in different plants.

DISCUSSIONS

Since inventory data for energy and transportation are commonly used for estimating inventory data for constituent materials, construction, demolition, and disposal and recycling, the difference of the magnitude in the inventory data for energy and transportation is largely influenced to the inventory data collection for constituent materials, construction, demolition, and disposal and recycling.

Table 1. Emission Inventory Data for Energy Used for Operation

Type of energy		Unit (*)	CO_2 emission ($kg\text{-}CO_2$/*)	SOx emission (kg-SOx/*)	NOx emission (kg-NOx/*)	PM emission (kg-PM/*)	Ref.
Coal (imported)		kg	2.36	(-)	(-)	(-)	1)
LPG for fuel		kg	3.03	#	#	#	1),2)
Gasoline		L	2.31	0.59×10^{-3}	#	#	1),2)
Kerosene		L	2.50	(-)	(-)	(-)	1),2)
Light oil		L	2.64	2.04×10^{-3}	19.77×10^{-3} *1 39.61×10^{-3} *2	1.66×10^{-3} *1 2.01×10^{-3} *2	1),2)
Heavy oil (Type A)		L	2.77	13.00×10^{-3}	# *1 2.38×10^{-3} *2	# *1 3.00×10^{-3} *2	1),2)
Heavy oil (Type C)		L	2.97	56.40×10^{-3}	# *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	(Av.)	kWh	0.407	0.13×10^{-3}	0.16×10^{-3}	0.03×10^{-3}	1),2)
	A Company	kWh	0.479	0.56×10^{-3}	0.43×10^{-3}	(-)	3)
	B Company	kWh	0.441	0.23×10^{-3}	0.32×10^{-3}	(-)	3)
	C Company	kWh	0.339	0.05×10^{-3}	0.08×10^{-3}	(-)	3)
	D Company	kWh	0.481	0.05×10^{-3}	0.09×10^{-3}	(-)	3)
	E Company	kWh	0.457	0.34×10^{-3}	0.25×10^{-3}	(-)	3)
	F Company	kWh	0.338	0.014×10^{-3}	0.039×10^{-3}	(-)	3)
	G Company	kWh	0.67	0.21×10^{-3}	0.31×10^{-3}	(-)	3)
	H Company	kWh	0.368	0.4×10^{-3}	0.5×10^{-3}	(-)	3)
	I Company	kWh	0.375	0.25×10^{-3}	0.21×10^{-3}	(-)	3)
	J Company	kWh	0.932	1.0×10^{-3}	0.39×10^{-3}	(-)	3)
Acetylene gas		m^3	3.38	(-)	(-)	(-)	1),2)

PM: Particulate matter
Note that each entry does not include mining and subsequent transport of corresponding energy source.
#: Refer to the literature by Nanzai *et al*, (2002).
*1: Fuel consumption by driving a truck and other related vehicles on 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), 2) Kawai *et al*. (2005b), 3) Homepage of each electric power company

Table 2. Emission Inventory Data for Transportation

		Unit (*)	CO_2 emission ($kg\text{-}CO_2$/*)	SOx emission (kg-SOx/*)	NOx emission (kg-NOx/*)	PM emission (kg-PM/*)	Ref.
Truck	Gasoline(2t)	km.t	0.200	0.0000600	0.000250	0.000250	1),2)
	Diesel(2t)	km.t	0.212	0.000167	0.00161	0.000136	3)
	Diesel(4t)	km.t	0.148	0.000116	0.00113	0.0000948	3)
	Diesel(6t)	km.t	0.111	0.0000873	0.000846	0.0000710	3)
	Diesel(8t)	km.t	0.100	0.0000791	0.000766	0.0000643	3)
	Diesel(10t)	km.t	0.122	0.0000941	0.000914	0.0000768	1),2)
	Diesel(11t)	km.t	0.101	0.0000794	0.000770	0.0000646	3)
	Diesel(15t)	km.t	0.0783	0.0000617	0.000597	0.0000502	3)
	Diesel(20t)	km.t	0.0714	0.0000549	0.000534	0.0000448	1),2)
Dump truck	Diesel(2t)	km.t	0.190	0.000150	0.00145	0.000122	3)
	Diesel(4t)	km.t	0.146	0.000115	0.00111	0.0000934	3)
	Diesel(6t)	km.t	0.119	0.0000935	0.0000906	0.0000761	3)
	Diesel(8t)	km.t	0.0966	0.0000761	0.0000737	0.0000619	3)

Table 2. Emission Inventory Data for Transportation (cont'd)

		Unit (*)	CO_2 emission ($kg-CO_2$/*)	SOx emission (kg-SOx/*)	NOx emission (kg-NOx/*)	PM emission (kg-PM/*)	Ref.
Dump truck	Diesel(10t)	km.t	0.106	0.0000836	0.000811	0.0000681	3)
	Diesel(12t)	km.t	0.138	0.000109	0.00106	0.0000888	3)
Agitator Truck *1	0.8-0.9m^3	km.m^3	0.378	0.000297	0.00288	0.000242	3)
	1.6-1.7m^3	km.m^3	0.426	0.000336	0.00325	0.000273	3)
	3.0-3.2m^3	km.m^3	0.266	0.000210	0.00203	0.000171	3)
	4.4-4.5m^3	km.m^3	0.247	0.000194	0.00188	0.000158	3)
Freight car *2		km.t	0.0219	0.00693	0.00844	0.00140	1),2)
Ship *3	500t class	km.t	0.162	0.00280	0.00470	0.0000721	1),2)
	1000t class	km.t	0.0999	0.00172	0.00289	0.0000444	1),2)
	2000t class	km.t	0.0615	0.00106	0.00178	0.0000273	1),2)
	5000t class	km.t	0.0324	0.000559	0.000937	0.0000144	1),2)
	10000t class	km.t	0.0199	0.000344	0.000577	0.00000886	1),2)

PM: Particulate matter

*1: Type of energy: Light oil, *2: Type of energy: Electric power, *3: Type of energy: Heavy oil (Type A)

Reference No.: 1) JSCE (2004), 2) Kawai *et al*. (2005b), 3) JCMA (2008)

Table 3. Emission Inventory Data for Constituent Materials

		Unit (*)	CO_2 emission ($kg-CO_2$/*)	SOx emission (kg-SOx/*)	NOx emission (kg-NOx/*)	PM emission (kg-PM/*)	Ref.
Cement	Normal portland cement	t	766.6	0.122	1.55	0.0358	1),2)
	Blast furnace slag cement	t	458.7	0.0809	0.919	0.218	1),2)
	Fly ash cement	t	624.0	0.0984	1.25	0.0289	1),2)
	Normal eco-cement	t	784.0	0.152	0.319	0.00652	1),2)
Aggregate	Coarse aggregate (Natural, crashed)	t	2.9	*0.00607*	*0.00415*	*0.00141*	1),2)
	Fine aggregate (Natural, crashed)	t	3.7	*0.00860*	*0.00586*	*0.00199*	1),2)
	Limestone aggregate	t	2.9	*0.00607*	*0.00415*	*0.00141*	1),2)
	Waste aggregate (Melted using fuel)	t	2293.6	*0.0309*	*0.0376*	*0.00624*	1),2)
	Waste aggregate (Melted electronically)	t	430.3	*0.123*	*0.150*	*0.0249*	1),2)
	Recycled aggregate (Type III) *1	t	3.1	*0.00127*	*0.0108*	*0.000655*	1),2)
	Recycled aggregate (Type I) *1	t	17.7	*0.00628*	*0.0289*	*0.00218*	1),2)
Mineral admixture	Blast furnace slag	t	26.5	*0.00836*	*0.0102*	*0.00169*	1),2)
	Fly ash	t	19.6	*0.00620*	*0.00754*	*0.00125*	1),2)
	Limestone powder	t	16.1	*0.0112*	*0.0103*	*0.00244*	1),2)
Steel	Electric furnace steel	t	767.4	0.134	0.124	0.0101	1),2)
	Basic oxygen furnace steel (Shapes)	t	1256.0	1.18	1.80	0.00781	1),2)
	Basic oxygen furnace steel (Bars)	t	1213.0	1.18	1.80	0.00759	1),2)
	Basic oxygen furnace steel (Wire rods)	t	1321.8	1.18	1.80	0.00898	1),2)

PM: Particulate matter

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 I and III of recycled aggregates represent high and low quality recycled aggregates, respectively.

Reference No.: 1) JSCE (2004), 2) Kawai *et al*. (2005b)

Table 4. Emission Inventory Data for Construction

		Unit (*)	CO_2 emission (kg-CO_2/*)	SOx emission (kg-SOx/*)	NOx emission (kg-NOx/*)	PM emission (kg-PM/*)	Ref.
Ready mixed concrete	Concrete plant *1,*2,*3	t	7.7	0.00342	0.0651	0.00331	1),2)
	Concrete mixer (1.5m^3) *1	m^3	0.73	0.000235	0.000289	0.0000542	1),2)
	Concrete mixer (1.75m^3) *1	m^3	0.75	0.000240	0.000295	0.0000554	1),2)
	Concrete mixer (2.5m^3) *1	m^3	0.61	0.000195	0.000240	0.0000450	1),2)
	Concrete mixer (3.0m^3) *1	m^3	0.62	0.000199	0.000244	0.0000458	1),2)
Concrete placing	Agitator truck (0.8-0.9m^3) *3	h	9.63	0.00758	0.147	0.00747	3)
	Agitator truck (1.6-1.7m^3) *3	h	21.09	0.0166	0.323	0.0164	3)
	Agitator truck (3.0-3.2m^3) *3	h	24.76	0.0195	0.379	0.0192	3)
	Agitator truck (4.4-4.5m^3) *3	h	32.55	0.0256	0.498	0.0253	3)
	Boom pump (40-45m^3/h) *3	m^3	0.56	0.000442	0.00858	0.000435	3)
	Boom pump (90-110m^3/h) *3	m^3	0.4	0.000340	0.00662	0.000336	1),2)
	Truck mounted concrete pump (40-45m^3/h) *3	m^3	0.39	0.000307	0.00596	0.000302	3)
	Truck mounted concrete pump (90-100m^3/h) *3	m^3	0.28	0.000224	0.00436	0.000221	3)
	Concrete pump (95-110m^3/h) *1	m^3	0.21	0.0000640	0.0000836	3.17×10^{-6}	3)
Compaction	Flexible shaft vibrator (Electric, 60-70mm) *1	h	0.2	0.0000772	0.0000950	0.0000178	1),2)
	Form vibrator (0.1kW) *1	h	0.0	7.02×10^{-6}	8.64×10^{-6}	1.62×10^{-6}	1),2)
	Direct drive surface vibrator (Compaction width: 1.2m) *4	h	2.9	6.05×10^{-7}	0.0000177	6.56×10^{-7}	1),2)
	Vibrator (High freq., 40mm)	h	0.11	0.0000351	0.0000459	1.74×10^{-6}	3)
	Vibrator (High freq., 50mm)	h	0.18	0.0000559	0.0000731	2.77×10^{-6}	3)
	Vibrator (High freq., 60mm)	h	0.34	0.000105	0.000138	5.22×10^{-6}	3)
	Vibrator (High freq., 70mm)	h	0.51	0.000156	0.000204	7.74×10^{-6}	3)
Curing	Normal curing	h	0	0	0	0	1),2)
	Steam curing *1,*5	m^3	38.5	0.0241	0.0317	0.0348	1),2)
	Steam curing (A plant) *5	t	16.3	0.0790	0.0200	0.0160	4)
	Steam curing (B plant) *5	t	22.0	0.107	0.0270	0.0220	4)
	Steam curing (C plant) *5	t	18.7	0.0910	0.0230	0.0190	4)
	Steam curing (D plant) *5	t	19.0	0.0920	0.0230	0.0190	4)
	Autoclave curing *1,*5	m^3	46.2	0.0289	0.0381	0.0417	1),2)
	Jet heater *6	h	10.7	0.000460	0.00720	0.0120	1),2)
Excava -tor	0.6m^3 *3	h	51.7	0.0398	0.774	0.0393	1),2)
	0.6m^3 (Adopted exhaust emission measures) *3	h	51.7	0.0398	0.542	0.0393	1),2)
Crawler crane	Mechanical, 16t capacity *3	h	17.8	0.0137	0.267	0.0135	1),2)
	Mechanical, 25-27t capacity *3	h	21.3	0.0164	0.320	0.0162	1),2)
	Hydraulic, 4.9t capacity *3	h	13.6	0.0104	0.203	0.0103	1),2)
Truck crane	Hydraulic, 4.9t capacity *3	h	12.2	0.00960	0.186	0.00946	3)
	Hydraulic, 10-11t capacity *3	h	12.2	0.00960	0.186	0.00946	3)
	Hydraulic, 16t capacity *3	h	14.2	0.0112	0.218	0.0111	3)
	Hydraulic, 20t capacity *3	h	14.7	0.0116	0.225	0.0114	3)
Wheel crane	4.8t capacity *3	h	28.9	0.0222	0.433	0.0219	1),2)
	15t capacity *3	h	31.6	0.0244	0.474	0.0240	1),2)
	25t capacity *3	h	53.6	0.0412	0.803	0.0407	1),2)
	5t (Adopted exhaust emission measures) *3	h	28.9	0.0222	0.303	0.0219	1),2)
	16t (Adopted exhaust emission measures) *3	h	38.9	0.0299	0.408	0.0295	1),2)
	25t (Adopted exhaust emission measures) *3	h	53.6	0.0412	0.562	0.0407	1),2)

Table 4. Emission Inventory Data for Construction (cont'd)

		Unit (*)	CO_2 emission ($kg\text{-}CO_2$/*)	SOx emission (kg-SOx/*)	NOx emission (kg-NOx/*)	PM emission (kg-PM/*)	Ref.
Motor grader	Blade length: 3.1m *3	h	24.7	0.0190	0.370	0.0188	1),2)
	3.1m (Adopted exhaust emission measures) *3	h	24.7	0.0190	0.259	0.0188	1),2)
Road roller	10-12t capacity *3	h	15.7	0.0121	0.235	0.0119	3)
	10-12t capacity (Adopted exhaust emission measures) *3	h	15.7	0.0123	0.168	0.0122	3)
	13-14t capacity *3	h	15.7	0.0121	0.235	0.0119	3)
Tire roller	3-4t capacity *3	h	4.44	0.00343	0.0667	0.00338	3)
	8-20t capacity *3	h	18.6	0.0143	0.278	0.0141	3)
	8-20t capacity (Adopted exhaust emission measures) *3	h	18.4	0.0145	0.197	0.0143	3)
	21-30t capacity *3	h	20.7	0.0160	0.310	0.0157	3)
Tamper (60-100kg capacity) *4		h	2.1	4.51×10^{-7}	0.0000132	4.89×10^{-7}	1),2)
Sprinkler (5500-6500L) *3		h	14.3	0.0110	0.107	0.00899	1),2)
Diesel generator	10kVA (Adopted exhaust emission measures) *3	h	7.5	0.00590	0.0801	0.00581	3)
	45kVA (Adopted exhaust emission measures) *3	h	18.5	0.0146	0.198	0.0144	3)
	75kVA (Adopted exhaust emission measures) *3	h	31.6	0.0243	0.331	0.0240	1),2)

PM: Particulate matter
*1: Type of energy: Electricity, *2: Type of energy: LNG, *3: Type of energy: Light oil, *4: Type of energy: Gasoline, *5: Type of energy: Heavy oil (Type A), *6: Type of energy: Kerosene
Reference No.: 1) JSCE (2004), 2) Kawai *et al*. (2005b), 3) JCMA (2008), 4) Landes (2009)

Table 5. Emission Inventory Data for Demolition

		Unit (*)	CO_2 emission ($kg\text{-}CO_2$/*)	SOx emission (kg-SOx/*)	NOx emission (kg-NOx/*)	PM emission (kg-PM/*)	Ref.
PC & RC	Demolished from the ground	m^3	15.6	0.0120	0.234	0.0118	1),2)
	Demolished from the roof	m^3	10.3	0.00794	0.154	0.00783	1),2)
	Underground	m^3	19.0	0.0147	0.285	0.0145	1),2)
	Footing beam	m^3	23.5	0.0181	0.353	0.0179	1),2)
	Foundation	m^3	25.6	0.0197	0.384	0.0195	1),2)
SRC	Demolished from the ground	m^3	20.4	0.0157	0.305	0.0155	1),2)
	Demolished from the roof	m^3	13.5	0.0104	0.202	0.0102	1),2)
	Underground	m^3	24.3	0.0187	0.364	0.0185	1),2)
Earth floor		m^3	11.1	0.00855	0.166	0.00843	1),2)
Plane concrete	Less than 0.2m thickness	m^3	6.3	0.00488	0.0951	0.00482	1),2)
	More than 0.2m thickness	m^3	9.3	0.00712	0.139	0.00703	1),2)
Tunnel		m^3	8.2	0.00631	0.123	0.00622	1),2)
Pavement	Concrete pavement	m^3	9.0	0.00692	0.135	0.00683	1),2)
Street cut	Welding machine	m^3	0.7	0	0	0	1),2)
Steel frame cut	Crawler crane, welding machine	t	7.0	0.00488	0.0951	0.00482	1),2)
Operation	Piling and loading	m^3	7.9	0.00611	0.119	0.00602	1),2)
Breaker	Hydraulic, 600-800kg capacity	h	29.8	0.0230	0.447	0.0226	1),2)
	Hydraulic, 1300kg capacity	h	51.7	0.0398	0.774	0.0393	1),2)

PM: Particulate matter
Reference No.: 1) JSCE (2004), 2) Kawai *et al*. (2005b)

Table 6. Emission Inventory Data for Disposal and Recycling

		Unit (*)	CO_2 emission (kg-CO_2/*)	SOx emission (kg-SOx/*)	NOx emission (kg-NOx/*)	PM emission (kg-PM/*)	Ref.
Landfill site for wastes	Leachate-controlled type	t	3.3	0.00447	0.0255	0.00198	1),2)
	Non-leachate-controlled type	t	1.6	0.00126	0.0246	0.00124	1),2)
Recycled aggregate	Type III, 14-30t/h, treated in situ	t	1.6	0.00120	0.0164	0.00119	1),2)
	Type III, 35-85t/h, treated in situ	t	1.3	0.000993	0.0135	0.000980	1),2)
	Type III, 47-100t/h, treated in situ	t	1.2	0.000934	0.0127	0.000922	1),2)
	Type III, 30t/h, treated outside the site	t	2.3	0.00101	0.00866	0.000524	1),2)
	Type I	t	5.7	0.00220	0.0101	0.000763	1),2)
	Type I, heating and rubbing method	t	43.6	0.0165	0.139	0.00624	1),2)

PM: Particulate matter
Reference No.: 1) JSCE (2004), 2) Kawai *et al*. (2005b)

In addition to energy used for operation, especially to electric power as stated previously, emission inventory data for transportation are very much influenced to the estimation of other inventory data. Although the data collected and calculated mainly from literature survey are shown for transportation in this study, it can be easily imaged that fuel consumption of a truck differs truck by truck, and also even in its traveling speed. Therefore preparation of emission inventory data by a truck and by its traveling speed may be the most accurate means of estimating emission amounts, but it is also clear that such preparation is distant. As a first step to estimate environmental impact emissions, transparent and reliable but average emission inventory data as shown in this study should be very useful. Then as the next step, according to the object of the estimation by a company or institute, its own collection of emission inventory data will be necessary for more accurate estimation. The emission inventory data for steam curing in Table 4 can be considered as that example. By collecting the data of each plant, not only accurate estimation of emission inventory data for precast concrete products can be made, but also measures for environmental reduction can be taken based on the results.

CONCLUSION

In this paper, some of emission inventory data related to concrete and concrete structures were renewed and new data were added. Also the regionality of the data was shown.

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