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ENVIRONMENTAL IMPACT EVALUATION FOR INFRASTRUCTURES MADE OF CONCRETE

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ABSTRACT

This paper outlines a rational evaluation method of environmental impact for concrete structures. For this purpose an inventory data analysis is introduced. Sample calculation is given showing the emission amount of CO_2, SOx, NOx and P.M through the life time of a given concrete member. In addition the concept of verification is introduced, which expects the comparison of different mix proportions, execution methods and treatment of concrete after demolition with regard to the selection of good environmental practices.
Keywords: environmental impact, inventory data, verification, concrete structures.

1 INTRODUCTION

For the realization of the Low Carbon Society civil engineering can play an important role with regard to sustainable development. Concrete is a primary construction material for a number of civil engineering projects. However in the process of manufacturing cements relatively large amount of carbon dioxide gas (CO_2) is emitted. In addition the emission of harmful gases is expected during the construction stage by the consumption of large amount of fossil fuels for running trucks, heavy machineries and equipments. Demolition of concrete structures also consumes a large amount of energy leaving behind a large amount of wastes. In this way it is necessary to evaluate the environmental impact in a quantitative manner through its life cycle. For this purpose an evaluation tool needs to be developed so that rational judgment against the degree of environmental impact can be made. It is also realized that several kinds of wastes and by-products have been used as concrete materials. Although this is a good practice for supporting sustainable development the performance of concrete using these wastes and by-products needs to be investigated.

In this paper an environmental impact evaluation method using inventory data is introduced. This method has been recently proposed by the 317 Research Committee (Chair man: Prof. Kawai, K., Hiroshima Univ., Secretary: Author) in the Concrete Committee of the Japan Society of Civil Engineer (JSCE) [1-4]. Method of calculation using inventory data is shown. Primary portions of this paper are extracted from Ref. [1] and [2].

2 CALCULATIONS OF ENVIRONMENTAL IMPACT USING INVENTORY DATA

Inventory data is necessary to provide common basis for the estimation of the amount of environmental-related emission gases. Collection method of inventory data includes an input-output analysis and 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 (i.e. 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.

In the said 317 research committee [3,4] the collection of inventory data regarding the life cycle of concrete structures was carried out with the process analysis. Intensive literature survey and hearing to the institutes concerned have been deliberately conducted to collect relevant data to concrete materials, other materials involved,

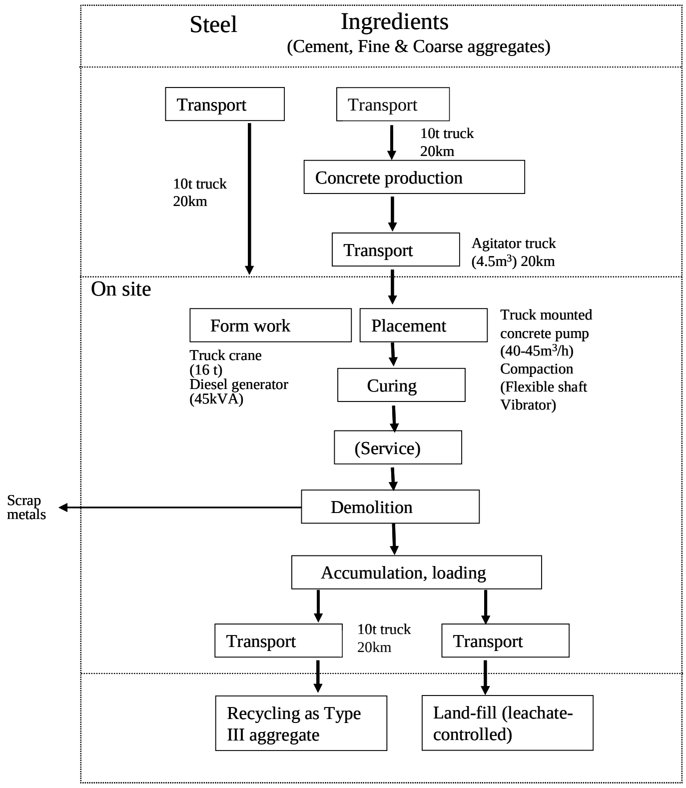

Fig.1 Domain under consideration for inventory data analysis [4]

construction, demolition, and disposal and recycling. Consequently emission inventory data of CO_2, SOx, NOx, and particulate matter (P.M.) were able to be prepared in an objective way. In addition most commonly used machines, instruments and other equipments on concrete structure construction were obtained. As a result, inventory data regarding 91 detail items in total was able to be obtained (See Ref. [2] and [5]). Furthermore fundamental inventory data of various kinds of energy such as electric power, LPG for fuel, LNG (imported), light oil, gasoline, heavy oil, kerosene, and acetylene gas were clarified. In addition, the method to estimate inventory data regarding the use of construction machinery, instruments, and other equipment that are normally employed in concrete structure construction, demolition works, and disposal and recycling was prepared.

By using these inventory data environmental impact caused by the construction of concrete structures can be considered as a performance parameter of the structures similarly to serviceability, safety, and durability of the structures. Comprehensive design method to meet structural and durability requirements as well as environmental aspect was investigated previously in order to confirm the applicability of these inventory data to environmental performance evaluation of concrete structures.

Sample calculation for a reinforced concrete structure is given as follows. Total volume of concrete is $100m^3$. Range for the evaluation covers its life cycle such as material production, execution, demolition and disposal and recycling. Two scenarios are demonstrated for the treatment of concrete after demolition like landfill or recycle as recycling aggregates. Fig.1 shows the range of evaluation for this sample calculation. Emission impact items are CO_2, NOx, SOx and Particulate Matter (P.M.) Amount of materials used, running time for construction machineries and equipments and transportation distance are shown in Table 1.

Result of the inventory data analysis is also shown in Table 1. Table 2 gives the relative amount of each emission gases and P.M. at each stage of its life cycle. More than 80 % of the CO_2 emission is attributed to the material production of cement and steel. Other emission gases of NOx and P.M. are significant for the execution and demolition stages. This exhibits that the inventory analysis reveals that the amount of not only CO_2 gas but also other emission gases can be evaluated in a quantitatively manner according to a given concrete structure.

Four case studies for different concrete structures such as pre-stressed concrete bridge, overflow dike of dam, retaining wall and secondary lining in tunnel were carried out in order to confirm the applicability of the inventory data analysis [2]. These calculations reveal that the method was effective in comparing varied design options for a given project.

Table 1 Inventory data analysis [4]

Process	Materials, machineries, equipments and methods		Unit	Quantity	CO_2 emission ($kg\text{-}CO_2$)	SO_x emission ($kg\text{-}SO_x$)	NO_x emission ($kg\text{-}NO_x$)	Particulate matter emission (kg-PM)
Materials	Cement	Normal portland cement	t	30	22964.7	3.66	46.47	1.07
	Aggregate	Coarse aggregate (Natural, crashed)	t	105	288.8	0.64	0.44	0.15
		Fine aggregate (Natural, crashed)	t	80	275.6	0.69	0.47	0.16
	Steel	Electric furnace steel	t	20	15105.7	2.68	2.48	0.20
Sub-total			-	-	38635	7.66	49.85	1.58
Execution	Ready mixed	Concrete plant	t	231.5	1777.9	0.79	15.06	0.77
		Agitator truck (4.4-4.5m^3)	h	2	67.6	0.05	0.51	0.04
		Truck mounted concrete pump (40-45m^3/h)	m^3	100	61.7	0.05	0.92	0.05
	Compaction	Flexible shaft vibrator (Electric, 60-70mm)	h	1	0.2	0.00 *	0.00 *	0.00 *
	Curing	Normal curing	h	310	0	0	0	0
	Truck crane	Hydraulic, 16t capacity	h	9.6	158.6	0.12	1.19	0.10
	Diesel generator	45kVA (Adopted exhaust emission measures)	h	9.6	184.4	0.14	1.93	0.14
Sub-total			-	-	2250.4	1.16	19.61	1.10
Demolition	PC & RC	Demolished from the ground	m^3	100	1559.7	1.20	23.37	1.18
	Steel cut	Welding machine	m^3	100	74.4	0	0	0
	Loading	Backhoe 0.6m^3	m^3	100	793.0	0.61	11.88	0.60
Sub-total			-	-	2427.1	1.81	35.25	1.79
Transportation	Truck	Diesel (10t)	km.t	9330	1141.0	0.88	8.53	0.72
	Agitator truck	4.4-4.5m3	km.m3	2000	506.1	0.39	7.58	0.38
Sub-total			-	-	1647.1	1.27	16.11	1.10
Waste / recycling	Landfill	Leachate-controlled type	t	231.5	379.4	0.29	5.68	0.29
	Recycled aggregate	Type III, 30t/h (treated outside)	t	231.5	527.8	0.23	2.00	0.12
Total 1	Waste treatment		-	-	43692	10.92	110.40	4.75
Total 2	Recycling as aggregates		-	-	43840	10.87	106.72	4.59

Note: Inventory data in use for this analysis is given in Ref. [2],[5]. * Too small to show in the given digits.

Table 2 Relative amount of each emission gases [4]

	CO_2 (%)	SOx (%)	NOx (%)	P.M. (%)
Materials	84.9	63.2	40.6	27.9
Execution	4.9	9.5	16.0	19.2
Demolition	5.3	14.9	28.7	31.4
Waste / recycling	1.2	1.9	1.6	2.1
Transportation	3.6	10.5	13.1	19.4

3 METHOD FOR EVALUATION OF ENVIRONMENTAL IIMPACT

Environmental impact needs to be evaluated and judged whether or not intended environmental aspect design is appropriate. In the proposed methodology of this judgment a process of verification is introduced. At each planning stage an environmental design must be quantitatively verified and inspected for its correctness. Each action also is inspected in its operation stage using monitoring tools and written records whether it follows the planning or not. Proper countermeasures are taken promptly to improve the situation, if necessary.

Fig.2 shows an example of verification in environmental design during the construction planning stage. A standard or conventional construction method is compared with an alternative method with respect to environmental impact. The alternative method is planned to reduce environmental impact so that its method will be employed if the reduction requirement is achieved. An environmental performance requirement can be given either absolutely or relatively such as 5t of CO_2 reduction or 5% of CO_2 reduction relative to a conventional method. The reduction requirement may be provided with an achieved percentage on given factors related to the goal of the environmental design.

The advantage of this method will be that the evaluation and inspection of the environmental performance of a concrete structure can be performed in the same methods as other performances such as serviceability, safety, and durability of the structure. However it is concerned that the priority of the selections for materials used and construction methods of a structure must be given to the mechanical performances and durability since these performances are strongly connected with the construction cost of the structure and also the approach regarding environmental consciousness will increase the construction cost. A system where the environmental consciousness reduces the whole construction cost of a concrete structure must be established.

Regarding the verification of the environmental performance of a concrete structure, a qualitative statement may be available instead of a quantitative statement shown in Fig.2. Also in that case, the preparation of a judgment criterion with several levels might be needed in order to verify the performance quasi-quantitatively. When a quantitative statement is used, absolute requirement and relative requirement are available. In either case,

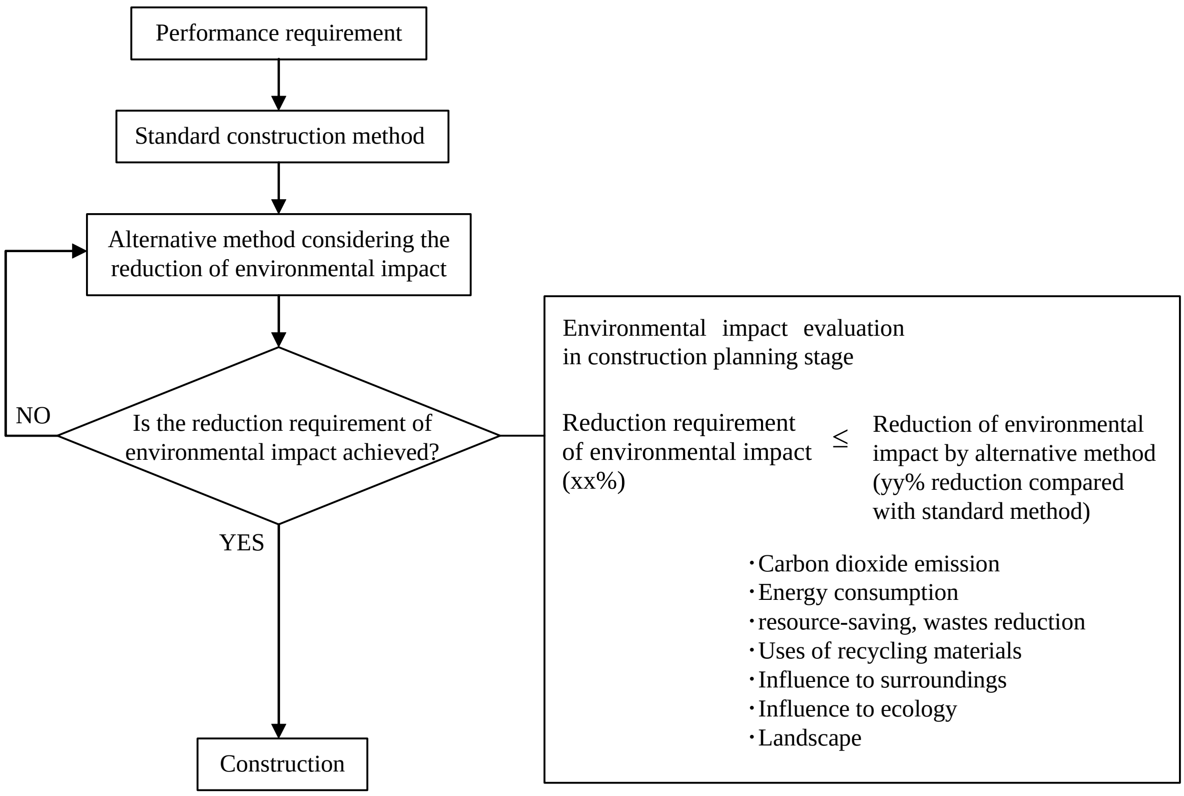

Fig. 2 Verification of environmental impact at construction planning stage [1]

multiple requirements can be stated. But when multiple requirements are prepared, it is difficult to decide which requirement is given to priority. That decision will depend upon countries and districts. In case of Japan, the lack of waste treatment sites is a serious problem. Therefore if the amount of waste emission is given as an environmental performance requirement, that requirement will have priority over other requirements in many cases. Also the application of an integration method to multiple requirements of environmental impact factors is one of the solutions. In this verification method, a weighting method is not mentioned. When multiple environmental factors are considered as an environmental performance, a decision maker, a designer, an owner, or a contractor of a structure should lead a weighting method according to construction conditions. Weighting factors will be also changed by country and district. Several factors used in an integration method depend upon countries and districts. An example integration method in the verification is described elsewhere.

4 CONCLUSIONS

In order to evaluate environmental impact quantitatively inventory data analysis is introduced. Sample calculation shows the emission amount of CO_2, SOx, NOx and P.M. This enables to compare relative amount emitted at each stage of the life cycle for concrete structures. In addition it is expected that through verification process different mix proportions, execution methods and treatment of concrete after demolition can be compared so as to allow to select appropriate practices taken for a given project.

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