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*- Technical Paper -*

# APPLICATIONS OF EMISSION INVENTORY IN PRECAST CONCRETE INDUSTRY

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ABSTRACT

This paper elaborates the applications of emission inventory in different cases. The first case presents the result of emissions produced by some precast concrete plants in relation to fuel consumption for operating the machinery and electric power consumption. The second case discusses on the most efficient method of box culverts construction with the least emissions between cast-in-situ and precast method. The sensitivity analysis was further done in each case to study of how the variation in total emission can be attributed to different variations in the unit-based emission value of each parameter.
Keywords: emission inventory, $CO_2$ emission, $SO_x$, emission, $NO_x$ emission, PM emission, precast concrete, sensitivity analysis.

## 1. INTRODUCTION

One of the major challenges of our present society is environmental conservation. As a result of environmental problems such as global warming, acidification, resource depletion, waste disposal, air pollution, etc., they greatly affect the survival of living things both in the present and the future. Environmental conservation in any aspect of the human activities is one of the efforts that need to be done to resolve this matter. Especially in Japan, the responsibility for being one of the countries that signed and ratified the Kyoto Protocol also strengthens the reason why this environmental conservation is so important to be considered.

As it provides an easily shaped, cost-effective, fire resistant, durable and strong material for nearly all types of infrastructural installations, building and houses, concrete has been popular for the last decades. The production of concrete worldwide has reached 25 billion tonnes per year; 3.8 tonnes per capita each year. It is used twice than the total of all building materials, including wood, steel, plastic and aluminum. In fact, it is believed that concrete is the second most consumed product on the planet after water [1]. However, the increase of concrete consumption also leads to one of the biggest environmental problems as an emission contributor. Like most other industrial manufacturing processes, the production of concrete implies significant amount of emissions to the atmosphere which are mostly generated from the cement production as one of the materials, creating up to 5% of worldwide man-made emissions of $CO_2$. The amount of $CO_2$ emission generated from cement industry itself has reached more than 8.5 million tonnes in 2008 [2]. The number will certainly be much greater if the amount of emissions from other sources along the concrete life cycle is taken into account. Using life cycle assessment (LCA), the amount of emissions is analyzed by considering the environmental impacts associated with all the stages of concrete's life, starting from the procurement of raw materials, production/manufacture, transportation, energy consumption, construction, maintenance, demolition, and disposal or recycling at the end of life.

The detail information on emissions obtained from this assessment will be useful in understanding the environmental problems and in monitoring progress in order to solve the problems. An emission inventory has been developed in recent years as one manifestation of this approach. By providing an up-to-date and more accurate information that is accessible by each and every single party involved in this industry, the causes of the problems can be identified, problem solving can be planned in the best possible way and thus, the reduction of environmental load in concrete industry can be achieved in the future.

Emission inventory is defined as listing, by source, of the amounts of emissions actually or potentially discharged into the atmosphere of a community during a given time period [3]. It normally consists of few aspects such as source or cause of the emission, details on each type of pollutant, coverage area, the period of estimation, methodology used in determining the amount of emission. Emission inventory is developed for a variety of reasons, such as for scientific purpose, strategy development, policy and regulation making, and for general knowledge/information to the public. Up to present moment, the estimation of carbon dioxide ($CO_2$),

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sulphur dioxide ($SO_x$), nitrogen oxide ($NO_x$) and particulate matter (PM) has been taken into account in the emission inventory in Japan. Moreover, it is classified into 6 groups, i.e. energy, transportation, construction material, construction work/equipment, demolition work/equipment, and disposal and recycling with 48 detail items in total and 139 parameters included on them [4,5]. Initially, Japan's emission inventory was developed specifically for infrastructure works that were very much done in Japan for a few last decades. However, the present inventory has been able to be used and further developed for any kind of works generally performed in the construction industry.

As one approach that makes full of use of emission inventory, unit-based emission value approach was applied in estimating the emissions generated in some cases in this paper. The term of unit-based emission value or generally called as emission factor is defined as the average amount of a specific emission discharged into the atmosphere by a specific parameter such as fuel, equipment, process, or sources in the specific area and time span based on the intensity of relevant activity. It is usually expressed as number of grams (or kilograms) of emission per unit of the certain parameter. Basically, the amount of emissions is determined by multiplying the unit-based emission value for each type of emissions of each parameter by the amount of each parameter used or consumed or produced in one period of time. Kawai et al. (2005) elaborate in details the unit-based emission values that have been determined up to now, classified into several groups as previously mentioned [4,5].

The aim of this study is to show the applications of emission inventory in real cases, particularly in precast concrete industry. The emission inventory can be applied from the simplest cases up to the more complicated ones with the same goal, which is to promote the reduction of environmental impact in the industry. Basically, this emission inventory is used to determine the amount of emissions released due to specific parameter, such as fuel, equipment, process or other sources. However, in more complex cases, it can also be used for such cases in the selection of materials or construction methods with the least emissions in any construction works. These cases will then be discussed in details in the next section.

## 2. APPLICATIONS OF EMISSION INVENTORY DATA

### 2.1 First Case: Emissions Due to Energy Consumption in Precast Concrete Plants

The first case shows the application of emission inventory in determining the emissions due to the electricity consumption for the whole production and fuel consumption for operating machinery and equipment in some precast concrete plants. Investigations were conducted in eight precast concrete plants in Chugoku area in Japan. The production of precast concrete was divided into two classifications of products, i.e. popular product and small-sized product. Five out of eight plants were responsible on producing the popular products and the rests on small-sized products. Popular product is described as a product that normally used in infrastructure work in Japan, such as hollow block pipe, drainage products, road boundary block, etc. As for small-sized product, it is a handy product that is normally found in home goods stores, such as small drainage block, gardening block, etc. The biggest amount of precast concrete production was produced by popular product plant, representing 80.33% of the total production with 130,608 tonnes per year, followed by small-sized product plants with 31,964 tonnes per year (19.67%).

The emissions which will be determined in this case are the emissions generated only by four parameters, namely the electricity consumption for the whole production, heavy oil (type A) consumption for steam curing boiler, diesel consumption for forklift and kerosene consumption for jet heater. Furthermore, the amounts of emissions per year are determined by multiplying the total usage of each parameter in one year production by the unit-based emission value [4,5]. Table 1 presents the amount of consumption of each parameter discussed in this case. In addition, the results of emissions generated by each of the parameter are also shown in the same table.

It was found that in most of the cases, the production of small-sized products generated higher emissions per ton of concrete compared to the production of popular products. Table 1 shows that the small-sized product plants obviously consume more electric power and other fuels than popular product plants, and therefore small-sized product plants emitted more emissions. The main reason of this phenomenon was because the production of small-sized products commonly depended more on machines rather than human labors. Line machine system which was powered by electricity was usually used in the production of small-sized products. The use of more forklifts in small-sized product plants was very influential to the emissions produced by the diesel consumption. Especially in this study, electric-fired steam curing method was also applied along the jet heater method and heavy oil-fueled steam curing method in small-sized product plants. It adds the explanation on why the amount of consumption of electricity and heavy oil (type A) were higher than those in popular product plants. In addition, factors such as different types, amounts and efficiencies of the machines, types of fuels and methods of curing were also influential to the amount of emissions in general cases in precast concrete production.

Further analysis was done to determine the sensitivity of total emission of $CO_2$, $SO_x$, $NO_x$, and PM to the variation of unit-based emission value of each parameter in this case, i.e. electricity, heavy oil (type A), diesel and kerosene. Basically, the sensitivity analysis was performed to investigate the robustness of this study. It has been known that the unit-based emission values which were used in the emission calculation are basically the average of the same values generated from several cases. It is very reasonable that these values will vary in each case, as in different plants, different areas, and so forth, and are influenced by a great number of factors. It is therefore useful to consider the effects of

Table 1. Amount of emissions per ton of concrete

| No | Plant | Unit (*) | Consumption per year | $CO_2$ emission (kg-$CO_2$/*) | $SO_x$ emission (kg-$SO_x$/*) | $NO_x$ emission (kg-$NO_x$/*) | PM Emission (kg-PM/*) |
|---|---|---|---|---|---|---|---|
| **1** | **Popular Product** | | | | | | |
| | - Electricity | kWh | 1,058,377 | 430,759.4 | 137,589.0 | 169,340.3 | 31,751.3 |
| | - Heavy Oil | liter | 86,700 | 240,159.0 | 1,127,100.0 | 206,346.0 | 260,100.0 |
| | - Diesel | liter | 23,435 | 61,868.4 | 47,807.4 | 463,310.0 | 38,902.1 |
| | - Kerosene | liter | 40,962 | 102,405.0 | 0 | 0 | 0 |
| **2** | **Small-sized Product** | | | | | | |
| | - Electricity | kWh | 2,038,004 | 829,467.6 | 264,940.5 | 326,080.6 | 61,140.1 |
| | - Heavy Oil | liter | 851,079 | 2,357,488.8 | 11,064,027.0 | 2,025,568.0 | 2,553,237.0 |
| | - Diesel | liter | 106,779 | 281,896.6 | 217,829.2 | 2,111,020.8 | 177,253.1 |
| | - Kerosene | liter | 340 | 850.0 | 0 | 0 | 0 |

likely changes in the key parameters of the total emissions. In other words, by knowing the sensitivity values, the accuracy of unit-based emission values of each parameter and its influence to the total emissions can be then accounted for the future use. In performing the analysis, ±5% variation of unit-based emission value of each parameter was applied in the sensitivity analysis. Fig. 1 shows one example of the results obtained from this analysis regarding to the total $CO_2$ emission.

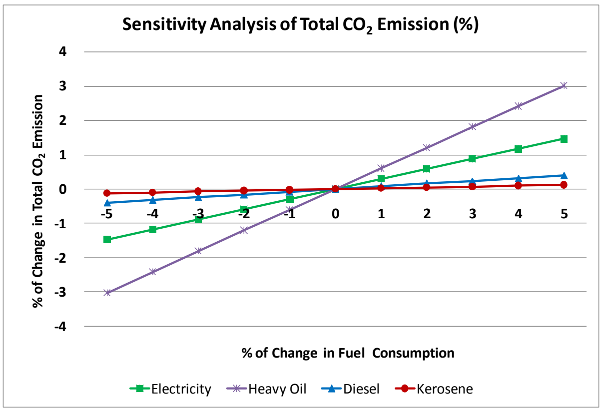



Fig. 1 Example of the result of sensitivity analysis in the first case

In this case, it can be concluded that heavy oil (type A) is the most influential parameter to the total emission in most of the emission types, i.e. $CO_2$, $SO_x$, and PM emission. It means that of the four parameters that exist in this case, heavy oil (type A) is the one that needs to be taken into account more than the others due to bigger influence of its variations to the total emissions. In the case of $NO_x$ emission, diesel is the most significant parameter. The ±5% variation of unit-based emission value of heavy oil (type A) produced an impact on the total emission of $CO_2$, $SO_x$, $NO_x$, and PM as much as ±3.02%, ±4.74%, ±2.10% and ±4.51%, respectively. Henceforth, the same sequence of the results is applied to other cases.

An impact of ±1.46%, ±0.16%, ±0.47% and ±0.15% were obtained in the case of electricity. Furthermore, the variation of unit-based emission value of diesel results in the change of total emission with ±0.40, ±0.10, ±2.43 and 0%. In the case of kerosene, significant change was only seen in the total of $CO_2$ emission with ±0.12%.

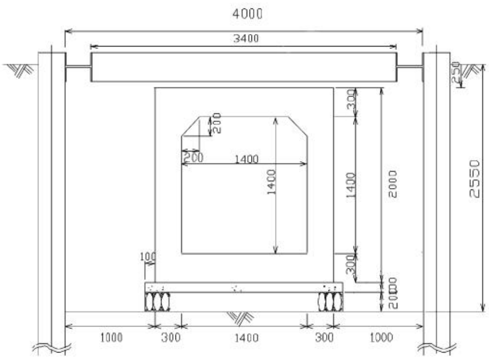
The execution of curing activity is one of the sources to the use of electricity, heavy oil (type A) and kerosene, specifically in this case. By applying the most effective curing method with the least emissions, it is believed that this effort will be beneficial in promoting the reduction of environmental impact. Based on the results of the sensitivity analysis, heavy oil (type A) is the significant parameter that influences the most to the total emissions (see Fig.1). Therefore, the application of heavy oil-fueled steam curing method will be further assessed by replacing it completely either by the electric-fired steam curing method or by the kerosene-fueled jet heater method.

It has been known that heavy oil-fueled steam curing method has been popular in Japan due to higher energy generated by heavy oil (type A) with 39.1 MJ/liter, compared to the ones produced by kerosene (36.7 MJ/liter) and electric power (9MJ/kWh) [4,5]. In addition, the low price of heavy oil (type A) in Japan is also one consideration. However, lower amounts of emissions produced either by kerosene and electricity compared to the ones of heavy oil (type A) could be considered as another factor in determining the type of curing method for future benefits, especially in this case study. Further analysis is conducted to determine the amount of emission reductions that can be achieved if both alternatives are implemented.

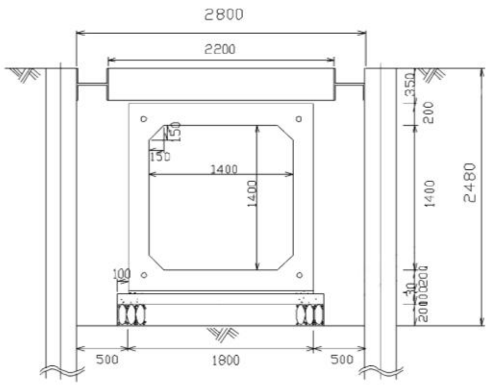
The results show that there will be a reduction of 2.32%, 94.8%, 42.1% and 90.1% in the total emission of $CO_2$, $SO_x$, $NO_x$, and PM, respectively if the kerosene-fueled jet heater method is used instead of heavy oil-fueled steam curing method. Higher amount of $CO_2$ emission reductions will be achieved if the electric-fired steam curing method is applied in this case with 21.82%. While in relation to the total emission of $SO_x$, $NO_x$, and PM, a reduction of 90.69%, 29.8% and 86.19%, respectively will be obtained as the results. The application of electric-fired steam curing method and kerosene-fueled jet heater method would be felt very useful in order to promote the reduction of environmental impact in this case. This approach will most likely be chosen if factors other than the environmental impact factor are ignored in the selection of the appropriate curing method. However, it should be noted that jet heater method is commonly used only for the precast products with small sizes, which some of them can also be produced in popular product plants.

## 2.2 Second Case: Construction Method Selection in Box Culvert Production

The purpose of this case was to determine the most effective alternative of box-culvert construction method with the least emissions. Two alternatives of box-culvert construction method emission were investigated in this case. As the first alternative, the box culvert was constructed in-situ using ready-mixed concrete whereas in the second alternative, it was constructed using precast concrete products with an open cut method. Fig. 2 illustrates the cross-section of the box culverts construction method on each alternative and Table 2 shows the mix proportions. The size of the first alternative of box-culvert was thicker compared to the one of the second alternative due to different compressive strengths. The estimation of all types of emissions for this case is considering the emissions generated by the use of energy, transportation, material, and construction machinery/equipment can be seen in Table 3 [4,5]. The amounts of emissions are presented in kilogram per unit of each item.




**Alternative 1**




**Alternative 2**

Fig. 2 Cross-section of box culverts on each alternative

Table 2. Mix Proportion

| Item | Type of Concrete | W/B | Unit content (kg/m$^3$) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | W | OPC | BB | BP | S | G |
| Foundation | Ready-mixed | 0.61 | 173 | - | 284 | - | 837 | 1028 |
| Box culvert | Ready-mixed | 0.51 | 175 | - | 343 | - | 775 | 1033 |
| | Precast | 0.35 | 174 | 400 | - | 100 | 652 | 1058 |

W : Water
BP: Blast-furnace slag powder
OPC: Ordinary portland cement
S : Sand
BB: Blast-furnace slag cement (type B)
G : Gravel

By using the unit-based emission value approach in the analysis, the results of emissions generated for both alternatives are shown in Fig. 3. The level of emissions produced using the second alternative were lower than those using the first alternative. With the second alternative, the amount of $CO_2$, $SO_x$, $NO_x$ (stationary sources), $NO_x$ (moving sources) and PM (moving sources) emissions could be reduced by 13.2%, 9.6%, 5.2%, 27.38% and 27.38%, respectively.

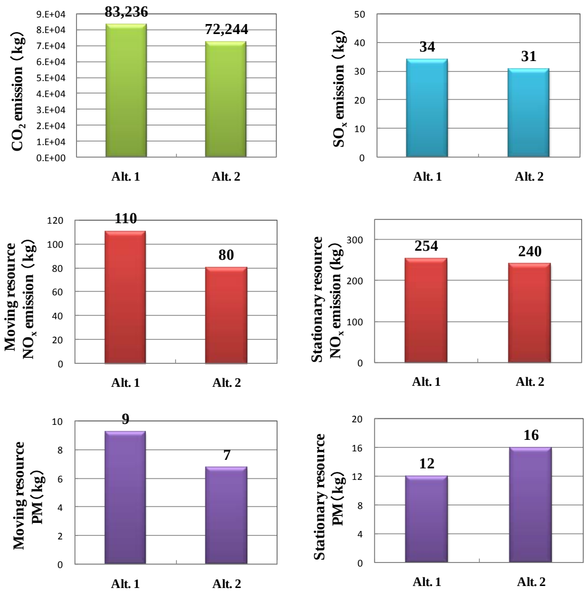



Fig. 3 Amounts of emissions on each alternative

Fig. 4 shows the breakdown of $CO_2$ emission which is classified by concrete production, transportation and construction. The emission produced in concrete production were the highest in both methods of box culvert construction with more than 70% of the total $CO_2$ emissions, followed by the emissions as a result of the use of transportation vehicles (17.7% for alt. 1 and 14.8% for alt. 2), and construction equipments (10.7% for alt. 1 and 14.4% for alt. 2).

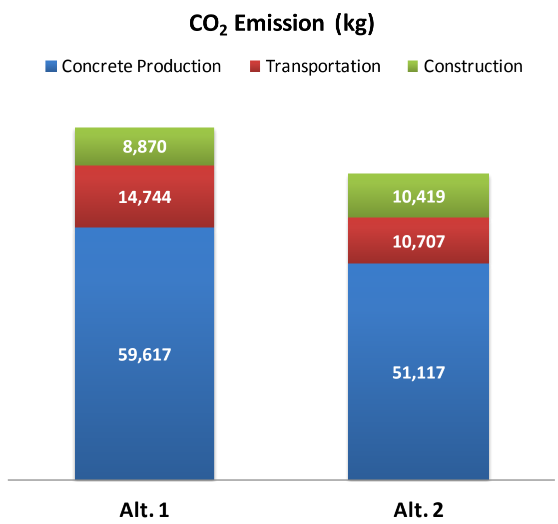



Fig. 4 The breakdown of total $CO_2$ emission

Table 3. Unit-based emission value related to the box culvert construction

| No | Group/Item | Units (*) | $CO_2$ emission (kg-$CO_2$/*) | $SO_x$ emission (kg-$SO_x$/*) | $NO_x$ emission (kg-$NO_x$/*) | PM emission (kg-PM/*) |
|---|---|---|---|---|---|---|
| **1** | **Energy** | | | | | |
| | Gas oil | liter | 2.8 | 0.0036 | 0.0408 | 0.0020 |
| | Purchased power | kWh | 0.4070 | 0.0001 | 0.0002 | 0.0000 |
| **2** | **Transportation** | | | | | |
| | Truck 10t | km·t | 0.10 | 0.0001 | 0.0008 | 0.0001 |
| | Dump truck 10t | km·t | 0.11 | 0.0001 | 0.0008 | 0.0001 |
| | Agitator body truck 4.5$m^3$ | km·$m^3$ | 0.25 | 0.0002 | 0.0019 | 0.0002 |
| **3** | **Concrete Production** | | | | | |
| | Cement | t | 766.60 | 0.1220 | 1.5500 | 0.0358 |
| | Blast furnace slag cement | t | 458.70 | 0.0800 | 0.9200 | 0.0200 |
| | Blast furnace slag powder | t | 26.50 | 0.0084 | 0.0102 | 0.0017 |
| | Fine aggregate | t | 3.70 | 0.0086 | 0.0059 | 0.0020 |
| | Coarse aggregate | t | 2.90 | 0.0061 | 0.0042 | 0.0014 |
| | Steel bar | t | 767.40 | 0.1339 | 0.1240 | 0.0101 |
| | Recycle sand | t | 2.80 | 0.0013 | 0.0108 | 0.0007 |
| | Concrete plant | t | 7.68 | 0.0034 | 0.0651 | 0.0033 |
| | Steam curing | $m^3$ | 38.48 | 0.0241 | 0.0317 | 0.0348 |
| **4** | **Construction** | | | | | |
| | Driving and extracting machine with static load 80.7-1471.0kN | h | 56.30 | 0.0435 | 0.5910 | 0.0428 |
| | Rough terrain crane 25t | h | 52.50 | 0.0406 | 0.7870 | 0.0400 |
| | Back hoe 0.45$m^3$ | h | 27.70 | 0.2140 | 0.4160 | 0.0211 |
| | Back hoe 0.8$m^3$ | h | 48.00 | 0.0371 | 0.7210 | 0.0366 |
| | Tamper 60-100kg | h | 2.10 | 0.0000 | 0.0000 | 0.0000 |
| | Concrete pump car 90-110$m^3$/h | h | 41.00 | 0.0317 | 0.6150 | 0.0312 |

Due to the significant portion of the $CO_2$ emissions emitted in concrete production, more detail elaborations were made in both cases (see Fig. 5). As it has been known, cement is one of the parameters that are very influential to the total emissions in concrete industry. It is proved once again in this case that the statement is true. Competing with the cement regarding to its influence to the total $CO_2$ emission was steel, followed by the other parameters in material group.

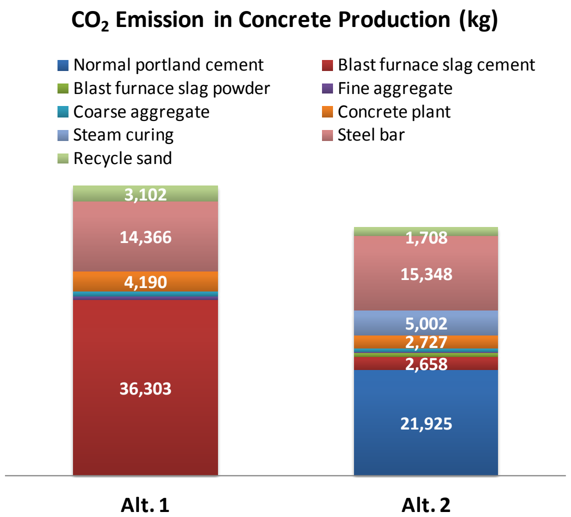



Fig. 5 $CO_2$ emission in concrete production

As shown in the first case, the sensitivity analysis with the same approach was also done in this case. In both alternative methods of box culvert construction, the results show that cement was very significant to the influence of the total emissions in all types of emissions. In the first alternative, the ±5% variation of unit-based emission value of cement produced an impact on the total emission of $CO_2$, $SO_x$, $NO_x$, and PM as much as ±2.20%, ±0.94%, ±1.00% and ±0.41%, respectively while in the second alternative, the impact of ±1.70%, ±0.64%, ±0.77% and ±0.25% were obtained. Steel bar and fine aggregate are also noteworthy for both alternatives in this case due to the large influence to the total emissions, after cement. The full results of the sensitivity analysis for both cases can be seen in Table 4.

General speaking, if the new alternative method in box culvert construction will be developed in the future, in addition to the emissions reductions that have resulted in the alternative itself, at least approximately 2 to 3% of variations in total emissions as been generated in the sensitivity analysis should be considered as well. This value is applied only in the case of $CO_2$ emissions. For other types of emissions i.e. $SO_x$, $NO_x$, and PM, at least 1 to 2% of the variations should be taken into account in the calculation. This approach is intended to ensure the suitability of new alternative method in relation to the total emissions.

Based on the cases which were discussed earlier, it is shown that the emission inventory can be useful for many kinds of efforts in order to promote the reduction of environmental impact in construction industry. As an outgrowth of its main purpose, not only that the emission inventory can be used in calculating the amount of greenhouse gas emissions in present time but it can also be used to predict/forecast the emissions that

Table 4. Results of sensitivity analysis

| No | Item | Sensitivity of Total $CO_2$ Emission (%) | | Sensitivity of Total $SO_x$ Emission (%) | | Sensitivity of Total $NO_x$ Emission (%) | | Sensitivity of Total PM Emission (%) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Alt. 1 | Alt. 2 | Alt. 1 | Alt. 2 | Alt. 1 | Alt. 2 | Alt. 1 | Alt. 2 |
| 1 | Cement | ± 2.20 | ± 1.70 | ± 0.94 | ± 0.64 | ± 1.00 | ± 0.77 | ± 0.41 | ± 0.25 |
| 2 | Fine Aggregate | ± 0.23 | ± 0.15 | ± 0.44 | ± 0.29 | ± 0.18 | ± 0.11 | ± 0.26 | ± 0.14 |
| 3 | Coarse Aggregate | ± 0.06 | ± 0.05 | ± 0.30 | ± 0.24 | ± 0.02 | ± 0.02 | ± 0.11 | ± 0.07 |
| 4 | Steel Bar | ± 0.9 | ± 1.06 | ± 0.37 | ± 0.44 | ± 0.03 | ± 0.04 | ± 0.04 | ± 0.04 |
| 5 | Blast Furnace Slag | - | ± 0.04 | - | ± 0.03 | - | ± 0.004 | - | ± 0.01 |

would result from an activity, process, or other sources in the future. Furthermore, with the addition of the results produced from the sensitivity analysis, they can be applied as the basis tool to plan the strategies that need to be taken by the involved parties to overcome the possible problems in concrete industry that may occur as quickly as possible.

It is obvious that the existence of emission inventory will be felt very much need in the future. Consideration on putting the environmental impact as one of the parameters along the technical performances, safety and serviceability in the design of concrete structure in Japan has also been prepared in this moment. For this reason, the wider coverage and more accurate emission inventory is hoped to be developed and widely applied for general purpose in concrete industry. The participation of all the parties involved in concrete industry is very important to the success of this objective.

## 3. CONCLUSIONS

The results which were obtained from this study are listed as follows:

(1) For the first case, it was found that small-sized product plants generated more emissions than the popular product plants due to the application of more machines, i.e. line machine system, forklifts, and electric-fired steam curing method.

(2) From the sensitivity analysis, it is found that heavy oil (type A) is the most influential parameter to the total emission in most of the emission types, i.e. $CO_2$, $SO_x$, and PM emission as much as ±3.02%, ±4.74%, and ±4.51%, respectively.

(3) The application of electric-fired steam curing method and kerosene-fueled jet heater method can be considered in promoting the reduction of environmental impact in future use due to the smaller amount of emissions compared to those of heavy oil-fueled steam curing method as seen in the first case.

(4) In the second case, it can be concluded that lower emissions were produced in the construction of box culvert using precast concrete with an open cut method. The amount of $CO_2$, $SO_x$, $NO_x$ (stationary sources), $NO_x$ (moving sources) and PM (moving sources) emissions could be reduced by 13.2%, 9.6%, 5.2%, 27.38% and 27.38%, respectively. In both alternatives, the concrete production seemed to produce the highest emission with more than 70% of the total $CO_2$ emissions, followed by the transportation and construction.

(5) Cement was proved to be the most influential parameter to the total $CO_2$ emission. In both alternative methods of box culvert construction, the ±5% variation of unit-based emission value of cement produced an impact on the total emission of $CO_2$, $SO_x$, $NO_x$, and PM as much as ±1.70 to 2.20%, ±0.64 to 0.94%, ±0.77 to 1.00% and ±0.25 to 0.41%, respectively.

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