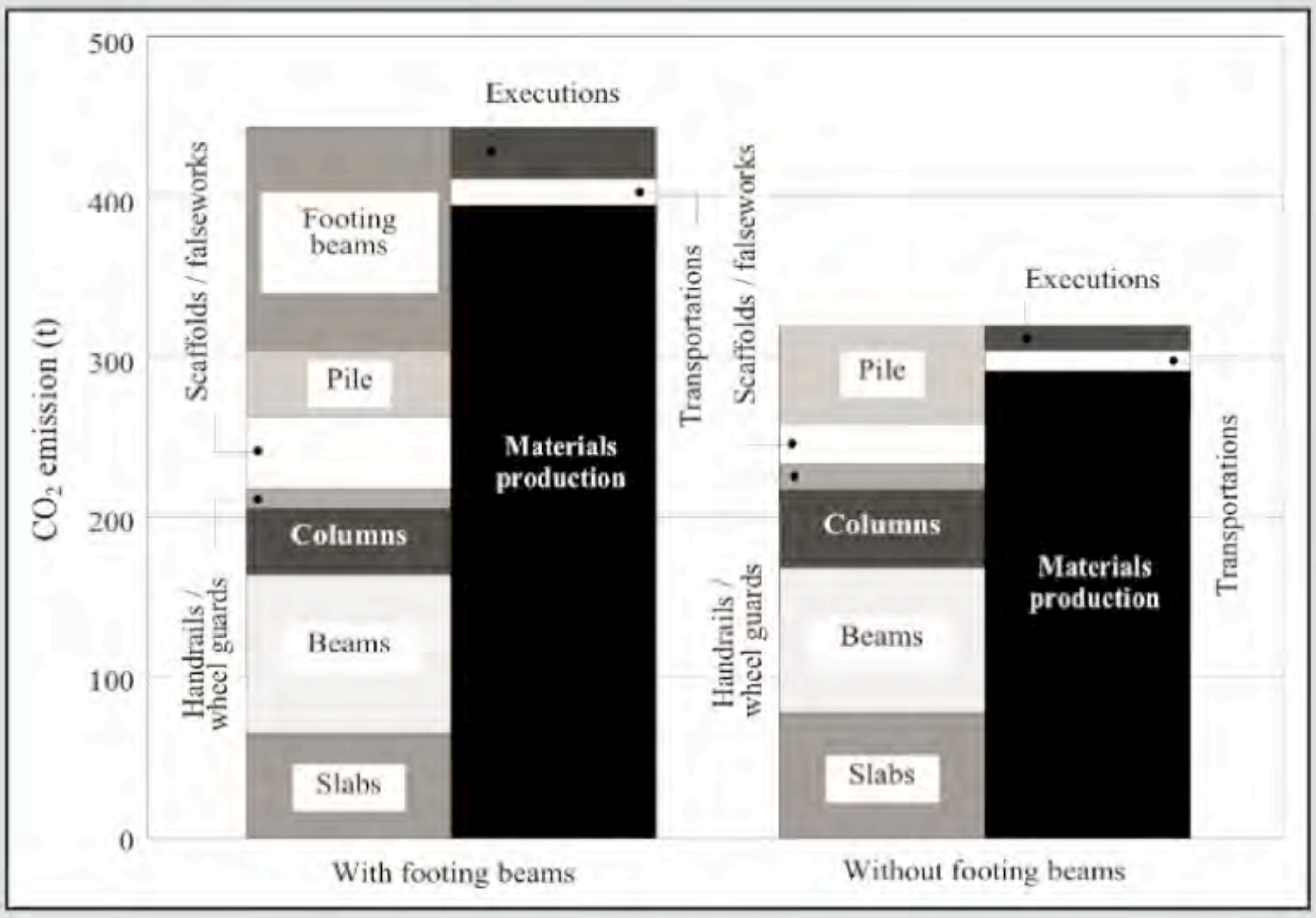
bulletin 47



Environmental design of concrete structures – general principles

technical report

Environmental design of concrete structures – general principles

Technical report
prepared by Task Group 3.6

August 2008

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category	minimum approval procedure required prior to publication
Technical Report	approved by a Task Group and the Chairpersons of the Commission
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This report was drafted by Task Group 3.6, *Guidelines for environmental design*, in Commission 3, *Environmental aspects of design and construction*:

Koji Sakai (Convener, Kagawa Univ., Japan)

Petr Hàjek (Czech Technical Univ. in Prague, Czech Republic), Makoto Hisada (Tohoku Univ., Japan), Kenji Kawai (Secretary, Hiroshima Univ., Japan), Anna Kjepso (Dr.techn. Olav Olsen a.s., Norway), Hiroyuki Mizuguchi (Univ. of Tokushima, Japan), Takafumi Noguchi (University of Tokyo, Japan), Petr Stepànek (Brno Univ. of Technology, Czech Republic), Masaki Tamura (Tokyo Metropolitan Univ., Japan)

Full address details of Task Group members may be found in the ***fib*** Directory or through the online services on ***fib's*** website, www.fib-international.org.

Cover image: CO_2 emission of a RC rigid frame viaduct (see Figure E-2).

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Postal address: Case Postale 88, CH-1015 Lausanne, Switzerland
Street address: Federal Institute of Technology Lausanne - EPFL, Section Génie Civil
Tel +41 21 693 2747 • Fax +41 21 693 6245
fib@epfl.ch • www.fib-international.org

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Preface

Although it is one of the most important materials in the construction sector, concrete causes an adverse environmental impact. Nevertheless, since concrete cannot be replaced with any other material, we need to continue producing and utilizing concrete.

As a result of the publication of *fib* Bulletins 18, 21 and 23 (elaborated by TG 3.2, 3.1 and 3.4) much information on the interaction between the environment and concrete structures was systematically processed. In addition, Task Group 3.3 on Environmental Design has presented a concept and framework for environmental design in which environmental aspects are incorporated into ordinary designs. From the previous work, the task to develop more detailed framework for practical environmental design of concrete structures was given to TG 3.6.

The purpose of this document is to provide the principles and procedures for designing concrete structures integrating environmental aspects. I hope that this report will be helpful for standardization bodies and code writers when introducing environmental aspects into their standards and codes. More reports on environmental issues and practical examples will be published by TGs 3.7, 3.8, and 3.9 in the future.

I would like to express my sincere thanks to the members of the Task Group for their contributions to the drafting of this report. I would also like to express my appreciation for the constructive review of our draft by the members of the *fib* Technical Council. We think that the framework of this report is a challenge; any criticism is welcome.

Takamatsu, May 2008

Koji Sakai
Convener, TG 3.6
Chair, Commission 3

Contents

1 Scope

Considering the current circumstances in global environmental issues, it is expected for the construction industry to contribute to the realization of a sustainable society by establishing environmental design systems for concrete structures and developing necessary technologies.

The ultimate purpose of environmental design for sustainability is to reduce impacts on nature, society and humans by evaluating and verifying the environmental performance of the design. Environmental performance can be evaluated by using indices such as resources, waste, energy, emission, etc. The performance requirements necessary for the verification of environmental performance is determined on the basis of the legislative regulation or the particular intents of specifiers, designers or owners.

This report provides general principles concerning consideration given to environmental impacts when conducting design, construction, use, maintenance/management, demolition, disposal and reuse after demolition of a concrete structure. This report is intended for the provision of the common information to incorporate environmental aspects into existing codes or specifications as environmental design.

Although the operation of buildings requires the biggest energy consumption by using heating and cooling equipment, it is not covered by this report. The environmental impacts related to land use and general ecological systems, which will be assessed at the planning stage of the project, are not included either. This report is applicable to both new and existing concrete structures.

2 Terms and definitions

emission	discharge from a system of chemical or physical entities (substances, heat, noise, etc.) into the environment (Hendriks 2000)
energy flow	input to or output from a unit process or product system, quantified in energy units (ISO 14041)
environment	surroundings in which an organization operates, including air, water, land, natural resources, flora, fauna, humans and their interrelation (ISO 14004)
environmentality	characteristic of influence on the environment
environmental impact	any change to the environment, whether adverse or beneficial, wholly or partially resulting from organisation's activities, products or services (ISO 14004)
environmental objective	overall environmental goal, arising from the environmental policy, that an organisation sets itself to achieve, and which is quantified where practicable (ISO 14004)

environmental risk	a concept that expresses a potential negative impact on the environment that may arise from some present process or future event
environmental risk management	activities which integrate recognition of environmental risk, assessment of environmental risk, development of strategies to manage it, and mitigation of environmental risk using managerial resources
environmental performance	measurable results of the environmental management system, related to the organisation's control of its environmental aspects based on its environmental policy, objectives and targets (ISO 14004)
environmental performance indicator (EPI)	specific expression that provides information about an organisation's environmental performance (ISO 14031)
environmental profile	list of effect scores for all environmental issues included in the life cycle of a system under investigation (Hendriks 2000)
global environment	an environment that is affected by global warming, ozone depletion, changes in ecosystems and other factors on a global scale, and the main environmental aspects to be considered include the emission of greenhouse gases and resource consumption
impact category	class representing environmental issues of concern to which LCA results may be assigned (ISO 14040)
indicator	quantitative, qualitative or descriptive measure
life cycle	consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to final disposal (ISO 14040)
life cycle assessment (LCA)	compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 14040)
local environment	indoor environment and outdoor environment of a structure in a limited area that influence the health of users of the structure
maintenance	a set of activities to be performed during the working life of a structure in order to enable it to fulfill the requirements for reliability (CEN/TC250)
multi-criteria analysis	method using a formal or informal procedure for weighing the effect scores in a life cycle analysis (Hendriks 2000)
non-renewable resource	resource that exists in a fixed amount that cannot be replenished on a human time scale

prevention of pollution	use of processes, practices, materials or products that avoid, reduce or control pollution, which may include recycling, treatment, process changes, control mechanisms, efficient use of resources and material substitution (ISO 14004)
raw material	primary or secondary material that is used to produce a product (ISO 14040)
regional environment	an environment that is affected by soil or water pollution in the surrounding area of activities related to a concrete structure. The main environmental aspects to be considered are the discharges of soil and water contaminants
renewable resource	resource that is grown, naturally replenished or cleansed
recycling	collection or processing of waste from a system, which results in a useful application in the same or a different system. (Hendriks 2000)
sustainability indicator	indicator related to environmental, economic or social aspects (i.e. environmental indicator, economic indicator or social indicator) (ISO/TS21929)
sustainable construction	construction that meets requirements of sustainable development
sustainable development	development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland Report 1987)
three pillars of sustainability	(1) environmental quality, (2) social equity and cultural issues, (3) economic constraints
uncertainty analysis	systematic procedure to ascertain and quantify the uncertainty introduced into the results of a life cycle inventory analysis due to the cumulative effects of input uncertainty and data variability (ISO 14041)
waste	any output from a product system which is disposed of (ISO 14040)
weighing	weighing the importance of various environmental effects against each other; weighing results in a limited group of scores that are representative of a product's environmental load; weighing takes place in the LCA assessment step (Hendriks 2000)

3 General description

3.1 Environmental issues

The true nature of global environmental problems is a result of economic society systems stemming from the explosion of industrialization since the Industrial Revolution, in which mass production, mass consumption and mass disposal have been pursued. Such systems have caused the destruction of ecological system due to the use of land, natural resources and energy, water pollution, the emission and diffusion of hazardous substances and greenhouse gases, and waste excretions, etc. Mankind has realized that these impacts exceed their allowable limits.

3.2 Sustainable development

Only some 200 years had passed since the end of the Industrial Revolution when the human race found itself faced with two extremely serious problems: resource/energy depletion and global warming. These problems arose as a result of the human race's enjoyment of convenient and comfortable lifestyles.

A sense of crisis arising from these circumstances has led to various movements over the past several decades. The first warning came in the form of a report to the Club of Rome titled "Limits to Growth" in 1971. Despite its devastating content, the report was not taken very seriously at the time of its publication. The "Declaration of the Human Environment" was adopted at the UN Conference on the Human Environment held in Stockholm in 1972, presenting the following principle concerning the environment-related rights and responsibilities of the human race:

"Man has the fundamental right to freedom, equality and adequate conditions of life, in an environment of a quality that permits a life of dignity and well-being, and he bears solemn responsibility to protect and improve the environment for present and future generations."

In other words, the Declaration of the Human Environment was the first clear statement of the human race's responsibility to protect and improve the environment, in addition to its fundamental right, and the Declaration greatly influenced subsequent international trends in environmental conservation. As the implementing agency of this Declaration, the UN Environment Programme (UNEP) was established. In 1987, the UN World Commission on Environment and Development published the Brundtland Report, which presented the following well-known concept of sustainable development:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

The report described three fundamental aspects: environmental protection, economic growth and social equality. After the publication of this report, the phrase "sustainable development" became firmly established as the final target of mankind. In other words, a paradigm shift to sustainable development has become very significant as a fundamental scheme in socio-economic activities.

In 1992, 20 years after the Stockholm Conference, the Rio Declaration was adopted at the UN Conference on Environment and Development (Earth Summit) held in Rio de Janeiro. At this conference, the importance of sustainable development to maintain balance between environmental conservation and economic growth was once again clarified, and participating nations signed the United Nations Framework Convention on Climate Change, which went into effect in 1994. The Kyoto Protocol for reduction in greenhouse gases was adopted at the Third Conference of the Parties to the United Nations Framework Convention on Climate

Change (COP3) held in Kyoto in 1997, and entered into force in February 2005, although the U.S has seceded from it. The Protocol defines greenhouse gas emission reduction targets for 2008/2012 for individual advanced countries, with the levels of 1990 set as the standard. The so-called "Kyoto Mechanism," including the clean development mechanism, emissions trading and other mechanisms for promoting the reduction of greenhouse gas emissions in developing countries and regions, was also introduced under the Protocol.

3.3 Sustainable construction

Recently, the companies manufacturing general industrial products have increased their concerns for environments. This is due to the fact that they have realized the limitation in their business in which the limits of resources are ignored.

Civil engineering structures and buildings greatly differ from general industrial products in the following points:

(1) They are not mass produced.
(2) They have long life spans.
(3) They have a high public profile.

It seems that due to these special features, the concept of environmental design in the life cycle scenario has not emerged in the construction sector.

Construction, which is one of world's biggest industries, exerts a heavy impact on the global environment because construction is a major consumer of land and raw materials and the running of buildings consumes much energy. The quality and quantity of construction will affect future generations. Therefore, construction industry has a significant role for sustainable development in which the needs of future generations have to be taken into consideration. In other words, sustainable construction has to be considered as part of sustainable development.

Traditional design and evaluation approach of structures has been based on three basic factors: quality, cost and time. However, according to the General Agenda 21 and Agenda 21 on Sustainable Construction, the three principal pillars of sustainability, namely,

(1) environmental issues
(2) economic constraints
(3) cultural-social aspects

should be considered in the design, construction, use and other life cycle phases of structures. In this report, only environmental aspects are dealt with. In Appendix D, however, environmental risk is additionally described as an economic constraint.

Sustainable construction will be achieved by taking the following factors into consideration:

(1) environmentally friendly construction materials
(2) efficient energy and resources consumption
(3) construction and demolition waste management

Construction materials produce environmental impacts at each stage of the life cycle of a structure, such as raw materials extraction, processing, manufacture, distribution, and construction work (on-site materials fabrication, use, and demolition waste). To reduce the environmental impacts, it may be the most important to minimize the amount of usage of virgin materials. Over-design should also be avoided.

The environmental design system of buildings and civil engineering structures, in which the selection of materials and structural shape, construction work, maintenance, and demolition/ recycling are included, should be established to minimize the use of resources and energy, to decrease the emission of greenhouse gases and other hazardous substances, and to control construction and demolition waste.

Concrete is made of cement, water and aggregates. Cement production consumes lots of energy and emits a large amount of CO_2. In addition, aggregate extraction causes natural destruction which includes land use, loss of eco-system, amenity loss etc. Construction and demolition waste is one of the serious problems in the construction industry. On the other hand, several industrial by-products, such as blast furnace slag, fly ash, silica fume etc., have been used for concrete. Thus, concrete has a great role for sustainable construction. In other words, sustainable concrete construction has to be considered.

3.4 Environmental design in the whole design

In general, a concrete structure shall be designed so that it can satisfy requirements regarding serviceability, safety, durability and environmentality of the structure throughout its design service life. Environmentality of a structure can be evaluated by using target indices (resources, energy, emission) and means indices (reduce, reuse, recycle) as environmental performance. Environmental performance requirements, which are necessary for the verification of environmental performance, is determined by a decision maker on the basis of legislative regulations, particular intents of specifiers or owners, or international agreements etc. Environmental performance requirements can refer to the following: selection of materials, construction methods, maintenance procedures, recycling procedures, amount of energy consumption, limitation of CO_2 emission, water pollution, soil contamination, dust, noise, vibration, chemical substances. This report shall provide general principles of basic consideration procedures concerning environmentality. Serviceability, safety and durability of structures that are not indicated in this report shall be in accordance with other appropriate standard specifications, and structures shall be designed to satisfy the requirements, including the above-mentioned environmental performances, comprehensively and in a well-balanced manner.

For rational judgment on sustainability of a structure, life-cycle cost will become an important factor. However, the economic aspects in sustainability are not dealt with as a performance requirement in this report because it should be satisfied at the first stage as the most fundamental requirement or it may change depending on the other factors.

4 Client's brief

4.1 Introduction

The client in this context is the owner or developer of the structure. The objective of this chapter is to describe, in understandable terms:

- **what** are the important environmental considerations,
- **why** these are important, and
- **how** such considerations are incorporated in the project.

It is very important that the client is able to describe the project in overall dimensions. A part of the project description must be devoted to the environmental aspects. The client is the party with the largest opportunity to implement environmental goals. The client has decision-making authority and can control the focus on environmental aspects. If the client is not willing to demonstrate an environmental focus and make such a description, the likelihood of other project participants succeeding in meeting proper environmental goals is very small.

Structural and durability designs are covered in most country's design codes. The inclusion of environmental design in a project is on the other hand largely governed by the client and may have varying motives and approaches, such as:

- To meet existing rules and regulations, driven by the responsibility of all parties.
- To obtain economical profits, in a short or long term.
- To obtain improved environmental performance, beyond rules, regulations and economical profit, driven by idealistic attitude towards sustainable construction.

Environmentally sound solutions may increase investment costs but provide savings in a life cycle perspective. It is important that the client is conscious of the responsibility of evaluating environmental and economical benefits in a life cycle perspective.

4.2 What, why and how on environmental issues

The client's brief should provide a concise description of the what, why and how with respect to environmental issues, to all parties involved in project execution. This is imperative for an effective implementation of environmental issues.

A **What** are the most important environmental considerations?

1 Environmental objectives

Primarily, a clarification of overall environmental objectives for the project should be made, the main issues being:

1.1 Percentage of reuse of concrete structure on site (in case of Demolition and Rebuilding (D&R) and rehabilitation projects)

1.2 Percentage of recycling on site (in the case of D&R and rehabilitation projects)

1.3 Percentage of use of recycled materials

1.4 Maximum volume of waste materials

1.5 Use of by-product materials

1.6 Actual materials used should be documented

1.7 LCA of materials should be requested, encouraging alternative choices

1.8 Actual emissions to air/water/soil should be documented

1.9 Noise, vibration and dust emission during construction should be assessed. This must be included in the planning phase.

2 Follow up system

A follow-up system for the specified environmental objectives should be established and applied, in order to manage a successful project accomplishment.

3 Environmental management – Consultants and contractors

Environmental management is part of the project accomplishment and is the responsibility of all parties involved, on their respective issues. It is the client responsibility to select qualified advisors, consultants and contractors that possess an environmental focus in their work and that consequently practice environmental management in their profession. All players should have an environmental management system incorporated in their routines and be experienced in its application.

B **Why** are these considerations important**?**

1 Environmental objectives

1.1 Reuse of an existing structure on site, in the case of D&R or rehabilitation, is considered the most environmentally friendly solution as it reduces transport, waste and use of raw materials.

1.2 Recycling of selected demolition waste on site, in the case of D&R and rehabilitation, helps reduce transport, waste material and use of raw materials.

1.3 Recycling of concrete rubble reduces waste production and use of new raw materials

1.4 Reduction in material waste reduces environmental impact by saving raw materials and reducing energy and land space used by alternative waste handling.

1.5 Use of by-product materials reduces environmental impact by the same mechanisms as reduction of waste material.

1.6 Documentation of material helps choosing environmentally friendly alternatives, it also helps ensure the quality of recycled materials and makes them more easily applicable to structural concrete.

1.7 LCA is the most practical tool for assessing environmental impact of a structure during its total lifecycle, from raw material to disposal. The solution with the lowest environmental impact may result in increased design and construction cost. LCC should also be performed as this often shows that the most environmentally sound solution also gives the lowest LCC.

1.8 Documentation of emission to air/water/soil aims to prevent emission of toxic material during the entire life span of the structure.

1.9 Assessment of noise, vibration and dust emission during construction is important as these emissions can disturb surroundings. In the cases of crushing and recycling on site these considerations are especially important.

2 Follow up system

2.1 Establishment of a follow up system is important in order to secure sufficient focus on environmental aspects and goals as described in the environmental objective programme. Applying such a system makes it possible to document fulfilment of the objectives.

3 Environmental management – Consultants and contractors

3.1 All players must possess and be familiar with the use of an environmental management system, both to ensure that environmental objectives are reached and to encourage consultants and contractors to focus on environmental aspects.

C **How** are environmental considerations incorporated?

The owner has a decision-making authority and can control the focus on environmental aspects in a project. It is obvious that the definition and introduction of environmental issues should be conducted by the owner. Environmental issues must be introduced at an early project stage, through an environmental objective program.

1 Environmental objectives

The more definite and accurate the environmental objectives are described, the easier and more likely they are to be successfully reached. How do we obtain these objectives?

1.1 Maximum reuse of existing structures will be reached only by adjusting the new structure to the existing. The existing structure must be assessed regarding physical and chemical properties, and all hazardous materials must be documented. Handling of hazardous material must be thoroughly planned, before any reuse or recycling of elements or structures.

1.2 Recycling on site requires careful planning for open space at the construction site where recycling can be carried out. Documentation of the quality of recycled materials should be demanded.

1.3 Maximum use of a recycled material in constructive elements requires sufficient documentation of the material quality. Undefined content and quality of a recycled material reduces its application fields.

1.4 Minimum volumes of waste material require early planning of reuse and recycling, including focus on differentiating amounts at an early stage. Ex: cutting and bending reinforcement at plant rather than site.

1.5 Use of by-product materials requires sufficient documentation of physical and chemical properties. This includes long term properties.

1.6 Use of environmentally friendly materials is secured by requesting documentation of environmental performance from the suppliers. For structural materials also properties related to design must be included.

1.7 LCA should be instructed and performed in the conceptual design phase.

1.8 Minimizing emission to air/water/soil should be specified and assessed with regard to topics such as leaching, gaseous emission and radiation from concrete.

1.9 Noise, vibration and dust emission can be controlled by including instructions for taking measures on how to collect dust and reduce noise in connection to crushing. Avoid noisy operations during early morning and late night.

2 Follow up system

2.1 A follow up system consists of measuring aids, revisions and checklists for the specified environmental objectives. The system should be approved by the client.

3 Environmental management – Consultants and contractors

3.1 Request documentation of the consultant's and contractor's environmental management system.

5 Conceptual design

5.1 Introduction

The most efficient time to make good decisions is in the early phase of a project, i.e. conceptual design phase. This is also the time when it is possible to make large errors.

Consequently it is important to implant the importance of environmental design in this phase.

The objective of this chapter is to describe; **what** are the important environmental considerations, **why** these are important, and **how** such considerations are incorporated at this stage.

An inherent problem in the construction industry is that few of the actors have experience with and competence in conceptual design. This is a challenge for all parties involved.

A holistic design of a structure should include structural, durability and environmental design.

Structural design: Design in accordance with structural standards including establishing basic assumptions. The design includes preparation of structural calculations, drawings and other required documentations. Structural design includes specification of materials, execution and control. The structural design focuses on the structure's ability to endure physical loading *imposed on the structure*.

Durability design: This comprises the design concerning the structure's ability to resist the environmental impact imposed *on the structure*.

Environmental design: This comprises the design of minimizing the environmental impact that *the structure imposes* on the environment during its entire life span, provided that structural and durability requirements are fulfilled.

5.2 What, why and how on environmental issues – Conceptual phase

A **What** are the most important environmental considerations for the conceptual design phase?

1 Perform LCA for different solutions
2 Assess emission to air/water/soil
3 Assess heat storage and thermal comfort
4 Design flexible structures
5 Harmonize the concept to existing situation

6 Vary concrete quality according to load
7 Consider longevity of concrete structures
8 Consider hybrid structures

B **Why** are these considerations important**?**

1 LCA is the most practical tool for assessing the environmental impact of a structure during its total lifecycle, from raw material to disposal
2 Assessment of emission is important to detect any leaching from cement-based materials, i.e., release of inorganic (heavy metals and salt) compounds to water.
3 Energy conservation is a key environmental issue. Assessment of heat storage properties of concrete can contribute to energy saving during the operating phase of the structure.
4 A flexible structure most likely extends structure's lifetime, and facilitates differentiated use. This fact yields a reduction in the structure's environmental impact on its surroundings.
5 Reuse of structural elements is more environmentally friendly than total demolition and rebuilding. Reuse of elements reduces energy consumption, waste production, transport, CO_2 emissions and use of raw materials.
6 Environmental impact from a structure varies with the concrete quality used. Appropriate utilization of concrete according to the performance requirements contributes to reduced environmental impact from the structure. Careful consideration is however needed to satisfy the right performance requirements of the structure. High strength concrete exerts a greater environmental impact than lower quality concrete, due to greater cement content, and subsequently increased CO_2 load. On the other hand, high grade concrete possesses better durability qualities.
7 Longevity of concrete structures increases environmental performance. Most durability problems concerning deterioration of concrete structures are related to the corrosion of reinforcement. Other common mechanisms are frost and AAR damage.
8 Hybrid structures in this context mean structures composed of concrete (incl. reinforced concrete) combined with other materials. In some cases it is possible to optimize the environmental design by composing hybrid structures.

C **How** are environmental considerations incorporated?

1 For performing LCA there are several suitable tools available, and they are constantly being improved
2 For assessment of emissions to air/ soil and water, a practical procedure is to assess the construction's neighbourhood and the possibility of contact with rain and ground water. Further, assessment of gaseous emission from concrete is necessary.
3 Assessment of energy efficiency should be done in cooperation with the different disciplines involved in designing the structures. Assessment of heat storage and thermal comfort are key issues regarding concrete properties.
4 Flexible structures involve large unobstructed areas and removable wall partitions. Such flexibility commonly requires large spans with few columns and beams.
5 Reuse of structural elements requires survey of existing construction in order to determine the capacities and conditions of existing structural elements.
6 To reduce the environmental impact from a structure, use high strength and quality concrete only when necessary. In areas that are not environmentally exposed or heavily loaded, apply lower grade concrete

7 Consider the longevity of concrete structures, by the use of FRP, stainless steel or other non corrosive reinforcement. The environmental impact of producing these alternative reinforcements must be assessed. Frost conditions must be assessed and AAR properties of aggregate documented.

8 Hybrid structures can include various amounts of materials in combination with concrete/reinforced concrete. Wider use of pre-stressed concrete and floor systems with hollow plastic spheres incorporated can reduce concrete material consumption considerably. Documentation of combined behaviour of the materials is a key issue. LCA and cost-benefit analysis may be helpful tools in choosing the best solution.

6 Performance requirements

The construction activity of a concrete structure includes the raw material extraction, the production of constituent materials, the execution, service, maintenance, demolition, disposal and reuse after demolition of the concrete structure, and the demolition, reuse and recycling of the materials and members. The influences of each stage and the whole stages of this activity on environment should be considered and can be evaluated as an index of environmental performance. The environmental performance requirements shall be specified by an owner in the planning and design stages of the structure. Some information on laws and specifications for setting the requirements are provided in Appendix A.

The whole life cycle of concrete structures is related to various environmental aspects such as global warming, consumption of resources and energy, waste emission, air pollution, water and soil pollution, and generation of noise and vibration. However, current guidelines and manuals regarding the design and construction of concrete structures do not specifically mention the influences of actions related to structure construction on environmental aspects. Hence this chapter describes basic concepts for environmental performance of concrete structures, which should be considered in their whole life cycle.

Environmental performance requirements of a concrete structure are expressed as set performance (S) which indicates the magnitudes of environmental impact factors or indicators. The outline of environmental aspects and indicators are described in the following subchapters. More details are provided in Appendix B.

6.1 Impact on global environment

Influences of the emission of greenhouse gases and the consumption of resources and energy in the manufacturing of materials for concrete structures and in the whole life cycle of the concrete structures on the environment shall be considered as environmental impacts which affect the global environment.

The Kyoto Protocol identifies the target gases or aerosols of carbon dioxide, chlorofluorocarbons and similar substances, methane and dinitrogen monoxide as substances that cause the greenhouse effect. Of these carbon dioxide is a chemical substance that is emitted as a result of a variety of economic activities, and is regarded as the most serious gas which affects the greenhouse effects.

Resources consumption in the concrete industry field is significantly greater than other fields, and it is necessary to make efforts to minimize the consumption of resources during the construction of concrete structures. Since fossil fuels are also consumed in heavy machinery and other equipment during the execution of concrete structures, it is desirable to use machinery and equipment that are highly energy efficient.

6.2 Impact on regional environment

Influences of the whole life cycle of concrete structures on air, water and soil and the emission of waste shall be considered as environmental impacts which affect regional environments.

Chemical substances, for which quantitative evaluation is considered difficult at this point although there is concern about their environmental impact, may be used in addition to chemicals that can be quantitatively evaluated, in each stage of concrete-related activities.

Since environmental impacts related to hexavalent chromium, strong alkali and other minor components such as endocrine-disrupting chemicals (environmental hormones) may be caused by a concrete structure in its surrounding environment, their impact must be considered as necessary.

6.3 Impact on construction site environment

Influences of dust, noise and vibration generated in the whole life cycle of the structure on workers' and neighbors' health shall be considered as environmental impacts which affect construction site environment.

The influence of dust generated by spraying concrete in the working and surrounding environments must be considered. If there are potential environmental impacts resulting from the noise and vibrations from each stage of activities related to the construction of concrete structures, appropriate measures to deal with them must be taken. Dust emission, noise and vibration in construction work environments may be regulated by law.

Environmental impact resulting from noise and vibration mainly occurs in a relatively limited area, including the site of an activity related to a concrete structure and its immediate surroundings. Noise can cause hearing loss, disturbances or discomfort, and a lack of sleep. Vibration can cause discomfort and damage to concrete structures. It is therefore necessary to manage the construction site and use low-noise and low-vibration vehicles and heavy machinery from the viewpoint of regional and working environments.

6.4 Impact on local environments

If necessary, influences of construction of structures on local environment shall be considered.

A local environment includes an indoor environment and an outdoor environment of a structure which means the environment influencing the health of users of structures.

In structures, radon or gases volatilized from concrete after execution such as ammonia may be concerned. Substances leaching from structures will be involved in the outdoor environment. The local environment is distinguished from the regional environment by its area of influence on the environment. The area related to the local environment is very limited.

7 Evaluation

Evaluation is an action of calculating, estimating or measuring the magnitudes of environmental impacts. The magnitudes evaluated here can be considered as retained performance (R) of the structure in the case where the influences on the environment are evaluated as an index to environmental performance.

7.1 LCA methods

Environmental performance of execution, service, maintenance, demolition, disposal and reuse after demolition of a concrete structure shall be quantitatively and objectively evaluated. In the evaluation of environmental performance, the goal and scope of the evaluation shall be clearly defined.

Emission of greenhouse gases, air pollution substances and wastes, and consumption of resources and energy will be evaluated with an LCA method. The tools for environmental impact evaluation are outlined in Appendix C.

7.1.1 Inventory analysis

Inventory analysis of greenhouse gases, air contaminants, resources and energy, and wastes shall be properly performed with an LCA method.

This inventory analysis is synonymous with that described in ISO 14040 "Environmental management – Life cycle assessment – Principle and framework." Specifically, it means investigating and summarizing resource and energy input and output substances within a preset scope of investigation, and is an essential task in lifecycle assessment.

7.1.2 Characterization and integration

Characterization and integration of greenhouse gases, air contaminants, resources and energy, and wastes shall be properly performed with an LCA method, if necessary.

This characterization and integration is synonymous with those described in ISO 14042 "Environmental management – Life cycle assessment – Life cycle impact assessment" in which potential environmental impacts are evaluated based on the results of the inventory analysis.

Characterization is a step to evaluate the degree of influence on each area of impact, such as global warming and air pollution. In other words, it can be done by classifying inventory data by related area of impact, multiplying by the characterization factor (depending on the degree of impact per unit quantity) and totaling them (see Fig.7-1).

Integration is a step to convert inventory data or the degree of influence of each area of impact, which was found by characterization, into a single index. It can be done by multiplying each inventory datum or the degree of influence of an area by the integration (weighting) factor and totaling them.

For this characterization and integration, current integration methods such as Eco-Indicator 99 (The Netherlands), Ecological Scarcity (Switzerland), EPS 2000 (Sweden) and LIME (Japan) can be used. A method appropriate to social, economical, cultural, regional and geographical characteristics valid in the place of the construction of concrete structures should be selected and used for the characterization and integration.

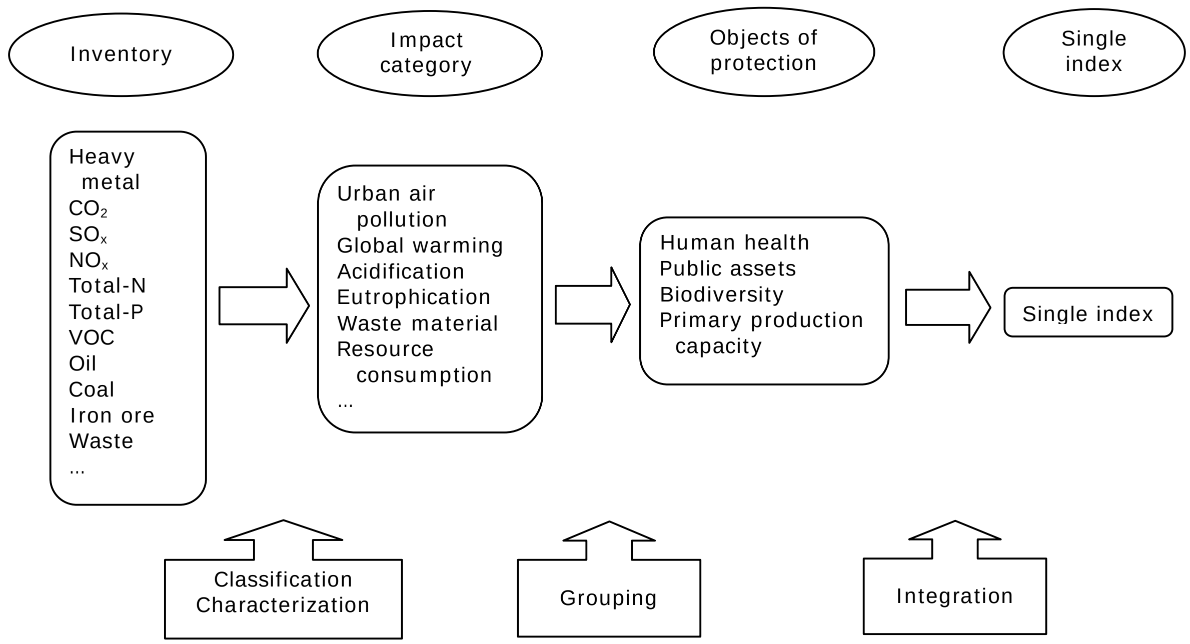


Fig. 7-1: An example of characterization and integration in an environmental impact assessment method

7.2 Measuring methods

Laws and regulations related to water quality, soil contamination and dust emission can be used in place of the evaluation procedure and verification. In this case, values based on past results, such as construction works under similar conditions, can be used for evaluations in the planning and design stages.

Evaluation of the identification and determination of water and soil contaminants and dusts shall be performed with an appropriate experimental method such as a testing or measuring method.

In the evaluation of environmental performance for noise and vibration, a direct measuring method may be used.

Observing laws and regulations related to noise and vibration can be used in place of the evaluation procedure and verification.

Environmental impact of radioactivity and electric and magnetic fields shall be properly evaluated, if necessary. It may be very rare that the impacts of radioactivity from concrete on human health must be taken into account.

It is assumed to be practical to use a method with which evaluations can be made as objectively as possible, such as confirming that there is no significant impact based on past cases under similar conditions.

7.3 Combined methods

In the evaluation of environmental performance for noise and vibration, a direct measuring method, a reliable prediction method, or their combination may be used.

8 Verification

Regarding the whole life cycle of a concrete structure, it shall be verified in the planning stage that the structure satisfies the environmental performance requirements.

In the framework of designs for verifying performance, verifying performance is an act of confirming that the performance requirements for a structure are satisfied by comparing the performance retained by the structure quantified by using an engineering index and the performance required for the structure, which is indicated by the same index. Thus, verification itself is a simple and objective act and usually does not involve supposition or judgment. In many cases, it only confirms whether the inequality is satisfied.

Environmental performance of a concrete structure is verified by confirming that the retained performance (R) of the structure defined by using engineering indexes regarding the environmental aspects of objects to be verified is larger (or smaller) than the set value (S) of performance determined by the performance requirements of the structure.

Whether the structure satisfies performance requirements for the environmental aspects subject to verification is confirmed by whether or not $R > S$ (or $R < S$). The direction of the inequality sign varies by the type of environmental aspect subject to verification. For example, in cases involving the lifecycle carbon dioxide emission, verification is achieved by setting the upper limit and confirming that the estimated carbon dioxide emission (R) of the structure is lower than the upper limit (S). Examples are provided in Appendix E. In cases involving the amount of byproducts used, it may be possible to decide that the requirement is met if the amount used for the structure (R) is larger than the predetermined minimum necessary amount (S).

If a structure satisfies the specification prescribed on the basis of past records that can guarantee performance, verification of performance can be omitted.

9 Inspection

Inspection shall be performed in each stage of the whole life cycle of the structure to confirm that the structure satisfies environmental performance requirements.

If the result of inspection shows that the structure does not satisfy environmental performance requirements, proper measures shall be taken.

A variety of measures can be taken for a structure that was considered to be unsatisfactory in terms of environmental performance, depending on the structural conditions, environmental aspects and the degree of dissatisfaction of performance. Since some measures may even increase the environmental impacts, it is necessary to take appropriate steps while considering the impact of measures themselves on the environment.

10 Records

10.1 General

Environmental performance verification systems for concrete structures are still subject to tria1 and error, and improvement of those aspects of the legal system that are related to the environment and methods for evaluating environmental performance and consolidation of inventory-related data is expected in the future. It is desirable to keep records to disclose the information related to the structure and to prepare for reevaluation in the future. Such information is also considered to be important for the future development of design methods.

These records just mean an environmental declaration.

10.2 Records on engineering history of structure

The content of operations conducted concerning production of constituent materials, construction, use, maintenance/management, demolition, disposal and reuse after demolition of a concrete structure shall be appropriately recorded, and records that are necessary shall be selected and retained.

At present, the evaluating method of environmental performance of a concrete structure is in a developing stage and not accurate enough. Therefore, it is necessary and effective to keep all for the future.

10.3 Records specified in environmental regulations and laws

Necessary records of operations concerning production of constituent materials, construction, use, maintenance/management, demolition, disposal and reuse after demolition of a concrete structure, which are specified in environment-related laws and regulations, shall be submitted to the relevant authorities and retained for future reference.

There are regulations and laws regarding environmental aspects in each country or local area. It is necessary to keep these records based on them.

10.4 Preservation period of records

In principle, records shall be retained during the service life of the structure.

It is desirable to maintain records throughout the service life of a structure because they may become necessary after completing its construction for the purposes of maintenance/management, demolition, and renewal. It is also desirable to record data on demolition, disposal and reuse since such data are valuable, and to retain them even after demolition if circumstances permit.

It is also desirable to keep environment-related records of concrete structures in an integrated manner, together with the main specifications of the structure, design documents, construction plans, construction records, report of inspection results, completion inspection results and other records related to design and construction.

Appendix A: Laws and specifications

Appendix A shows treaties, regional and national laws and specifications that would be useful to introduce environmental design for concrete structures.

Table A-1 gives the treaties that would be recognized as basic rules for considering environmental impact on a global scale.

Table A-1: Examples of treaties

Environmental Impact		Examples
Whole environment		Declaration of the United Nations Conference of the Human Environment (Adopted in 1972)
		Declaration on Environmental Policy (Adopted in 1974)
		Rio Declaration on Environment and Development (Adopted in 1992)
		Johannesburg Declaration on Sustainable Development (Adopted in 2002)
		Convention on Environmental Impact Assessment in a Transboundary Context (Adopted in 1991, Entered into force in 1997)
Global Environment	Global Warming	United Nations Framework Convention on Climate Change (Adopted in 1992, Entered into force in 1994) Kyoto Protocol to the United Nations Framework Convention on Climate Change (Adopted in 1997, Entered into force in 2005)
	Ozone-layer Depletions	Vienna Convention for the Protection of the Ozone Layer (Adopted in 1985, Entered into force in 1988) Montreal Protocol on Substances that Deplete the Ozone Layer (Adopted in 1987, Entered into force in 1989)
	Desertification	United Nations Convention to Combat Desertification in Countries Experiencing Serious Drought (Adopted in 1994, Entered into force in 1996)
Regional Environment	Air Pollution	Convention on Long-range Trans-boundary Air Pollution (Adopted in 1979, Entered into force in 1983)
	Water Pollution	Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (Adopted in 1972, Entered into force in 1975)
	Final Disposal	Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (Adopted in 1989, Entered into force in 1992)
	Toxic Substance	Stockholm Convention on Persistent Organic Pollutants (POPs) (Adopted in 2001, Entered into force in 2004)
Local Environment	Fauna and Flora	Convention on Wetlands of International Importance Especially as Waterfowl Habitat (Adopted in 1971, Entered into force in 1975)
		Convention on Biological Diversity (Adopted in 1992, Entered into force in 1993)
	Others	Antarctic Treaty (Adopted in 1959, Entered into force in 1961)
		Convention Concerning the Protection of the World Cultural and Natural Heritage (Adopted in 1972, Entered into force in 1975)

Table A-2 lists the regional and national laws that would be recognized as criteria or requirements for considering environmental impact in regions and nations.

Table A-2: Examples of regional and national laws

Environmental Impacts		Examples (EU, U.S. and Japan)
Whole environment		National Environmental Policy Act (U.S., 1969)
		National Environmental Education Act (U.S., 1990)
		EC Convention, Article 174 (EC, 1957)
		Basic Environment Law (Japan, 1993)
Global Environment	Global Warming	Law Concerning the Promotion of the Measures to Cope with Global Warming (Japan,1998)
	Energy Consumption	Energy Supply and Environment Coordination Act (U.S., 1974)
		Law Regarding the Rationalization of Energy Use (Japan, 1979)
	Ozone-layer Depletions	Clean Air Act (U.S., 1990)
		Regulation No 2037/2000 of the European Parliament and of the Council on substances that deplete the ozone layer (EC, 2000)
		Law Concerning the Recovery and Destruction of Fluorocarbons (Japan, 2001)
Regional Environment	Air Pollution	Clean Air Act (U.S., 1990)
		Directive 2001/81/EC of the European Parliament and of the Council on the national emission ceilings for certain atmospheric pollutants (EC, 2001)
		Air Pollution Control Law (Japan, 1968)
	Water Pollution	Clean Water Act (U.S., 1948)
		Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy (EC, 2000)
		Water Pollution Control Law (Japan,1968)
	Noise, Vibration	Directive 2002/49/EC EC of the European Parliament and of the Council on the assessment and management of Environmental noise (EU, 2000)
		Noise Regulation Law, Vibration Regulation Law (Japan, 1968)
	Soil Contamination	Comprehensive Environmental Response, Compensation and Liability Act (U.S., 1980)
		Soil Contamination Countermeasures Law (Japan, 2002)
	Offensive Odor	Offensive Odor Control Law (Japan, 1971)
	Toxic Substance	Toxic Substances Control Act (U.S., 1976)
		Directive 76/769/EEC on approximation of the Member States' laws, regulations, and administrative provisions concerning limits on marketing and use of certain dangerous substances and preparations (EC, 1976)
		Law Concerning the Examination and Regulation of Manufacture, etc of Chemical Substances (Japan, 1973)
	Final Disposal	Resource Conservation and Recovery Act (U.S., 1976)
		Council Directive 75/442/EEC on waste (EC, 1975)
		Council Directive 91/689/EEC on hazardous waste (EC, 1991)
		Basic Law for Establishing the Recycling-Based Society (Japan, 1970)
		Waste Disposal and Public Cleansing Law (Japan, 1970)
		Law for the Promotion of Effective Utilities of Resources (Japan, 1991)
Local Environment	Fauna and Flora	Endangered Species Protection Act (U.S., 1973)
		Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (EC, 1992)
		Nature Conservation Law (Japan, 1972)
	Others	Forest Management Act (U.S., 1973)
		Urban Green Space Conservation Law (Japan, 1973)

Table A-3 gives the specifications that would be recognized as effective technical information or performance requirements in an environment-conscious design and construction for concrete structures.

Table A-3: Examples of specifications

Environmental Impacts	Examples (Japan)
Global Warming	Promotion System for Global Warming Control Measures 2005 (Tokyo Metropolitan Ordinance on Environmental Preservation of 1969) **Level AA: Carbon Dioxide Reduction Ratio 5.0% or more** **Level A+: Carbon Dioxide Reduction Ratio 2.0% or more** **Level A : All Measures* of Targeted Basic Plan on Carbon Dioxide Reduction are implemented.** **Level B : Not all Measures* of Targeted Basic Plan on Carbon Dioxide Reduction are implemented.** **All Measures of Energy Consumption Plan are implemented.** **Level C : Not all Measures of Energy Consumption Plan are implemented.** *** The measures are legislated by Tokyo metropolitan government.**
Air Pollution	Effluent Standard for Particulate Matters (PM) on Trucks (Law Concerning Special Measures for Total Emission Reduction of Nitrogen Oxides and Particulate Matters, Japan, 2001) **Not more than 0.49g/kWh (The case of over 3.5ton weight)**
	Effluent Standard for NOx on Trucks (Law Concerning Special Measures for Total Emission Reduction of Nitrogen Oxides and Particulate Matters, Japan, 2001) **Not more than 5.9g/kWh (The case of over 3.5ton weight)**
Water Pollution	Effluent Standard for Chromate(VI) (Water Pollution Control Law, Uniform National Effluent Standards, Japan, 2004) **Not more than 0.5mg/L**
	Effluent Standard for pH (The case of sea) (Water Pollution Control Law, Uniform National Effluent Standards, Japan, 2004) **Not less than 5.0 and not more than 9.0**
Noise, Vibration	Noise Criteria (The case of IV type in an industrial area) (Noise Regulation Law, Japan, 1968) **Not more than 70dB (A) in the daytime**
Soil Contamination	Effluent Standard for Chromate(VI) (Notice No.16 on the Emission Soil Contamination, Ministry of the Environment, Japan, 2001) **Not more than 0.05mg/L**
Final Disposal	Limited value for a major supplier of waste (Enforcement Order of Ministry of the Environment, Japan, 2001) **Normal industrial waste 1000ton or more / year** **Special industrial waste 50 ton ore more / year**

Appendix B: Environmental aspects and indicators

B.1 Introduction

As mentioned in chapter 6 of this report, the influences of each stage and the totality of the stages of construction activities on the environment should be considered. Therefore, Appendix B describes the relations between the general environmental aspects, which are generally categorized for environmental evaluation in other industries, and the construction stages.

The environmental issues in concrete should be evaluated or verified by using more scientific, quantitative, qualitative or descriptive parameters, for example, the amount of CO_2, concentration of Cr(VI) in soil or cement, and so on, so that the environmental impact indicators (EII) can be determined as quantitative, qualitative or descriptive measures for checking the influence of some human activities on the environment. Such important indicators are also described in this appendix.

B.2 Global environment

The global environment is an environment that may be affected by global warming, ozone depletion, changes in ecosystems and other factors on a global scale, and the main environmental aspects to be considered include the emission of greenhouse gases and resource consumption. When the production of constituent materials of a concrete structure and the construction, service, maintenance/management, demolition, disposal and reuse after demolition of a concrete structure, are regarded as affecting the environment due to the emission of greenhouse gases and air contaminants, the consumption of resources and energy, the discharges of waste, and others, the corresponding items shall be taken into account.

B.2.1 Greenhouse gases, air contaminants

If greenhouse gases or their precursors that may potentially absorb and reradiate infra-red rays are released into the atmosphere, the climate may change and have extremely harmful effects on ecosystems, socio-economic functions and the health and welfare of humans. To control this, the United Nations Framework Convention on Climate Change was held in 1992. Subsequently, the 3rd session of the Conference of the Parties to the United Nations Framework Convention on Climate Change was held in Kyoto and the Kyoto Protocol (United Nations Framework Convention on Climate Change), aimed at the reduction of greenhouse gases, was adopted in 1997 and came into effect in February 2005.

The goal of the Kyoto Protocol is to reduce the emission of greenhouse gases (GHG) and their precursors by at least 5% of the total produced in advanced countries and countries undergoing the transition to a market economy from 1990 levels between 2008 and 2012. The Protocol also established the rate of reduction for each country. For example, Japan is obliged to cut its emission by 6%. The Kyoto Protocol identifies the target gases or aerosols of carbon dioxide (CO_2), chlorofluorocarbons (CFCs) and similar substances, methane (CH_4) and dinitrogen monoxide (N_2O) as substances that cause the greenhouse effect. Of these, CO_2 is a chemical substance that is emitted as a result of a variety of economic activities, and is regarded as the most serious greenhouse gas in evaluations of environmental impacts.

In relation to concrete, CO_2 is emitted during the de-carbonation of limestone and consumption of fossil fuels in cement production and consumption of fossil fuels in concrete work. The average basic unit for CO_2 emissions in the world's cement production is approximately 0.87kg-CO_2/kg-cement, 20 to 30% of which can be absorbed by carbonation of crushed concrete in demolition. Although CFCs may be used for polyurethane foam and insulation materials used during construction of concrete structures, CH_4 and N_2O are rarely used in concrete-related activities. Other harmful chemicals that cause air pollution are nitrogen oxides (NOx) and sulfur oxides (SOx), which are generated during the consumption of fossil fuels. Methods for evaluating the environmental impacts of these substances have already been proposed, and quantitative evaluations are possible for each stage of concrete-related activities.

The EIIs of Greenhouse gas (GHG) emissions depend mainly on the amount of CO_2, methane, and nitrous oxide involved. It is possible to compute the total GHG emission amount expressed as a CO_2 equivalent which is calculated by multiplying the mass of each GHG emission by its global warming potential (GWP). GWPs are based on the radiative forcing (heat absorbing ability) of each GHG as well as the decay rate of each gas relative to carbon dioxide over a 100 year time horizon. For example for CO_2 the GWP = 1, for methane GWP = 23 and for nitrous oxide GWP = 296 (see [Keoleian *et al.* (2005)]).

Particulate emissions mostly emanate from the cement production industry and from aggregate production. Particulate emissions from exhaust gas range from 0.3 to 1.0 kg/tonne and much of this kiln dust is collected in fabric filter houses and then reintroduced into the kiln feed. In the past, before there was a concerted effort to capture particulate emissions, the sodium and potassium plumes from cement plant chimneys settled over the countryside where they helped to combat acid rain. Now they are mainly carried out in clinker streams where they create problems with alkali aggregate reactions.

B.2.2 Resource/energy consumption

Resource consumption in construction is significantly greater compared with other fields, and it is necessary to make efforts to minimize the consumption of resources during the construction of concrete structure. Since fossil fuels are also consumed in heavy machinery and other equipment during the construction of concrete structures, it is desirable to use machinery and equipment that are highly energy efficient. Since the consumption of resources and energy is an important factor when handling environmental impacts in an integrated manner, it is desirable to calculate the resource and energy consumption in each stage of activities related to concrete structures.

Consumption of raw material resources is one group of EIIs. It is possible to define for concrete (or a concrete structure) the main raw materials which are used during its production: coal, limestone, natural gas, oil, sand, water.

B.3 Regional environment

A regional environment is an environment that may be affected by air, soil or water pollution in the surrounding area of activities related to a concrete structure, and the main environmental aspects to be considered are the discharges of air, soil and water contaminants.

B.3.1 Water/soil contaminants

When the construction, service, maintenance/management, demolition, disposal and reuse after demolition of a concrete structure are regarded to affect water and soil, the corresponding items shall be taken into account. Chemical substances, for which quantitative evaluations are considered difficult at this point although there is concern about their environmental impact, may be used in addition to chemicals that can be quantitatively evaluated, in each stage of concrete-related activities.

Since environmental impacts caused by hexavalent chromium, strong alkali and other minor components may be given by a concrete structure in its surrounding environment, their impact must be considered if necessary. The impact of strong alkali and heavy metals that are characteristic of concrete-related work must also be taken into consideration because touching fresh concrete with bare hands may cause skin problems. Since hexavalent chromium (Cr(VI)) and other heavy metals are present in minute amounts in natural clay minerals that are used as materials in cement production, they can also be found in manufactured cement. It has been known that these minor heavy metals elute into water used for mixing concrete and washing tools and mixers when concrete is being produced. Elution from hardened concrete in use has also been identified although in extremely small amounts. However, there are many unknown points concerning the amount of elution, its extent and term of its impact.

It is also necessary to consider endocrine-disrupting chemicals (environmental hormones) based on future movements since their impact has not been fully clarified. Nonyl phenol and other surface active agents, which have been used in small amounts in some cases, are designated as endocrine-disrupting chemicals (environmental hormones) and their use will be discontinued.

Emissions into water at each life-cycle stage of concrete (concrete structure) comprise biological oxygen demand, ammonia, phosphate emissions, oils, suspended matter, and dissolved matter.

B.3.2 Construction byproducts

Construction byproducts can be roughly divided into surplus soil removed from construction sites and construction waste. Disposal of construction waste is stipulated by the Wastes Disposal and Public Cleaning Law (in Japan, for instance). Construction-related waste includes wood, metal and concrete debris generated in concrete work. These byproducts are classified as industrial waste. It is therefore necessary to consider an appropriate disposal in accordance with the Waste Disposal and Public Cleaning Law when disposing of them as waste. Recycling of construction byproducts that can be reused as materials without being processed or those with potential for reuse is encouraged under the Law for Promotion of Utilization of Recyclable Resources (Recycling Law, this is also the situation in Japan, for instance).

The above-mentioned wood and concrete debris generated in concrete work are recyclable materials subject to the Recycling Law. The Recycling Law also requires preparation of plans for utilizing recycled resources, promotion of such usage, and reports on the implementation of the plans to be kept for one year after the completion of construction above a certain scale. These requirements are intended to control the amount of construction byproducts that are generated and promote their systematic and efficient reuse.

Life-cycle solid waste generation is mostly associated with the demolition stage of concrete or a concrete structure.

B.4 Construction site environment

When the construction, service, maintenance/management, demolition, disposal and reuse after demolition of a concrete structure are regarded as affecting the environment due to noise and vibration, the corresponding items shall be taken into account. If there are potential environmental impacts resulting from the noise and vibration from each stage of activities related to concrete structures, appropriate measures to deal with them must be taken.

Environmental impact resulting from noise and vibration mainly occurs in a relatively limited area, including the site of activity related to a concrete structure and its immediate surroundings. Noise can cause hearing loss, disturbances or discomfort, and lack of sleep. Vibration can cause discomfort and damage to buildings. It is therefore necessary to manage the construction site and use low-noise and low-vibration vehicles and heavy machinery in accordance with the Noise Regulation Law and the Vibration Regulation Law, from the viewpoint of regional and working environments.

Noise pollution is not normally a public concern as cement and/or concrete component plants are usually placed at a distance from habitation. At the construction site the use of superplasticizers to produce high slump concrete that requires a minimum of vibration has greatly reduced the problem of on-site noise. Traffic congestion due to the delivery of cement and concrete components, concrete members and/or ready-mixed concrete is currently being mitigated by using large energy-efficient delivery vehicles.

If there is any potential environmental impact other than those mentioned above, such as radioactivity and electric/magnetic fields, in addition, in each stage of activities concerning a concrete structure and construction work, appropriate measures must be taken for the environmental assessment. Although there are also concerns regarding sick-house syndrome caused by formaldehyde and house dust, asbestos, CFCs in insulating materials and other factors related to the indoor environment for users of a concrete structure, there are few cases where the impact of these problems should be a concern in concrete structures for the field of civil engineering.

It is also necessary to consider the problems associated with the use of wooden formwork, which causes deforestation, offensive smells, particles of soot, the obstruction of sunlight, landscape disturbances and topographic changes as environmental aspects whenever necessary.

Currently the health of employees is being adversely affected by the increased chromium content of cement. This increased chromium content is mostly derived from the burning of waste products. The only solution seems to be to prevent fresh concrete from coming into contact with the skin, and most containers of cement carry such a warning.

B.5 Others

Visual pollution resulting from quarries being used to gain raw material for cement production or for obtaining sand and gravel can be reduced by sculpturing the sites so that they follow the natural topography, and when abandoned they can be planted with vegetation that can make them blend in with their natural surroundings. Unfortunately most quarries have a very long life and any attempt to sculpture the topography for a visual effect is counter-productive to the efficiency of the quarrying process. The most effective end use might be for educational or recreational purposes with special attention being paid to public safety.

Radon (^{222}Rn) gas might be emitted from the aggregate in concrete.

Appendix C: Tools for environmental impact evaluation

C.1 General

A wide range of tools for environmental impact evaluation have been developed in the last 15 years [*fib* (2004)]. Most of them are using methods based on basic principles of the LCA methodology according to the ISO 14040 series of standards [ISO 14040 (1997), ISO 14041 (1998), ISO 14042 (2000), ISO 14043 (2000)]. The main differences among evaluation methods are in the specification of goal and scope of the evaluation process and in the definition and recognition level of the corresponding solution system model. Some models focus on environmental evaluation of the construction based upon the materials and structural elements used (e.g. BEES, ENVEST, EcoQuantum); some methods on evaluation of different industrial processes (e.g. GEMIS, SimaPro); and some on more general sustainability aspects of structural components and buildings. The latter group of tools is represented by rating tools like SBTool (former GBTool), BREEAM, LEED, CASBEE and others. These rating tools are not directly based upon the LCA methodology, but may use LCA data when evaluating construction materials with regard to environmental impacts.

C.2 Environmental labels and declarations for construction products

An environmental label or declaration is a type of claim which indicates what environmental aspects and corresponding measures are associated with a product or service. The ISO 14020 series of standards "Environmental Labels and Declarations" [ISO 14020 (2000), ISO 14021 (1999), ISO 14024 (1999), ISO/TR 14025 (1999)] establishes the general principles for environmental labels and declarations. There are three types of environmental declarations:

Type I: Environmental labels (according to ISO 14021) are based on criteria which are established by third parties. In principle, the criteria relate to the various environmental aspects and impacts, and take account of the entire life cycle of the product.

Type II: Environmental claims (according to ISO 14024) which are made by the manufacturer or distributor.

Type III: Environmental declarations (according to ISO/TR 14025). EPD – an Environmental Product Declaration [EPD] covers quantified environmental data for a product with pre-set categories of parameters based on the ISO 14040 series of standards. The EPD system has the potential to become a global communication tool to make possible the provision of objective, comparable and credible information about the environmental performance of products and services. It has already grown into a worldwide applicable system.

C.3 Eco-indicator method

An eco-indicator method can be used for complex environmental impact evaluation. The method represents a complex method for evaluation of environmental effects damaging the ecosystem and human health. The eco-indicator of a material or process represents a single score expressing a normalized and weighted environmental load. The environmental load is usually determined using the life cycle analysis data. The determination of the eco-indicator score is made in three steps:

1. Inventory of all relevant flows (emissions, resource extractions and land-use) in all processes within the life cycle of a product.

2. Determination of damage caused by flows to three damage categories (human health, ecosystem and resources).
3. Weighting of normalized scores of three damage categories.

The basic concept of the eco-indicator method implemented in Eco-indicator 99 methodology [Goedkoop and Spriensma (2000)] is shown in Fig. C-1.

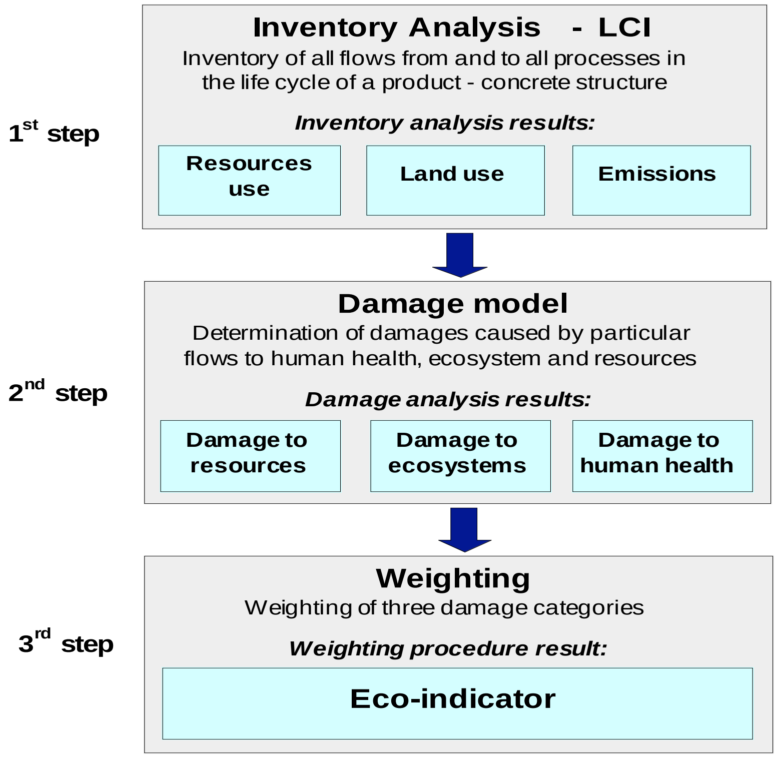


Fig. C-1: The three-stage core concept of the Eco-indicator methodology

The system contains eco-indicators for important materials and processes. The values of eco-indicators are available for materials, processing aspects, transport processes, energy generation processes and waste disposal scenarios. These values are based mainly on European data sets. Weighting of environmental effects is based on the damage function approach. The damage function presents the relation between the impact and the damage to human health, the ecosystem and resources.

C.4 Complex LCA of products and processes using SimaPro and EcoQuantum tools

SimaPro Life Cycle Assessment software [PRé Consultants (2001)] represents a complex tool for collection, analysis and monitoring of environmental information about products and services. It enables modeling and analysis of complex life cycles in a transparent way according to the ISO 14040 principles. The software includes a database with inventory data for the most commonly used materials and processes. The software version SimaPro 5 contains several impact assessment methods: Eco-indicator method, CML 1992&2000, EPS 2000, EDIP and Ecopoints. Based on the specific aspects of the LCA study it is possible to choose the most appropriate type of impact assessment method using a theme or damage approach.

EcoQuantum represents a software tool developed specifically for the building industry based upon the SimaPro system.

C.5 Environmental/economic performance balance – BEES model

The method is based on the Life Cycle Assessment and Life Cycle Cost approaches applied to a comparison process of generic building product alternatives. The method uses selected inventory flows and consequent environmental impacts for evaluation of corresponding environmental performance within a particular Life Cycle stage. The method uses a weighting approach to combine environmental and economic performance measures into a single performance score. Also the importance of different environmental impacts is expressed using pre-defined or user-defined weights. The resulting environmental scores represent relative environmental impacts (damage), among competing alternatives.

There are 12 basic environmental impact categories and 2 economic categories included in the BEES 3.0 model (BEES = Building for Environmental and Economic Sustainability) [Lippiatt (2002)] - see Table C-1.

Table C-1: Overview of impact categories included in BEES 3.0 model

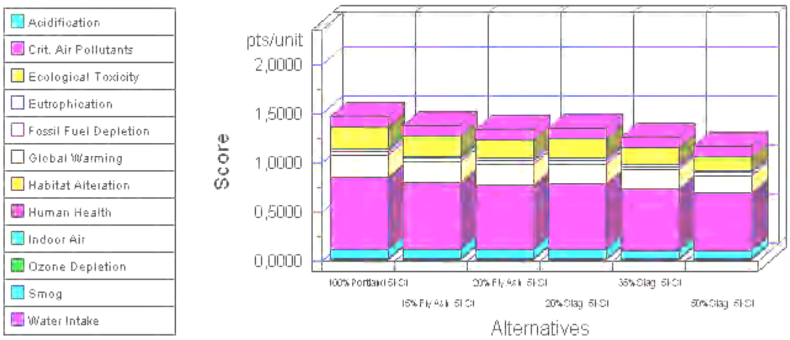
Performance	*Impact category*
Environmental Performance	Global Warming
	Acidificaton
	Eutrophication
	Fossil Fuel Depletion
	Indoor Air Quality
	Habitat Alteration
	Water Intake
	Criteria Air Pollutants
	Human Health
	Smog
	Ozone Depletion
	Ecological Toxicity
Economic Performance	First Cost
	Future Costs

It is possible to use three sets of pre-defined weights for the weighting of environmental impacts. The model enables also the use of user-defined weights. Weighting of environmental versus economic performance can be set by percentage of importance. The example of output from the program BEES 3.0 is shown in Fig. C-2.

C.6 Global Emission Model for Integrated Systems – GEMIS

GEMIS [Öko-Institut (2001)] is a life-cycle analysis program and database for energy, material, and transport systems. It was developed as a tool for the comparative assessment of environmental effects such as production of harmful emissions, waste, and cost analysis based on LCA methodology. The system contains an extensive database of environmental data. This database covers for each process:

- efficiency, power, capacity factor, lifetime
- direct air pollutants (SO_2, NO_x, halogens, CO, NMVOC, particulates)



Note: Lower values are better

Category	100OPC5KSI	15Ash5KSI	20Ash5KSI	20Slag5KSI	35Slag5KSI	50Slag5KSI
Acidification--5%	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001
Crit. Air Pollutants--6%	0,1054	0,1040	0,1035	0,1036	0,1022	0,1008
Ecolog. Toxicity--11%	0,2285	0,2021	0,1933	0,1937	0,1676	0,1415
Eutrophication--5%	0,0236	0,0227	0,0223	0,0224	0,0215	0,0207
Fossil Fuel Depl.--5%	0,0386	0,0376	0,0373	0,0378	0,0371	0,0365
Global Warming--16%	0,2294	0,2122	0,2064	0,2075	0,1910	0,1746
Habitat Alteration--16%	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Human Health--11%	0,7308	0,6851	0,6698	0,6729	0,6295	0,5862
Indoor Air--11%	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Ozone Depletion--5%	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001
Smog--6%	0,0984	0,0942	0,0927	0,0931	0,0890	0,0850
Water Intake--3%	0,0133	0,0132	0,0132	0,0132	0,0132	0,0132
Sum	1,4682	1,3713	1,3387	1,3444	1,2513	1,1587

Fig. C-2: Comparison of environmental performance (by impact) of 6 alternatives of RC columns from different type of concrete (results from BEES 3.0 tool)

- greenhouse-gas emissions (CO_2, CH_4, N_2O, SF_6, etc.)
- solid waste (ashes, overburden, FGD residues, process waste)
- liquid pollutants (AOX, BOD_5, COD, N, P, inorganic salts)
- land use.

It is possible using GEMIS to evaluate the environmental impact of energy, transport and other material processes. The evaluation of impacts using GEMIS covers the total life-cycle including fuel delivery, use of construction materials, waste treatment, transport etc. GEMIS allows evaluation of results using aggregated indicators like: greenhouse gases into CO_2 equivalents, air pollutants into SO_2 equivalents, resources into CER and CMR as well as external costs.

GEMIS was developed in 1987-1989 and since then the model has been continuously upgraded and updated (GEMIS 4.4 version - 2006). It is freely available software, currently widely used in OECD countries as well as in many other countries.

C.7 Tools for life cycle assessment of buildings

The environmental performance of building is defined by the combination of effects like: energy consumption (including operation as well as embodied energy), use of materials in construction elements, water consumption, air pollution, waste generation, effects on building location etc. These impacts are considered during the whole life time of a building – in all life phases from material acquisition, through the construction, operation and maintenance phases up to the demolition and recycling phase.

Several tools for Life Cycle Assessment of buildings with different scope levels have been developed and are used for the evaluation of building environmental impact in different countries [Desmyter and Martin (2001)]. Examples of such packages include Eco-Quantum [IVAM] and GreenCalc [Sureac Trust] from the Netherlands, Envest [BRE a] from the UK, OGIP [T.h.e. Software] from Germany, and Athena [Athena Institute] from Canada.

C.8 Rating systems for sustainability assessment of buildings

Sustainability includes environmental, economic and social aspects. Thus building rating systems have to integrate many issues from all three sustainability aspect groups. Some tools are using results obtained from different environmental (LCA) and technical assessment methods (e.g. GBTool and SBTool). Some rating systems are not based upon LCA (e.g. LEED).

Several methods for sustainability evaluation of buildings were developed since the late 1990s. Most of the available methods are based on regional conditions and data sets. In Table C-2 there is a brief overview of some widely used rating tools available. The GBTool (Green Building Tool) [Larsson], LEED [GBC], BREEAM [BRE b] and CASBEE [JSBC] tools have been widely used in the building practice. The GreenGlobes tool represents a new system based on the web-based on-line approach.

Table C-2: Selected widely used rating systems for sustainability assessment of buildings

Tool	Country	Comments
GBTool SBTool	International	Criteria-based comprehensive framework to assess new & retrofit buildings – offices, multi-unit residences and schools
BREEAM	United Kingdom	Criteria-based rating assessment method for housing (EcoHomes), offices, schools and industrial buildings
LEED	U.S.A., Canada	Criteria-based rating assessment method for new and existing buildings
GreenGlobes	U.S.A., Canada	Web-based on-line tool covering guide for integrating green design principles and an assessment protocol
CASBEE	Japan, China	Criteria-based assessment system of building environmental efficiency

SBTool (Sustainable Building Tool) represents a new version of the GBTool software designed to assess the sustainability performance of buildings. SBTool is the software implementation of the Green Building Challenge (GBC) assessment method that has been developed by many international teams under the leadership of Natural Resources Canada and since 2002 of International Initiative for a Sustainable Built Environment (iiSBE). SBTool represents a very comprehensive framework implemented and tested in many different countries all over the world. SBTool can be customized to suit the specific assessment needs, taking into account regional differences, contextual settings, different technologies, building traditions and cultural values that exist in various regions and countries.

SBTool is suitable for approximate complex assessments of a wide range of environmental performance parameters, all related to performance benchmarks that are relevant to the specific region/country and building occupancy. The evaluation is performed by scores, which are normalized and weighted. The scores are assigned in a range of -1 to +5 (-1: performance below the acceptable level, 0: minimum acceptable performance, 3: good practice, 5: best practice).

There are four levels of parameters included in the GBTool: *Issues, Categories, Criteria* and *Sub-Criteria*. The weighting of Issues and Category parameters is made by experts in the Vote worksheet and the weighting of Criteria and Sub-Criteria parameters is made automatically by a system in the Weight worksheet. Scores are multiplied by the weights and the weighted scores are shown in the Results worksheet.

The main issue areas are:
A – Site Selection, Project Planning and Development
B – Energy and Resource Consumption
C – Environmental Loadings
D – Indoor Environmental Quality
E – Service Quality
F – Social and Economic Aspects
G – Cultural and Perceptual Aspects

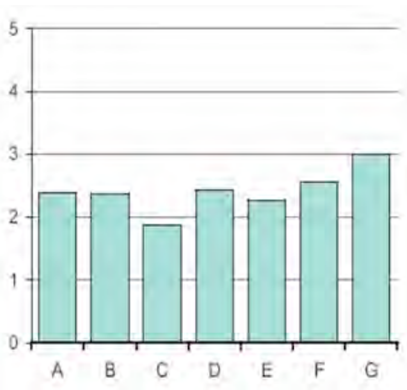
The results of SBToll assessment obtained using scores and defined weights are presented in two forms: Relative Performance Results showing weighted scores (-1 to +5) relative to the benchmarks and Absolute Performance Results (Fig. C-3).

Assessor performance results for Green Park, Dorval, Canada

Predicted performance results based on information available during Design Phase	*Active Phase (set in Region file)*	Design Phase

Relative Performance Results

0 = Acceptable Practice; 3 = Good Practice; 5 = Best Practice



Performance Issue Areas

Design Phase scores indicate Potential Performance as predicted by an assessment of building features and plans for construction and operation that are developed during the design process.

Project Information

This is a New construction project with a total gross area of 42000 m2. It has an estimated lifespan of 50 years, and contains the following occupancies: Office and Apartment and is located in Dorval, Canada. The assessment is valid for the Design Phase.

Assumed life span is 50 years, and monetary units are in CD	Amortization rate for embodied energy of existing materials is set at 2 %

	Assessor Score		
With current context and building data, the number of active low-level parameters is:	146	Max. potential low-level parameters:	149
The number of active low-level mandatory parameters with a score of less than 2 is:	1	Active low-level mandatory parameters:	9

	To see a full list of issues, Categories and Criteria, go to the issues worksheet.	Active Weights	Weighted scores
A	Site Selection, Project Planning and Development	8%	2.4
B	Energy and Resource Consumption	22%	2.4
C	Environmental Loadings	26%	1.9
D	Indoor Environmental Quality	22%	2.4
E	Service Quality	16%	2.3
F	Social and Economic aspects	5%	2.5
G	Cultural and Perceptual aspects	3%	3.0
	Total weighted building score		2.3

Absolute Performance Results

		By area	By area & occupancy	
1	Total net consumption of primary embodied energy for structure and envelope, GJ/m2	12.09	1.85	GJ/m²*maph
2	Net annualized consumption of embodied energy for envelope and structure, MJ/m2*yr.	241.70	37.03	MJ/m²*maph
3	Net annual consumption of delivered energy for building operations, MJ/m2*year	191.89	29.39	MJ/m²*maph
4	Net annual consumption of primary non-renewable energy for building operations, MJ/m2*yr.	241.90	37.06	MJ/m²*maph
5	Net annualized primary embodied energy and annual operating primary energy, MJ/m2*yr.	483.61	74.08	MJ/m²*maph
6	Total on-site renewable energy used for operations, MJ/m2*yr.	20.47	3.14	MJ/m²*maph
7	Net annual consumption of potable water for building operations, m3/year	274.50	42.05	m³/m²*maph
8	Annual use of grey water and rainwater for building operations, m3/year	2865.00	438.88	m³/m²*maph
9	Net annual GHG emissions from building operations, kg. CO2 equivalent per year	10.95	1.68	kg/m²*maph
10	Total present value of 25-year life-cycle cost for total project, CD per m2	8,010		
11	Proportion of gross area of existing structure(s) re-used in the new project, percent	0%		
12	Proportion of gross area of project provided by re-use of existing structure(s), percent	0%		

Fig. C-3: SBTool results worksheet

Appendix D: Environmental risk management

This appendix introduces the concept of environmental risk and outlines a method for management of controlling environmental risks in construction activities of concrete structures from the viewpoint of economy.

The environmental risk can be expressed as damage expectation which is a product of the probability, *P* of environmental impact and the loss, *L* due to it. The probability demonstrates the ease of generating and the frequency of environmental impact. The loss includes expenses for restoration of the environment and compensation for residents after the damage and also incorporates expenses for the prevention of damage due to the environmental impact.

The environmental risk should be evaluated throughout the life cycle of concrete which ranges from raw material extraction to waste disposal after the demolition of the structure and be controlled by means of appropriate measures to reduce the risk. The evaluation and control of environmental risk can be, for example, conducted in the following procedures as shown in Fig. D-1, by means of event-tree analysis based on probabilistic risk assessment, an example of which is demonstrated in Fig. D-2.

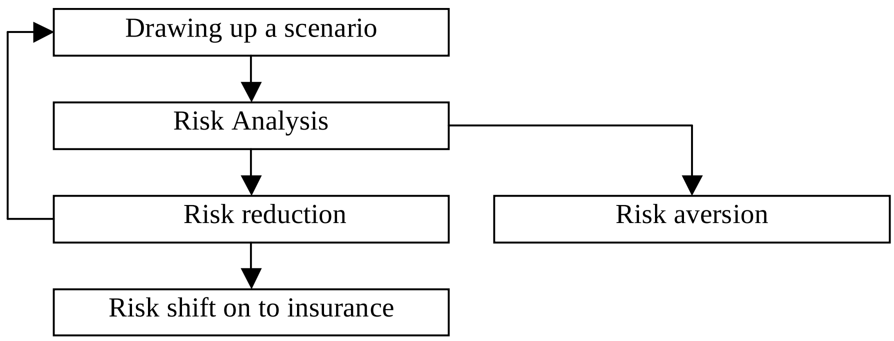


Fig. D-1: Flow of risk management

A scenario of production of concrete and construction of concrete structure	Dust damage	Ground-water pollution	Soil pollution	Noise damage	**Probability**	**Loss**	**Risk**
	Yes 0.2	Yes 0.15	Yes 0.1	Yes 0.3	0.0009	200	0.180
				No 0.7	0.0021	190	0.399
			No 0.9	Yes 0.3	0.0081	80	0.648
				No 0.7	0.0189	70	1.323
		No 0.85	Yes 0.1	Yes 0.3	0.0051	150	0.765
				No 0.7	0.0119	140	1.666
			No 0.9	Yes 0.3	0.0459	30	1.377
				No 0.7	0.1071	20	2.142
	No 0.8	Yes 0.15	Yes 0.1	Yes 0.3	0.0036	180	0.648
				No 0.7	0.0084	170	1.428
			No 0.9	Yes 0.3	0.0324	60	1.944
				No 0.7	0.0756	50	3.780
		No 0.85	Yes 0.1	Yes 0.3	0.0204	130	2.652
				No 0.7	0.0476	120	5.712
			No 0.9	Yes 0.3	0.1836	10	1.836
				No 0.7	0.4284	0	0

Fig. D-2: Event-tree analysis

1) A scenario composed of various events, an example of which is shown in Table D-1, is assumed for the life cycle of a concrete structure from extraction of resources to final disposal of wastes.

Table D-1: Assumed scenario

- A concrete building which has a basement floor is constructed in a conventional manner in low-lying downtown area along a river.
- Constituent materials are transported into the site (Event 1) and site-mixed concrete is produced.
- Washing water is drained to the river after separated from sludge and neutralized (Event 2).
- The sludge is used for backfilling materials on site after it is dehydrated, condensed and consolidated (Event 3).
- Fresh concrete is pumped and consolidated with vibrator (Event 4).

2) All the damage anticipated to human beings, nature and ecological system, which are caused by the environmental impacts due to the events in the scenario through the production of concrete and the construction of concrete structures, are listed, an example of which is shown in Table D-2.

Table D-2: Anticipated damage

Event	Assumed damage due to environmental impact	Probability	Loss
1	Dust damage during aggregate discharge	0.20	20
2	Groundwater pollution due to alkaline water emission	0.15	50
3	Soil pollution due to hexavalent chromium leaching	0.10	120
4	Noise damage during concrete consolidation	0.30	10

3) The probability, P_i, and loss, L_i, of the damage in event i under the conditions of the scenario are estimated through document survey, inquiry survey, etc.

4) The combinational probability, P_j, and combinational loss, L_j, of consequent damage caused by case j which is a combination of damage in each event are calculated as follows:

$$P_j = \prod_{i=1}^{m} P_{ij}\,, \quad L_j = \sum_{i=1}^{m} L_{ij}$$

P_{ij} and L_{ij} denote respectively the probability and the loss of the damage in event i in case j. m denotes the number of events.

5) The environmental risk, R_j, in case j is calculated by multiplying the probability, P_j, by the loss, L_j, as follows:

$$R_j = P_j \times L_j$$

6) The total risk, R_{total}, is calculated by summating all R_j as follows:

$$R_{total} = \sum_{j=1}^{n} R_j$$

7) If the total risk is within the allowable range, it is usually retained. If it is beyond the allowable range, preventive measures or aversion measures are taken.

8) If there is any damage which have extremely low probability but extremely heavy loss as shown in Fig. D-3, the risk is usually shifted on to insurance, which is the equitable transfer of the risk of a potential loss.

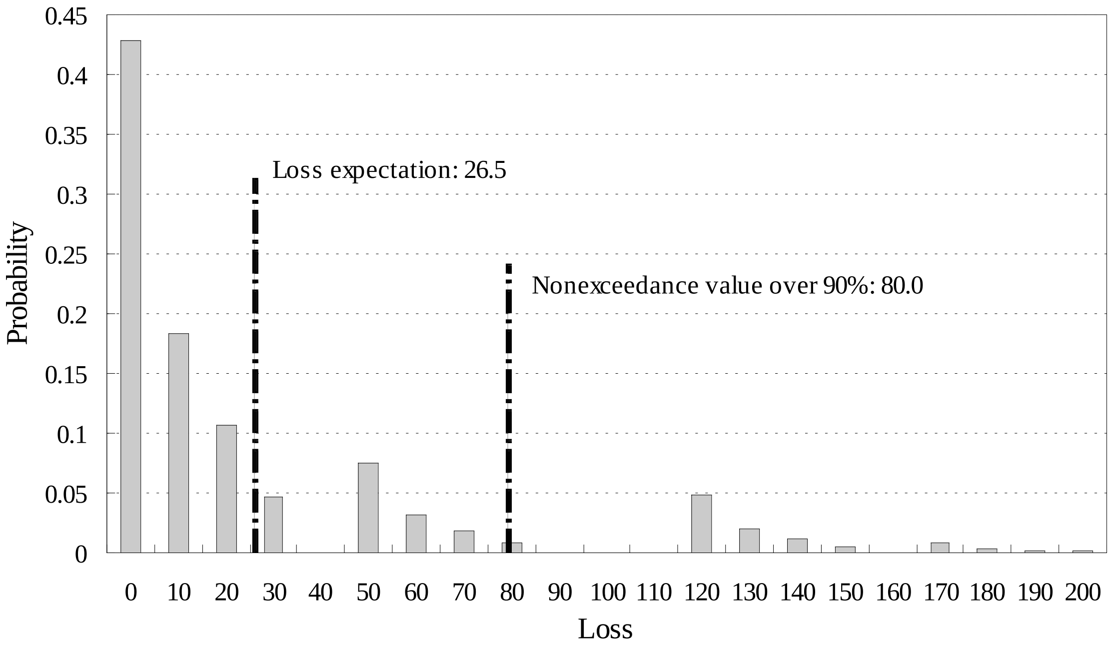


Fig. D-3: Probabilistic distribution of damage without any preventive measures

9) In the case of preventive measures, possible preventive measures to reduce the damage are listed.
10) The cost, C_i, for the preventive measure for the damage in event *i* is estimated and the probability, $P^p{}_i$, of the damage in event *i* reduced by the preventive measure is also estimated.
11) The risk with preventive measures in case *j*, $R^p{}_j$, reduced by applying the preventive measures is recalculated by replacing P_{ij} with $P^p{}_{ij}$ which denotes the probability of the damage in event *i* in case *j* with the preventive measure. If no preventive measure is taken for the damage, $P^p{}_{ij}$, remains unchanged at P_{ij}.
12) The total risk with the preventive measures, $R^p{}_{total}$, is calculated by adding C_i to the summation of $R^p{}_j$ as follows:

$$R_{ptotal} = \sum_{j=1}^{n} R^p{}_j + \sum_{i=1}^{m} C_i$$

Figure D-4 shows an example of the reduction of total risk by applying a preventive measure.
13) A set of preventive measures which minimizes the total environmental risk is adopted.

The effectiveness of preventive measures should be monitored throughout the life of concrete. If ineffectiveness of the preventive measures is observed, other measures should be taken after reevaluating the risk according to the same procedure.

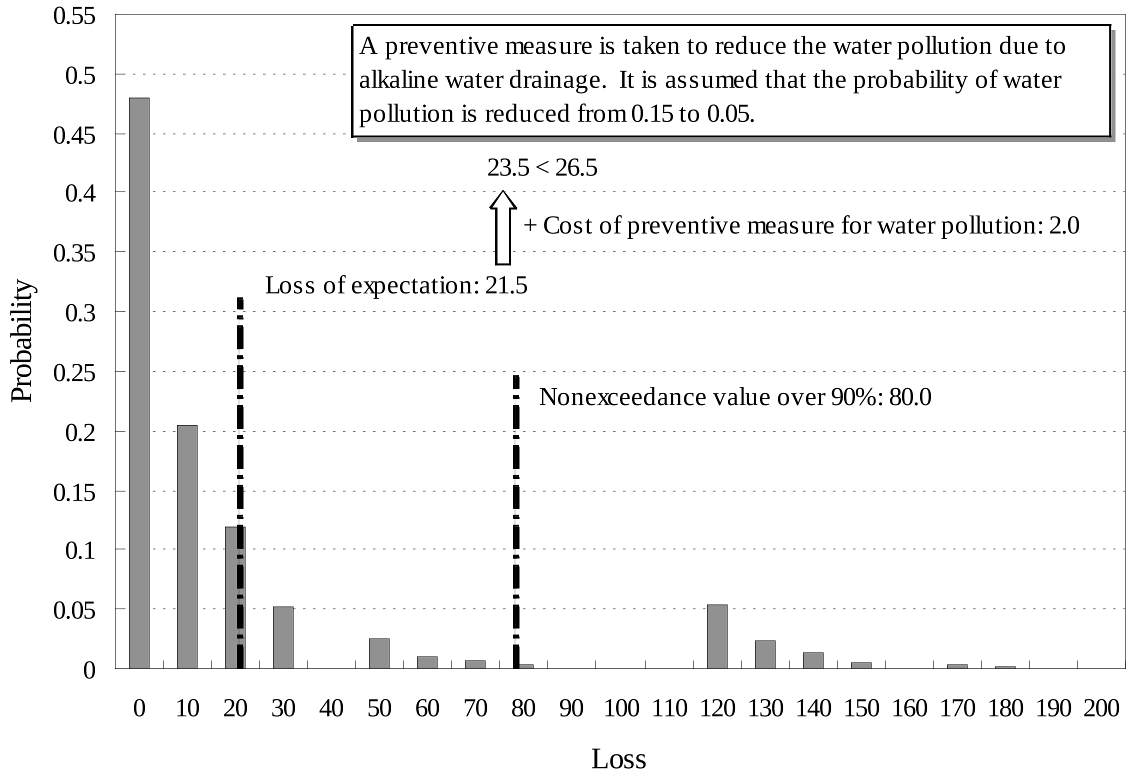


Fig. D-4: Probabilistic distribution of damage with a preventive measure

Appendix E: Examples of environmental design

This appendix provides two examples illustrating how to apply environmental design to concrete structures. These examples focus on CO_2 emission only at the construction stage in the life cycle of a structure.

E.1 **Reinforced concrete rigid frame viaduct** [Sakai (2005)]

E.1.1 General

Railway crossings cause traffic congestion and have large impacts on the regional environment and traffic safety problems. To solve these problems, it is necessary to introduce overhead crossings at railway facilities. Construction of railway overpasses in urban residential areas where crossings are used may involve a variety of restrictions in many cases. In such a situation, reinforced concrete rigid frame viaduct is considered in this case study. A rigid frame bridge usually has footing beams at the joints between piles and columns to absorb unevenness in the bearing capacity of piles and ensure seismic performance.

E.1.2 Environmental performance requirements

As the environmental performance requirements of a rigid frame viaduct, the followings are set:

20% reduction of CO_2 emission

Limiting noise, vibration, air contamination to certain values

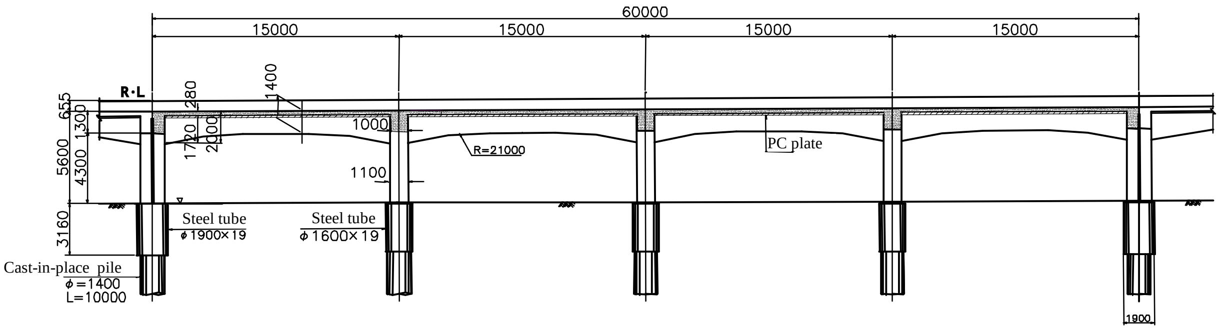
E.1.3 Solution

In order to satisfy the above environmental performance requirements, a structural type that ensures the required seismic performance by increasing the bearing capacity of piles and reinforcing the joints between piles and columns with steel tubes is introduced as shown in Fig. E-1.

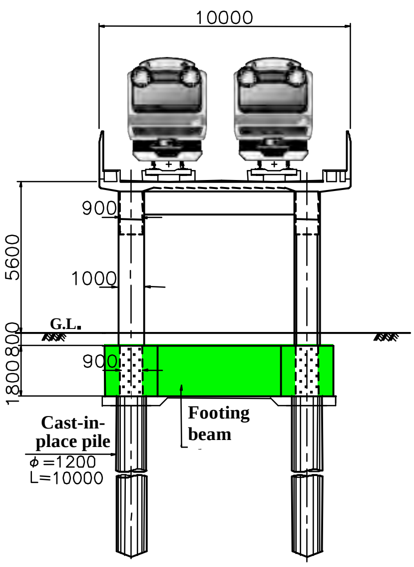
E.1.4 CO_2 emission of reinforced concrete rigid frame viaduct and verification

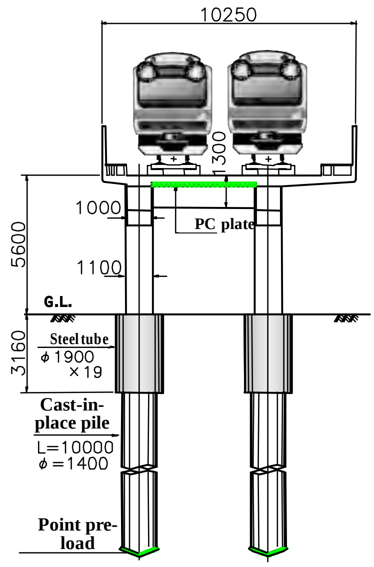
The CO_2 emission from materials, transport and construction was calculated for the structural types with and without footing beams. Figure E-2 shows the results. By adopting a structure without footing beams, CO_2 emission was reduced by approximately 28% in all, compared with the conventional reinforced concrete rigid frame viaduct. Fulfillment of the environmental requirement was verified: the environmental performance requirement regarding CO_2, S, was less than the retained performance, R. It can also be said that the selection of this structural type reduces impacts on the local environment such as traffic congestion, noise, vibration and air contamination that accompany the construction work.

For the calculation of CO_2 emission, the JSCE unit-based substance emission data base [JSCE (2006)] was used.



(a) General view (no footing beam)





(b) Sectional view (with footing beam) *(c) Sectional view (without footing beam)*

Fig. E-1: RC rigid frame viaduct

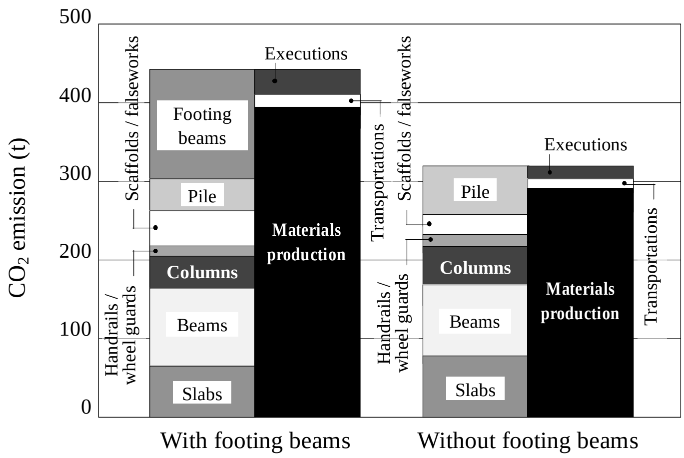


Fig. E-2: CO_2 emission of RC rigid frame viaduct

E.2 Ultra high-strength steel fiber-reinforced concrete (UFC) pedestrian bridge [Sakai (2005)]

E.2.1 General

There was a plan to renew a reinforced concrete pedestrian bridge across a river. Considering the span of the bridge of approximately 50m, a three-span prestressed concrete bridge was conventionally one option. However, according to the required performance regarding environmental impact reduction, a new technology needed to be introduced.

E.2.2 Environmental performance requirement

A 20 percent reduction of CO_2 emission in the construction of a pedestrian bridge was required as the environmental performance requirement, compared with a conventional structure.

E.2.3 Solution

Ultra high-strength steel fiber-reinforced concrete (UFC) can dramatically reduce the dead weight of a structure because of its excellent strength characteristics. The foundations can be thinner as a result and may also lead to a reduction in the construction costs. The maintenance cost can also be reduced because of the excellent durability of UFC. Table E-1 and Fig. E-3 show the mix proportions and the bending behavior of UFC. Steel fibers of 0.2 mm in diameter, 15 mm in length and 2800N/mm^2 in tensile strength were mixed. UFC was used to construct a 50.2-meter-long 2.4-meter-wide outer-cable prestressed bridge with an unreinforced box-type closed section with variable web height (upper slab thickness = 5 cm, web thickness = 8 cm). Figures E-4 and E-5 show the general view and cross section of this bridge, respectively. The dead weight of the bridge was 560 kN. Precast blocks consisting of three types of segment blocks were manufactured at a precast concrete product plant. They were cured twice. Sheet curing was first conducted in an open-air environment, followed by 48-hour steam curing at 90°C. If this bridge was to be designed as a three-span prestressed concrete simple slab bridge (hereinafter referred to simply as a “PC bridge”), which is thought to be the most rational for its conditions, its dead weight would be 2,780 kN, approximately 5 times that of the UFC bridge. Figure E-6 shows a general view of the hypothetical PC bridge.

E.2.4 CO_2 emission of UFC pedestrian bridge and verification

The CO_2 emission from the production of the materials, steel forms, and UFC beams or pre-tension hollow beams and the transport and construction were calculated for UFC and PC bridges. Figure E-7 shows the results. By utilizing UFC, CO_2 emission could be reduced by approximately 25% in all, compared with a conventional PC bridge. Fulfillment of the environmental requirement was verified, i.e. the environmental performance requirement regarding CO_2, S, was less than the retained performance, R.

For the calculation of CO_2 emission, the JSCE unit-based substance emission data base [JSCE (2006)] was used.

Table E-1: Mix proportions of RPC

Water	Cement	Grain (quartz, sand, etc.)	Steel fibers	Super-plasticizer
180	818	1479	157	24

Unit: kg/m^3, the water includes water content in superplasticizer, 19 kg/m^3

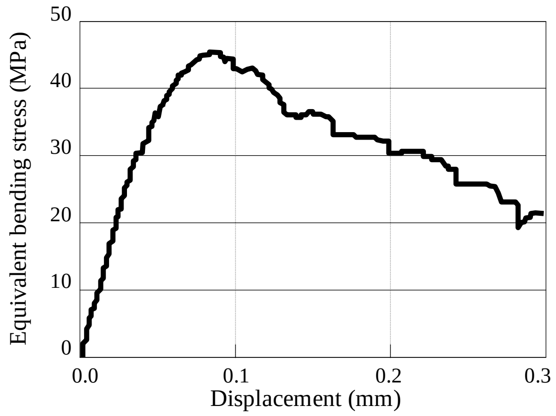


Fig. E-3: Flexural behavior of ultra high-strength steel-fiber reinforced concrete

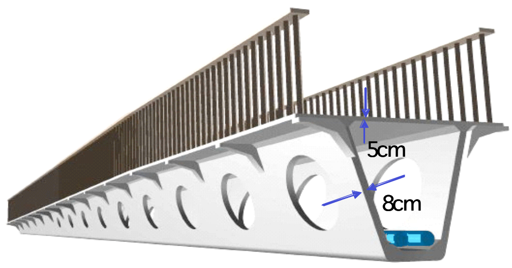


Fig. E-5: Sectional view of UFC bridge

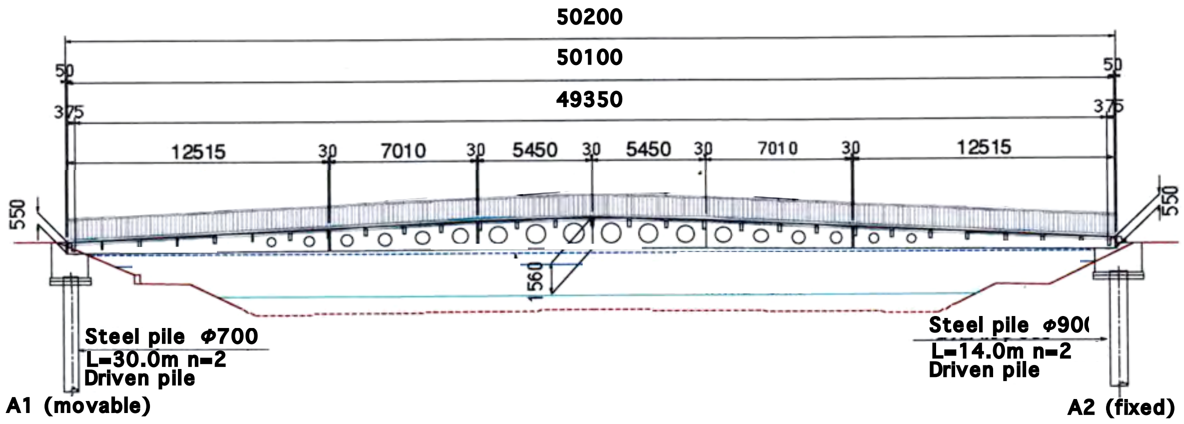


Fig. E-4: General view of UFC bridge

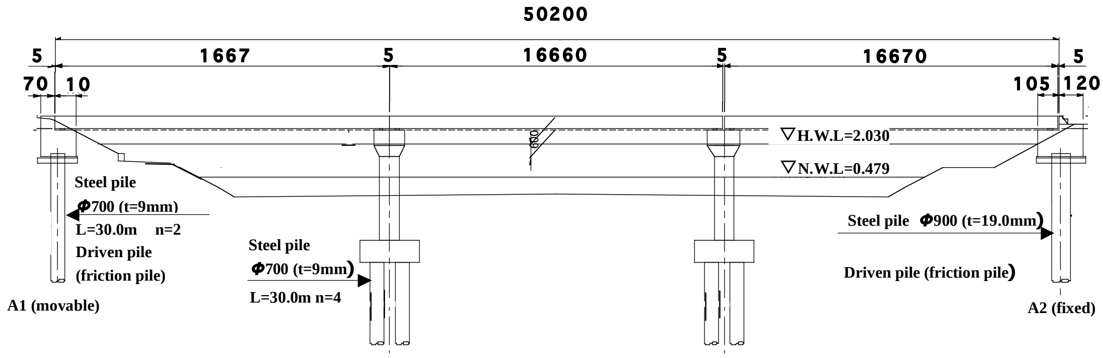


Fig. E-6: General view of hypothetical PC bridge

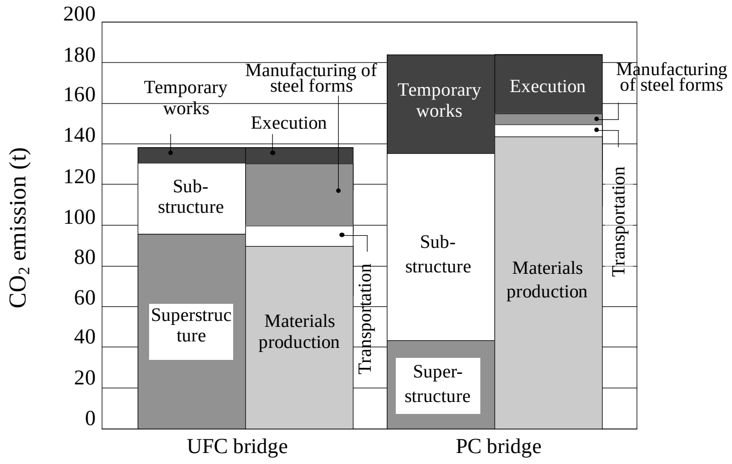


Fig. E-7: CO_2 emission of UFC and PC bridges

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