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Study of Parameters Contributing to the Environmental Impact in Precast Concrete Production

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ABSTRACT

Like most other industrial manufacturing process, the production of concrete implies emissions to the atmosphere which consist of the emissions from the manufacturing of raw materials, transportation, construction, maintenance, demolition and also disposal and recycling process at the end of its life. This paper considers a few parameters that contribute to the emissions in precast concrete production, i.e. electricity consumption, fuel consumption for boiler steam curing, diesel consumption for forklift, and kerosene consumption for jet heater. The amount of emissions emitted from waste concrete treatment is also being considered in this paper. The data involved were obtained from 2007-2008 report of precast concrete production in 9 plants around Chugoku area in Japan under one company. The result shows that type of machine, degree of efficiency, type of fuel and method of curing are some of the contributing factors to the differences in the amounts of emissions in precast concrete production.

INTRODUCTION

Concrete has been used for years, and it is today the most widely applied building material worldwide. It is estimated that present consumption of concrete in the world is approximately 10-12 billion tons every year. Concrete has many advantages as it provides an easily shaped, cost-effective, fire resistant, durable and strong material for nearly all types of infrastructural installations, buildings and houses.

In Japan, the demand of precast concrete construction is progressively increasing year by year with the tendencies toward high rise construction. Precast concrete structure is a system where parts, members and elements of structures are produced beforehand at the factory or on site, and transported to the site of construction [Takahashi 2000]. This system has many advantages compared to ordinary concrete construction such as precision of measurement for members, improvement of material quality, short period of works, reduction of work forces at site and many more.

Like most other industrial manufacturing processes, the production of concrete itself implies emissions to the atmosphere. Concrete is a composite material consisting mainly of aggregate, cement and water. The major part of the emissions from concrete production is related to the production of the cement as one of the materials. However apart from the ones that come from cement production, this paper will discuss a few other parameters in relationship with the emissions, especially in precast concrete production. Electricity consumption, fuel consumption for boiler steam curing, diesel consumption for forklift, and kerosene consumption for jet heater and concrete waste treatment are the parameters which will be discussed in further detail in contributing the amount of emissions. The emissions that will be considered in this study include the emissions of Carbon dioxide (CO_2), Sulfur Oxides (SO_x), Nitrogen Oxides (NO_x) and Particulate Matter (PM). As one of the developed countries which ratified the Kyoto Protocol, Japan has the commitment to reduce its greenhouse gases emission by 6% from the base year's emissions (1990 for CO_2, CH_4 and N_2O while 1995 for HFCs, PFCs and SF_6) during the first commitment period, from 2008 to 2012. Therefore, accurate emissions inventories and estimation are more essential than ever, including the ones from precast concrete production.

OBJECTIVE AND SCOPE OF STUDY

This study aims at providing an accurate and reliable inventory data of emissions in precast concrete production. Moreover, it will be used as a basis for evaluating the environmental impact of precast concrete production in general cases. Under one precast company, further investigations of 9 plants around Chugoku area in Japan were made in order to obtain the important data for this study. As for now, only 5 parameters, i.e. electricity consumption, fuel consumption for boiler steam curing, diesel consumption for forklift, kerosene consumption for jet heater and concrete waste treatment will be discussed in this paper. According to the agreement, all the data showed later are confidential and for this reason they will be encrypted.

METHODOLOGY

The precast concrete production was divided into 3 classifications of product, i.e. popular, large-sized and small-sized product. 5 out of 9 plants were producing the popular products, one plant was producing the large-sized products and the rest were producing the small-sized products. Popular product is described as a product that normally used in infrastructure work in Japan, such as the hollow block pipe, drainage products, and the boundary block to separate footpath and traffic lane. A big size and/or heavy weight product such as culvert, slab and special product is classified under large-sized product. As for small-sized product, it is described as product that can easily be carried like the one that usually sold at the home centre such as small drainage block, gardening block, etc. It can be concluded that starting September 2007 until August 2008, the biggest amount of precast concrete production was produced from 5 plants of the popular product, representing 68% of total production while the rest amount was divided almost equally for the plants of large-sized and small-sized products. From 5 parameters as mentioned earlier, the amounts of emissions would be determined by multiplying the total usage of each parameter in one year with the value from Table 1 which was the unit-based emissions obtained from previous studies [JSCE 2004, Kawai 2005]. These values were observed and calculated according to the sources of the emissions and then were classified by the type of the emissions. Having time and technical constrains, the data of electricity consumption in one plant of large-sized products was not successfully obtained and therefore it will not be included in the calculations.

INVENTORY ANALYSIS

As stated in *Assessment for Environmental Impact of Concrete: Part 2 (Japan Society of Civil Engineers*, Table 1 shows the inventory data of unit-based emissions based on the type of energy used for general operations in concrete construction while Table 2 shows the inventory data of unit-based emissions as results of the concrete waste treatment based on previous studies. Furthermore, by using these inventory data, the amounts of emissions which were generated by the 5 parameters in 9 plants are resumed in Table 3. It should be taken as a notice that some unknown values in Table 1 and 2 would influence the amounts of emissions which were generated by the 5 parameters in the following calculations.

Table 1. Emission Inventory Data for Energy

No.	Type of Energy	Unit (*)	Energy (MJ/*)	Oil (kg/*)	Coal (kg/*)	Natural Gas (kg/*)	CO_2 emission (kg-CO2/*)	SO_x emission (g-SOx/*)	NO_x emission (g-NOx/*)	PM Emission (g-PM/*)
1	Kerosene	L	2.66[#1]	0.07	-	-	0.15[#1]	1.53[#1]	1.13[#1]	unknown[#1]
			36.7[#2]				2.5[#2]	unknown[#2]	unknown[#2]	unknown[#2]
									unknown[#3]	
2	Diesel	L	3.17[#1]	0.08	-	-	0.18[#1]	1.55[#1]	1.15[#1]	1.66[#1]
			38.2[#2]				2.64[#2]	2.04[#2]	19.77[#2]	2.01[#2]
									39.61[#3]	
3	Heavy oil (type A)[#4]	L	4.19[#1]	0.11	-	-	0.24[#1]	1.67[#1]	1.26[#1]	unknown[#1]
			39.1[#2]				2.77[#2]	13[#2]	unknown[#2]	3[#2]
									2.38[#3]	
4	Eletricity	kWh	9.00	0.12	0.07	0.02	0.407	0.13	0.16	0.03

#1 Emissions per unit of fuel consumption from mining activity

#2 Emissions per unit of fuel consumption by using a public road and truck for transportation activity (Nanzai *et. al* 2002)

#3 Emissions associated with fuel consumption per unit of construction machinery operation (Nanzai *et. al* 2002)

#4 Heavy oil (type A) : oil with kinematic viscosity (max.) of 20mm^2/S (50^{o}C), pour point (max.) of 5^{o}C, and sulfur content (max.) of No. 1: 0.5 wt%; No. 2: 2 wt% (JIS K2205).

Steam curing machine was used in all plants, including the one plant of large-sized products. The only difference is that plant had no boiler for producing its own steam. This plant had to buy it from other nearby company and for that there is no emissions generated by this parameter. For the other plants, the emissions were generated by the use of heavy oil (type A) for the boiler steam curing. This type of oil is classified as one of the distillate products, commonly used for marine diesel engines, small boiler, etc. [PAJ 2009]. As for concrete waste treatment, it was normally well treated prior to its disposal at landfill rather than transformed the waste into recycled aggregate.

Table 2. Emission Inventory Data For Concrete Waste Treatment

No.	Type of Concrete Waste Treatment	Unit (*)	Type of Energy [#1]	Energy Input [#2] (GJ)	Oil Conversion (kg)	Purchased Power (kWh)	Waste Generation (wet-kg)	CO_2 emission (kg-CO2/*)	SO_x emission (kg-SOx/*)	NO_x emission (kg-NOx/*)	PM Emission (kg-PM/*)
1	**Landfill site for waste**										
	- Leachate-controlled type	t	L	0.0568	0.72	2.72	1000	3.3	0.00447	0.0255	0.00198
			E	0.0237							
			Ha	0.0226							
	- Non leachate controlled type	t	L	0.0186	0.53	-	1000	1.6	0.00126	0.0246	0.00124

Unit for light oil, heavy oil and kerosene : liter/ton of concrete; power : kWh/ton of concrete

#1 Type of energy : E- Purchased power, L=light oil, Ha- Heavy oil type A, K=Kerosene

#2 Conversion into calorific value

Table 3. Amounts of Emissions Based on 5 Parameters

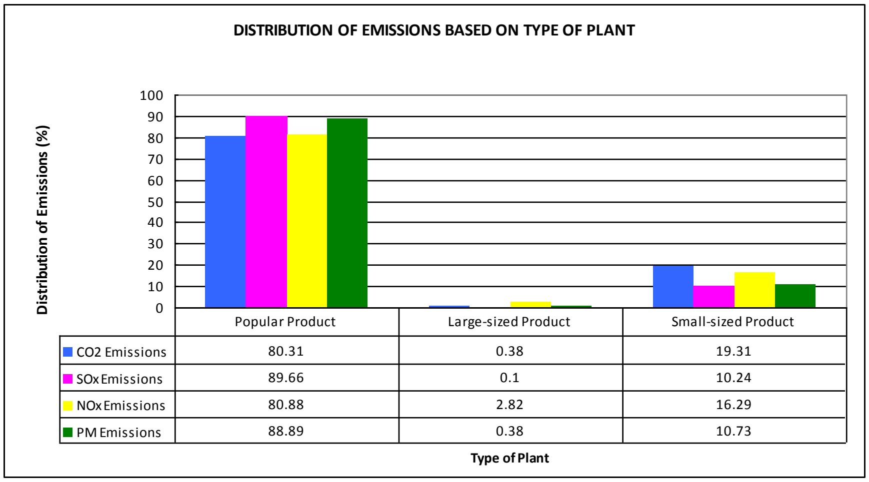
No.	Plant	Unit (*)	Energy Input #2 (GJ/*)	Oil Conversion (kg/*)	Coal Conversion (kg/*)	Natural Gas (kg/*)	Purchased Power (kWh/*)	Waste Generation (wet-kg/*)	CO_2 emission (kg-CO2/*)	SO_x emission (kg-SOx/*)	NO_x emission (kg-NOx/*)	PM Emission (kg-PM/*)
POPULAR PRODUCT												
1	**A with total production of 46,346 tons per year**											
	- Electricity Consumption	kWh	8,014.17	106,855.56	62,332.41	17,809.26	-	-	362,418.44	115.76	142.47	26.71
	- Fuel Oil for Boiler Steam Curing #1	L	8,475.24	23,843.38	-	-	-	-	600,419.66	2,817.85	515.88	650.27
	- Diesel for Forklift	L	1,579.68	3,308.24	-	-	-	-	109,171.92	84.36	1,637.99	83.12
	- Kerosene for Jet Heater	L	0	0	-	-	-	-	0	-	-	-
	- Waste Concrete Treatment	t	188.97	2,395.40	-	-	9,049.28	3,326,940	11,178.52	14.87	84.84	6.59
2	**B with total production of 1,455 tons per year**											
	- Electricity Consumption	kWh	1,154.36	15,391.44	8,978.34	2,565.24	-	-	52,202.63	16.67	20.52	3.85
	- Fuel Oil for Boiler Steam Curing #1	L	1,408.97	3,963.85	-	-	-	-	99,816.95	468.46	85.76	108.11
	- Diesel for Forklift	L	142.33	298.08	-	-	-	-	9,836.64	7.60	147.59	7.49
	- Kerosene for Jet Heater	L	0	0	-	-	-	-	0	-	-	-
	- Waste Concrete Treatment	t	10.08	127.74	-	-	482.58	177,420	596.13	0.79	4.52	0.35
3	**C with total production of 33,377 tons per year**											
	- Electricity Consumption	kWh	4,668.24	62,243.16	36,308.51	10,373.86	-	-	211,108.05	67.43	82.99	15.56
	- Fuel Oil for Boiler Steam Curing #1	L	8,547.26	24,046.00	-	-	-	-	605,522.00	2,841.80	520.27	655.80
	- Diesel for Forklift	L	1,642.22	3,439.20	-	-	-	-	113,493.60	87.70	1,702.83	86.41
	- Kerosene for Jet Heater	L	0	0	-	-	-	-	0	-	-	-
	- Waste Concrete Treatment	t	55.87	708.26	-	-	2,675.64	983,690	3,305.20	4.40	25.08	1.95
4	**D with total production of 39,384 tons per year**											
	- Electricity Consumption	kWh	2,811.13	37,481.76	21,864.36	6,246.96	-	-	127,125.64	40.61	49.98	9.37
	- Fuel Oil for Boiler Steam Curing #1	L	11,170.32	31,425.46	-	-	-	-	791,350.22	3,713.92	679.93	857.06
	- Diesel for Forklift	L	437.01	915.20	-	-	-	-	30,201.60	23.34	453.14	22.99
	- Kerosene for Jet Heater	L	12.48	23.80	-	-	-	-	850.00	-	-	-
	- Waste Concrete Treatment	t	49.98	633.60	-	-	2,393.60	880,000	2,956.80	3.93	22.44	1.74
5	**E with total production of 10,046 tons per year**											
	- Electricity Consumption	kWh	1,694.14	22,588.56	13,176.66	3,764.76	-	-	76,612.87	24.47	30.12	5.65
	- Fuel Oil for Boiler Steam Curing #1	L	3,675.40	10,340.00	-	-	-	-	260,380.00	1,222.00	223.72	282.00
	- Diesel for Forklift	L	277.71	581.60	-	-	-	-	19,192.80	14.83	287.96	14.61
	- Kerosene for Jet Heater	L	0	0	-	-	-	-	0	-	-	-
	- Waste Concrete Treatment	t	-	-	-	-	-	-	-	-	-	-
LARGE-SIZED PRODUCT												
6	**F with total production of 29,118 tons per year**											
	- Electricity Consumption	kWh	-	-	-	-	-	-	-	-	-	-
	- Fuel Oil for Boiler Steam Curing #1	L	0	0	-	-	-	-	0	0	0	0
	- Diesel for Forklift	L	215.45	451.20	-	-	-	-	14,889.60	11.51	223.40	11.34
	- Kerosene for Jet Heater	L	0	0	-	-	-	-	0	-	-	-
	- Waste Concrete Treatment	t	24.73	313.46	-	-	1,184.18	435,360	1,462.81	1.95	11.10	0.86
SMALL-SIZED PRODUCT												
7	**G with total production of 10,181 tons per year**											
	- Electricity Consumption	kWh	5,084.86	67,798.08	39,548.88	11,299.68	-	-	229,948.49	73.45	90.40	16.95
	- Fuel Oil for Boiler Steam Curing #1	L	582.59	1,639.00	-	-	-	-	41,273.00	193.70	35.46	44.70
	- Diesel for Forklift	L	278.67	583.60	-	-	-	-	19,258.80	14.88	288.95	14.66
	- Kerosene for Jet Heater	L	1,458.90	2,782.64	-	-	-	-	99,380.00	-	-	-
	- Waste Concrete Treatment	t	37.60	476.60	-	-	1,800.48	661,940	2,224.12	2.96	16.88	1.31
8	**H with total production of 11,999 tons per year**											
	- Electricity Consumption	kWh	2,259.75	30,129.96	17,575.81	5,021.66	-	-	102,190.78	32.64	40.17	7.53
	- Fuel Oil for Boiler Steam Curing #1	L	1,822.06	5,126.00	-	-	-	-	129,082.00	605.80	110.91	139.80
	- Diesel for Forklift	L	325.46	681.60	-	-	-	-	22,492.80	17.38	337.48	17.13
	- Kerosene for Jet Heater	L	0	0	-	-	-	-	0	-	-	-
	- Waste Concrete Treatment	t	68.73	871.20	-	-	3,291.20	1,210,000	4,065.60	5.41	30.86	2.40
9	**I with total production of 9,784 tons per year**											
	- Electricity Consumption	kWh	2,180.79	29,077.20	16,961.70	4,846.20	-	-	98,620.17	31.50	38.77	7.27
	- Fuel Oil for Boiler Steam Curing #1	L	985.32	2,772.00	-	-	-	-	69,804.00	327.60	59.98	75.60
	- Diesel for Forklift	L	291.08	609.60	-	-	-	-	20,116.80	15.54	301.83	15.32
	- Kerosene for Jet Heater	L	0	0	-	-	-	-	0.00	-	-	-
	- Waste Concrete Treatment	t	3.79	48.04	-	-	181.48	66,720	224.18	0.30	1.70	0.13

#1 Heavy oil type A is used for boiler steam curing

#2 Conversion into calorific value

Based on the observations, it was found that plants that produced popular products has emitted the highest amounts of CO_2, SO_x, NO_x, and PM emissions while the plants of small-sized products occupied the second place and the plant of large-sized products in the third place (see Figure 1). The biggest amount of emissions was CO_2 emission, followed by NO_x, SO_x, and PM. Without considering the type of products it can be calculated that for 1 ton of precast concrete production, 22.66 kg-CO_2, 0.0673 kg-SO_x, 0.0433 kg-NO_x and 0.0167 kg-PM were emitted in average value.

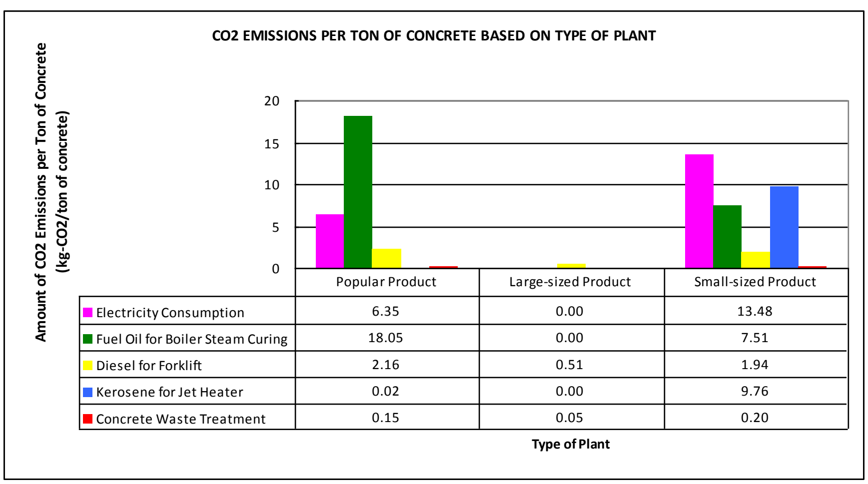
As it can be expected from the name, popular product was the one that is frequently ordered so it is easy to explain why this type of product generated more than 80% of total emissions in all plants in one year.



	Popular Product	Large-sized Product	Small-sized Product
CO2 Emissions	80.31	0.38	19.31
SOx Emissions	89.66	0.1	10.24
NOx Emissions	80.88	2.82	16.29
PM Emissions	88.89	0.38	10.73

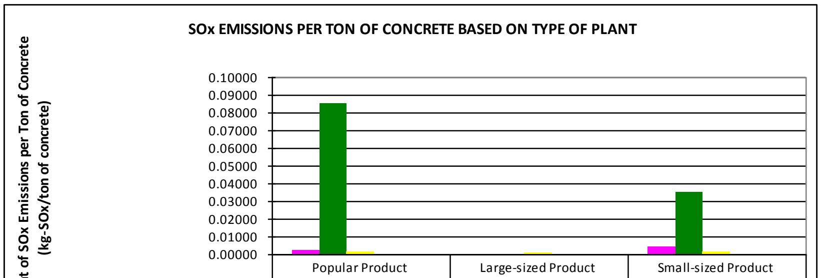
Fig. 1. Average Percentage of Emissions Distribution Based on Type of Plant

Figure 2 to 5 illustrate the amounts of all emissions which generated by the consumption of electricity, fuel oil for boiler steam curing, diesel for forklift, kerosene for jet heater and the treatment of concrete waste.



	Popular Product	Large-sized Product	Small-sized Product
Electricity Consumption	6.35	0.00	13.48
Fuel Oil for Boiler Steam Curing	18.05	0.00	7.51
Diesel for Forklift	2.16	0.51	1.94
Kerosene for Jet Heater	0.02	0.00	9.76
Concrete Waste Treatment	0.15	0.05	0.20

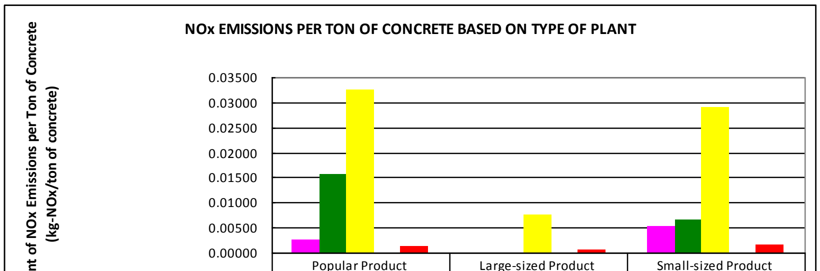
Fig. 2. Amount of CO_2 Emissions per Ton of Concrete Based on Type of Plant



	Popular Product	Large-sized Product	Small-sized Product
Electricity Consumption	0.00203	0.00000	0.00430
Fuel Oil for Boiler Steam Curing	0.08471	0.00000	0.03526
Diesel for Forklift	0.00167	0.00040	0.00150
Kerosene for Jet Heater	0.00000	0.00000	0.00000
Concrete Waste Treatment	0.00020	0.00007	0.00027

Type of Plant

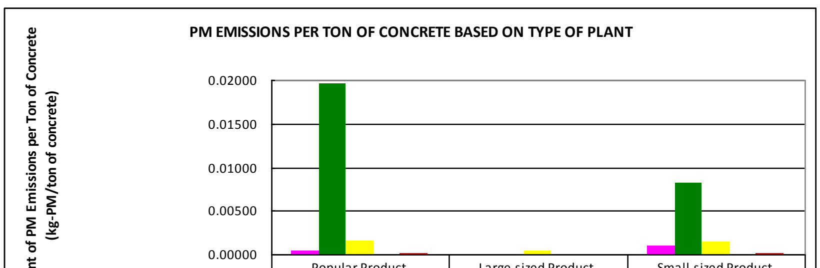
Fig. 3. Amount of SO_x Emissions per Ton of Concrete Based on Type of Plant



	Popular Product	Large-sized Product	Small-sized Product
Electricity Consumption	0.00250	0.00000	0.00530
Fuel Oil for Boiler Steam Curing	0.01551	0.00000	0.00646
Diesel for Forklift	0.03238	0.00767	0.02904
Kerosene for Jet Heater	0.00000	0.00000	0.00000
Concrete Waste Treatment	0.00114	0.00038	0.00155

Type of Plant

Fig. 4. Amount of NO_x Emissions per Ton of Concrete Based on Type of Plant



	Popular Product	Large-sized Product	Small-sized Product
Electricity Consumption	0.00047	0.00000	0.00099
Fuel Oil for Boiler Steam Curing	0.01955	0.00000	0.00814
Diesel for Forklift	0.00164	0.00039	0.00147
Kerosene for Jet Heater	0.00000	0.00000	0.00000
Concrete Waste Treatment	0.00009	0.00003	0.00012

Type of Plant

Fig. 5. Amount of PM Emissions per Ton of Concrete Based on Type of Plant

In above figures, the amounts of emissions generated by the three types of plants are shown in fluctuant results. Most of the cases, the production of popular products emitted the highest amounts of emissions based on 5 parameters. However, there are big differences within the results of the plant that produced large-sized products and the ones that produced small-sized products. The production of small-sized products seemed to generate higher rates of emissions compared to the production of large-sized products. This fact can be caused by many factors such as different types, amounts and efficiencies of the machines, different types of fuel and also methods of curing. In the plant of small-sized products, the production was depending more on machines rather than human labor. Line machine system was usually used in the production of small-sized products, not in the production of large-size products and for that, the higher emissions as results of that kind of machine were generated. It is more reasonable because of the emissions which generated from diesel consumption for forklift and also from concrete waste treatment were the only ones that had been considered in the calculation of total emissions in the plant of large-sized products.

CONCLUSIONS

The results of this study are as follows:

- After evaluating the environmental impact of the 9 plants of precast concrete production, it can be concluded that the plants which produced popular products generated more than 80% in all types of emissions, followed by the plants of small-sized products at 2nd place and the plant of large-sized products at 3rd place.
- Type of machine, degree of efficiency, type of fuel and method of curing are some of the contributing factors to the differences in the amounts of emissions in precast concrete production, limited to this case study.
- In general, these emissions can be reduced by using recycled materials, lower emission fuel, or different method of curing and waste treatment in the future. Nevertheless, factors such as availability and cost for using these alternative approaches will affect the ultimate decisions.

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