Committee Report : JCI- TC221A

Technical Committee on Environmental Impact Assessment of Cement and Concrete

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Abstract

We conducted a survey and study with the aim of proposing an appropriate assessment method to reduce the multifaceted environmental impacts of the cement and concrete industry. To this end, conventional and advanced methods were validated by surveying and collating standards, specifications, and academic literature, and an appropriate method was recommended. In addition, to collect the latest inventory data for this sector, we conducted literature and interview surveys to build inventory data at each stage of the life cycle in Japan. Further, based on the results of the aforementioned survey, we presented model cases of environmental impact assessment for cement, civil engineering structures, and buildings.

Keywords: Environmental impact, life cycle assessment, CO_2 emissions, resource consumption, waste and by-products

1. Introduction

In the context of sustainable development goals (SDGs) and the Paris Agreement, the cement and concrete industry has adopted a number of SDG-conscious initiatives, and as part of these efforts, various activities are being implemented to reduce its environmental impacts. Although the principles and guidelines for assessing the environmental impacts of cement and concrete have been defined in ISO 13315 and other standards, specific assessment methods and inventory data are not currently developed. As a result, different assessors use different assessment methods and inventory data, leading to reduced assessment scopes and partial assessment of items. In light of this, the sustainability of cement and concrete should be evaluated comprehensively from multiple perspectives, e.g., environmental, economic, and societal, to satisfy SDGs. In this context, the main purpose of this committee report was to propose a comprehensive evaluation method for multifaceted environmental impacts associated with cement and concrete based on a realistic and valid environmental impact assessment framework.

Table 1 lists the members of the committee. To achieve the aforementioned goals, the

Table 1: Committee members

Chairman of Committee	Kenji KAWAI	Hiroshima University
Secretary of Committee	Takeshi IYODA	Shibaura Institute of Technology
Secretary of Committee	Shunichiro UCHIDA	Taiheiyo Cement Corporation
Secretary of Committee	Hiroyoshi KATO	Tokuyama Corporation
Secretary of Committee	Akio KOYAMA	Meiji University
Committee members	Takeo ISHIDA*	Mitsubishi UBE Cement Corporation
	Toshiya IHAYA	Oriental Shiraishi Corporation
	Yusuke KIRINO	Taiheiyo Cement Corporation
	Yoichiro KUNIEDA	Tokyo Metropolitan University
	Yasuhiro KURODA	Shimizu Corporation
	Kensuke KOBAYASHI	Prefectural University of Hiroshima
	Atsumi SAWAMURA	Toda Corporation
	Tatsuo SHINMI	Tokuyama Corporation
	Yutaro TANAKA+	Mitsubishi UBE Cement Corporation
	Sumire NAKAMURA	Port and Airport Research Institute
	Michael HENRY	Shibaura Institute of Technology
	Koichi MATSUZAWA*	Building Research Institute
	Shintaro MIYAMOTO	Tohoku University
	Kosuke YOKOZEKI	Toyo University
	Toru YOSHIMOTO	Japan Cement Association
	Satoshi WATANABE	Taisei Corporation

+: to May 2023, *: from May 2023

Assessment Method Working Group (WG) and Inventory Data WG were established and their activities were planned based on the status report on the environmental impacts of cement and concrete prepared in the feasibility study. The Assessment Method WG verified the validity of conventional and advanced assessment methods in terms of functional units, system boundaries, impact categories, recycling practices, and assessment methodology; and recommended an appropriate assessment method for the cement and concrete sector. Based on existing data, the Inventory Data WG conducted literature and interview surveys to manage up-to-date inventory data for each stage of concrete life cycle, including constituent material production, concrete production, construction, demolition, and disposal and recycling. Further, based on the aforementioned results, the WGs were reorganized into the Cement WG, the Civil Engineering Structures WG, and the Building Structures WG to construct model cases for environmental impact assessment. The Cement WG surveyed typical amounts of activity for ready-mixed concrete and concrete products (e.g., mix proportions, amount of material used, operating hours for heavy machinery, transportation distance, etc.) and methods for calculating CO_2 absorption during service and demolition. On this basis, it prepared a model-case environmental impact calculation tool (Excel sheet). The Civil Engineering Structures WG compared and investigated various construction elements, including alternative materials, and precast and cast-in-place construction in PC bridges, box culverts, breakwaters, tunnel linings, and other structures. The Building Structures WG used the material amount data for the model building published in the “LCA Guidelines for Buildings” by the Architectural Institute of Japan, and investigated how the environmental impact assessment results are affected by the application of environmentally friendly concrete to piles and above-ground frames, changing the grade of the planned service period, and using recycled aggregate during reconstruction, focusing on concrete.

This paper presents a summary of the results of this committee’s activities.

2. Activities of Assessment Method WG

2.1 Survey method

We surveyed and collated standards, specifications, and academic literature with the aim of ascertaining an appropriate assessment method for environmental impact assessment of cement and concrete. We surveyed 36 domestic and foreign standards and specifications. For academic papers, we focused on domestic literature and conducted a detailed survey of 134 articles published by major academic societies and journals. **Tables 2** and **3** present a summary of the standards and specifications surveyed, as well as a summary of the academic papers.

Table 2: Summary of standards and specifications surveyed

Classification	Publisher / Organization developing standards and specification	Number
Civil engineering	Japan Society of Civil Engineers	3
Architecture	Architectural Institute of Japan, Institute for Built Environment and Carbon Neutral for SDGs, US Green Building Council, Building Research Establishment	6
Concrete	Japan Concrete Institute, ZENNAMA	4
Cement	Global Cement and Concrete Association	5
LCA	Japan Environmental Management Association for Industry, Sustainable Management Promotion Organization, Japan Environment Association	9
Other	Ministry of Land, Infrastructure, Transportation and Tourism, Ministry of Economy, Trade and Industry, Ministry of the Environment, The Association for Evaluating and Labeling Housing Performance, Japan Sustainable Building Consortium, ISO/TC 59/SC 17	9
Total		36

Table 3: Summary of academic literature surveyed

Publisher	Magazine title	Number
Japan Society of Civil Engineers	Proceedings of the Annual Conference of the Japan Society of Civil Engineers, Proceedings of JSCE, Journal of JSCE, Proceedings of Annual Meeting of Environmental Systems Research, Environmental Systems Research	16
Architectural Institute of Japan	Summaries of technical papers of Annual Meeting Architectural Institute of Japan, Transactions of AIJ: Journal of Architecture and Planning, Transactions of AIJ: Journal of Environmental Engineering, AIJ Journal of Technology and Design	26
Japan Concrete Institute	Proceedings of the Japan Concrete Institute, Concrete Research and Technology, Concrete Journal	23
Japan Cement Association	Abstracts of the Annual Meeting of Cement and Concrete Engineering, Cement Science & Concrete Technology, Cement and Concrete	29
The Institute of Life Cycle Assessment, Japan	Journal of Life Cycle Assessment	5
Japan Society of Material Cycles and Waste Management	Proceedings of the Annual Conference of Japan Society of Material Cycles and Waste Management, Journal of the Japan Society of Material Cycles and Waste Management	8
Other	-	27
Total		134

2.2 Details of survey and investigation

The WG conducted a survey and investigation of the following items based on standards, specifications, and literature.

(1) Survey subjects
  ・Survey of assessment subjects
  ・Study of environmental impact categories
(2) Functional unit
(3) System boundary
(4) Handling of waste and by-products
(5) Inventory analysis
(6) Impact assessment method

2.3 Summary of the activity results

Table 4 presents a summary of the survey results. In existing assessment cases in the cement and concrete sector, simple assessment methods are often adopted. More detailed assessment methods are expected to be adopted in the future, leading to a steady reduction in environmental impacts. However, implementation of such detailed assessment methods involves risks such as increasing the amount of inventory data required and errors between

Table 4: Environmental impact assessment methods and their contents

Item	Simple assessment method	Detailed assessment method
Impact category	Assess only impact on global warming (CO_2 emissions)	Assess multiple impact categories
Functional unit	Use number, weight, or volume as basis	・Use results of modifying mix proportions for constant compressive strength as basis ・Account for usage conditions and environment, and set so all performance requirements are at or above target values
System boundary	Assess only manufacturing stage	Assess entire life cycle
Handling of waste and by-products	Uniform cutoff without item-by-item classification	・Classification of waste and by-products (or co-products), system expansion of waste, and cut-off of by-products ・Classify by item and set up appropriate scenarios for each
Impact assessment method	Not performed (inventory analysis only)	Combined use of LIME* if subject to assessment in Japan

*LIME: abbreviation for the life cycle impact assessment method based on endpoint modeling which is an LCIA methodology developed in Japan

assessors. **Table 5** lists items that should be considered particularly important during inventory analysis in the cement and concrete sector. It is advisable to check whether the areas of high impact are adequately accounted for in any assessment in reference to the listed items. In addition, advanced assessment methods have been developed considering not only environmental aspects but also economic and social costs. On the other hand, since the universal implementation of these methods is difficult at present, assessors are required to select appropriate methods after fully investigating the advantages and disadvantages of each method.

Table 5: Items to be considered in inventory analysis

Item	Notable items
Assessment scope (System boundary)	Assessment results from only the manufacturing stage may differ from those of the entire life cycle (cases exist where the environmental burden at the time of service and at the time of treatment and disposal is large).
Inventory database	There are two types of analysis methods, the process analysis and the input-output analysis, and it is necessary to understand the advantages and disadvantages of each method to use them.
Cement production	The amount of waste and by-products used in cement production varies greatly depending on the cement type, country of manufacture, and age, so impact should be considered using appropriate data.
Service life	When service life (durability) differs, the assessment results may be reversed when converted to environmental burden in terms of years.
Demolished concrete	Recycling methods vary widely from country to country and from year to year, so the impact needs to be considered using appropriate data.
	CO_2 absorption from the atmosphere needs to be taken into account.

3. Activities of Inventory Data WG

3.1 Survey method

The aim of this WG was to manage the inventory data necessary to analyze environmental impacts of cement and concrete. It was assumed that the managed inventory data would be used as background data for this purpose. In other words, in the assessment of cement and concrete, buildings, and civil engineering structures, we assumed that assessors themselves collect the amount of materials used and energy consumed, and use this as background data (intensity) to assess the environmental impacts associated with the production procedures of the materials and energy. Based on the results of this WG, we constructed model cases for the environmental impact assessment of concrete constituent materials, concrete, and concrete structures, and made our results publicly available.

The inventory data survey focused on the cement and concrete sector. The WG presented survey methods and concepts for inventory data, and compiled the latest inventory data corresponding to each stage of the concrete life cycle, including common data on energy and transportation, as well as the constituent material production (cement, aggregate, water, admixtures, and rebar and prestressing steel), concrete production, construction, demolition, and disposal and recycling.

3.2 Details of survey and investigation

This WG conducted a survey and investigation of the following inventory data items specific to the cement and concrete sector:

(1) Inventory data survey method
(2) Energy and transportation
(3) Cement production
(4) Aggregate production
(5) Water and admixtures
(6) Rebar and prestressing steel
(7) Concrete production
(8) Construction
(9) Demolition
(10) Disposal and recycling

3.3 Summary of the activity results

(1) Inventory data survey method

Various methods were considered for the collection of input and output data to manage inventory data, including raw material and energy for subject processes. Examples of methods considered included extracting data from literature such as existing research papers and handbooks, processing data based on statistical data, and collecting data through fact-finding surveys. In this investigation, we did not specify a singular method of data collection and decided to collect data using a variety of sources. While conducting the survey, we collected data using the process analysis method based on past literature and data review, revised the collected data to make the figures more accurate, and compiled the results.

At the beginning of the committee report, we presented the purpose and definition of inventory data collection, explained trends in the background database, and collated basic concepts of data management concerning the purpose of inventory analysis, the scope of assessment subjects, the concept of functional units, the configuration of basic flows to be addressed, data collection methods, the concept of cutoff, and limitations of assessments.

(2) Energy and transportation

First, we collated inventory data on energy commonly required in collecting inventory data on each stage of the concrete life cycle, including material production, concrete production, construction, demolition, and disposal and recycling. We presented the latest values for energy input, fossil resource consumption, and various emission intensities related to mining, transportation to Japan, refining, and transportation to final demand points as inventory data related to the procurement stage for various fuels. We also surveyed and collated the latest values for CO_2 emission intensity, SO_x emission intensity, NO_x emission intensity, and particulate matter emission intensity of various fuels that are environmental impacts resulting from their consumption.

For transportation, we used values related to round trips from the source to the destination made by trucks, agitator trucks, freight cars, and ships as inventory data. We calculated inventory data for outbound trips as loaded and inbound trips as unloaded, and presented them as the respective average values of inventory data for outbound and inbound trips corresponding to the same distances.

(3) Cement production

For cement production, we used data obtained from the Japan Cement Association. We calculated respective inventory data using the latest values obtained from a survey of the inputs of energy, raw materials (natural, by-products, and waste), and additives required to produce 1 ton of not only Portland cement, but also Portland blast-furnace slag cement type B (BB) and Portland fly-ash cement type B. We also conducted our own survey and investigation of primary transportation data and presented their values.

(4) Aggregate production

For aggregate production, we presented inventory data derived from the results of two surveys on environmental impacts. The first covered the environmental impacts of fuel and electricity consumption during mining, transportation, and crushing of rocks using heavy machinery for particle size adjustment in the production of crushed stone and crushed sand. The second focused on the energy consumption during crushing for particle size adjustment in the production of slag aggregate, recycled aggregate, and municipal solid waste melted slag aggregate as well as the amount of the by-products effectively utilized.

(5) Water and admixtures

For water and admixtures, we used the latest values obtained from a survey of energy inputs corresponding to the production of different types of water (tap water, industrial water, groundwater, and supernatant water), fly ash, blast furnace slag, limestone powder, silica fume, and chemical admixtures to calculate the respective inventory data.

(6) Rebar and prestressing steel

For rebar for reinforced concrete (RC), electric furnace steel is generally used. After refining, continuous casting is used to produce round steel and deformed bars using heating and rolling processes. Blast furnace steel is generally used for prestressing steel. Currently, there is a lack of unified inventory data for rebar and prestressing steel materials. To address the heterogeneity of data calculated and published by various organizations using different methods, we introduced a method to estimate inventory data on steel materials. To this end, we calculated inventory data based on the energy input for each steel material using energy statistics.

(7) Concrete production

We primarily investigated concrete production using electric power equipment and curing consuming heavy oil. Curing is usually performed to ensure early strength during the manufacture of secondary concrete products or as part of cold-weather measures at construction sites to prevent initial frost damage. We presented inventory data of these two cases based on existing literature and case studies.

(8) Construction

For construction, we collected inventory data on each type of construction equipment used in concrete works, such as concrete mixers, agitator trucks, pump trucks, vibrators, cranes, and backhoes. If the actual operating rates were not known for certain construction equipment, we consulted the “Equipment Cost Calculation Chart”1) to obtain the standard operating hours per day (annual operating hours / (annual standard operating days x 8 hours)). For this, we assumed the standard working day to comprise 8 working hours.

(9) Demolition

In the case of demolition, we primarily focused on the environmental impacts of demolition work performed using construction machinery, such as backhoes, attributable to the fuel required for their operation. Demolition methods for RC structures depend on the location environment, the structure type, and the scale and shape of the structure. The "Revised New Demolition Methods and Cost Estimation"2) lists the standard labor productivity unit for demolition work. We used this as a reference in this investigation, and calculated the fuel consumption in the demolition of RC structures. We surveyed and collated the key points related to the demolition of RC structures, steel-framed RC structures, unreinforced concrete, and concrete pavement for each case, and presented the results.

(10) Disposal and recycling

We focused on disposal and recycling arising from the disposal and treatment of construction by-products generated during demolition work. In particular, we addressed landfill disposal and recycled aggregate (roadbed material, and recycled coarse and fine aggregate). In this investigation, energy input related to disposal and recycling was set, the resulting environmental impacts were calculated, and inventory data related to disposal and recycling were compiled.

4. Activities of Cement WG

4.1 Purpose

We constructed model cases and calculated estimates to assess the environmental impact of cement throughout its life cycle. We considered ready-mixed concrete and concrete products as examples of common cement applications.

4.2 Details of the investigation

In the model case involving ready-mixed concrete, we conducted a case study to calculate environmental impact by defining the system boundary to extend from production of constituent materials to concrete production, construction, demolition, and disposal and recycling (**Fig. 1**). To capture data on the amount of activity for concrete mixing, material usage, heavy equipment operation hours, and transportation distance, we surveyed domestic cases in Japan, and used data that were considered typical. The results revealed that, in addition to CO_2 emissions and fossil resource consumption during production of constituent

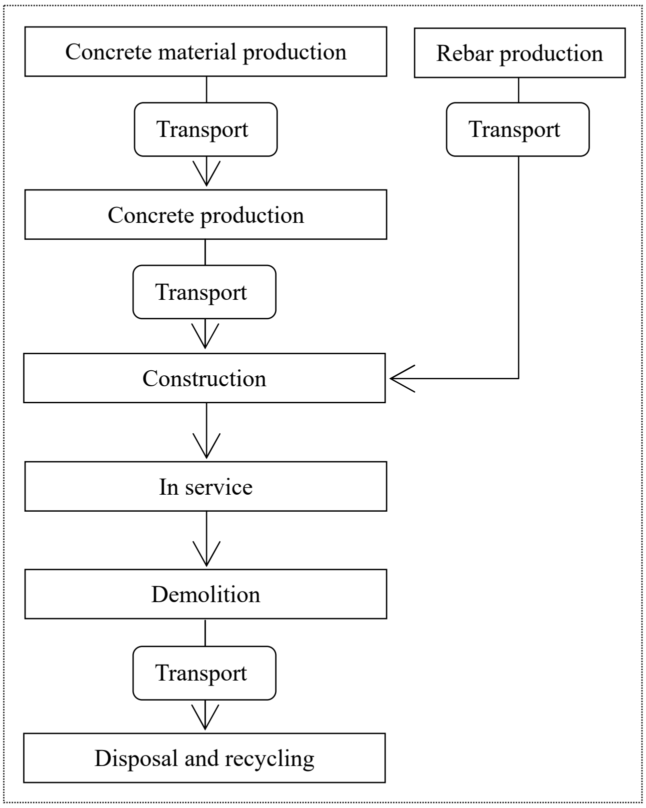

Fig.1: Scope of assessment in the model case of ready-mixed concrete

materials, waste generated during the production of steel bars and landfills generated with demolished concrete are also important factors. In addition, waste utilization during cement production has a significant environmental benefit. Thus, besides the environmental burden, the environmental benefit was also considered.

In the model case involving concrete products, we also conducted a case study to calculate the environmental impact after defining the system boundary to extend from the production of the constituent materials to construction, demolition, and disposal and recycling. In this model case, we set a lower water-cement ratio (W/C) compared to the previous model case, and assessed the environmental impact of steam curing and installation using heavy machinery at a construction site. The results revealed that in addition to the environmental impacts identified in the previous model case, CO_2 emissions and fossil resource consumption during steam curing and installation need to be considered.

4.3 Summary of the activity results

We constructed model cases and calculated estimates by considering ready-mixed concrete and concrete products as examples of common applications of cement. In addition to reiterating the need for a comprehensive assessment of the various environmental impacts of cement and concrete over their life cycles, we believe that we were able to provide concrete examples of such assessments.

5. Activities of Civil Engineering Structures WG

5.1 Purpose

We targeted several RC structures, particularly civil engineering structures, and assessed their environmental impacts while accounting for actual construction scenarios and other factors. Five model cases were considered as cases for investigation, and environmental impact assessments of materials and construction were performed based on the results of the Inventory Data WG and the Assessment Method WG.

5.2 Details of model cases and investigation

This WG investigated the following model cases:

(1) Comparison of applying cast-in-place and precast members

(a) Comparison via box culvert construction

We considered box culverts with identical inner airspace and compared their onsite construction and block manufacture. The results indicated that the use of blocks allows a higher concrete strength to be used, which increases the amount of cement in the mix, but exhibits lower CO_2 emissions and lower environmental impacts owing to the reduction in the total amount of concrete.

(b) Comparison in the context of bridge superstructure construction

We investigated the application of precast members in bridge superstructures. Although precast members were observed to increase concrete strength, a fully precast structure increased the girder height and the total concrete volume slightly, thereby increasing CO_2 emissions.

(2) Impact of cement type and aggregate transportation distance on tunnel lining concrete

We assessed the environmental impact of applying different cement-type lining concrete (ordinary Portland cement (OPC) and BB) and transporting aggregates over short and long distances. Despite the high impacts of the materials used, CO_2 emissions were reduced when the BB was used and aggregates were transported over short distances. Moreover, the use of OPC was observed to be advantageous due to the increased waste utilization and larger environmental contribution.

(3) Impact of using epoxy resin-coated rebar designed for the same service life in marine environments

To consider a structure constructed using a ship in a marine environment, we set the start of corrosion as service life, and compared the cases using regular rebar and epoxy-coated rebar. When regular rebar was used, the cover and W/C of concrete was estimated to be low, i.e., the total amount of concrete and cement used was larger, increasing CO_2 emissions. The inventory data for epoxy resin-coated rebar were not collected by this committee; other references have been cited instead.

(4) Effect of cement type change accounting for design service life

We considered cases in which the cement type and covering was changed to prolong design life in a salt-laden environment. We collated CO_2 emissions per unit service life and performed environmental impact assessment.

(5) Assessment of concrete pavement accounting for fatigue cracking

The life cycle of concrete pavements obtained using the empirical design method3) necessitates the replacement of all concrete slabs after 20 years of service life4). This WG focused on fatigue cracking based on fracture probability, and devised a life cycle in which only concrete slabs with fatigue cracking considered as damage were replaced. This new design method was compared with the conventional design method. CO_2 emissions and environmental impacts were observed to be considerably less in the new design method. In addition, higher slab thickness corresponded to a reduction in the number of pavement slabs to be repaired due to improved fatigue endurance, further reducing the assessment values.

5.3 Summary of the activity results

We set up various model cases to assess CO_2 emissions and environmental impacts. The environmental impacts of materials were observed to exceed those of construction and other factors. However, this may not be true in all cases. Reduction in inventory was observed to reduce CO_2 emissions due to the influence of the system boundary. Moreover, in terms of the environmental impacts determined by the sum of emissions and benefits, the use of OPC was advantageous because it increased waste utilization. The effect of using materials made from by-products was also observed to be significant. We believe that we were able to clarify the superiority of systems like Japanese cement production, which utilizes a large amount of waste to produce clinker.

6. Activities of Building Structures WG

6.1 Purpose

We aimed to construct model cases for RC buildings. To this end, we performed environmental impact assessment referring to examples of past efforts. In particular, we selected a standard building, conducted an environmental impact assessment based on the results of the Inventory Data WG, and then compared it to the impact of changing the primary concrete type.

6.2 Details of investigation

The WG investigated the following items:

(1) Subject building

The building subject to this investigation was mid- to low-rise multi-unit residential building of RC construction listed in **Table 6**. This case was a standard proposal for a model apartment complex, which can be found in "Chapter 8 of the LCA Guidelines for Buildings (2006 Edition)”5). However, environmental impacts were evaluated only in relation to concrete and concrete works, assuming in-situ cast-in-place concrete piles (100 % new piles).

Table 6: Outline of subject building

Item	Specification
Building use	Housing complex
Structure	Reinforced concrete construction
Number of stories	9 stories above ground
Number of dwelling units	88 units
Total floor space	7280.85 m^2

(2) Assessment system

We calculated the environmental impacts on buildings by inputting information and confirming the conversion results to processes based on the input values in the “① Material Quantity Conversion Sheet”, converting the process conversion results to environmental impacts in the “② Calculation Sheet”, aggregating the environmental impacts in the “③ Inventory Sheet,” and integrating and evaluating the environmental impacts using LIME3 in the “④ Impact Evaluation Result Sheet”.

(3) Comparative investigation items

We conducted case studies of concrete when environmentally friendly materials, such as blended cement and recycled aggregate, were used, and when its service life was extended (the grade of the planned service period was changed).

Further, we conducted surveys on the standard mix proportions of concrete for buildings and the standard labor productivity units involved in concrete work, and investigated them to ensure a realistic assessment. On the other hand, some cases, e.g., formwork with insufficient inventory data, were excluded from the assessment.

6.3 Summary of the activity results

We surveyed guidelines issued by the Architectural Institute of Japan, standard mix proportions of concrete plants, and standard labor productivity units for building construction work, and constructed a system capable of assessing the environmental impacts of RC buildings.

In addition, we used the proposed assessment system and estimated the environmental impacts of using blended cement, mineral admixtures, and recycled aggregate on RC buildings, besides the effect of extending service life.

7. Conclusions

The purpose of this report was to present an appropriate method for assessing multifaceted environmental impacts in the cement and concrete sector. To this end, a survey and study were conducted. By surveying and collating standards, specifications, and academic literature, we recommended a suitable assessment method. We also collected the latest inventory data at each stage of the concrete life cycle in Japan using the process method. Further, by presenting model cases for cement, civil engineering structures, and buildings, we believe we have demonstrated a realistic and valid method for assessing environmental impacts in the cement and concrete sector.

References

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