Committee Report : JCI- TC081A

Technical Committee on Minimization of Global Warming Substances and Wastes in Concrete Sector

Koji SAKAI, Takafumi NOGUCHI, Eiji OWAKI, Kenji KAWAI, Akio KOYAMA

Abstract

Along with clarifying the situation regarding concrete-related material flows in Japan as a whole and in individual regions, as well as material flows by material and industry, the generally available and used inventory data were collected and inventory data was calculated from questionnaire surveys. The constituent technologies of CO_2 emissions reduction technologies at the various life cycle stages were identified, the amounts of CO_2 emissions reduction achievable through the application of these technologies were estimated, and the various issues were discussed. Lastly, some recommendations were made for achieving low-carbon emissions and full recycling of resources in the concrete sector.

Keywords: Concrete, greenhouse gases, waste products, material flow, inventory, recommendations

1. Introduction

Global warming has become a political issue across the world and various initiatives to solve this problem are being undertaken with a growing sense of urgency. All industries are clearly being required to further reduce emissions of greenhouse gases resulting from their production activities. Enormous amounts of resources and energy are consumed by the concrete sector. The world's annual cement production is believed to exceed 3.0 billion tons, and that of concrete to far surpass 15.0 billion tons. Considerable amounts of energy are also being used for construction and transportation. All these figures are predicted to increase severalfold in the future. Since there is no substitute construction material for concrete, which is made of the most abundant resources on earth, the concrete sector will have to face up to the necessity of drastically reducing the environmental impact of concrete use and its demolition.

Taking this situation into account, this technical committee was established in order to study from all angles the reduction of the environment impact of the concrete sector through the minimization of greenhouse gases and waste products. This technical committee is an extension activity of the Technical Committee on the Environmental Performance of Concrete Structures, JCI-TC-055FS, which ended in FY2007. It carried out a broad investigation of the constituent technologies, the comprehensive technology systems, social systems, etc., required to minimize greenhouse gases and waste products from the concrete sector. Concretely, in order to clarify the situation regarding concrete-related material flows in Japan as a whole and in individual regions, as well as material and substance flows by material and industry, the information was collected through various concrete sector related associations and organizations and the questionnaire surveys were conducted at the national level. Furthermore, the generally available and used inventory data were collected, the calculation methods based on this data and based on the collected data were investigated, the analyses of the influence factors were carried out regarding inventories based on the collected data. The constituent technologies of CO_2 emissions reduction technologies at the various life cycle stages were identified, the amounts of CO_2 emissions reduction achievable through the application of these technologies were estimated, and the various technical, economic, and social issues associated with these technologies were discussed. Lastly, based on the studies and research of this technical committee, some recommendations for achieving low-carbon emissions and full recycling of resources in the concrete sector were made.

Table 1 lists the members of the technical committee.

Table 1: Committee members

Chairperson	Koji SAKAI	Kagawa University
Secretaries	Takafumi NOGUCHI	The University of Tokyo
	Kenji KAWAI	Hiroshima University
	Akio KOYAMA	Meiji University
	Eiji OWAKI	Taisei Corporation
WG on Materials Flow		
Convener	Takafumi NOGUCHI	The University of Tokyo
Members	Yasuji ITOH	Ready-mixed Concrete Industrial Association
	Shinji IWASAKI	East Nippon Expressway Company Limited
	Susumu KAMITA	Sumikin Koka
	Mitsuaki KAWAMURA	Shimizu Corporation
	Ryoma KITAGAKI	The University of Tokyo
	Hideo JINTA	Japan Crushed Stone Association
	Koichi HASHIMOTO	Showa Corporation
	Shigeru TAKAHASHI	Japan Cement Association
	Seiji HASHIMOTO	National Institute for Environmental Studies
	Takayoshi MIZOGUCHI	Masuo Recycle

	Koji SAKAI	Kagawa University
WG on Inventory Data		
Convener	Eiji OWAKI	Taisei Corporation
Members	Seiki AMANO	Japan Precast Concrete Products Association
	Yoshitaka ISHIKAWA	Electric Power Development
	Harutake IMOTO	BASF Pozzolith
	Hiroshi KATAHIRA	Public Works Research Institute
	Masayoshi KONISHI	Sumitomo Osaka Cement
	Shinri SONE	National Institute of Land and Infrastructure Management
	Shigeru TAKAHASHI	Japan Cement Association
	Koji SAKAI	Kagawa University
WG on Portfolio		
Convener	Kenji KAWAI	Hiroshima University
Members	Atsushi UENO	Tokyo Metropolitan University
	Manabu KANEMATSU	Tokyo University of Science
	Yasuhiro KURODA	Shimizu Corporation
	Masamichi TEZUKA	Oriental Shiraishi Corporation
	Yasuhiro DOSHO	Tokyo Electric Power Company
	Takeju MATSUKA	Hazama Corporation
	Hiroshi MURATA	Taisei Corporation
	Koji SAKAI	Kagawa University
WG on Social System		
Convener	Akio KOYAMA	Meiji University
Members	Satoshi ARIKAWA	Building Research Institute
	Yoshitaka KATO	The University of Tokyo
	Taichirou KAWANISHI	Urban Renaissance Agency
	Nobufumi TAKEDA	Obayashi Corporation
	Masaki TAMURA	Kogakuin University
	Takashi MAMIYA	Kajima Corporation
	Ippei MARUYAMA	Nagoya University
	Kunio YANAGIBASHI	Takenaka Corporation
	Koji SAKAI	Kagawa University

2. Material flows of concrete

2.1 Significance of understanding material flows

Japan and other industrialized nations enjoy convenient and affluent lifestyles by collecting large amounts of natural resources and manufacturing and consuming many different products and services. On the other hand, the creation of large amounts of exhaust gases, waste water, and solid waste is associated with the production and consumption of such products and services, and these by-products are returned to the natural environment's atmosphere, hydrosphere, and geosphere. Various environmental issues are basically caused by the fact that such massive material flows largely exceed the resource recycling capacity and the waste product purification capacity of the natural environment. Deforestation and loss of biodiversity caused by excessive logging in the past, and climate change caused by large emissions of carbon dioxide and other gases are typical examples of environmental issues on a global scale that have been brought about by massive material flows resulting from human activity.

Concrete is the second most widely consumed substance on earth after water[1)], and it undeniably is a substance that has an enormous influence on the creation of a recycling-based society, not only from the aspect of resource consumption, but also from the aspect of future waste production. The material flows in Japan in FY2006 are shown in **Fig. 1**[2)]. One can see in this figure that civil engineering structures and architectural structures account for 750 million tons, or approximately half of the total material input of 1.82 billion tons. Since annual production of ready-mixed concrete in FY2006 was 118,981,736 m^3, (approximately 273 million tons), this means that approximately 15% of Japan's total material input was for concrete. Japan generates 580 million tons of waste products, of which 230 million tons are recycled for use, which corresponds to just 12.5% of total material input. In FY2005, 77,000,000 tons of construction waste was generated, with demolished concrete accounting for 40% thereof, which is a lower level in waste output than in material input as in other materials and products. However, in the near future, the production of large amounts of demolished concrete as waste is expected, and it is therefore important to find ways to effectively use such waste for other than road substrate.

In order to analyze the relationship between human society, which is characterized by massive material flows, and environmental issues, it is essential to grasp and analyze the various material flows between the natural environment and human society, as well as among the various groups of human society. Many aspects need to be studied with an eye to the future, including, with regard to the upstream side of the material flows in the concrete sector, measures for land use alteration due to the removal of large quantities of rocks, with regard to the downstream side, measures to deal with the comparatively large amounts of wastes and greenhouse gases being generated, and linking the upstream and downstream sides, the role of the concrete sector with regard to material recycling including other industries. An accurate grasp of the material flows is required as the base for such study.

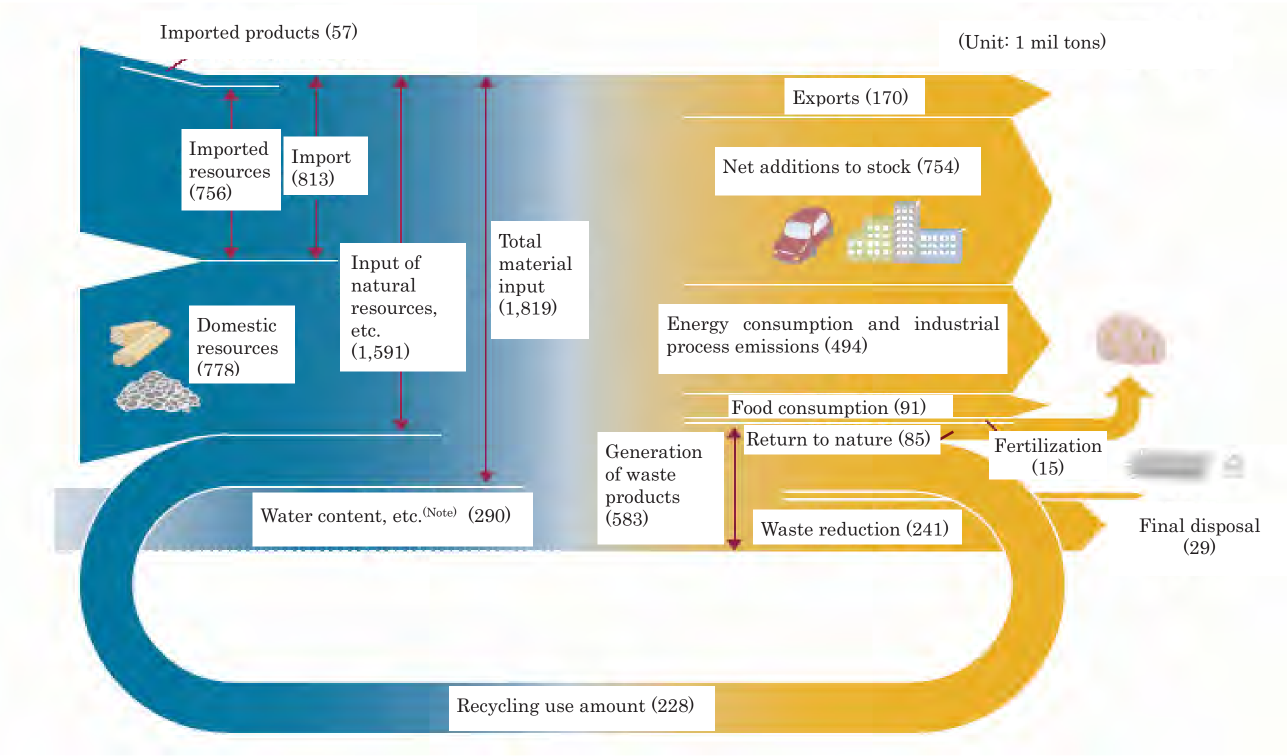

Figure 1: Material Flows in Japan (FY2006) [2)]

2.2 Material flows of materials and products

(1) Investigation purpose and method

In order to clarify the present material flow situation as regards concrete and concrete structures (<1> to <3> below) and identify the optimum state of future material flows as well as the tasks required to achieve it, document investigations, and hearings and questionnaires to related organization were conducted. The investigation objects were cement, mineral admixtures (ground granulated blast furnace slag and coal ash), chemical admixtures, aggregate (crushed stone/manufactured sand, gravel/sand and slag aggregate), water, ready-mixed concrete, rebars, forms, concrete products, concrete structures (civil engineering structures and architectural structures), and demolished concrete.

<1> Changes in national annual production amount, construction amount, and generation amount (by type and by application)

<2> Changes in annual production amount, usage amount, construction amount, and generation amount (by type and by application) by region

<3> Changes in annual import/export of materials, products, and waste by region (or by prefecture)

An example of the investigation findings is presented below.

(2) National production amount, construction amount, and generation amount

The changes in the sales amounts of blast furnace slag by application are shown in **Fig. 2**[3]. The main sale destinations of granulated blast furnace slag are domestic cement, export cement, and fine aggregate, and those of air-cooled blast furnace slag are coarse aggregate and road substrate. Combined sales of blast furnace slag for ground granulated blast furnace slag and domestic cement accounted for 63.4% of the total in FY1995 and have been declining since then, whereas sales of blast furnace slag for export cement have been on the increase since 1995.

Changes in floor area of architectural structures in which construction work started are shown in **Fig. 3**[4]. Total floor area of construction work started peaked in 1990, and by 2007, had declined to about 57% of that peak. Owing in part to the effect of the economic stagnation following the subprime mortgage crisis in 2008, this decline is expected to continue for some time.

The changes in the construction amount by type of prestressed concrete structures (PC structures) are shown in **Fig. 4**[5]. There is no large difference with civil engineering structures in general, and construction peaked in 1999. In FY2008, the amount of construction had declined to 54% of peak level, and is expected to further decline. Road bridge decks account for 73% of the total, and the ratio of all bridges, including railroad bridges and other types of bridges is high.

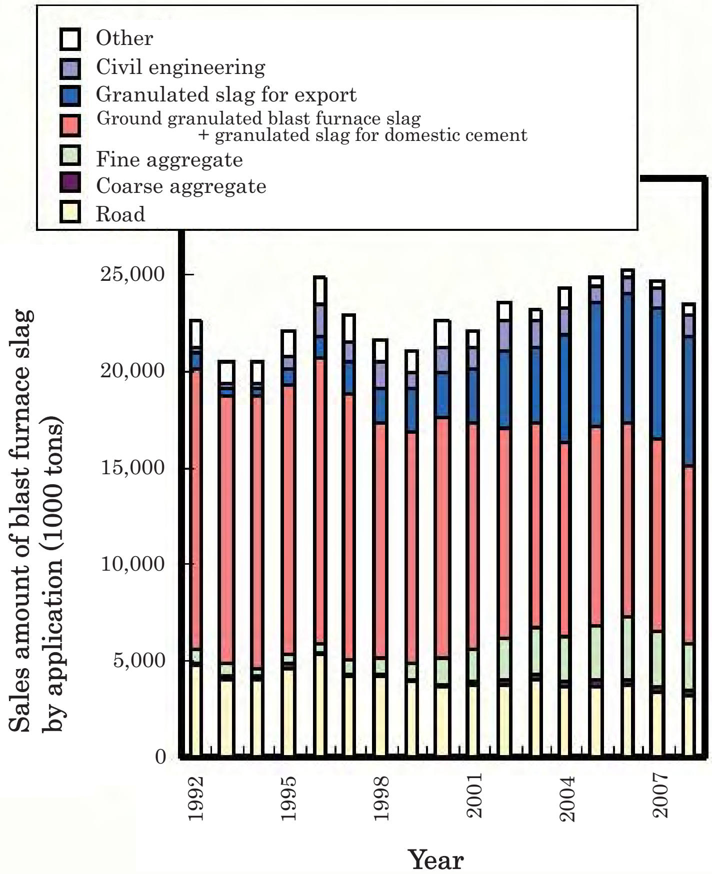

Figure 2: Changes in Sales Amounts of Blast Furnace Slag by Application[3)]

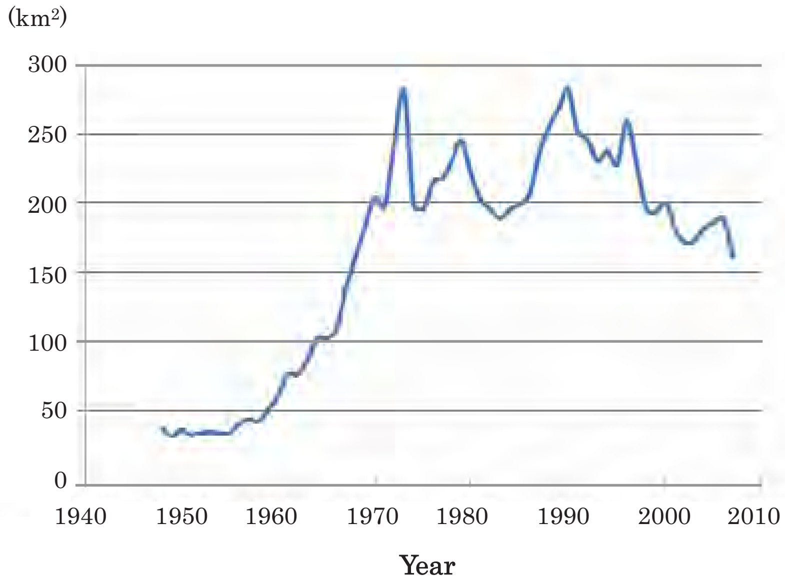

Figure 3: Changes in Floor Area of Construction Work Started[4)]

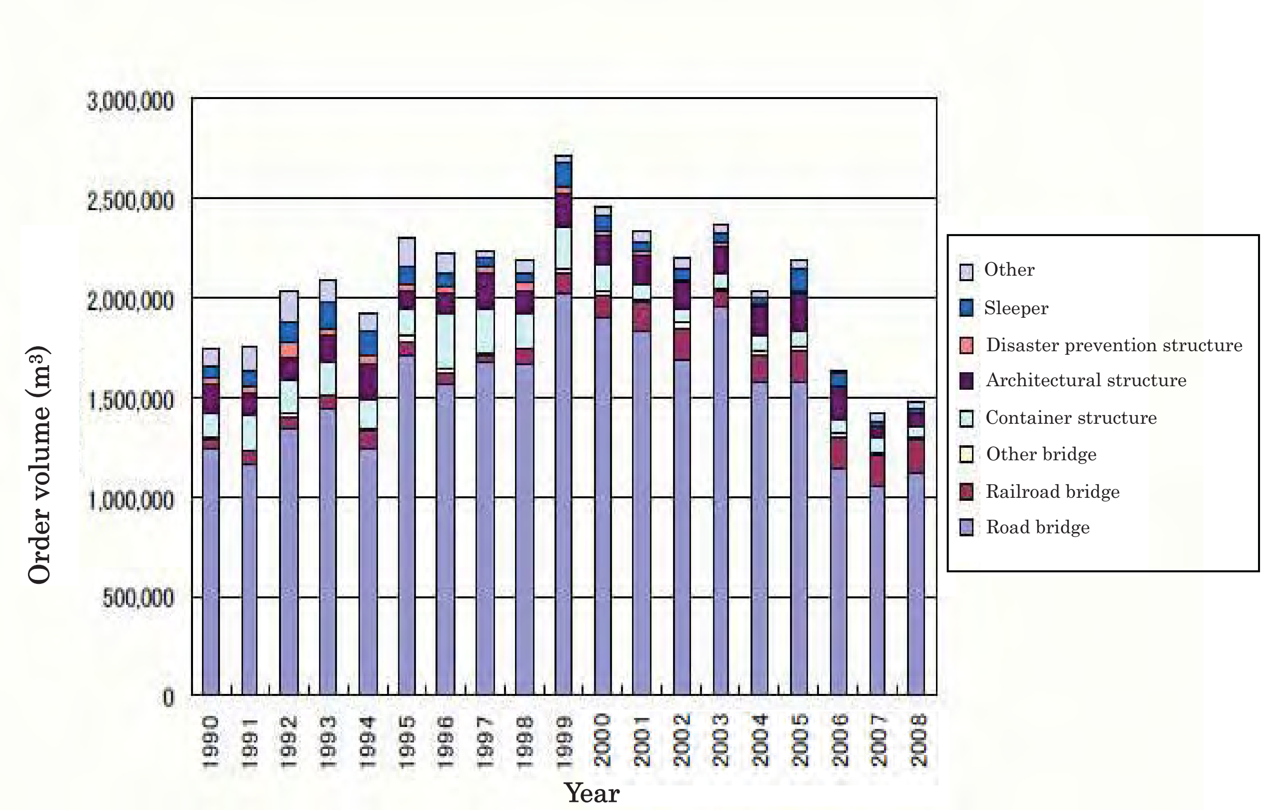

Figure 4: Changes in Order Volume of PC Structures[5)]

(3) Production amount, usage amount, construction amount, and generation amount by region

As an example, the regional distribution of generation amount of coal ash is shown in **Fig. 5**. Coal ash occurs across a broad zone from Hokkaido to Okinawa, but as there is a gap between production and demand, in some parts supply constraints exist depending on the distance from the demand area. As can be seen in this figure, the generation amount of coal ash in the Kanto area is particularly low compared to other areas.

(4) Imports and exports of materials, products, and waste by region

As an example, the annual production amounts and sales amounts of cement by region are shown in **Fig. 6**. As the overall trend, districts where cities are concentrated import cement, and the Chugoku district and Kyushu district export cement. Exporting districts have a concentration of cement plants, and the location of these plants either by the sea or in close proximity to the sea enables voluminous exports by ship. Exports by ship accounted for 67.6% of all primary transport of cement in FY2008. The Hokkaido, Hokuriku, and Shikoku districts saw a small volume of exports and imports in 1975 and 1985, but exports from these districts have been on the increase since 1995. The Tohoku district has a small volume of exports and imports and its status may be said to be close to local production for local consumption.

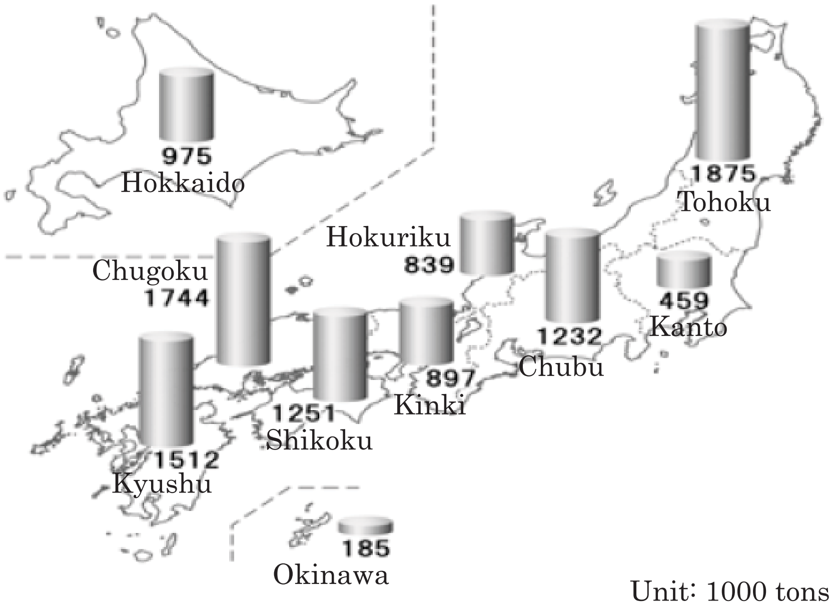

Figure 5: Generation Amounts of Coal Ash by Region

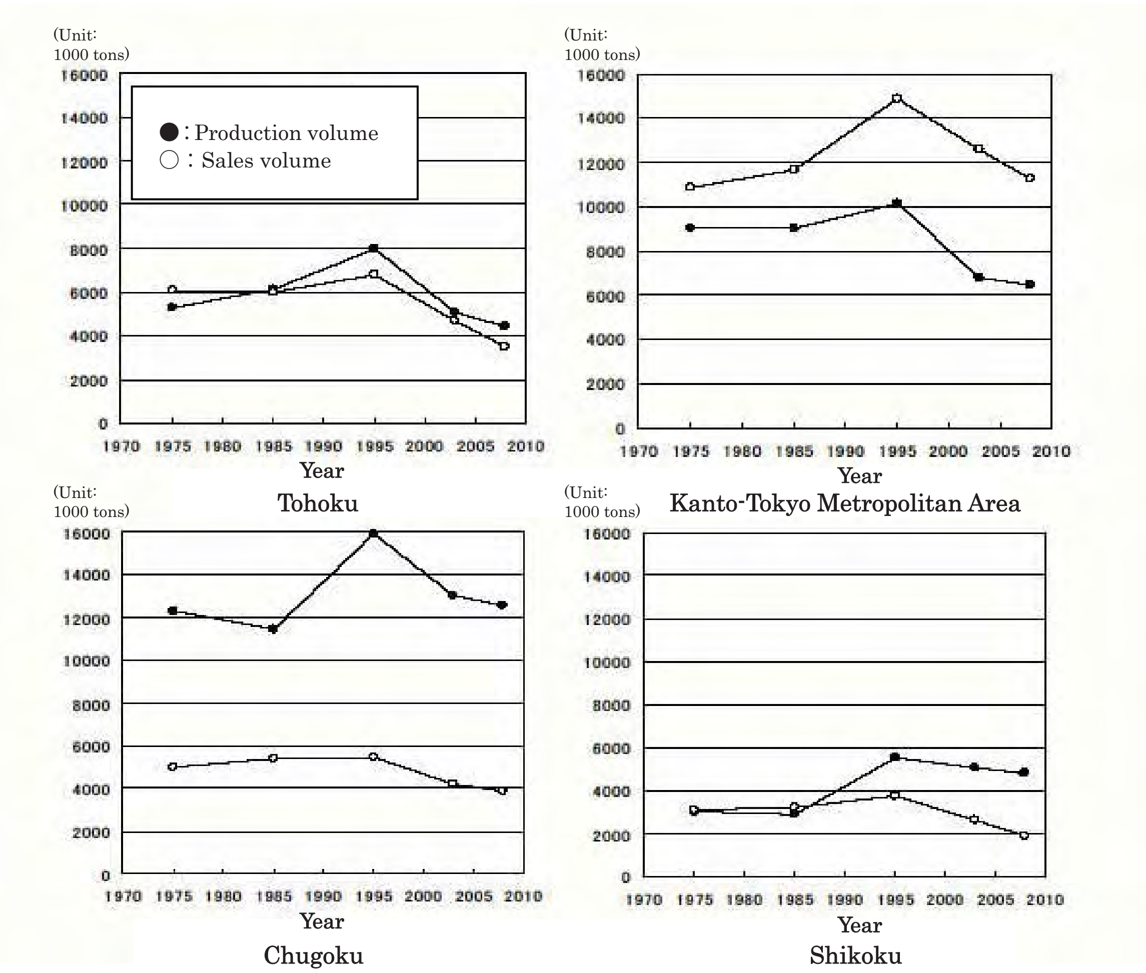

Figure 6: Changes in Production Amount and Sales Amount of Cement by Region

3. Inventory related to concrete sector

3.1 Compling inventory data and its importance

(1) Compling inventory data

Regarding the lifecycle from the manufacture of materials to demolition and reuse, we studied inventory data related to concrete and concrete structures. We began by collecting released and published data and verified the data's calculation process. If the data used for calculation, the calculation method, and the system boundaries were known, these features were compiled and usage notes based on these features were written up. If suitable inventory data was not available, the calculation of such data was attempted. Furthermore, among the material flow study results presented in the previous chapter, the inventory data based on the questionnaire survey results was also calculated. The results were then compared with inventory data calculated from economic statistics, and they are believed to more closely reflect realities such as work processes and regional characteristics.

The activities of the technical committee focused mainly on the specific CO_2 emissions as the inventory data.

(2) Importance of inventory data

Inventory data related to the concrete sector is used for example for environmental impact assessment when performing social capital improvements. In the case of the construction projects, which is closely linked with the concrete sector, it is possible to select project schemes, work items, materials, and construction methods that minimize the impact on the environment, by conducting evaluations using suitable inventory data at the planning, design, construction, maintenance, demolition, and disposal stages. As mentioned earlier, the material flows related to the concrete sector are massive, and thus securing inventory data is of great importance for environmental impact reductions on a global scale.

Inventory data involves a different vantage point from material flows, through they are essentially the same thing. Therefore, one must ensure that there are no omissions regarding inputs, production, discharged substances, and energy. In the case of inventory data related to the concrete sector, such data can include the importation of resources and energy, the use of industrial by-products, and the recycling of waste products, and may involve boundaries with other related sectors. Therefore, based on a grasp of the characteristics of each group of inventory data, such information must be applied to the respective assessments.

3.2 Materials used in concrete and concrete structures

(1) Cement

The CO_2 emissions by the cement industry announced by the Japan Cement Association is well known. Programs to raise energy efficiency, etc., are successfully being implemented by Japanese companies, and the cement produced in Japan has a low specific emission compared with that produced by other countries. However, when waste products are incinerated for heat source in Japan, there are a number of characteristics, including the fact that the resulting CO_2 emissions are not added on to cement production, and neither are the CO_2 emissions from the generation of electric power purchased from outside the company, that need to be taken into consideration.

(2) Admixtures

Domestic manufactures have not released the specific CO_2 emissions for ground granulated blast furnace slag. Ground granulated blast furnace slag uses as raw material the by-product generated in the process of producing hot pig iron, and is produced through pulverizing, classifying, etc. In Japan, the energy consumption and CO_2 emissions related to the generation of slag are tacked on to steel production. Inventories related to pulverizing etc. should be recorded for ground granulated blast furnace slag, but details are not available. On the other hand, there is also the view, principally overseas, that CO_2 emissions, etc., related to the generation of slag should be borne by slag users. Thus, caution is required when using inventories, and attention should be paid also to future trends.

Fly ash is used as a raw material of cement and also as an admixture for concrete. Similarly to ground granulated blast furnace slag, the environmental impact related to the generation of fly ash is considered to lie with the production of electric power, which is the main product. Thus, as regards the use of fly ash, only loads related to its classifying and transportation are considered. When it is used as an admixture, it is transported in small quantities compared to when it is used as a raw material of cement, and thus tends to be less energy efficient. Judicious selection of the means of transport and transport distance allow minimization of the usage amount of Portland cement and is effective in terms of reducing environmental impact.

In addition to the above, the use of silica fume and limestone powder is spreading, but the preparation of inventory data is still in an incipient stage and the growth of studies in this respect is being awaited.

(3) Chemical admixtures

The detailed composition and manufacturing process of chemical admixtures often being company secrets, inventory data is unavailable. The technical committee calculated the specific CO_2 emissions based on a questionnaire survey of the Japan Concrete Admixture Association. The data obtained from the survey responses spanned a broad range, but given that the smallness of the unit quantity of chemical admixture in relation to the concrete mix proportion, the use of such admixtures by the concrete sector is not considered to be an issue.

(4) Aggregate

With regard to natural aggregate, considering recent material flows in Japan and generally employed production processes, calculations were performed separately for production at rivers and inland, and for production of sea sand. Moreover, with regard to crushed stone and crushed sand, inventory data was calculated based on the production figures of the Japan Crushed Sand Association. Further clarification of inventory data, including the investigation of the appropriateness of these calculations and mutual validation with other released information is called for.

Inventory data about recycled aggregate made from demolished concrete was compiled through a survey of the existing literature. The higher the quality of the recycled aggregate, the higher the environmental impact tends to be. Further, there are large differences according to the scale of production. If a reduction in environmental impact through the use of recycled aggregate is sought, their quality and the generation of by-products and waste products should be also carefully considered.

In addition, aggregate that uses by-products, such as slag aggregate, is also used. Similarly to the case of ground granulated blast furnace slag, inventory data is not sufficiently made available. Trends and other information concerning the distribution of environmental impact for steel-related by-products need to be followed in the future.

(5) Water

Inventory data regarding drinking water and industrial water is reported via water purification plants, but the figures differ depending on the report. Further, in the case of plants that pump up underground water for industrial use, separate calculation is required for each plant. Further studies on the selection of these figures and the calculation methods will be needed.

(6) Rebars and other steel members

The rebars and other steel members used in the concrete sector are often electric steel. The main ingredient of electric steel being iron scrap, its energy consumption and environmental impact can be calculated as quite low compared with converter steel, whose manufacture starts with iron ore and coal. However, the origin of iron scrap is converter steel and thus boundary setting is not easy. Further, crude steel and by-product gas are produced as intermediate products. If these products are treated as intermediate products, the environmental impact is divided among them. On the other hand, "crude steel" is sometimes used as conversion indicator integrating various existing end products. By-product gas is often used in the processing of crude steel, and crude steel used as a substitute index for end products does include the environmental impact related to by-product gas. Based on the above, many different inventory data are being reported, which is conducive to confusion, and thus careful consideration is called for regarding the use of the available data.

(7) Formwork

There are few examples of reports on formworks, and the released data concerns mainly plywood. As the boundaries differ greatly depending on whether imported materials are used, whether drying and glueing processes are involved, and whether CO_2 emissions during incineration are included, caution is called for when using this data. Further, the inventory data could not be verified with regard to steel formworks. As a result, the only recourse is to perform calculations based on steel boards, but as mentioned above, caution is called for regarding the treatment of steel products.

3.3 Concrete production

Various inventories are being reported for concrete production. The technical committee conducted a survey of member companies of the National Federation of Ready-Mixed Concrete Industrial Associations and compiled the inventory data based on the obtained information.

3.4 Concrete products

The inventory data of concrete products was calculated based on the questionnaire surveys reported in the previous chapter. There are a number of related organizations, but the Japan Prefabricated Construction Suppliers & Manufacturers Association and the Japan Prestressed Concrete Contractors Association were selected.

As calculations by product type were not feasible, the data was organized by application, namely architecture and civil engineering.

3.5 Construction of concrete structures

For civil engineering structures, organization of the inventory data by type of structure based on existing case studies was attempted. Moreover, with regard to architectural structures, the systematic organization of inventory data according to the structure of the building and its application is already being done by the Building Contractors Society, and this data was sorted. For PC structures, inventory data was sorted using the superstructure of bridges as a case study. Moreover, since the specifications of the superstructure strong reflect the specifications of the substructure, consideration of the substructure was also studied.

All this data is important as a guide, but concrete structures usually being one-off products, applications must be studied in accordance with each type of information.

3.6 Maintenance of concrete structures

Maintenance covers an extremely broad array of conditions both in terms of materials and the type of work according to the maintenance method to be applied. Taking bridge structures as an example, inventory data related to preventive maintenance, repair, demolition, and redecking were examined, and used the results as an inventory data application example.

3.7 Demolition and disposal of concrete structures

Demolition work differs depending on the type and size of the structure. Inventory data was calculated taking as an example the demolition of a housing complex consisting of multiple buildings.

Regarding the intermediate processing and final disposal of demolished concrete, questionnaire surveys were done among processing and disposal operators, and inventory data was calculated. For intermediate processing, the recycled material items to be produced were also listed. For final disposal, site preparation may also be involved, resulting in greater inventory data breadth. The investigation covered operators throughout Japan, but the number of respondents was insufficient and the continuation of research is desired.

3.8 Regarding the use of inventory data

The inventory data related to the concrete sector was compiled based on existing reports and the results of questionnaire surveys conducted by the technical committee. This data is important as basic data for activities for reducing the environmental impact of the concrete sector. On the other hand, a number of issues have been pointed out, including the facts that detailed data does not exist or is not released and that system boundaries are unclear or not unified. It is important to perform fair and transparent environmental assessments using data that is neither incomplete nor redundant. To this end, it is important to promote the organization of boundaries between industries, the acquisition of data, and the preparation of specifications and procedures that standardize data acquisition methods.

In addition, various points of caution must be observed with regard to the application of inventory data, as mentioned in this report. As a full description of the details regarding those points is not possible to show due to space limitations, specific CO_2 emission data are not included in this report. For the specific figures, please refer to the committee report[6)].

4. Combination (portfolio) of technologies enabling low carbon and resource recycling, and required social systems

4.1 Social background for low carbon and resource recycling

(1) Environmental considerations in concrete sector

The concrete sector involves a large number of parties, including producers of raw materials, ready-mixed concrete, and PC products, contractors and users of structures, and demolition, treatment, and disposal operators. The environmental impact of the concrete sector as a whole can be reduced through the selection of environmentally friendly products and work methods at every design stage, along with the minimization of CO_2 emissions and waste generation within the scope of production activities of all the parties involved.

The Architectural Institute of Japan publishes the Recommendations for Environmentally Conscious Practice of Reinforced Concrete Buildings[7)], which include examples of various types of application of environmental considerations in the concrete sector. While it is understood that the application of such environmental considerations is effective for reducing environmental impact, it is not necessarily quantified, and as a result it is not possible to set a numerical target for the rate of reduction of CO_2 emissions for 2050, for example. Thus, it is considered important to seek to quantify inasmuch as possible each factor for environmental load reducing technologies.

(2) Portfolio and future trends

Based on various statistics, current quantities of the various raw materials used by the concrete sector are estimated to have declined by about 40% to 50% compared to 1990, about 20% to 30% compared to 2000, and about 10% to 20% compared to 2005. Considering the reduction of greenhouse gases and waste products as a straightforward comparison with the past based on material quantities only, such declines in the amounts of materials used could be said to be having a tremendous effect. However, it goes without saying that this course is not desirable for the concrete sector. The quantities of materials used by the concrete sector are expected to remain unchanged or gradually decrease in the future. Thus the total amount of greenhouse gases and waste products produced by the concrete sector is predicted to gradually decrease even if nothing is done, but if further growth of the concrete sector for the sake of sustainable development is expected, more aggressive measures to reduce greenhouse gases and waste products will be required. In other words, in numerical terms, it is not enough to achieve reductions or minimization of total quantities, and the minimization of the various basic units for greenhouse gases and waste products must be aimed for. As mentioned above, fluctuations in total quantities are largely determined by economic and social conditions, and are not easily controlled by engineers in the concrete sector. On the other hand, basic units are little affected by economic and social conditions, and they are figures that can be reduced as the result of technological development on the part of engineers involved with concrete. Thus, the minimization of greenhouse gases and waste products lies in essence in the minimization of the various basic units.

(3) Current social system and policies

As part of efforts to achieve a low-carbon society, Japan's various sectors have been doing their utmost with regard to the measures and policies prescribed in the Kyoto Protocol Target Achievement Plan in order to achieve the targets of the first commitment period of the Kyoto Protocol, along with securing 13 million tons of carbon as Japan's forest carbon sink target (3.8% relative to base year total emissions) and the implementation of the Kyoto mechanism (1.6% relative to base year total emissions). In order to ensure the achievement of its Kyoto Protocol commitment to a 6% reduction in carbon emissions, with regard to its targets achievement status and progress regarding individual measures and policies, Japan performs checks that include the preparation and collection of various types of data, and is engaged in a process of adding and strengthening measures and policies as part of ongoing revisions of its action plan[8].

As part of efforts to promote policies related to the creation of a recycling-based society, Japan established the Fundamental Plan for Establishing a Sound Material-Cycle Society in March 2003 in order to promote policies in this direction. This plan calls for the comprehensive promotion of activities for the realization of an international recycling-based society, including the promotion of achievement of material flow index targets and activity index targets, and their integration with a recycling-based society/low-carbon society and a society that harmoniously coexists with nature for a sustainable society, in order to achieve a recycling-based society both within and outside Japan. In addition, based on the above situation regarding indexes, the Second Fundamental Plan for Establishing a Sound Material-Cycle Society was established in March 2008, and developments regarding resource productivity for fossil fuel resources and biomass resource input rates will be closely monitored.

4.2 Design stage

(1) Use of mineral admixtures

Currently 97% of blended cement sold and used in Japan is portland blast-furnace slag cement. For public works, the active promotion of the procurement of portland blast-furnace slag cement as a designated procurement item per the Law on Promoting Green Purchasing is needed. We set conditions for the popularization and spread of portland blast-furnace slag cement and studied the extent of the reduction in CO_2 emissions that could be obtained based on the estimated figure in relation to the current figure. Estimates were produced for two cases, the case where type B portland blast-furnace slag cement is actively used at sites where the influence of the longer curing period is small, and at sites where its merits can be fully exploited, and the case where type A portland blast-furnace slag cement is actively used instead of ordinary portland cement. The condition setting details are omitted here, but for the above two cases, the results were the attainability of CO_2 emissions reductions of 9% and 14%, respectively. In order to achieve these reductions, among others, the following items will be required as a social system: 1) Promotion of use at locations where the merits of the use of blended cement or mineral admixtures can be exploited; 2) Clarification of cracking mechanism and study of countermeasures; 3) promotion of acceptance system related to long-term curing; 4) study on the feasibility of applying blended cement or mineral admixtures to houses and buildings; 5) Spurring the use of blended cement or mineral admixtures among construction work orderers and contractors; and 6) promotion of development of new blended cements.

(2) Use of recycled materials

According to a forecast of waste generation calculated based on a fact-finding survey conducted by the Ministry of Land, Infrastructure, Transport and Tourism in FY2000, the amount of demolished concrete will increase from 35 million tons in FY2000 to 50 million tons in 2020. According to the ministry, its policy with regard to demolished concrete is to maintain the current recycling rate (98%) by expanding the recycling applications of recycled concrete. One of the issues related to the recycling of demolished concrete is the dissolution of trace constituents. If trace constituents are contained by hardening inside concrete, like recycled aggregate, dissolution should be almost non-existent, but if demolished concrete is used in such a manner that it comes in contact with soil, such as in the case of road substrate, dissolution of trace constituents risks occurring and affecting the environment.

(3) Lifetime extension

The average lifetime of housing in Japan is said to be approximately 30 years, which is remarkably short compared to the average lifetime of 77 years in the U.K. and that of 55 years in the U.S. A reinforced concrete three-story condominium with a total floor area of 1,440 m^2 uses about 2.6 ton/m^2 of concrete, and a steel reinforced concrete eight-story condominium with a total floor area of 2,400 m^2 uses about 2.1 ton/m^2 of concrete. If the lifetime of housing were to triple, this would result in the reduction of concrete of about 1.7 ton/m^2 for RC medium-rise housing, and of about 1.4 ton/m^2 for SRC high-rise housing. Moreover, looking at energy consumption of housing over the entire lifecycle (calculated period of 25 years), it is well known that the usage stage accounts for a huge 75%, energy consumption during the member fabrication and execution stage amounts to more than 5 years of energy consumption during the usage stage, and the fact that the shorter the lifecycle, the greater that ratio, clearly illustrates the energy benefit to be had by extending the lifetime of housing.

Likewise for infrastructure facilities, the CO_2 emissions reduction effect to be obtained by extending the lifetime of structures is also important and may readily be imagined even without the benefit of detailed studies. An estimate of the durability of structures based on a report[9)] by Subcommittee 216 of the Japan Society of Civil Engineers found that, compared to today's execution using currently available standard materials, if execution were carried out today using superior concrete assumed to yield a quality comparable to that of structures built in the past, the period until structure replacement would be 197 years against just 41.8 years, approximately a five-fold lifetime difference. It is easy to imagine the tremendous effect in terms of lower environmental impact that enhancing structure durability, in other words extending the useful life of structures, could have.

4.3 Raw material manufacturing stage

(1) Cement

If the source of the calcium in the cement is principally limestone, the only way to reduce CO_2 emissions from non-energy sources is to reduce the cement clinker production amount. However, by using by-products and wastes from other industries as fuel and raw materials, the cement manufacturing industry plays the role of veins for the whole industrial establishment. Therefore, large production decreases may cause problems in terms of the reduction of wastes. On the other hand, regarding CO_2 emissions from energy sources, at the device and manufacturing system level, energy saving using current technologies is considered to have reached almost the limit. A study on the use of recycled concrete material instead of limestone as the source of calcium in cement, and a preliminary study on low-temperature firing technology for cement clinker have been launched as NEDO projects and are the subject of high expectations for the reduction of CO_2 emissions from non-energy sources and energy sources.

In order to properly evaluate the cement manufacturing industry with regard to the reduction of CO_2 emissions and waste generation, a system for evaluating the level of contribution to the reduction of waste generation, including products from other industries, in cement manufacturing, is considered to be necessary. To this end, it is essential to develop integrated indexes allowing the evaluation of the reduction of CO_2 emissions and waste generation.

(2) Aggregate

Regarding CO_2 emissions related to aggregate, the impact of CO_2 emissions from the transportation of aggregate can be said to be much greater than CO_2 emissions from fuel consumption during manufacturing. This is because aggregate extraction sites and the demand locations that use aggregate as an ingredient of concrete are rarely next to each other. In terms of raw materials, there are vast quantities of aggregate derived from industrial waste leftover from other industrial fields. Besides promoting the effective use of industrial by-products generated in fields outside the construction industry, the active use of such aggregate is also important in terms of economizing natural resources required for concrete itself. The creation of a system for increasing the use of aggregate from industrial by-products through the selection of suitable combinations, like current blended aggregates, is needed.

(3) Rebars

Almost all the rebars (steel reinforcing bars) used in the concrete sector are electric furnace steel, resulting in a reduction in annual CO_2 emissions of about 15 million tons compared to the case of steel made in blast furnaces being used. In this sense, the rebars that are currently in circulation may be said to already be environmentally friendly.

The development of a new material for concrete reinforcement to reduce their environmental impact is desired, and reducing the amount of anchor bars consisting of main reinforcing bars and shear reinforcing bars in high-density reinforcement arrangements through the mechanical anchorage method is one such method[10)]. In trial calculation cases for civil engineering and architectural structures, the effect was a reduction of 2% to 10% of the total rebar amount. Further, using this construction method, the reinforcing bar arrangement work is rationalized, resulting in a shorter construction period, and a reduction in CO_2 emissions during execution can also be expected.

4.4 Concrete manufacturing stage

CO_2 emissions during concrete manufacturing are said to be on the order of 1.0 kg- CO_2 /ton. Given the growing requirement that a low-carbon society comes, there is room for further rationalization, but current CO_2 emissions during concrete manufacturing are largely dependent on the specifics of each plant, and there is the matter of how much effort small plants in particular can be expected to make. With regard to the possibility of reducing the consumption of operating energy of manufacturing plants, completely stopping plant operations during lunch breaks should reduce the load power during standby, but this would yield a reduction of only about 50 kW compared to average daily power usage of 1,600 kWh, thus quite a limited effect in view of the total. As a way to reduce the gas oil consumed by transportation equipment and vehicles, idling stop systems for agitator trucks and vehicle allocation systems that use GPS are beginning to be used at concrete manufacturing plants. Moreover, in some cases agitator trucks perform churning with electric motors while waiting at construction sites, thereby further lowering gas oil consumption. If the switch to hybrid systems for transportation vehicles further increases, overall gas oil usage will further decline, but the introduction of such systems being costly, support measures such as tax breaks or subsidies which are introduced on ordinary vehicles of the hybrid type are considered to be essential.

The wastes generated either directly or indirectly by ready-mixed concrete plants are thought to consist mainly in sludge cake and concrete debris arising from leftover concrete and returned concrete. Assuming ready-mixed concrete production to be 100 million m^3 in recent years, the annual amount of leftover concrete and returned concrete is between 2 million m^3 and 3 million m^3. In addition to the development and promotion of various reduction technologies, the creation of a legal structure and a ready-mixed concrete trading system in order to reduce the amount of leftover concrete and returned concrete would be desirable.

4.5 Construction stage

The amount of CO_2 generated through the operation of construction machinery is considered to include most of CO_2 directly emitted during the construction stage. Under the Designation System for Fuel Efficient Construction Machinery of the Ministry of Land, Infrastructure, Transport and Tourism, the development of technologies to reduce the fuel consumption of the construction machinery of the various manufacturers is being promoted, with particular emphasis on the three main categories of power shovels, bulldozers, and wheel loaders. Further, the website of the Ministry of Land, Infrastructure, Transport and Tourism features a List of Construction Machinery with Reduced CO_2 Emissions, and it appears that reductions in fuel consumption of 20% to 30% compared to older models are being achieved for construction equipment such as power shovels and wheel loaders through the introduction of hybrid and other technologies. Moreover, for relatively small heavy machinery, electrically powered models are also being developed, contributing to the reduction of environmental impact in terms of exhaust gas and noise besides CO_2 emissions. On the other hand, there are examples of the fuel consumption of agitator trucks being reduced by 14% on average by installing a fuel saving operation support device relaying instructions for fuel saving operation to the operator, and of fuel consumption of power shovels being reduced by about 20% by equipping them with an automatic idling stop system, suggesting that it may be possible to cut CO_2 emissions by about 10% through thorough implementation of fuel saving operation.

4.6 Service stage

The proportion of service stage emissions to lifecycle CO_2 emissions of RC structures is generally said to be high, but the higher the number of years of service, the higher that ratio naturally is. By one estimate, an RC office building in operation produces emissions of 40 kg-CO_2/m^2/year[11)]. An approach to reducing CO_2 emissions from building operation is to make full use of the thermal storage performance of the concrete structure. An overseas study found that a masonry house (2-story, 2 LDK type) can save between 9 tons and 15 tons in CO_2 emissions over a service span of 60 years, compared to a structure without benefit of the heat storage performance of concrete[12)]. Moreover, assuming a service life of 70 years for an RC office building, CO_2 emissions from repair and refurbishment as a percentage of lifecycle CO_2 emissions is on the order of 20% to 30%, which is a relatively high percentage[11)], and thus reducing CO_2 emissions from repair and modification is also important.

4.7 Demolition and treatment stage

CO_2 emissions from the use of heavy machinery in the demolition stage are about 29.0 kg- CO_2/ton, but can be reduced to about 25% if hybrid heavy machinery is used. The level of CO_2 emissions during the transportation stage differs according to the basic unit for transportation that is selected, but if fuel efficiency improvements are implemented based on the Revised Energy Conservation Law, a reduction of 30% in CO_2 emissions may be obtained. The basic unit of CO_2 emissions for intermediate treatment of demolished concrete is on the order of 2.5 to 3.0 kg- CO_2/ton, and heavy machinery use accounts for about two thirds, so if the fuel efficiency of heavy machinery were improved by about 25%, as discussed above, this would yield an efficiency improvement of about 1/6th (17%). On the other hand, the basic unit of CO_2 emissions for the recovery of aggregate differs greatly depending on whether or not heating is used. If only mechanical grinding is used, the basic unit is about 1.5 times that for normal intermediate treatment of demolished concrete, and in the case of the heating and rubbing method, it is said to be about 15 times.

If the transition to low-carbon energy sources further progresses, it may be possible to further reduce CO_2 emissions from demolition and transportation, but the huge amount of concrete waste would likely be a problem. JIS standards for recycled concrete as aggregate are currently being defined and the required technologies are becoming established, but this market is failing to develop owing to cost and the issue of what to do with the by-product powder.

4.8 Precast concrete

A study[13)] calculating the respective CO_2 emissions in the case of a 12-story 120-apartment condominium designed and built with the precast method (frame-wall structure) and a similar building designed and built with the conventional method showed that while a longer service life could be set for the former, resulting in lower annual CO_2 emissions, the precast method did not necessarily result in lower CO_2 emissions in terms of the total $LCCO_2$ amount. However, in the transportation stage, the precast method allows a reduction in CO_2 emissions about 20% greater than achievable with the conventional method, and it is judged that adoption of the precast method allows a greater overall reduction in $LCCO_2$. Thus, in judging which construction method to adopt, consideration of the characteristics of the precast method with regard to CO_2 emissions is thought to be important going forward.

4.9 Portfolio from perspective of lifecycle

Technologies to minimize the basic unit of greenhouse gases and wastes at individual stages of the lifecycle of concrete contribute to the reduction of the total amounts for these stages, but technologies that minimize the total amount of greenhouse gases and wastes over the lifecycle encompassing all the stages are also required. Such overarching technologies are a combination (portfolio) of the various constituent technologies, but given that the levels of contribution of the various stages against total lifecycle emissions differ greatly, there is a dominant stage with regard to the minimization of the total amount of emissions. This stage is thought to differ between civil engineering structures and architectural structures. Namely, in the case of civil engineering structures, the raw material manufacturing stage has the largest weight, while in the case of architectural structures, it is either the raw material manufacturing stage or the service stage that has the largest weight. At any rate, all the constituent technologies introduced in the descriptions of each stage are considered to be technologies that can fully be applied in combination. In particular, since promoting the switch to hybrid power sources in common for all the stages would reduce the CO_2 emissions of the totality of the stages, such promotion at the policy level is desirable.

4.10 Issues in the concrete sector for achieving a low-carbon and recycling-based society

The awareness of the concrete sector that it needs to change its accustomed ways of producing is evident from the various examples of CO_2 emissions reducing technologies and other efforts for achieving a low-carbon and resource recycling society in all the lifecycle stages. However, while a large variety of technology development is being performed, these new technologies are not being used broadly. Thus we need to develop and introduce measures and policies to promote the diffusion of such technologies.

Moreover, even if today's technologies were broadly disseminated and effectively combined, this would by no means guarantee the realization of the ambitious goal of halving today's CO_2 emissions. Thus, new ways of doing things, not just in terms of technologies but also business practices, etc., have to be invented. In other words, innovative technologies and social systems are needed. Naturally, the introduction of such innovations is likely to raise issues within the context of existing social systems, and it will be important to devise ways for society, organizations, and people to smoothly bring about a new society. Further, not just the concrete sector, but society as a whole, needs to share a common awareness and agreement to move forward in the aim to become a low-carbon and resource recycling society.

5. Recommendations by the committee

The IPCC Fourth Assessment Report[14)] pointed out that warming of the climate system is unequivocal, and explicitly presented scenarios of CO_2 concentration and temperature rises. Then debates regarding CO_2 emissions reduction targets were held based on these scenarios, and in 2008, the Japanese government announced its Action Plan for Achieving a Low-Carbon Society, which set forth the aim of reducing CO_2 emissions by 60% to 80% by

2050. Further, the Basic Law for Prevention of Global Warming, which was approved by the Cabinet in March 2010, established the targets of further cutting CO_2 emissions to 25% below 1990 levels by 2020.

In light of this background, two indicators may be considered as measures for achieving these CO_2 emissions reductions. They are total emissions reduction and basic unit reduction. Which indicator to prioritize depends on the situation of each country or region as well as the field that is targeted, but both are effective evaluation indicators for CO_2 emissions reduction. On the other hand, the absolute amount of CO_2 emissions by Japan's concrete and construction industries is thought to be in a pattern of decrease owing to the rapid drop in construction investment. However, thinking farther into the future, further reductions cannot be unnecessary, and efforts to achieve greater reductions from present levels are called for, as such CO_2 emissions reduction efforts will directly lead to the development of innovative technologies. In other words, the development of innovative technologies will lead to the creation of new demand, which in turn will result in the sustainable development of the concrete and construction industries.

Moreover, most concrete wastes are being effectively used at present as road substrate, etc. However, disruptions of that demand-supply balance are emerging as road construction decreases. Considering the immense stock of concrete accumulated until now, the development of concrete waste processing strategies is an extremely important task.

In consideration of the above and based on the surveys and research done by this technical committee, the following recommendations were made for the concrete sector in order to achieve a low-carbon and resource recycling society.

1) The organizations and companies in the concrete sector should draft and implement action plans for the reduction of CO_2 emissions and wastes.
2) Evaluation indicators and tools for the reduction of CO_2 emissions and wastes should be developed and used to assess environmental performance.
3) Targets for the reduction of CO_2 emissions and wastes should be set in the concrete sector for 2020 and 2050, the development of technologies and systems to achieve these targets should be promoted, and the resulting technologies and systems should be broadly implemented.
4) Human resources capable of action to achieve the reduction of CO_2 emissions and waste products should be fostered.

6. Afterword

Following the conclusion of the work of the Technical Committee on the Environmental Performance of Concrete Structures after three years, in 2008, further investigative study was carried out for an additional two years, focusing on global warming and waste products. Over this five-year period, conditions have changed remarkably in terms of the rising social awareness concerning the need to reduce CO_2 emissions and achieve sustainability. This change in awareness has been spurred by the fact that it has become clear that global resources/energy and warming issues caused by the increase of the world's population and the rapid economic growth of developing countries are extremely critical for mankind. CO_2 emissions by the world's concrete sector from material manufacturing to demolition and recycling are conservatively estimated at 4.8 billion tons. This figure corresponds to 16.5% of the 29.0 billion tons of CO_2 emissions from fossil fuel use, and it is certain to double in the future. Thus the concrete sector is under tremendous pressure to cut its CO_2 emissions. Full recycling and reuse of concrete-related waste products through low environmental impact processing is also an inescapable requirement. Should the concrete sector be unable to respond to these requirements, the importance of concrete is bound to decline little by little. The concrete sector cannot be said to have seriously addressed these issues thus far. However, the time is ripe for action. The concrete sector must demonstrate the will to mount a full-scale effort on these issues if it wants to continue to play its social role and achieve further development.

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