Newsletter
Japan Society of Civil Engineers
Concrete Committee
No. 72, Sep 2024

SUBCOMMITTEE 234

RESEARCH SUBCOMMITTEE ON APPLICATION OF NEW TECHNOLOGIES IN THE CONCRETE FIELD TOWARD CARBON NEUTRALITY

Introduction

Following the Paris Agreement in 2015, Japan declared its goal of achieving carbon neutrality (CN) by 2050. The IPCC's AR6, released on August 9, 2021, determined for the first time that global warming is caused by human activities. Efforts toward the realization of CN should be done immediately. According to the Ministry of Land, Infrastructure, Transport and Tourism in Japan, the construction industry (both civil engineering and building construction) accounts for more than 10% of CO_2 emissions, of which cement accounts for 3.8%, and the concrete industry is no exception in the CN trend. In December 2021, the Japan Society of Civil Engineers (JSCE) established the "Research Subcommittee on the Application of New Technologies in the Concrete Field toward Carbon Neutrality (Committee 234, Chair: Yoshitaka Kato)" and published **the Concrete Library165 "Implementing new technology for achieving carbon neutrality in concrete field"** based on its activities over the past year and a half (Concrete Library: technical Japanese publications approved by JSCE). The library provides basic knowledge and trends on CN, the latest information on concrete-related technologies that contribute to CN, recent measures and prospects for the use of low carbon concrete, and prospects and issues from a medium- to long-term perspective. This report outlines the library and describes the challenges and future developments toward CN.

Responsibility for this report

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Outline of chapters

This library consists of four parts, including two supplementary documents:

Part I contains basic knowledge and trends on CN and existing Concrete Libraries contributing to CN.

Part II contains the latest information on concrete-related technologies that contribute to CN.

Part III contains the latest information on concrete-related technologies that can be used as a technical reference for owners. In addition, the recent application of low-carbon concrete is discussed, and the policies and prospects for its use are presented.

Part IV summarizes the prospects and issues from the medium- and long-term viewpoints, and the details are outlined in the supplementary document.

In the following sections, the contents of each chapter are briefly explained.

Part I: Trends toward decarbonization& direction of the concrete sector

At present, all activities aimed at reducing the CO_2 emissions of concrete are considered to contribute to low-carbon concrete, so this library avoids a strict definition and refers to all concrete in which efforts have been made to reduce the CO_2 emissions of concrete, albeit to varying degrees, as 'low carbon concrete.'. The term 'low-carbon concrete structures' is not limited to concrete materials but also refers to concrete structures in which efforts have been made to reduce CO_2 emissions during their construction or life cycle (**Fig. 1**). Focusing on existing structures, the use of low carbon repair materials and construction machinery in the maintenance and demolition stages and demolition methods with low CO_2 emissions can contribute to low carbon structures over their life cycle, while they are still under development: they thus need future research and development.

It is important to understand the current situations of the concrete sector and to set back-casting targets to discuss what needs to be done as a concrete industry to achieve CN. Focusing on ready-mixed concrete for civil engineering applications, the approximate CO_2 emissions of concrete used in general civil engineering construction were estimated using statistics on ready-mixed concrete shipments and cement sales. Then, the average unit cement content was estimated to be 350 kg/m^3. The

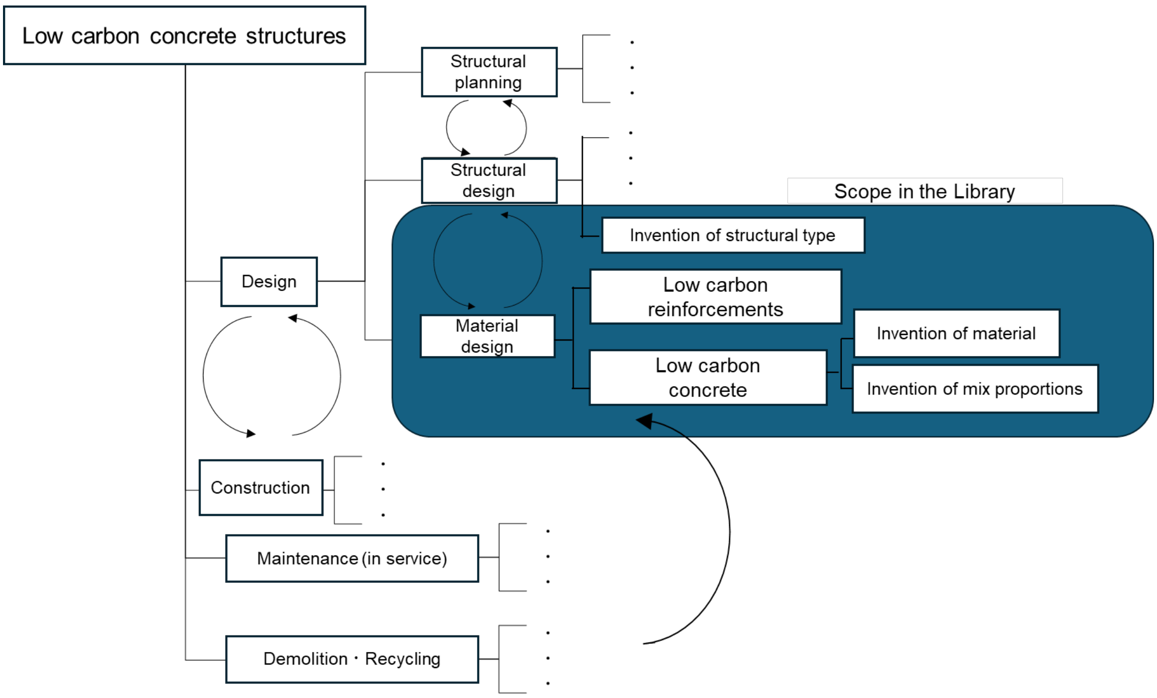


Fig. 1 Definition of the concrete structures and concrete towards low carbon emission and scope in Concrete Library 165

average CO_2 emissions were estimated to be about 290 kg-CO_2/m^3 using ordinary Portland cement (OPC) and about 180 kg-CO_2/m^3 using Portland blast-furnace slag cement type B (including production, manufacture and transport steps). These values are not intended to be standard for judging "low carbon" but can be used for approximate comparisons. Considering these values, it is necessary to achieve 149.4 kg-CO_2/m^3 for concrete made with OPC in 2030. It is necessary to consider how far CO_2 emissions can be reduced with existing technologies and what low-carbon technologies can be used to achieve the 46% target in 2030, before 2050. If not, what low-carbon technologies need to be promoted and to what extent should be discussed.

In addition, many of the current low-carbon concrete technologies are based on the effective use of industrial by-products, and these technical bases have already been published as Concrete Libraries; Part I also organizes the existing libraries in terms of concrete materials, design, construction, maintenance and operation, demolition and recycling/recovery. In terms of recent use of existing technologies, these existing libraries are very helpful while new materials such as CO2 absorbing concrete, for which development has been progressing in recent years, cannot be dealt with in the existing libraries, and the rapid establishment of a framework for their implementation in the field is expected in the future.

Part II: Update and Future Prospects of Concrete Technologies for CN

Focusing mainly on concrete materials, Part II collects information on the initiatives contributing to CN in the relevant industries, their prospects, and examples of individual technologies. It also summarizes the barriers and challenges to the actual implementation of concrete technologies and outlines the matters necessary for the future use of concrete technologies that contribute to CN. First, the status of cement, blast-furnace slag, fly ash, non-ferrous slag, electric furnace steel used for rebar and form steel, aggregates, and admixtures are summarized, as well as the outlook in terms of their production volumes and CN initiatives. Then, the status of CO_2 emissions, future responses and the issues involved in the ready-mixed and precast concrete industries are also summarized.

In addition, the new concrete material technologies contributing to CN, which have been very actively researched and developed in recent years, are organized into three main categories: i) technologies to reduce CO_2 emissions by reducing cement use, ii) cement-free concrete technologies, and iii) CO_2 utilization technologies. The details of the individual technologies are summarized using the designed sheet, in which the CO_2 reduction effect and the waste utilization rate are outlined in addition to the technical overview so that the various technologies can be evaluated using a unified index as far as possible. In addition to the construction experiences, the sheet also shows the structural type and structural members of potential applications based on the developers' ideas while specifying the points when using the technology. A total of 33 technologies are summarized in the sheets, and an overview of 9 carbon capture and utilization (CCU) technologies that are recently of interest was organized.

Finally, the barriers in the current construction production system to the application of various concrete technologies contributing to CN to various structures are summarized in terms of 'standards and certification systems,' 'concrete production facilities,' 'material supply systems,' 'material quality' and 'concrete quality'. The countermeasures to overcome these issues and barriers are mentioned from several perspectives, and the need for discussions to extend to design and maintenance is indicated.

Part III: Use and prospects of concrete towards low carbon emission from a short-term perspective

Part III presents measures for the use of low-carbon concrete conforming to the existing standards of each entity, as well as measures that do not depend on the entity, focusing on the characteristics of the concrete, etc. Part III is intended for the immediate implementation of low-carbon concrete. Therefore, it mainly uses existing technologies, such as concrete containing high-volume mineral admixtures. It is summarized in the categories for ports, rivers, railways, and roads, respectively.

It is well known that low-carbon concrete generally requires a more extended curing period than that using OPC or early-high-strength Portland cement. Part III investigated how much longer the curing period should be for low-carbon concrete, using daily average temperatures in 19 sites throughout Japan based on Japan Meteorological Agency data for 2021 for several sites. As a general trend, the values for Portland blast-furnace slag cement type B (BFS replacement level: 30~60wt.%) and type C (BFS replacement level: 60~70wt.%) were lower than those for OPC, but the difference between type B and type C was relatively small. This suggests that, in the sites where the concrete with type B slag cement has already been implemented, implementing concrete with type C slag cement would be possible. As a striking trend, in the case of Naha (a warmer city in Japan), the prerequisite curing days for both type B and type C were at least as high as those for OPC in other sites. In relatively warm regions, it is easy to secure the number of curing days required for low-carbon concrete.

It should be noted, in low-temperature environments, that the delay in setting, increase in bleeding, and reduced early-age strength development are often problems. To solve these problems, the use of high-early-strength Portland cement as a binder and keeping the curing temperature close to room temperature at an early age can shorten the time necessary for finishing the cast-in-place concrete. Construction in low-temperature environments can be handled by devising mixing and curing methods.

Part IV: Medium- and long-term challenges and prospects for the concrete sector towards CN

Even if the CN technologies organized in Part II are implemented immediately in structures such as those exemplified in Part III, it is still challenging to achieve the CN goal. Therefore, the discussions and studies on "What should be done for achievement?" are summarized in Part IV, as outlined below.

The international roadmap towards CN in the cement and concrete industries is the Global Cement and Concrete Association (GCCA) Action Plan published in 2021, which presents the decarbonization scenarios envisaged to achieve CN by 2050. For each of these, the potential reductions are presented in **Table 1**. Focusing on the breakdown, “Efficiency in clinker production” and “Efficiency in concrete production,” as well as “Savings in cement & binders,” have a great impact, accounting for around 40%: various studies are thus underway, as presented in Part II. The potential for "Efficiency in design & construction" is also expected to be relatively high, at 22%, on which “construction” sectors are therefore actively working. On the other hand, the potential contribution of "design" sectors to decarbonization has hardly been discussed, so there is still much room for extensive study.

JSCE Standard Specification for Concrete Structures [Design] 2022 edition defines ‘environmental performance’ as one of the performance requirements and requires consideration about it in schematic design phase. The social infrastructure development should align with the SDGs so that essential measures for ‘environmental performance’ are desirable, while details have yet to be discussed. A

Table 1 Action plan for CN (made based on [1])

Scenario	Contribution to net zero (Compared with 2020)
Efficiency in clinker production	11 %
Efficiency in concrete production	11 %
De-carbonization of electricity	5 %
Savings in cement & binders	9 %
Efficiency in design & construction	22 %
CO2 sink: re-carbonation	6 %
Carbon capture and utilization/ storage（CCUS）	36 %

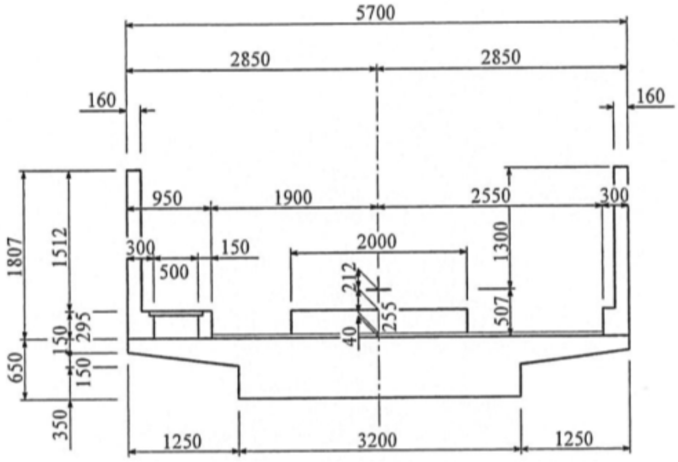
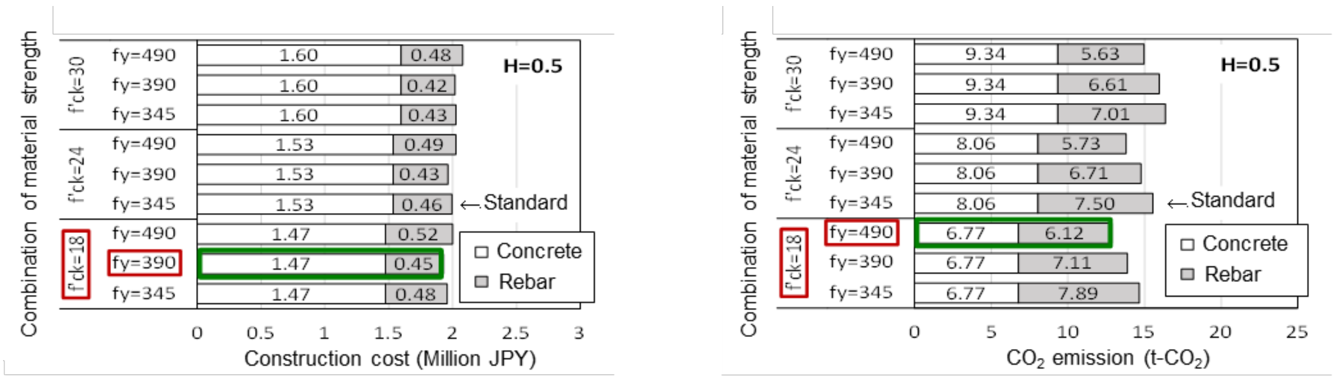


Fig. 2 Cross-sectional view of RC simple girder for railroad used in the trial estimation



a) Construction cost (material and construction)

b) CO_2 emission (Input-Output analysis)

Fig. 3 Estimation results

feasibility case study has been conducted in Part IV. The amount of rebar required to satisfy the safety requirement was calculated for the combination of concrete strength of 18, 24, and 30 N/mm^2 and rebar types of SD 345, 390, and 490 for the RC simple girder for railways (girder height 0.5 m) shown in **Fig. 2**: then, construction costs and CO_2 emissions were calculated. Note that the requirements for service-ability and durability were not taken into account. The results are shown in **Fig 3**. According to the construction cost, the combination of 18 N/mm^2 concrete and SD390 reinforcing bars was the best choice (**Fig. 3a**) while the different combination was for the lowest CO_2 emissions (**Fig. 3b**). The CO_2 emission intensity used in the calculations was 1453 kg-CO_2/t for steel bars and 342 kg-CO_2/m^3 for concrete. Still, the influence of concrete, which accounts for much of the volume of RC girder members, was significant: therefore, CO_2 emissions were minimized under conditions that minimized it. The results suggest that when CO_2 emissions are used as a decision-making indicator, the design solution may differ from the one designed with the conventional construction cost minimization.

A structure's design shape and form will be changed when it is designed with different decision-making indicators, such as CO_2 emissions. Such a concept should be widely implemented, and it is expected that new ideas for effective material and structural design can be explored. This will enhance the synergy among all the sectors involved in construction, leading to a drastic change. In this context, it is insufficient to discuss only among the concrete sectors; holistic discussion is essential. Other structures (steel structures, steel-concrete composite structures, FRP structures, soil structures, CSGs, etc.) can be selected to reduce CO_2 emissions if the required performance can be met. The civil engineers involved in construction should share these critical issues to optimize the whole system so that multidisciplinary discussions will be more important in the future.

Conclusions

Although the activities of the Subcommittee234 have been completed, there are still many outstanding issues, so discussions are continuing. Many important ideas have been discussed from various viewpoints toward the CN. These opinions are presented in detail in the supplementary document of this Concrete Library. In any case, the optimum solution for the direction towards CN has yet to be explored and discussion should continue. Creating new ideas for developing the infrastructure from a new perspective for achieving CN is important, so again, multidisciplinary cooperation is essential.

Reference

[1] Global Cement and Concrete Association: https://gccassociation.org/2050-net-zero-roadmap-one-year-on/ (Accessed 2024/09/12)